CHAPTER 8

OTHER RODUCT MANUFACTURE AND USE

Authors

Section 8.3

Michael Roger Czerniak (UK), Sébastien Raoux (France/USA) and Andrea Zille (Italy/Portugal)

Appendix 1 to Volume 3

Sébastien Raoux (France/USA) and Andrea Zille (Italy/Portugal)

Contents

Equations

Figures

Tables

8 OTHER PRODUCT MANUFACTURE AND USE

Users are expected to go to Mapping Tables in Annex 5, before reading this chapter. This is required to correctly understand both the refinements made and how the elements in this chapter relate to the corresponding chapter in the 2006 IPCC Guidelines.

8.1 INTRODUCTION

No refinement.

8.2 EMISSIONS OF SF_6 AND PFCs FROM ELECTRICAL EQUIPMENT

No refinement.

8.3 USE OF SF_6 AND PFCs IN OTHER PRODUCTS

8.3.1 Introduction

This source category excludes the following source categories that are addressed elsewhere in the *2006 IPCC Guidelines*:

- Production of SF_6 and PFCs (Section 3.10);

- Production and use of electrical equipment (Section 8.2);

- Primary and secondary production of magnesium and aluminium (Chapter 4); and

- Semiconductor and flat panel display manufacturing (Chapter 6).

Identified remaining applications in this source category include:

- SF_6 and PFCs used in military applications, particularly SF_6 used in airborne radar systems, e.g., Airborne Warning and Control System (AWACS), and PFCs used as heat transfer fluids in high-powered electronic applications;

- SF_6 used in equipment in university and research particle accelerators;

- SF_6 used in equipment in industrial and medical particle accelerators;

- 'Adiabatic' applications utilising the low permeability through rubber of SF_6 and some PFCs, e.g., car tires and sport shoe soles;

- SF_6 used in sound-proof windows;

- PFCs used as heat transfer fluids in commercial and consumer applications;

- PFCs used in cosmetics and in medical applications;

- Other uses e.g. gas-air tracer in research and leak detectors.

- PFCs and other fluorinated compounds in the manufacturing of textiles and waterproofing of electronic circuits

8.3.2 Methodological issues

8.3.2.1 CHOICE OF METHOD

The *good practice* method is to use either consumption data from users of SF_6 or PFCs or top-down import, export and consumption data from national SF_6 producers and distributors, disaggregated by major type of SF_6 or

PFC application. Acquiring this data will entail a survey of all producers and distributors of SF_6 and PFCs to identify total net SF_6 and PFC consumption. Once the data are obtained, the amount of SF_6 and PFC consumed by application in this source category should be estimated.

MILITARY APPLICATIONS

SF_6 EMISSIONS FROM OPERATION OF AWACS

SF_6 is used as an insulating medium in the radar systems of military reconnaissance planes of the Boeing E-3A type, commonly known as AWACS. The purpose of the SF_6 is to prevent electric flashovers in the hollow conductors of the antenna, in which high voltages of more than 135 kV prevail. When the plane ascends, SF_6 is automatically released from the system and into the atmosphere to maintain the appropriate pressure difference between the system and the outside air. When the plane descends, SF_6 is automatically charged into the system from an SF_6 container on board. Most emissions occur during the pressure-balancing process on ascent, but emissions from system leakage can also occur during other phases of flight or during time on the ground. Annual emissions per plane have been estimated to be 740 kg, while the charge of each system is approximately 13 kg.

Figure 8.2   **Decision tree for SF_6 from AWACS**
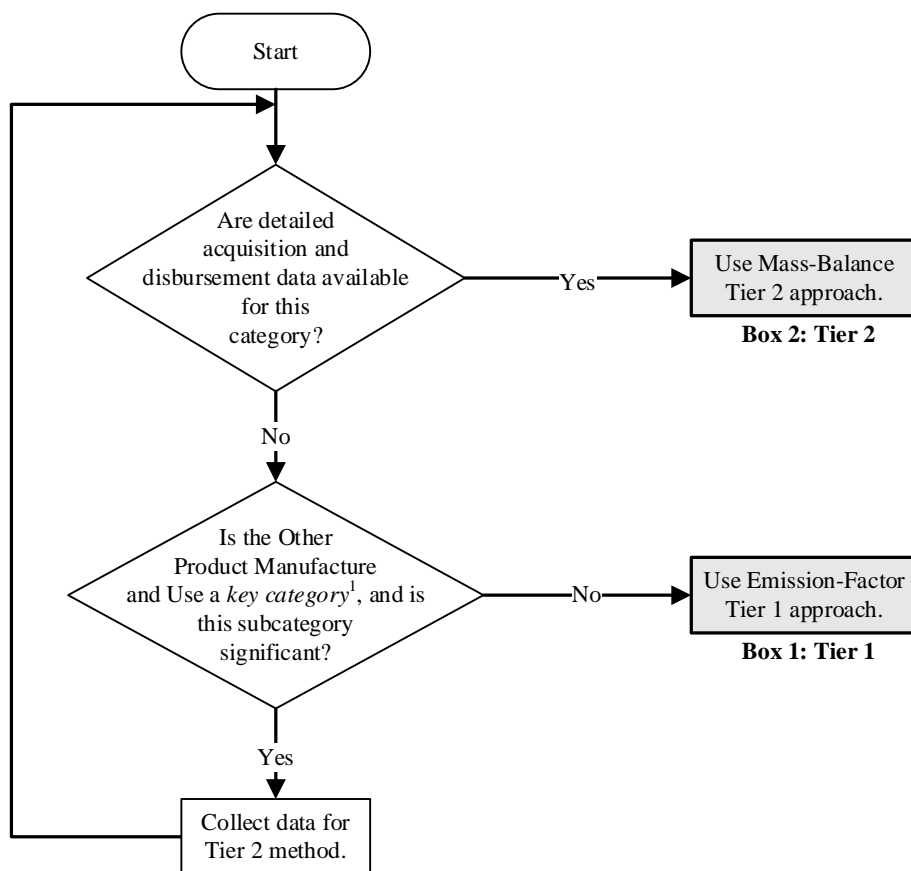
Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

Tier 1 method – SF_6 emissions per plane

If a country does not have data on SF_6 consumption by its AWACS, it may use a per-plane emission factor to estimate emissions. An emission factor of 740 kg per plane per year is presented in Table 8.7 below; this figure is based on estimates of SF_6 emissions from NATO Boeing E-3As. Note that actual emissions per plane are strongly influenced by the average number of sorties (take-offs) per plane per year. More frequent sorties will raise the emission rate above 740 kg/plane; less frequent sorties will lower it. Leakage rates during flight or during time on the ground will also affect the emission rate.

