CHAPTER 8

OTHER PRODUCT MANUFACTURE AND USE

Authors

Sections 8.1, 8.2, and 8.3

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Section 8.4

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Contents

Equations

Figures

Tables

8 OTHER PRODUCT MANUFACTURE AND USE

8.1 INTRODUCTION

This chapter outlines methods for estimating emissions of sulphur hexafluoride (SF_6) and perfluorocarbons (PFCs) from the manufacture and use of electrical equipment and a number of other products. It also provides methods for estimating emissions of nitrous oxide (N_2O) from several products. In most of these applications, the SF_6, PFC, or N_2O is deliberately incorporated into the product to exploit one or more of the physical properties of the chemical, such as the high dielectric strength of SF_6, the stability PFCs, and the anaesthetic effect of N_2O. However, the applications discussed here have a wide range of emission profiles, ranging from immediate and unavoidable release of all of the chemical (e.g., use of PFCs as atmospheric tracers) to largely avoidable, delayed release from leak-tight products after 40 years of use (e.g., manufacture and use of sealed-pressure electrical equipment). The estimation methods presented in the chapter have been tailored to reflect these differences in emission profiles.

Section 8.2 details methods for estimating SF_6 and PFC emissions from electrical equipment. Section 8.3 details methods for estimating emissions from the manufacture and use of a wide variety of other industrial, commercial, and consumer products that contain SF_6 and PFCs, excluding those discussed elsewhere in this volume (e.g., PFC emissions from electronics manufacturing, which are discussed in Chapter 6). (Please see the introduction to Section 8.3 for the list of excluded sources.) Finally, Section 8.4 discusses methods for estimating N_2O emissions from anaesthetics, propellants, and other product uses.

8.2 EMISSIONS OF SF_6 AND PFCs FROM ELECTRICAL EQUIPMENT

8.2.1 Introduction

Sulphur hexafluoride (SF_6) is used for electrical insulation and current interruption in equipment used in the transmission and distribution of electricity. Emissions occur at each phase of the equipment life cycle, including manufacturing, installation, use, servicing, and disposal. Most of the SF_6 used in electrical equipment is used in gas insulated switchgear and substations (GIS) and in gas circuit breakers (GCB), though some SF_6 is used in high voltage gas-insulated lines (GIL), outdoor gas-insulated instrument transformers and other equipment. The aforementioned applications may be divided into two categories of containment. The first category is 'Sealed Pressure Systems' or 'Sealed-for-life Equipment', which is defined as equipment that does not require any refilling (topping up) with gas during its lifetime and which generally contains less than 5 kg of gas per functional unit.[1] Distribution equipment normally falls into this category. The second category is 'Closed Pressure Systems', which is defined to include equipment that requires refilling (topping up) with gas during its lifetime. This type of equipment generally contains between 5 and several hundred kg per functional unit. Transmission equipment normally falls into this category. Both categories of equipment have lifetimes of more than 30 to 40 years. In Asia, significant quantities of SF_6 are used in gas-insulated power transformers (GIT).

Electrical equipment is the largest consumer and most important use of SF_6, globally. It significantly contributes to worldwide SF_6 emissions. However, the importance of this source varies considerably from region to region and from country to country. The emissions from this category depend not only on the installed (banked) or consumed quantities of SF_6, but also very much on the tightness of the products and the handling processes applied. Regional average emission rates presently vary between far less than 1 percent to more than 10 percent. In general, emission rates have declined significantly since 1995. Targeted industry actions have reduced emissions by 50 to 90 percent in Europe and Asia (Ecofys, 2005; Aoyama, 2004). These actions include (1)

[1] Formal definitions of 'sealed-pressure system' and 'closed-pressure system' are contained in International Electrotechnical Commission (IEC) Standard 60694. (IEC, 1996)

designing equipment to require a smaller charge of SF_6 and to be more leak tight and (2) improving handling processes and handling equipment for all life cycle stages.[2]

In some regions (e.g., North America and Japan), perfluorocarbons (PFCs) are used as dielectrics and heat transfer fluids in power transformers. PFCs are also used for retrofitting CFC-113 cooled transformers. One PFC used in this application is perfluorohexane (C_6F_{14}). In terms of both absolute and carbon-weighted emissions, PFC emissions from electrical equipment are generally believed to be much smaller than SF_6 emissions from electrical equipment; however, there may be regional exceptions to this pattern.

8.2.2 Methodological issues

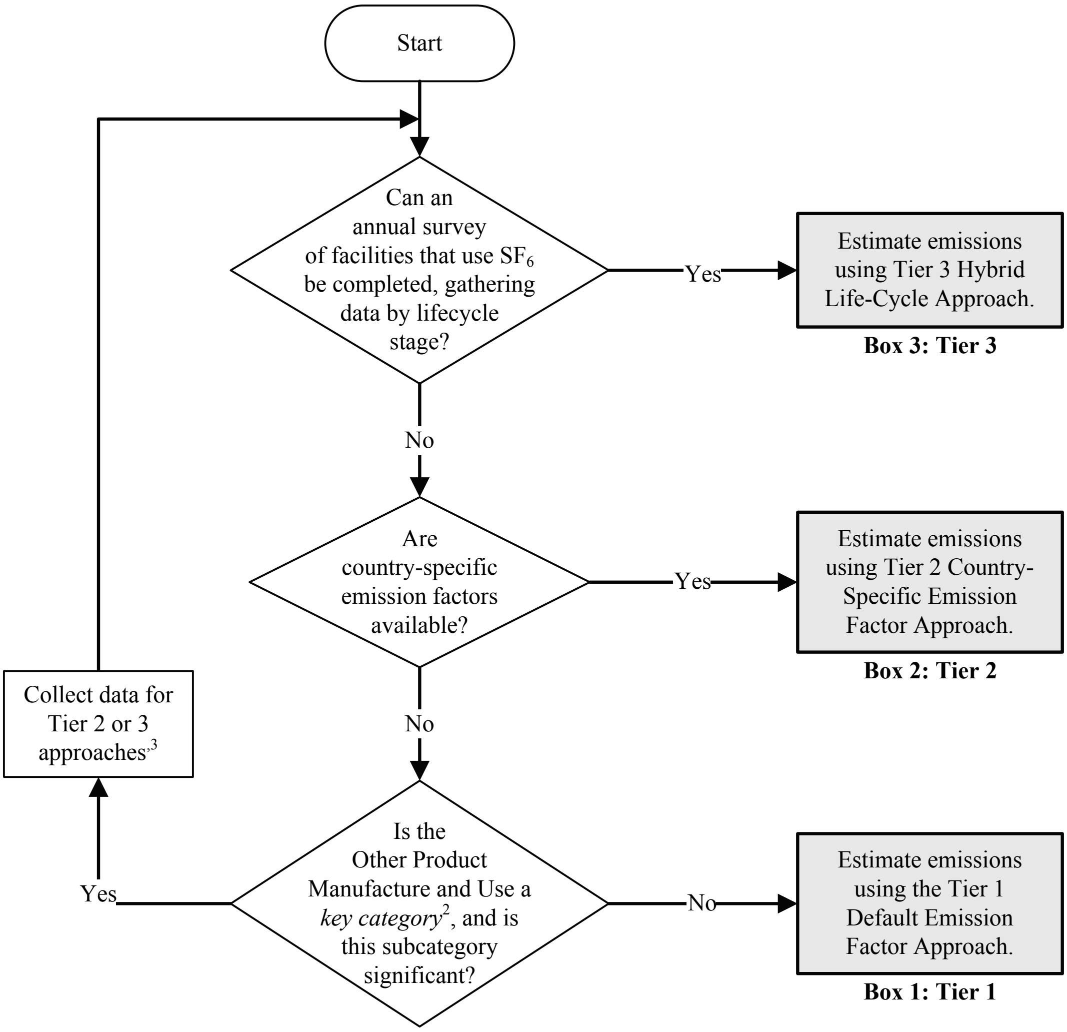
8.2.2.1 CHOICE OF METHOD

Emissions of SF_6 from electrical equipment can be estimated in a variety of ways with varying degrees of complexity and data intensity. This section describes *good practice* for using a Tier 1 method (the default emission-factor approach), a Tier 2 method (the country-specific emission-factor approach), and a Tier 3 method (a hybrid that can use either mass-balance or emission-factor approaches for different life cycle stages, depending on country-specific circumstances). Generally, emissions estimates developed using the Tier 3 method, which is implemented at the facility level, will be the most accurate. Estimates developed using the Tier 1 method will be the least accurate.

As is true for other emission sources, the tier selected will depend on data availability and whether or not the category is *key*. Figure 8.1, Decision Tree for SF_6 from Electrical Equipment, summarises the process for choosing among Tiers 3, 2, and 1. *Good practice* in choosing between the mass-balance and emission-factor variants of the Tier 3 approach is discussed in detail in Section 1.5 of Chapter 1. This choice will depend both on data availability and on country-specific circumstances. As a first step in assessing the importance of SF_6 emissions from electrical equipment and the other categories discussed in this chapter, inventory compilers are encouraged to contact chemical producers and suppliers as well as electrical equipment manufacturers and utilities and/or their industry associations. These organisations can provide basic information on chemical consumption and on equipment stocks and applications that can help the inventory compiler estimate emissions and identify sources that merit further investigation. They can also provide important advice and support in establishing more extensive data collection systems to support Tier 2 and Tier 3 estimates.

[2] International Council on Large Electric Systems (CIGRE) has published a guide on SF_6 handling, Guide for the Preparation of customized "Practical SF_6 Handling Instructions," Task Force B3.02.01, CIGRE Publication No.276, August 2005. (CIGRE, 2005)

Figure 8.1 Decision tree for SF_6 from electrical equipment[1]



Note:
1. In selecting an estimation method, it is *good practice* also to consider the criteria presented in Table 1.7, Chapter 1, Section 1.5 of this volume for choosing between the mass-balance and emission-factor variants of each tier.
2. 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.
3. It is *good practice* to contact National/Regional associations of utilities/users and manufacturers to collect, check, and aggregate actual and historical data.

TIER 1 METHOD – DEFAULT EMISSION FACTORS

The Tier 1 approach is the simplest approach for estimating SF_6 and PFC emissions from electrical equipment. (Henceforth in this section, 'SF_6' will be used to denote 'SF_6 and/or PFCs.') In this method, emissions are estimated by multiplying default regional emission factors by, as appropriate, the SF_6 consumption of equipment manufacturers and/or by the nameplate SF_6 capacity of the equipment at each life cycle stage beyond manufacturing in the country. The term Installation Emissions may be omitted if (1) installation emissions are not expected to occur (i.e., for closed-pressure equipment) or (2) installation emissions are included in the emission factor for emissions from Manufacturing or Use. Default emission factors are given in Tables 8.2 to 8.4.