> **EQUATION 8.12**
> **EMISSIONS FROM AWACS (DEFAULT EMISSION ACTOR)**
>
> $$User\ Emissions\ =\ 740\ kg \bullet Number\ of\ planes\ in\ AWACS\ fleet$$

TABLE 8.7	
SF$_6$ EMISSIONS PER PLANE PER YEAR	
Emissions per plane per year (kg SF$_6$)	**Uncertainty**
740 kg	±100 kg
Source: Schwarz (2005)	

Table 8.8 includes information on national AWACS fleets worldwide (Boeing, 2005); like other activity data, it may quickly go out of date. Countries are in the best position to know the numbers of planes in their AWACS fleets.

TABLE 8.8							
NATIONAL AWACS FLEETS							
Country/ Organisation	**USA**	**Japan**	**France**	**UK**	**Other NATO**	**Saudi Arabia**	**Total**
No. AWACS	33	4	4	7	17	5	70
Source: Boeing (2005)							

Tier 2 method – user mass-balance method

The most accurate method for estimating SF$_6$ emissions from AWACS is to track SF$_6$ consumption by the systems. To do so, the following equations, which are similar to the utility-level variant of the Tier 3 method for electrical equipment, may be used. Note that for AWACS, acquisitions and disbursements of SF$_6$ containers are likely to be considerably more important to the result than acquisitions and retirements of operating systems.

> **EQUATION 8.13**
> **EMISSIONS FROM AWACS (USER MASS-BALANCE)**
>
> $$User\ Emissions\ =\ Decrease\ in\ SF_6\ Inventory\ +\ Acquisitions\ of\ SF_6$$
> $$-\ Disbursements\ of\ SF_6 -\ Net\ Increase\ in\ AWACS\ Fleet\ Charge$$

Where:

Decrease in SF$_6$ Inventory	= SF$_6$ stored in containers at the beginning of the year – SF$_6$ stored in containers at the end of the year
Acquisitions of SF$_6$	= SF$_6$ purchased from chemical producers or distributors in bulk + SF$_6$ purchased from AWACS manufacturers or distributors with or inside of new planes + SF$_6$ returned to site after off-site recycling
Disbursements of SF$_6$	= SF$_6$ contained in AWACS that are transferred to other entities + SF$_6$ returned to suppliers + SF$_6$ sent off-site for recycling + SF$_6$ destroyed

Net Increase in AWACS Fleet Charge = 13 kg $\bullet$ (New AWACS – Retiring AWACS)

SF$_6$ AND PFC EMISSIONS FROM OTHER MILITARY APPLICATIONS

There is wide range of military applications using PFCs or SF$_6$.[1] Military electronics are believed to be an important and growing application of PFC heat transfer fluids, which are valued for their stability and dielectric properties. The fluids are used in ground and airborne radar (klystrons), avionics, missile guidance systems, Electronic Counter Measures (ECM), sonar, amphibious assault vehicles, other surveillance aircraft, lasers, SDI (Strategic Defense Initiative), and stealth aircraft. PFCs may also be used to cool electric motors, particularly in applications where noise reduction is valued, e.g., in ships and submarines. The specific PFCs used in these applications are believed to be similar to those identified as heat transfer fluids in electronics manufacturing in Chapter 6. Spray cooling, jet impingement cooling, and pool boiling appear to be the favoured systems for heat removal. In all of these cooling applications, the PFC is contained in a closed system, and neither replacement nor replenishment of the PFC liquid appears to be required. Thus, the greatest opportunities for emissions are the manufacture, maintenance, and, especially, the disposal of the equipment.

SF$_6$ is used in high-performance ground and airborne radar systems in their hollow conductors for transmission of high-frequency energy pulses at high voltages from the klystron. Another application of SF$_6$ is as an oxidant of lithium in Stored Chemical Energy Propulsion System (SCEPS), e.g., in naval torpedoes and in infrared decoys (Koch, 2004). Apparently, these applications of SF$_6$, like those of the PFC heat transfer fluids enumerated above, are generally more or less enclosed, but servicing and testing procedures may lead to emission. The use of SF$_6$ for the quieting of torpedo propellers has also been reported (NIST, 1997).

In addition, SF$_6$ may be emitted as a by-product of the processing of nuclear material for the production of fuel and nuclear warheads. SF$_6$ is known to be emitted from neutralising excess fluorine during the production of nuclear fuel for civilian applications (AREVA, 2005).

Although it is believed that the total amounts of SF$_6$ and PFCs consumed and emitted in this sector may be significant, no data on quantities are publicly available so far. Therefore, inventory compilers should try to collect further information from the relevant authorities and, if possible, their suppliers. As noted above, the greatest opportunities for emissions from many of these applications appear to be the manufacture, maintenance, and disposal of the equipment. Thus, if inventory compilers can acquire information on emission rates during the manufacture, maintenance, and disposal of the equipment, along with the quantities of equipment manufactured, in use, and disposed, they can use the Tier 2 or Tier 3 method for electrical equipment to estimate emissions. For applications with different emissions profiles (e.g., prompt emissions), the appropriate equation from Section 8.2 may be used.

SF$_6$ EMISSIONS FROM UNIVERSITY AND RESEARCH PARTICLE ACCELERATORS

SF$_6$ is used in university and research operated particle accelerators as an insulating gas. Typically, high voltage equipment is contained and operated within a vessel filled with SF$_6$ at a pressure exceeding atmospheric pressure. Charges range from five kilograms to over ten thousand kilograms, with typical charges falling between 500 and 3 000 kg. When the equipment requires maintenance, the SF$_6$ is transferred into storage tanks. SF$_6$ losses occur primarily during gas recovery and transfer, when pressure relief valves are actuated, and through slow leaks.

Based on two recent studies annual SF$_6$ losses range between 5 and 7 percent of vessel capacity per year and generally depend on the vessel opening frequency plus the efficiency of the recovery and transfer equipment. World banked capacity is roughly estimated to be 500 tonnes with annual SF$_6$ emissions of 35 tonnes.