It is good practice to use the following equation:

EQUATION 8.1
DEFAULT EMISSION FACTOR METHOD

$$\text{Total Emissions} = \text{Manufacturing Emissions} + \text{Equipment Installation Emissions} + \text{Equipment Use Emissions} + \text{Equipment Disposal Emissions}$$

Where:

Manufacturing emissions = Manufacturing Emission Factor • Total SF_6 consumption by equipment manufacturers

Equipment installation emissions = Installation Emission Factor • Total nameplate capacity of new equipment filled on site (not at the factory).

Equipment use emissions = Use Emission Factor • Total nameplate capacity of installed equipment. The 'use emission factor' includes emissions due to leakage, servicing, and maintenance as well as failures

Equipment disposal emissions = Total nameplate capacity of retiring equipment • Fraction of SF_6 remaining at retirement

TIER 2 METHOD – COUNTRY-SPECIFIC EMISSION FACTOR METHOD

The Tier 2 method uses the same basic equation as Tier 1, but requires reliable country-specific emission factors for each life cycle stage. Country-specific emission factors will be more accurate because they reflect the unique circumstances in which electrical equipment is used in a given country. In addition, if detailed data for equipment retirement are available, emissions due to retirement can be estimated more accurately. The expression for Equipment Disposal Emissions in the Tier 2 method includes terms accounting for SF_6 recovery at retirement and disposal, as follows:

EQUATION 8.2
EQUIPMENT DISPOSAL EMISSIONS UNDER COUNTRY-SPECIFIC EMISSION FACTOR METHOD

Equipment disposal emissions = Total nameplate capacity of retiring equipment • Fraction of SF_6 remaining at retirement • (1 – fraction of retiring equipment whose SF_6 is recovered • recovery efficiency • fraction of recovered SF_6 recycled, reused with no further treatment, or destroyed*)

*This final term is intended to account for emissions during chemical recycling and destruction.

Note that to be considered Tier 2, estimates must be developed using only country-specific emission factors.

TIER 3 HYBRID METHOD – EMISSIONS BY LIFE CYCLE STAGE OF EQUIPMENT

The Tier 3 method is the most accurate approach for estimating actual emissions of SF_6 from electrical equipment. This method is detailed but flexible, accommodating a wide range of national circumstances. The method is implemented at the facility level and includes separate equations for each phase of the life cycle of equipment, including equipment manufacture, installation, use, and disposal. Depending on the type of equipment, the life cycle stage, and country-specific circumstances, either a mass-balance approach or country- (or facility-) specific emission factors may be used. In general, it is *good practice* to use the mass-balance approach, except where (1) emission rates from a process are near or below the precision of the measurements required for the mass-balance approach (e.g., 3 percent of nameplate capacity per year or less), (2) equipment is never serviced during its lifetime (as is expected to be the case for sealed pressure equipment), or (3) equipment stocks are growing very rapidly, as may be the case in countries where electrical equipment has been introduced within the last 10-20 years.

The hybrid approach enhances accuracy by permitting use of the mass-balance approach for some processes and life cycle stages and the emission-factor approach for other processes and life cycle stages. However, the combination of different approaches also introduces opportunities for double-counting or overlooking emissions. Inventory compilers need to be aware of this problem and take steps to avoid it. Table 8.1, Avoiding Double-Counting or Overlooking Emissions, provides examples of both the problem and some potential solutions.

The annex to this chapter (Annex 8A) briefly describes an example of the Tier 3 approach as it has been applied in Germany. This example is intended to illustrate rather than prescribe; the precise approach taken by any given country will depend on country-specific circumstances.

Ideally, data are obtained for every equipment manufacturer, electricity transmission and distribution facility (utility), equipment disposer (which may be a manufacturer, electric utility, or other entity), and SF_6 recycling or destruction facility in the country, and the emissions of all manufacturers, utilities, disposers, and recycling or destruction facilities are summed to develop the national estimate. The basic equation is:

EQUATION 8.3
TIER 3 TOTAL EMISSIONS

$$\begin{aligned} Total\ Emissions = & \sum Equipment\ Manufacturing\ Emissions \\ & + \sum Equipment\ Installation\ Emissions \\ & + \sum Equipment\ Use\ Emissions \\ & + \sum Equipment\ Disposal\ and\ Final\ Use\ Emissions \\ & + \sum Emissions\ from\ SF_6\ Recycling\ and\ Destruction \end{aligned}$$

Where:

Equipment Manufacturing Emissions at the facility level can be estimated by Equations 8.4A and 8.4B.

Equipment Installation Emissions at the facility level can be estimated by Equations 8.5A and 8.5B.

Equipment Use Emissions at the facility level can be estimated by Equations 8.6A and 8.6B.

Equipment Disposal and Final Use Emissions at the facility level can be estimated by Equations 8.7A and 8.7B.

Emissions from SF_6 Recycling and Destruction at the facility level can be estimated by Equations 8.8 and 8.9.

In the above equation, national emissions for each phase are equal to the sum of the emissions of all equipment manufacturers, equipment users, equipment disposers, or SF_6 recyclers/destroyers at that phase. In practice, it is not always possible to obtain data for every facility; in these cases countries may use one of the extrapolation methods discussed in Section 8.2.2.3, Choice of Activity Data.

Equipment manufacturing emissions

Equipment manufacturing emissions can be estimated using either a *pure mass-balance* approach or a mixture (*hybrid*) of a mass-balance approach for some processes and an emission-factor based approach for others. The pure mass-balance approach is preferred except where a substantial fraction of a manufacturer's emissions come from processes whose emission rates fall below the precision of the measurements required for the mass-balance approach (e.g., 3 percent of nameplate capacity per year or less). In these cases, it is *good practice* to use emission factors to estimate emissions from the processes with very low emission rates and to use the mass-balance approach to estimate emissions from the other manufacturing processes.

Pure mass-balance approach: Using the pure mass-balance approach, the total emissions of each equipment manufacturer can be estimated using the following equation:

EQUATION 8.4A
EQUIPMENT MANUFACTURING EMISSIONS - PURE MASS-BALANCE

$$\begin{aligned} Equipment\ Manufacturing\ Emissions = & Decrease\ in\ SF_6\ Inventory + Acquisitions\ of\ SF_6 \\ & - Disbursements\ of\ SF_6 \end{aligned}$$

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 returned by equipment users or distributors with or inside of equipment + SF_6 returned to site after off-site recycling

Disbursements of SF_6 = SF_6 contained in new equipment delivered to customers + SF_6 delivered to equipment users in containers + SF_6 returned to suppliers + SF_6 sent off-site for recycling + SF_6 destroyed

Hybrid approach: This method first requires that manufacturers separate the gas flows associated with processes for which the mass-balance approach will be used from the gas flows associated with processes for which the emission-factor approach will be used. Emissions from the former can then be estimated using the approach outlined in Equation 8.4A. Emissions from the latter can be estimated by multiplying the total nameplate capacity of equipment undergoing each process (e.g., filling) by the country- or facility-specific emission factor for that process. Total emissions for each manufacturer are then estimated by summing the emissions from both sets of processes, using the following equation:

EQUATION 8.4B
EQUIPMENT MANUFACTURING EMISSIONS - HYBRID

$$Equipment\ Manufacturing\ Emissions = Equation\ 8.4A + \sum Nameplate\ capacity\ of\ equipment\ undergoing\ each\ process^{*} \bullet Emission\ factor\ for\ that\ process$$

* Excluding that covered by Equation 8.4A

Equipment installation emissions

Equipment installation emissions may be estimated using either a *mass-balance* or an *emission-factor* approach. Again, the mass-balance approach is preferred except where emission rates are very low.

Pure Mass-balance approach: Using the mass-balance approach, the total emissions of each equipment installer can be estimated using the following equation:

EQUATION 8.5A
EQUIPMENT INSTALLATION EMISSIONS - PURE MASS-BALANCE

$$Equipment\ Installation\ Emissions = SF_6\ used\ to\ fill\ equipment - Nameplate\ capacity\ of\ new\ equipment$$

Hybrid approach: This method first requires that users separate the gas flows associated with equipment for which the mass-balance approach will be used from the gas flows associated with equipment for which the emission-factor approach will be used. Emissions from the former can then be estimated using the approach outlined in Equation 8.5A. Emissions from the latter can be estimated by multiplying the newly installed nameplate capacity of each equipment type by the country- or facility-specific installation emission factor for that type. Total emissions for each installer are then estimated by summing the emissions from both sets of equipments, using the following equation:

EQUATION 8.5B
EQUIPMENT INSTALLATION EMISSIONS - HYBRID

$$Equipment\ Installation\ Emissions = \text{Equation 8.5A} + \sum Nameplate\ capacity\ of\ new\ equipment\ filled\ on\ site^{*} \bullet Installation\ emission\ factor$$

* Excluding that covered by Equation 8.5A

Equipment use emissions

Equipment use emissions may be estimated using either a *pure mass-balance* or a *hybrid* approach. The pure mass-balance approach is likely to be appropriate for countries where (1) electrical equipment that uses SF_6 has been in use for 10-20 years or more, and (2) emissions from sealed-pressure systems are likely to be negligible. The hybrid approach is likely to be appropriate for other countries.

Pure mass-balance approach: Using the pure mass-balance approach, the total emissions of each equipment user can be estimated using the following equation:

EQUATION 8.6A
EQUIPMENT USE EMISSIONS - PURE MASS-BALANCE

$$Equipment\ Use\ Emissions = SF_6\ used\ to\ recharge\ closed\ pressure\ equipment\ at\ servicing - SF_6\ recovered\ from\ closed\ pressure\ equipment\ at\ servicing$$

Hybrid approach: This method first requires that users separate the gas flows associated with equipment for which the mass-balance approach will be used from the gas flows associated with equipment for which the emission-factor approach will be used. Emissions from the former can then be estimated using the approach outlined in Equation 8.6A. Emissions from the latter can be estimated by multiplying the total nameplate capacity of each type of equipment by the country- or facility-specific emission factor for that type of equipment. The emission-factor approach is likely to be more accurate for sealed-pressure equipment everywhere and for all types of equipment in countries where electrical equipment has been used for less than 10-20 years. Total emissions for each user are then estimated by summing the emissions from both sets of equipment, using the following equation:

EQUATION 8.6B
EQUIPMENT USE EMISSIONS - HYBRID

$$\begin{aligned} &\textit{Equipment Use Emissions} = \text{Equation 8.6A} \\ &+ \sum \textit{Nameplate capacity of equipment installed}^{*} \bullet \textit{Use emission factor} \end{aligned}$$

* Excluding that covered by Equation 8.6A

Equipment disposal and final use emissions

Equipment disposal and final use emissions may be estimated using either a *pure mass-balance* or a *hybrid* approach, based on country-specific circumstances. In both the pure mass-balance and hybrid approaches, emissions from closed-pressure equipment are estimated using a mass-balance equation. In the pure mass-balance approach, emissions from sealed-pressure systems are also estimated using a mass-balance equation. In the hybrid approach, emissions from sealed-pressure systems are estimated using an emission-factor-based term.