Switzerland has developed a voluntary program to reduce SF$_6$ emissions from particle accelerators. Suggestions and techniques for reducing SF$_6$ emissions from these sources exist.

---

[1] David Harris and James Hildebrandt, "Spray Cooling Electrical and Electronic Equipment," *COTS Journal*, November 2003; C. Shepherd Burton, "Uses and Air Emissions of Liquid PFC Heat Transfer Fluids from the Electronics Sector," Draft report prepared for Scott C. Bartos, U.S. Environmental Protection Agency.

Figure 8.3   Decision tree for SF₆ from research accelerators
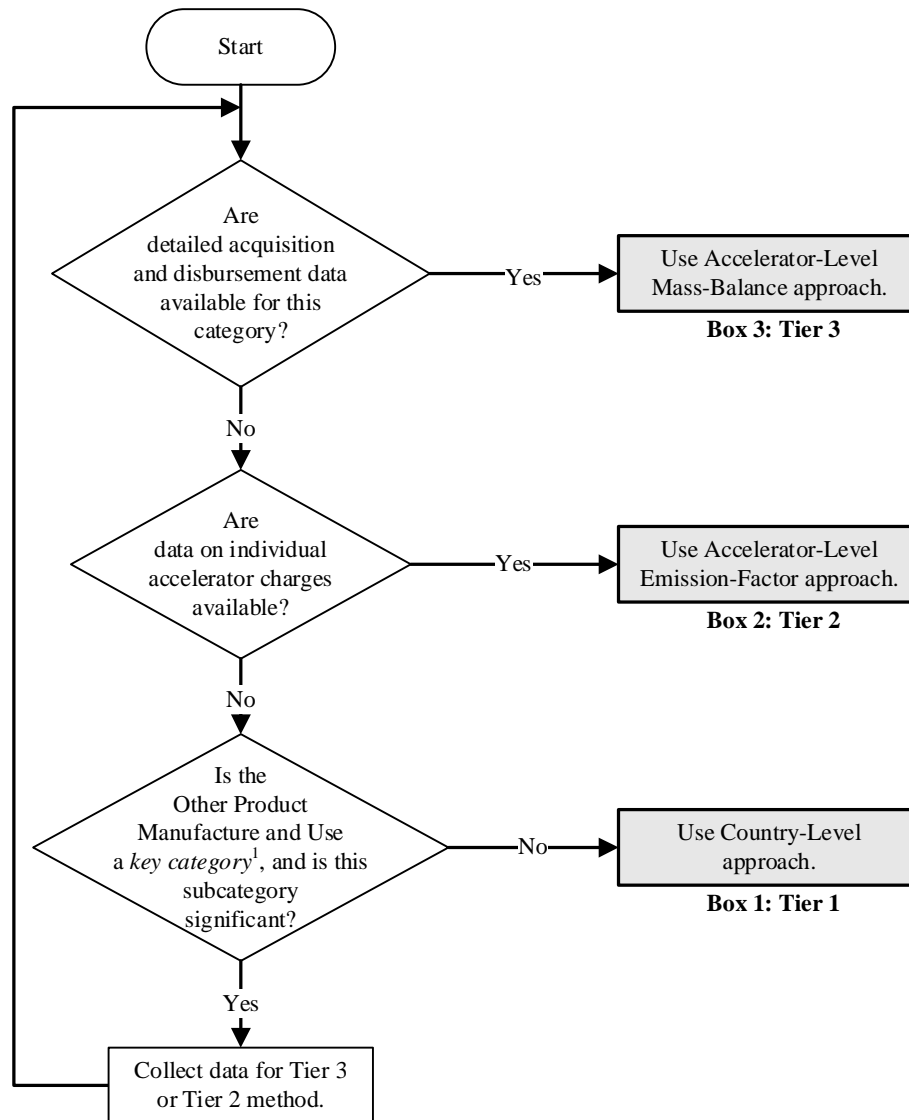
Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

Tier 1 method – country-level method

In cases where individual user accelerator charge data is unavailable, one extremely rough method involves determining the total number of university and research particle accelerators in the country and using several factors to determine the country-level annual emission rate as noted in Equation 8.14. For this Tier 1 method, the only data that requires collection is the total number of university and research particle accelerators in the given country.

EQUATION 8.14
UNIVERSITY AND RESEARCH PARTICLE ACCELERATOR EMISSIONS (COUNTRY-LEVEL)

$$Emissions = (Number\ of\ university\ and\ research\ particle\ accelerators\ in\ the\ country)$$
$$\bullet (SF_6\ Use\ Factor) \bullet (SF_6\ Charge\ Factor,\ kg)$$
$$\bullet (SF_6\ university\ and\ research\ particle\ accelerator\ Emission\ Factor)$$

Where:

Number of university and research particle accelerators in the country
= The total number of university and research particle accelerators in the country. This

rough method does not require countries to determine the number of accelerators that use SF_6. To determine if a country has a particle accelerator, go to http://www-elsa.physik.uni-bonn.de/Informationen/accelerator_list.html

SF_6 Use Factor   = 0.33 Approximately one third of university and research particle accelerators use SF_6 as an insulator.

SF_6 Charge Factor = 2400 kg, SF_6, the average SF_6 charge in a university and research particle accelerator.

SF_6 university and research particle accelerator Emission Factor
     = 0.07, the average annual university and research particle accelerator emission rate as a fraction of the total charge.

Tier 2 method – accelerator-level emission-factor approach

If data on the quantity of SF_6 contained within each university and research accelerator are available, a default emission factor of 7 percent may be multiplied by the total SF_6 charge contained in university and research accelerators in the country. The total country SF_6 emission rate from university and research accelerators is therefore calculated from Equation 8.15.

EQUATION 8.15
UNIVERSITY AND RESEARCH PARTICLE ACCELERATOR EMISSIONS (ACCELERATOR-LEVEL EMISSION FACTOR)

$$Total\,Emissions = SF_6\,university\,and\,research\,particle\,accelerator\,Emission\,Factor$$
$$\bullet \sum Individual\,Accelerator\,Charges$$

Where:

     SF_6 university and research particle accelerator Emission Factor

         = 0.07, the average annual university and research particle accelerator emission rate as a fraction of the total charge.

     Individual User Accelerator Charges

         = SF_6 contained within each university and research accelerator.

Tier 3 method –accelerator-level mass-balance method

SF_6 emissions from university and research facilities operating particle accelerators may be most accurately determined at the user level on an accelerator-by-accelerator basis. Emission calculations are estimated by tracking accelerator charge as well as SF_6 consumption and disposal. As detailed in Equation 8.16, the total emissions are equal to the sum of the individual users' emissions. Note, under this method, as the overall SF_6 emission rate from particle accelerators is small compared to other SF_6 uses, the associated SF_6 lost in manufacturing is considered negligible and is not included in the calculation.

EQUATION 8.16
TOTAL RESEARCH ACCELERATOR EMISSIONS

$$Total\ Emissions = \sum Individual\ Accelerator\ Emissions$$

Each particle accelerator's emissions can be calculated as follows:

EQUATION 8.17
RESEARCH ACCELERATOR EMISSIONS (ACCELERATOR-LEVEL MASS-BALANCE)

$$Accelerator\ Emissions\ =\ Decrease\ in\ SF_6\ Inventory\ +\ Acquisitions\ of\ SF_6$$
$$-\ Disbursements\ of\ SF_6\ -\ Net\ Increase\ in\ Accelerator\ Charge$$

Where:

     Decrease in SF_6 Inventory   = SF_6 stored in containers at the beginning of the year – SF_6 stored in containers at the end of the year

     Acquisitions of SF_6 = SF_6 purchased from chemical producers or distributors in bulk + SF_6 purchased from accelerator manufacturers or distributors with

	or inside of new accelerator components + SF_6 returned to site after off-site recycling
Disbursements of SF_6	= SF_6 contained in components transferred to other entities + SF_6 returned to suppliers + SF_6 sent off-site for recycling + SF_6 destroyed
Net Increase in Accelerator Charge	= SF_6 Charge of New Components – SF_6 Charge of Retiring Components

SF_6 EMISSIONS FROM INDUSTRIAL AND MEDICAL PARTICLE ACCELERATORS

SF_6 is used as an insulating gas in two types of industrial particle accelerators (low and high voltage) and also in medical (cancer therapy) particle accelerators, as is the case for university and research particle accelerators. However, the emission and charge factors for industrial and medical particle accelerators are different from those of university and research accelerators, as discussed below.

Global banked capacity for industrial particle accelerators is roughly estimated to be 500 tonnes with annual SF_6 emissions of 35 tonnes. Global banked capacity for medical (radiotherapy) particle accelerators is roughly estimated to be less than 5 tonnes with annual SF_6 emissions of less than 5 tonnes. (Schwarz, 2005).

Figure 8.4   **Decision tree for industrial and medical particle accelerators**
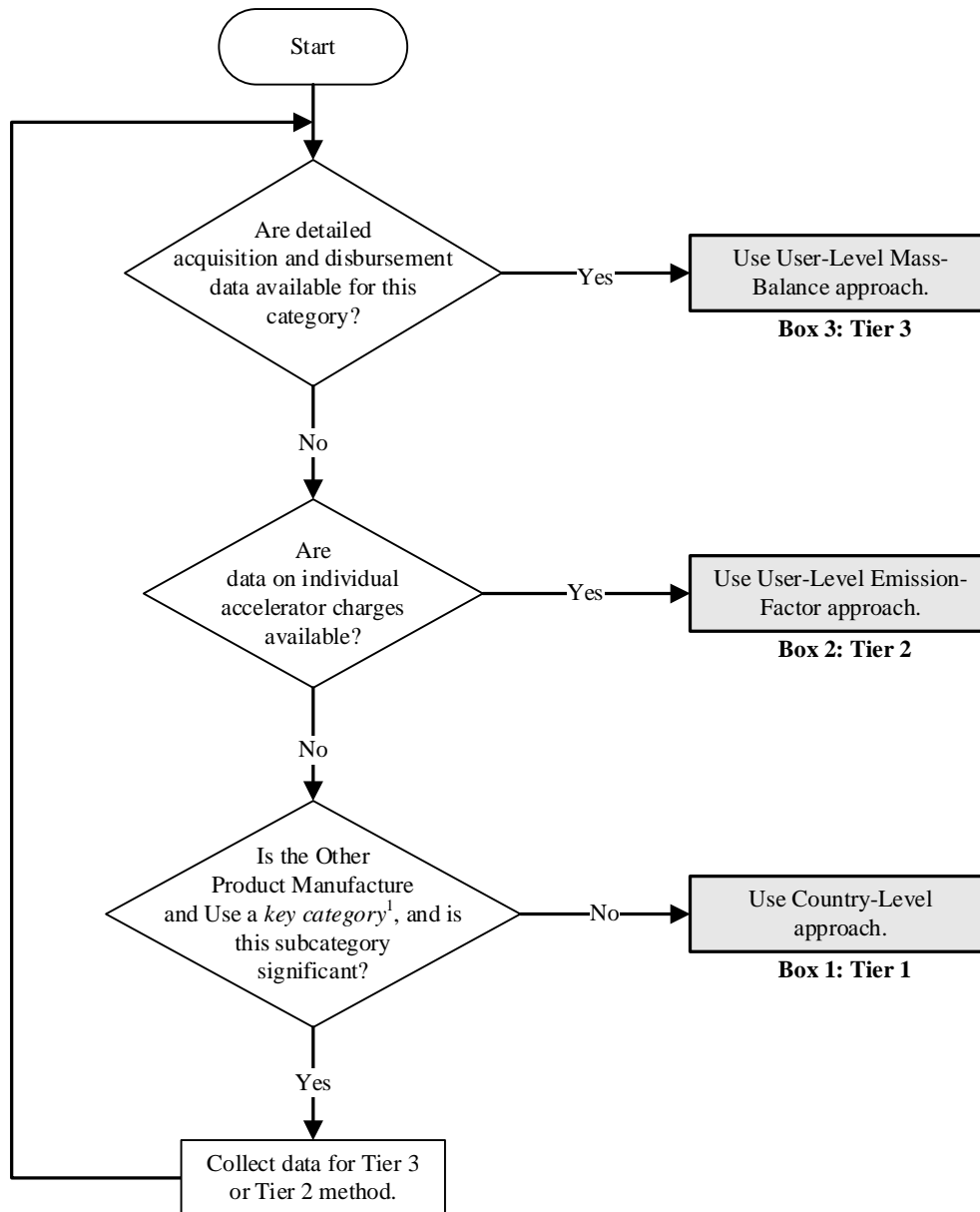
Note:

1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

Tier 1 method – country-level method

In cases where individual user accelerator charge data is unavailable, one extremely rough method involves determining the total number of particle accelerators by process description in the country and using factors to determine the country level annual emission rate as noted in Equation 8.18. For this Tier 1 method, the only data that requires collection is the total number of particle accelerators which contain SF_6 by process description in the given country.