Pure mass-balance approach: In countries where the gas-collection infrastructure (including recovery equipment, technician training, and economic or legal incentives to recover) is not very well-developed or widely applied, it is *good practice* to use the pure mass-balance approach, as follows:

EQUATION 8.7A
EQUIPMENT DISPOSAL AND FINAL USE EMISSIONS - PURE MASS-BALANCE

$$\begin{aligned} \textit{Disposal and Final Use Emissions} &= \textit{Emissions from closed} \cdot \textit{pressure equipment} \\ &+ \textit{Emissions from sealed} \cdot \textit{pressure equipment } (\textit{MB}) \end{aligned}$$

Where:

Disposal and final use emissions from closed-pressure equipment = Nameplate capacity of retired closed-pressure equipment – SF_6 recovered from retired closed-pressure equipment, and

Disposal and final use emissions from sealed-pressure equipment (*MB*) = Nameplate capacity of retired sealed-pressure systems – SF_6 recovered from retired sealed-pressure systems

Note that if the inventory compiler uses the emission-factor approach to estimate 'use emissions' from sealed-pressure equipment, a term should be subtracted from the second equation to avoid double counting. See Table 8.1, Avoiding Double-Counting or Overlooking Emissions: Two Examples, for this term.

Hybrid approach: In countries where the disposal of equipment is well controlled and understood (i.e., where an efficient gas collection infrastructure is in place) and where emissions from use of sealed-pressure equipment are accounted for under 'use' above, the hybrid approach may be used, as follows:

EQUATION 8.7B
EQUIPMENT DISPOSAL AND FINAL USE EMISSIONS - HYBRID

$$\begin{aligned} \textit{Disposal and Final Use Emissions} &= \textit{Emissions from closed pressure equipment} \\ &+ \textit{Emissions from sealed pressure equipment } (\textit{EF}) \end{aligned}$$

Where:

Disposal and final use emissions from closed-pressure equipment = Nameplate capacity of retired closed-pressure equipment – SF_6 recovered from retired closed-pressure equipment, and

Disposal emissions from sealed-pressure equipment (*EF*) = [(Nameplate capacity of retired sealed-pressure systems) – (Nameplate capacity of retired sealed-pressure systems • Use emission factor • Lifetime of equipment)] • (1 – fraction of retiring equipment whose SF_6 is recovered • recovery efficiency)

As noted above, emissions estimated using the above approach should be periodically checked, e.g., by using a pure mass-balance approach and/or assessing recovery frequency and practices. Inventory compilers should pay particular attention to the fraction of retiring equipment whose SF_6 is recovered and to the fraction of the charge that is recovered when recovery is performed ('recovery efficiency'). Even in countries where it is the norm to recover SF_6 from retiring equipment, some venting may occur, and the venting of just a few percent of the SF_6 in retiring equipment will drive emission rates far above the minimum that is technically achievable and that would otherwise be a reasonable basis for an emission factor.

Emissions from SF_6 recycling and destruction

Some SF_6 emissions occur after the chemical is recovered. These emissions include (1) emissions associated with recycling of SF_6, and (2) emissions associated with the destruction of SF_6. (Emissions associated with the shipment of SF_6 to off-site recyclers or destruction facilities are considered negligible.) Emissions from recycling of SF_6 are generally expected to be small — on the order of less than one percent of the total quantity fed into the recycling process. However, these emissions may be higher if state-of-the art handling equipment and practices are not used. In most cases, recycling is expected to occur on the site of the equipment manufacturer or user. In other cases, recycling may take place at a centralised recycling facility that is not associated with a chemical producer. Finally, recycling may take place on the premises of a chemical producer. Recycling emissions from chemical producers will be accounted for under chemical production (see Section 3.10 of this volume) and should not be included here.

Emissions associated with the destruction of SF_6 depend on the destruction efficiency of the process and the quantity of SF_6 fed into the process. Given the high stability and dissociation temperature of SF_6, the destruction efficiency may be as low as 90 percent. Thus, up to 10 percent of the SF_6 fed into the destruction process could be emitted. The quantity of gas fed into the destruction process is generally expected to be small compared to that recycled. However, this may vary from country to country.

It is *good practice* to develop country-specific emission factors for recycling and destruction that are based on full consideration of country-specific logistics and practices for SF_6 recycling and destruction.

Emissions from recycling of SF_6 may be estimated using the following equation:

EQUATION 8.8
EMISSIONS FROM RECYCLING OF SF_6*

Emissions from Recycling = Recycling emission factor • Quantity SF_6 fed into recycling process

*Emissions from recycling that occurs at chemical production facilities should be excluded.

Emissions from destruction of SF_6 may be estimated using the following equation:

EQUATION 8.9
EMISSIONS FROM DESTRUCTION OF SF_6

Emissions from Destruction = Destruction emission factor • Quantity SF_6 fed into destruction process

TABLE 8.1
AVOIDING DOUBLE-COUNTING OR OVERLOOKING EMISSIONS: TWO EXAMPLES

Example 1 – Double Counting	Example 2 – Omission
Situation: An emission-factor approach is used to estimate emissions from sealed-pressure equipment during use, and a mass-balance approach is used to estimate emissions during disposal of sealed-pressure equipment.	**Situation:** A mass-balance approach is used to estimate emissions during *use* of closed-pressure equipment, but an emission-factor approach is used to estimate emissions during *disposal* of closed-pressure.
Potential problem: Emissions during use may be double-counted because some of the SF_6 that is found to be missing when the equipment is disposed has already been counted as emitted during use.	**Potential problem:** Emissions that occur between the final servicing of the equipment and its disposal may be overlooked. These 'final use' emissions may account for a significant fraction of total use emissions, particularly if the equipment is refilled every 10 years or more.
Solution: Subtract lifetime use emissions (Nameplate capacity of retired sealed-pressure systems • Use emission factor • Lifetime of equipment) from emissions during disposal.	**Solution:** Use the mass-balance approach for both the use and disposal phases of the closed-pressure equipment life cycle.