EQUATION 8.18
INDUSTRIAL/MEDICAL ACCELERATOR EMISSIONS (COUNTRY-LEVEL)

Emissions = Number of particle accelerators that use SF_6 by process description in the country

$\bullet\ SF_6$ *Charge Factor, kg* $\bullet\ SF_6$ *applicable particle accelerator Emission Factor*

Where:

Number of particle accelerators by type in the country

> = The total number of particle accelerators by type (industrial high voltage, industrial low voltage and radiotherapy) that use SF_6 in the country, 1, 2, etc. (Only count particle accelerators that use SF_6. This differs for the Tier 1 calculation for university and research particle accelerators)

SF_6 Charge Factor = The average SF_6 charge in a particle accelerator by process description as noted below.

SF_6 particle accelerator Emission Factor

> = The average annual SF_6 particle accelerator emission rate as a fraction of the total charge by process description.

TABLE 8.9 AVERAGE SF_6 CHARGE IN A PARTICLE ACCELERATOR BY PROCESS DESCRIPTION	
Process Description	**SF_6 Charge Factor, kg**
Industrial Particle Accelerators – high voltage (0.3-23 MV)	1300
Industrial Particle Accelerators –low voltage (<0.3 MV)	115
Medical (Radiotherapy)	0.5[a]
[a] This is the average of values ranging from 0.05 kg to over 0.8 kg, depending on model and manufacturer. Source: Schwarz (2005)	

Tier 2 method – user-level emission-factor approach

If data on the quantity of SF_6 contained within each industry and medical accelerator are available, use the Tier 2 method for university and research facilities; however, multiply the emission factor for each process description provided below by the total, country-specific SF_6 charge for that process description.

TABLE 8.10 EMISSION FACTOR FOR EACH PROCESS DESCRIPTION, (SF_6 EMISSIONS FROM INDUSTRIAL AND MEDICAL PARTICLE ACCELERATORS)	
Process Description	**Emission Factor, kg /kg SF_6 charge**
Industrial Particle Accelerators – high voltage (0.3-23 MV)	0.07
Industrial Particle Accelerators – low voltage (<0.3 MV)	0.013
Medical (Radiotherapy)	2.0[a]
[a] This emission factor is the average of values ranging from 1 kg to 10 kg per kg charge, depending on model, manufacturer, and service intervals. Source: Schwarz (2005)	

Tier 3 method – user-level mass-balance method

To calculate SF_6 emissions from industrial and medical particle accelerators, use the same Tier 3 method as the university and research facilities. The customer service organisations for manufacturers and distributors of the equipment are likely to have information on equipment stocks, imports, and exports, and on the quantities of SF_6 used to fill and refill the equipment.

EMISSIONS FROM OTHER APPLICATIONS OF SF_6 AND PFCs

It is *good practice to* contact all gas producers/distributors to identify SF_6 and PFC users and to investigate the gas consumption of source categories other than those mentioned above. The key difference among the applications discussed below is the typical delay between the purchase of the SF_6 or PFC and the release of the chemical. In some cases (e.g., SF_6 used in sound-proof glazing, PFCs used as heat transfer fluids), the chemical is fairly well contained during the life of the equipment or product, and most emissions are associated with the

manufacture and disposal of the product. In these cases, the delay between the purchase of the chemical and its final emission depends on the lifetime of the product, ranging from three years for tyres and sport-shoes to 25 years for sound-proof glazing. In other cases (e.g., use of SF_6 and PFCs as tracers or in medical applications), the chemical is fully emitted within a year of its purchase. If, as a result of an initial survey, applications with distinctive delayed emissions appear significant, then *good practice* is to use a source category-specific emission calculation, taking into account the delay in emissions.

Adiabatic uses

Adiabatic uses of SF_6 and some PFCs exploit the low permeability of these gases through rubber. Historically, SF_6 has been the dominant gas in these applications; however, PFCs with similar molecular weights (such as C_3F_8) have recently been used as well. Applications with a delay period of 3 years include or car tyres, sport shoe soles and tennis balls (Schwarz *et al.*, 1996). For applications with emissions that are delayed by three years, the following formula can be used.

EQUATION 8.19
ADIABATIC PROPERTY APPLICATIONS

$$Emissions\ in\ year\ t\ =\ Sales\ in\ year\ (t\ -3)$$

Sound-proof glazing

Double-glazed sound-proof windows: Approximately one-third of the total amount of SF_6 purchased is released during assembly (i.e., filling of the double glass window) (Schwarz/Leisewitz, 1999). For the stock of gas remaining inside the window (capacity), an annual leakage rate of 1 percent is assumed (including glass breakage). Thus, about 75 percent of initial stock remains at the end of its 25-year lifetime. The application of SF_6 in windows began in 1975, so disposal is only beginning to occur. Emissions from this source sub-category should be calculated using Equations 8.20 to 8.22:

EQUATION 8.20
DOUBLE-GLAZED WINDOWS: ASSEMBLY

$$Assembly\ Emissions\ in\ year\ t =\ 0.33 \bullet SF_6\ purchased\ to\ fill\ windows\ assembled\ in\ year\ t$$

EQUATION 8.21
DOUBLE-GLAZED WINDOWS: USE

$$Leakage\ Emissions\ in\ year\ t\ =\ 0.01 \bullet Capacity\ of\ Existing\ Windows\ in\ year\ t$$

EQUATION 8.22
DOUBLE-GLAZED WINDOWS: DISPOSAL

$$Disposal\ Emissions\ in\ year\ t = Amount\ Left\ in\ Window\ at\ End\ of\ Lifetime\ in\ year\ t$$
$$\bullet (1\ -Recovery\ Factor)$$

Unless country-specific data are available, a default recovery factor value of zero should be assumed in Equation 8.22. If no specific information is available for these sub-source categories, *good practice* is to treat them as prompt emissions.

Fluorinated compounds used to waterproof electronic circuits

There are two basic processes to adding waterproofing layers onto assembled electronic circuits:

1. Liquid-based PFOS or PFOA-containing films, applied by aerosol spray or immersion, or

2. Long-chain perfluorocarbon polymers applied by gas-phase reaction in a plasma.

The second process can result in emissions of fluorinated compounds (FCs) and is therefore the focus of this guidance. The plasma deposition process involves the introduction of a variety of hydrocarbon gases where the hydrogen atoms are replaced by fluorine supplied from an FC gas source that is decomposed in the plasma. Periodically, the process chamber is also cleaned using FC gases in a way similar to the way that TFD chambers are cleaned in the semiconductor industry. (See the *2006 IPCC Guidelines*, Volume 3, Chapter 6 and the *2019 Refinement*, Volume 3, Chapter 6.)

Table 8.11 below provides default emission factors, expressed in grams of gas per circuit board, for the three FCs understood to account for the vast majority of GWP-weighted emissions from this process. Inventory compilers should apply all three emission factors to the number of circuit boards waterproofed to obtain a complete estimate of emissions from this source category.

TABLE 8.11 (NEW) EMISSION FACTOR FOR WATERPROOFING OF ELECTRONIC CIRCUITS	
Gas Emitted	**Emissions (g)/Circuit Board**
CF_4	0.006
C_2F_6	0.004
CHF_3	0.003
Note:	
Figures are expert judgement conducted by authors of Chapter 8 based on confidential data from Edwards Vacuum Ltd., 2017.	
The emissions used to develop these emission factors were measured by FTIR on a working facility installation, and were originally expressed in terms of gCO_2/week/chamber. The numbers above were calculated based on the assumption that each process chamber processes 60,000 circuit boards per week. The emissions included both higher-GWP gases (CF_4, C_2F_6 and CHF_3) and lower-GWP gases (CH_4, C_3F_6, COF_2, C_2H_4), but emission factors are provided only for higher-GWP gases as their emissions are dominant (8,453,881 vs. 830 gCO2eq/week/chamber). Because the actual proportions of the emitted gases are sensitive process information for the company that provided the data, the GWP-weighted emissions were divided equally among the three emitted gases on a gCO2eq basis, and were then converted into grams of gas, to obtain the emission factors in Table 8.11.	

EQUATION 8.22A (NEW)
WATERPROOFING OF ELECTRONIC CIRCUITS

$$Emissions_i = EF_i \bullet n$$

Where:

Emissions$_i$ = Emissions of each gas i listed in Table 8.11

n = Number of circuit boards manufactured

EF$_i$ = Emission factor for gas i in Table 8.11

Textile, carpet, leather and paper fluorinated treatment emissions

Fluorine-based treatment processes are used to control the surface properties of textile, carpet, leather, or paper fibres, and – inter alia – to enhance their hydrophobicity, to increase their stain resistance, dyeing ability, or mechanical strength, and to produce wrinkle-free materials (Lacasse & Baumann 2004; Schindler & Hauser 2004; Singha 2012; Gulrajani 2013; Roshan 2014). The main treatment technologies currently in use are based on wet processes, including the pad-dry-cure method among others (Roshan 2014; Heydebreck et al. 2016; Goswami 2017; Williams 2018). Another emerging technology is based on plasma processes used to treat, etch, or deposit polymers on the surface of the substrate (Morent et al. 2008; Jafari et al. 2013; Zille et al. 2015; Gotoh et al. 2017).

Although several international and national reports refer to the possible off-gas emissions of fluorinated compounds (FC) into the atmosphere during wet and plasma treatments of textile, carpet, leather, and paper, no representative emission factors appear to be available to estimate greenhouse gas (GHG) emissions from such processes (EPA 1997; Schönberger & Schäfer 2003; MoEU 2012; DEPA 2013; UNIDO et al. 2017). It is probable that FCs emissions of wet-based processes mainly occur during the pad-dry-cure process or other thermal coating processes, but the amount of unreacted input chemicals that may be emitted through evaporative losses or the type and amount of by-products formed during these processes as well as their relevance as GHG gases do not appear to have been thoroughly characterized (IPPC 2003; OECD 2004). The extent to which plasma-based textile treatment processes have penetrated volume production is unclear, but, by analogy with plasma-based processes used in the electronics industry, and considering that many FC molecules are particularly stable and difficult to disassociate, the utilization efficiency of the input gas is likely to be limited, and FC emissions resulting from the incomplete use of input gases such asCF_4, C_2F_6, CHF_3, SF_6, and other fluorine-containing molecules in plasma processes may be significant. Since the authors were not able, at the time of publication of the *2019 Refinement*, to estimate the volume of fluorinated compounds that are used or emitted by the textile, carpet, leather, and paper industries, FC emissions in this sector could represent a significant new source, due to the large volume of substrates treated and the sheer size and global nature of the industry (KEMI 2014).

While it does not appear feasible at the time of publication of the *2019 Refinement* to apply a reporting methodology for this new source category based on default emissions factors (e.g. based on representative emission factors to estimate emissions of GHGs per mass or per surface area of substrate treated), a three-tiered methodological framework (Tier 1, Tier 2a, Tier 2b) to report emissions once default emission factors become available is proposed. In addition, a Tier 3 method that can readily be applied, based on measured emission factors is also provided. Countries seeking to report FC emissions from textile, carpet, leather and paper industries should work with equipment manufacturers and users of such equipment to measure equipment-specific, process-specific, or site-specific emission factors, with the aim of developing representative default emission factors that could be used for site-specific, domestic, or industry-wide inventories.[2] The proposed Tier 1, Tier 2a, Tier 2b, and Tier 3 methods are described in Appendix 1. Possible Approaches for Estimating FC Emissions from Textile, Carpet, Leather and Paper Industries: Basis for Future Methodological Development, and preliminary guidance about how to measure emissions factors and develop defaults is also provided.