A special case of the Tier 3 method: the utility-level, pure mass-balance approach

Countries that satisfy the *good practice* criteria for using the pure mass-balance approach beyond equipment manufacturing (i.e., countries where emissions during equipment installation, use, and disposal account for 3 percent or more of facility-level gas flows, where electrical equipment has been used for 10-20 years or more, and where emissions from sealed-pressure equipment are negligible), may, with little or no loss of accuracy, use a simplified version of the Tier 3 method to estimate emissions during equipment use. When summed together and reformulated in terms of facility-level gas flows, equations 8.5A, 8.6A, and 8.7A result in the following equation:

EQUATION 8.10
UTILITY-LEVEL MASS-BALANCE APPROACH

User Emissions = Decrease in SF_6 Inventory + Acquisitions of SF_6 – Disbursements of SF_6 – Net Increase in the Nameplate Capacity of Equipment

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 equipment manufacturers or distributors with or inside of equipment + SF_6 returned to site after off-site recycling

Disbursements of SF_6 = SF_6 contained in equipment that is sold to other entities + SF_6 returned to suppliers + SF_6 sent off-site for recycling + SF_6 destroyed

Net Increase in Nameplate Capacity of Equipment = Nameplate Capacity of New Equipment – Nameplate Capacity of Retiring Equipment

Although the utility-level approach is less detailed than the full life cycle approach, it is simple, and for those countries whose national circumstances permit its use, it provides estimates that are closely related to actual gas loss.

SF_6 EMISSIONS FROM MANUFACTURING OF ELECTRICAL COMPONENTS

Some electrical equipment components may contain 1 percent or less by weight of SF_6 in the insulating medium of the product. These components include but are not limited to medium voltage cast resin instrument transformers and high voltage bushings. In medium voltage (up to 52 kV) cast resin instrument transformers, SF_6 is used to fill up micro-cavities in the resin insulation to improve the dielectric quality and durability of the product. In High Voltage (above 52 kV) bushings, SF_6 is used as the blowing agent for the polyurethane resin in certain parts of the insulation system to improve the dielectric quality and durability of the product.

SF_6 emissions solely result from the casting/blowing process for the solid insulation of the product. All SF_6 used is assumed to be emitted at the manufacturing stage. To estimate emissions from this source, the pure mass-balance approach for equipment manufacturers (Equation 8.4A) may be used, setting the SF_6 contained in new equipment equal to zero.

Emission reduction measures focus on limiting losses/improving rate of recycling by suction devices and/or improved casting processes. SF_6 in this type of high voltage bushings may be replaced by another blowing agent in the future.

8.2.2.2 CHOICE OF EMISSION FACTORS

Because emission rates can vary not only from country to country but from facility to facility, inventory compilers using emission-factor based methods are encouraged to develop and use their own emission factors. Surveying a representative sample of equipment manufacturers and utilities within the country is an effective way to develop such factors. In general, it is *good practice* to document the evidence and reasoning supporting the selected emission factors, and to review these factors at least every 5 years.

Factors that influence emission rates include the design of the equipment (which varies depending on when and where the equipment was manufactured), SF_6-handling practices, availability of state-of-the-art handling equipment, SF_6 prices, and regulations (e.g., recovery requirements). Variation of any one of these can change emission rates over time or among countries.

TIER 1 METHOD

Suggested default emission factors have been developed for some regions based on recent research. These factors are shown in Tables 8.2-8.4 below.

It is *good practice* to select default emission factors from countries and regions with equipment designs and SF_6-handling practices similar to those of the country whose emissions are being estimated. Because Japan and Europe supply most of the global demand for electrical equipment, equipment designs are likely to be similar to those of either Japan or Europe. With the exception of the factors for the U.S., regional default emission factors are those documented for 1995, i.e., before any special industry actions for emission reduction were implemented. In Japan in 1995, approximately 70 percent of the SF_6 used to test equipment during manufacture was recovered, and a similar percentage was recovered during equipment maintenance for equipment rated 110 kv or higher. (The 70 percent recovery fraction reflected recovery from an initial pressure of about 5 bars absolute to a final pressure of 1 to 1.5 bars absolute.) No gas was recovered from equipment rated lower than 110 kV (Maruyama *et al*., 2000). In Europe in 1995, gas supply systems for equipment manufacture were usually decentralised, and filling tubes were not self-closing. Gas was recovered to approximately 0.05 bars absolute during manufacturing and maintenance (Ecofys, 2005).

TABLE 8.2
SEALED PRESSURE ELECTRICAL EQUIPMENT (MV SWITCHGEAR) CONTAINING SF_6: DEFAULT EMISSION FACTORS

Phase / Region	Manufacturing (Fraction SF_6 Consumption by Manufacturers)	Use (Includes leakage, major failures/arc faults and maintenance losses) (Fraction per Year of Nameplate Capacity of All Equipment Installed)	Disposal (Fraction Nameplate Capacity of Disposed Equipment)	
			Lifetime (years)	Fraction of charge remaining at retirement [b]
Europe [a]	0.07	0.002	>35	0.93
Japan [c]	0.29	0.007	Not reported	0.95

[a] Source: 'Reductions of SF_6 Emissions from High and Medium Voltage Electrical Equipment in Europe,' Ecofys, June, 2005.