PFCs used as heat transfer fluids in consumer and commercial applications

PFCs are used as heat transfer fluids in a number of high-power-density commercial and consumer electronic applications. Commercial applications include cooling for supercomputer, telecommunication, and airport radar systems, as well as drive units (rectifiers) on high-speed trains (Burton, 2006). These applications consume much smaller volumes of liquid PFCs than electronics manufacturing, but are believed to be significant among 'niche' applications. Consumer applications include cooling kits for desktop computers that are operated at high voltages to increase their processing speed. The specific PFCs used in these applications are believed to be similar to those identified as heat transfer fluids in electronics manufacturing in Chapter 6. In all of these applications, the liquid PFCs are used in closed modules, indicating that most emissions occur during the manufacture, maintenance, and disposal of the product or equipment. Thus, if inventory compilers can acquire information on emission rates during the manufacture, maintenance, and disposal of the equipment, along with the quantities of equipment manufactured, used, and disposed each year, they can use the Tier 2 or Tier 3 method for electrical equipment to estimate emissions. For applications with different emissions profiles (e.g., prompt emissions), the appropriate equation from Section 8.2 may be used.

---

[2] For the explanation about the role of Appendices please refer to the Overview Chapter

PFCs used in cosmetic and medical applications

PFCs with relatively large molecular weights (e.g., $C_{10}F_{18}$) are used in cosmetic and medical applications, exploiting their ability to carry oxygen to living tissue (May, 2006). Cosmetic applications include anti-wrinkle creams and are estimated to consume fairly small amounts. Current and potential medical applications include storage of pancreatic tissue for transplants (using the 'two-layer method'), eye surgery (to repair retinal tears), pneumonectomy (lung therapy and diagnosis), use as a contrast agent in ultrasonic and MRI examinations, blood extension, wound healing, and treatment of diseases of the middle ear. All but the first two medical applications involve only small quantities and/or are at the research stage. Storage of pancreatic tissue is a small but growing application. Emissions from medical uses are uncertain but are believed to be small.

In all of these applications, the PFC is believed to be emitted into the atmosphere within one year of its purchase. Thus, emissions from these sources can be estimated using Equation 8.23 for prompt emissions.

Any other uses of SF_6 and PFCs

Other applications for SF_6 and PFCs that are not specifically addressed above include their use as tracers (in leak detection, indoor and outdoor tracking of air-masses, and oil recovery[3]) and use of SF_6 in the production of optical cables (for fluorodoping of glass fibres[4]). Often the gases or liquids are emitted within one year of purchase. In this case, *good practice* in calculating SF_6 and PFC emissions from these 'prompt' emissive applications is to use the following formula:

EQUATION 8.23
PROMPT EMISSIONS

$$Emissions\ in\ year\ t\ =\ (0.5 \bullet Amount\ Sold\ in\ year\ t) + (0.5 \bullet Amount\ Sold\ in\ year\ t - 1)$$

This equation is similar to the equation for prompt ozone depleting substances (ODS) Substitute applications (e.g., aerosols and solvents) addressed in Chapter 7 of this volume. The equation covers more than one year because both sales and emissions are assumed to be continuous over the year; that is, chemical sold in the middle of year t-1 is not fully emitted until the middle of year t.

8.3.2.2 CHOICE OF EMISSION FACTORS

For 'other' source categories of SF_6 and PFCs that contribute substantially to a country's SF_6 and PFCs emissions, countries are encouraged to develop country-specific emission factors based on occasional surveys of representative subsets of sources. It is *good practice* to clearly document such emission factors. Default emission factors are provided above for AWACS, accelerators, waterproofing of electronic circuits, prompt emissive applications and adiabatic applications, including windows.

8.3.2.3 CHOICE OF ACTIVITY DATA

No refinement.

8.3.2.4 COMPLETENESS

No refinement.

8.3.2.5 DEVELOPING A CONSISTENT TIME SERIES

No refinement.

---

[3] D. Vlachogiannis *et al*. (2005). This paper indicated that some fraction of injected PFCs and SF_6 was destroyed during fuel combustion, but the magnitude of this fraction (compared to the fraction of injected chemical that escaped before combustion) was unclear.

[4] See further information on this application in Schwarz (2005).

8.3.3   Uncertainty assessment

No refinement.

8.3.4   Quality assurance / quality control (QA/QC), reporting and documentation

No refinement.

8.4 N₂O FROM PRODUCT USES

No refinement.

References

SECTIONS 8.1 - 8.3

References newly cited in the 2019 Refinement

DEPA. (2013) Survey of PFOS, PFOA and other perfluoroalkyl and polyfluoroalkyl substances. In: *Part of the LOUS-review Environmental Project No. 1475, 2013*, The Danish Environmental Protection Agency, Copenhagen, Denmark.

Goswami, K.K. (2017) *Advances in carpet manufacture*. India: Woodhead Publishing.

Gotoh, K., Shohbuke, E., Ryu, G. (2017) Application of atmospheric pressure plasma polymerization for soil guard finishing of textiles. *Textile Research Journal* 88: 1278-1289.

Gulrajani, M.L. (2013) *Advances in the dyeing and finishing of technical textiles*. Elsevier.

Heydebreck, F., Tang, J., Xie, Z., Ebinghaus, R. (2016) Emissions of Per- and Polyfluoroalkyl Substances in a Textile Manufacturing Plant in China and Their Relevance for Workers' Exposure. *Environmental Science & Technology* 50: 10386-10396.

IPPC. (2003) Reference Document on Best Available Techniques for the Textiles Industry. In: *BREF*, European Commission, Joint Research Centre, Seville, Spain: Integrated Pollution Prevention and Control (IPPC).

Jafari, R., Asadollahi, S., Farzaneh, M. (2013) Applications of Plasma Technology in Development of Superhydrophobic Surfaces. *Plasma Chemistry and Plasma Processing* 33: 177-200.

KEMI. (2014) Chemicals in textiles - Risks to human health and the environment. In: *Report 6/14*, ed. SC Agency, Arkitektkopia, Stockholm.

Lacasse, K., Baumann, W. (2004) *Textile Chemicals: Environmental data and facts*. Springer Science & Business Media.

MoEU. (2012) BAT Guide for textile industry. In: *Project TR-2008-IB-EN-03 Activity no: 2.1.4.b.3*: Ministry of Environment and Urbanism of Turkey (MoEU)

Morent, R., De Geyter, N., Verschuren, J., De Clerck, K., Kiekens, P., Leys C (2008) Non-thermal plasma treatment of textiles. *Surface and Coatings Technology* 202: 3427-3449.

OECD. (2004) Emission Scenario Document on Textile Finishing Industry - ENV/JM/MONO(2004)12. In: *OECD SERIES ON EMISSION SCENARIO DOCUMENTS* Paris, France: OCDE.

Roshan, P. (2014) *Functional finishes for textiles: improving comfort, performance and protection*. cambridge, UK: Woodhead Publishing.

Schindler, W.D., Hauser, P.J. (2004) *Chemical finishing of textiles*. Elsevier.

Schönberger, H., Schäfer, Y. (2003) Best Available Techniques in Textile Industry - 200 94 329 UBA-FB 000325/e. In: *TEXTE series*, ed. NCANS Environmental Research Of The Federal Ministry Of The Environment, Federal Environmental Agency, Berlin, Germany.

Singha, K. (2012) A review on coating & lamination in textiles: processes and applications. *American Journal of Polymer Science* 2: 39-49.

UNIDO, UNITAR, UNEP. (2017) Guidance on best available techniques and best environmental practices for the recycling and disposal of articles containing polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on Persistent Organic Pollutants. In: United Nations Institute for Training and Research (UNITAR), Geneva, Switzerland.

US EPA. (1997) Profile of the Textile Industry - EPA 310-R-97-009. In: EPA Office of Compliance Sector Notebook Project.

Williams, J.T. (2018) *Waterproof and Water Repellent Textiles and Clothing*. Cambridge, UK: Elsiever, Woodhead Publishing.

Zille, A., Oliveira, F.R., Souto, A.P. (2015) Plasma Treatment in Textile Industry. *Plasma Processes and Polymers* 12: 98-131.

References copied from the 2006 IPCC Guidelines

Aoyama, T. (2004). Japan Electrical Manufacturers' Association (JEMA), "The Situation of Reduction in SF$_6$ Emissions from Gas-insulated Electrical Equipment In Japan" Paper and presentation delivered to the Conference on SF$_6$ and the Environment, Scottsdale, Arizona, December 1-3, 2004.

AREVA (2005). AREVA, World energy experts, Activity and Sustainable Development Report 2004. (Registered office: rue Le Peletier – 75009 Paris – France, http://www.areva.com/), published in July 2005.

Boeing (2005). "E-3 AWACS in Service Worldwide", March 2005. Boeing Integrated Defense Systems, P.O. Box 516, St. Louis, MO 63166, (Available from http://www.boeing.com/defense-space/ic/awacs/docs/E-3AWACS_overview.pdf)

Burton, C. S. (2006). "Uses and Air Emissions of Liquid PFC Heat Transfer Fluids from the Electronics Sector," Report prepared for Scott C. Bartos, U.S. Environmental Protection Agency.Ecofys (2005). Reductions of SF_6 Emissions from High and Medium Voltage Electrical Equipment in Europe, Final Report to CAPIEL, S, Wartmann and J. Harnisch, June 28, 2005

CIGRE (2005). International Council on Large Electric Systems (CIGRE) Publication No.276: Guide for the Preparation of customized "Practical SF_6 Handling Instructions", Task Force B3.02.01, August 2005.

FEPC and JEMA (2004). Federation of Electric Power Companies (FEPC) and the Japan Electrical Manufacturers' Association (JEMA), "Japanese Emission Factors." (Personal communication from Mr. Kiyoshi Saitoh of Japan Electrical Manufacturers Association (JEMA) to Mr. Kiyoto Tanabe, IPCC Technical Support Unit, November, 2004.)

Harris, D., and Hildebrandt, J. (2003). "Spray Cooling Electrical and Electronic Equipment," *COTS Journal*, November 2003.

IEC (1996). International Electro-technical Commission (IEC) Standard 60694: "Common specifications for high-voltage switchgear and controlgear standards," Second edition, 1996-05. Geneva, Switzerland.

Koch, E.C. (2004). "Special Materials in Pyrotechnics: III. Application of Lithium and its Compounds in Energetic Systems;" *Propellants, Explosives, Pyrotechnics*, Volume 29, Issue 2, Pages 67 - 80, 2004

Maruyama, S. and Meguro, M. (2000). "SF_6 Gas Emission Reduction From Gas-Insulated Electrical Equipment in Japan.", Paper presented at the Conference on SF_6 and the Environment: Emission Reduction Strategies in San Diego, USA (November 2000).

May, G. (2006). F_2 Chemicals Limited. Personal communication with Deborah Ottinger Schaefer, January 23, 2006.

NIST (1997). Gases for Electrical Insulation and Arc Interruption: Possible Present and Future Alternatives to Pure SF_6; by L. G. Christophorou, J. K. Olthoff, D. S. Green; NIST Technical Note 1425, National Institute of Standards, November 1997.

Schwarz, W. (2005). Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002. Research Report 201 41 261/01, UBA-FB 000811/e, Umweltbundesamt, Berlin.

Schwarz, W. (2006). "The German Monitoring System for SF_6 Emissions from Equipment for Electricity Transmission and Distribution."

Schwarz, W. and Leisewitz, A. (1996). Current and future emissions of fluorinated compounds with global warming effect in Germany (in German). Report UBA-FB 1060 1074/01, Umweltbundesamt, Berlin.

Schwarz, W. and Leisewitz, A. (1999). Emissions and reduction potentials of HFCs, PFCs, and SF_6 in Germany. Report UBA-FB 298 41 256, Umweltbundesamt, Berlin.

Smythe, K. (2004). 'Trends in SF_6 Sales and End-Use Applications: 1961-2003.' International Conference on SF_6 and the Environment: Emission Reduction Technologies, December 1-3, 2004, Scottsdale, AZ.

U.S. EPA (2004). U.S. Inventory of Greenhouse Gases and Sinks, 1990-2002. U.S. Environmental Protection Agency, April, 2004.

Vlachogiannis, D., *et al.* (2005). Assessment of the impact of SF_6 and PFCs reservoir tracers on global warming, the AEOLOS study, Non-CO_2 Greenhouse Gases (NCGG-4), coordinated by A. van Amstel, Rotterdam, p. 389-396.