[b] This refers to the percentage of the original charge or nameplate capacity remaining in the equipment at end of life; it represents the fraction of the nameplate capacity potentially emitted before the equipment is recycled or disposed.

[c] Based on data reported by the Federation of Electric Power Companies (FEPC) and the Japan Electrical Manufacturers' Association (JEMA) (FEPC and JEMA, 2004). These organisations did not distinguish among equipment types in reporting average emission factors. The factors are therefore intended to be applied to all equipment types, including sealed pressure systems, closed pressure systems, and gas-insulated transformers.

Note: The emission factors above reflect the practices and technologies in place in 1995, i.e., before mitigation measures were implemented. References per footnotes a and c show how these developed further upon successive implementation of various voluntary measures later on. Another reference (Schwarz, 2006) relates state-of–the-art emission factors to mitigation measures in Germany.

TABLE 8.3 CLOSED PRESSURE ELECTRICAL EQUIPMENT (HV SWITCHGEAR) CONTAINING SF_6: DEFAULT EMISSION FACTORS				
Phase / Region	Manufacturing (Fraction SF_6 Consumption by Manufacturers)	Use (Includes leakage, major failures/arc faults and maintenance losses) (Fraction per Year of Nameplate Capacity of All Equipment Installed)	Disposal (Fraction Nameplate Capacity of Disposed Equipment)	
			Lifetime (years)	Fraction of charge remaining at retirement [c]
Europe [a]	0.085[b]	0.026	>35	0.95
Japan [d]	0.29 [b]	0.007	Not reported	0.95
U.S.[e]	[f]	0.14 [g]	>35	[h]

[a] Source: 'Reductions of SF_6 Emissions from High and Medium Voltage Electrical Equipment in Europe,' Ecofys, June, 2005.

[b] Includes emissions from installation

[c] This refers to the percentage of the original charge or nameplate capacity remaining in the equipment at end of life; it represents the fraction of the nameplate capacity emitted before the equipment is recycled or disposed.

[d] Based on data eported by the Federation of Electric Power Companies (FEPC) and the Japan Electrical Manufacturers' Association (JEMA) (FEPC and JEMA, 2004). These organisations reported average emission factors that include emissions from all equipment types, including sealed pressure systems, closed pressure systems, and gas-insulated transformers.

[e] From the U.S. Inventory of Greenhouse Gases and Sinks, 1990-2002. (U.S. EPA, 2004). Value is from 1999, first year for which representative country-specific data were available.

[f] No country-specific value available.

[g] Includes emissions from installation.

[h] Disposal emissions are included in use emission factor in the US.

Note: The emission factors above reflect the practices and technologies in place in 1995, i.e., before mitigation measures were implemented. References per footnotes a and d show how these developed further upon successive implementation of various voluntary measures later on. Schwarz (2006) relates state-of–the-art emission factors to mitigation measures in Germany.

TABLE 8.4 GAS INSULATED TRANSFORMERS CONTAINING SF_6: DEFAULT EMISSION FACTORS				
Phase / Region	Manufacturing (Fraction SF_6 Consumption by Manufacturers)	Use (Includes leakage, major failures/arc faults and maintenance losses) (Fraction per Year of Nameplate Capacity of All Equipment Installed)	Disposal (Fraction Nameplate Capacity of Disposed Equipment)	
			Lifetime (years)	Fraction of charge remaining at retirement [a]
Japan [b]	0.29	0.007	Not reported	0.95

[a] This refers to the percentage of the original charge or nameplate capacity remaining in the equipment at end of life; it represents the fraction of the nameplate capacity emitted before the equipment is recycled or disposed

[b] Based on data reported by the Federation of Electric Power Companies (FEPC) and the Japan Electrical Manufacturers' Association (JEMA) (FEPC and JEMA, 2004). These organisations did not distinguish among equipment types in reporting average emission factors. The factors are therefore intended to be applied to all equipment types, including sealed pressure systems, closed pressure systems, and gas-insulated transformers.

Note: The emission factors above reflect the practices and technologies in place in 1995, i.e., before mitigation measures were implemented. References per footnote b show how these developed further upon successive implementation of various voluntary measures later on. Schwarz (2006) relates state-of–the-art emission factors to mitigation measures in Germany.

TIER 2 METHOD

Emission factors for the Tier 2 method are generally developed on the basis of data collected from representative manufacturers and utilities that track emissions by life cycle stage, essentially using the Tier 3, pure mass-balance method at their facilities for at least one year. (The disposal emission factor should also account for emissions that occur downstream of the utility site, as discussed below.) These emissions by life cycle stage are then divided by the corresponding SF_6 consumption or equipment capacity at that life cycle stage (i.e., SF_6 consumption for manufacturing emissions, total existing equipment capacity for use emissions, and retiring equipment capacity for final use and disposal emissions) to develop emission factors. For example, to develop an emission factor for manufacturing, total emissions from the survey of manufacturers are summed and then divided by the total SF_6 consumption of surveyed manufacturers. This emission factor can then be applied to the manufacturing sector as a whole, using national SF_6 consumption by manufacturers. A similar approach can be used to estimate and apply emission factors for equipment use.

The emission factor for disposal should fully account for three factors: (1) the recovery frequency (the fraction of equipment whose charge is recovered), (2) the recovery efficiency (the fraction of charge recovered when recovery is performed), and (3) the emissions from recycling and destruction of the recovered gas. The quantities in (1) and (2) will be automatically accounted for in emission factors based on use of the Tier 3 mass-balance method at representative utilities. However, the quantity in (3) reflects emissions that occur both on site and downstream of the utility/user. Thus, it must be accounted for separately. See the Tier 3 Method discussion below for guidance on estimating recycling and destruction emission factors.

The facility-level variant of the Tier 3 approach may also be used to develop emission factors, but these will be applied at a more aggregated level, i.e., to equipment manufacturing and use (where the latter includes installation, use, and disposal) rather than to each lifecycle stage.

TIER 3 METHOD

Because the Tier 3 method encourages the use of emission factors only when emission rates from processes are quite low (e.g., 3 percent of nameplate capacity per year or less) or when electrical equipment has only recently been introduced into a country, emission factors for this method may be difficult to measure directly using a mass-balance approach. To estimate Tier 3 emission factors, therefore, engineering studies may be used, identifying potential leak points and loss mechanisms and assigning probabilities and emission rates to these. Expected losses from service and maintenance should be factored into overall emission rates, as should losses from rare but catastrophic events that result in the loss of most of the equipment’s charge. Past experience with similar processes and designs should be considered. To ascertain and verify emission factors for use, surveys of equipment in the field may be carried out after several years of use, with the number of years determined by the expected leak rate and the limit of detection of the measuring equipment. Manufacturer statistics on equipment failure rates should be monitored to help ensure that catastrophic or gradual loss rates are not higher than expected. Disposal emissions are extremely sensitive to recovery frequencies (the fraction of equipment whose charge is recovered) and to recovery efficiencies (the fraction of charge recovered when recovery is performed, which, due to time considerations, may be lower than what is technically achievable). Thus, these should be monitored and documented carefully before establishing disposal emission factors.

Emission factors for recycling of recovered SF_6 may be based on professional judgement. Emission factors for destruction may be based on the rated destruction efficiency of the destruction technology, assuming that the technology is maintained and operated in a way that maintains its rated destruction efficiency.

8.2.2.3 CHOICE OF ACTIVITY DATA

The activity data necessary to carry out the various estimation methods may be gathered from chemical manufacturers, equipment manufacturers, equipment users, and equipment disposers and/or their industry associations in the country or the region. The best source(s) of data vary depending upon the method and national circumstances.

TIER 1 METHOD

SF_6 consumption by equipment manufacturers: SF_6 consumption by equipment manufacturers can be estimated using information from the manufacturers on their purchases of SF_6, their returns of SF_6 to chemical producers, and changes in their inventory of SF_6 in containers. If information from equipment manufacturers is unavailable or incomplete, information from chemical producers and/or distributors on their sales to equipment manufacturers (less any returns) may be used.

***Nameplate capacity of new and retiring equipment*:** Nameplate capacity can be estimated using one or more of the following data sources: (1) information from equipment manufacturers/importers on the total nameplate capacity of the equipment they manufacture or import and export, (2) information from utilities on the total nameplate capacity of the equipment they install and retire each year, or (3) if information from (1) or (2) is not available, information from chemical manufacturers/importers on their sales of SF_6 to equipment manufacturers. The first two data sources are preferable to the third, because gas sales to equipment manufacturers will differ from the nameplate capacity of new equipment installed in the country, particularly if equipment imports or exports are significant. In estimating the nameplate capacities of new and retiring equipment, inventory compilers should include the nameplate capacity of imported equipment and exclude the nameplate capacity of exported equipment. (See Section 7.5, Refrigeration, Box 7.1, Accounting for Imports and Exports of Refrigerant and Equipment, for a full discussion of how to treat imports and exports in estimating these quantities. This guidance is directly applicable to this category.)

In the case of retiring equipment, capacity or sales information should be historical, starting in the year when the current year's retiring equipment was built. Typical values for the lifetime of electrical equipment range from 30 to 40 years. If information on the total nameplate capacity of retiring equipment is not available, it can be estimated from new nameplate capacity, using the estimated annual growth rate of equipment capacity. In estimating the growth rate, it is *good practice* to consider both the number of pieces of equipment sold each year and the average nameplate capacity of the equipment.[3]

The following equation can be used to estimate retiring nameplate capacity, if this information is not available directly:

EQUATION 8.11
RETIRING NAMEPLATE CAPACITY

$$\text{Retiring Nameplate Capacity} = \text{New Nameplate Capacity} / (1 + g)^{L}$$

Where:

L = equipment lifetime

g = rate of growth

According to a 2004 global survey, the average annual growth rate of SF_6 sales to equipment manufacturers between 1970 and 2000 was approximately 9 percent. (Smythe, 2004). In the absence of country-specific information, a default factor of 9 percent may be used.

***Total nameplate capacity of installed equipment*:** The total nameplate capacity of equipment can be estimated using the same data sources as are used to estimate the nameplate capacity for new and retiring equipment. If data from equipment manufacturers is used, it should include data on sales over the full lifetime of the equipment (30 to 40 years).

TIER 2 METHOD

Quantities can be estimated as for Tier 1 above.

TIER 3 METHOD

To implement the Tier 3 method, information must be gathered at two levels. At the facility level, gas flows must be tracked correctly according to the Tier 3 method. At the national level, information from facilities (manufacturers, users, and disposers of equipment) must be collected, checked, summed, and if necessary, extrapolated to include estimates of emissions from facilities in the country that do not collect data. Guidance regarding the information to be tracked by facilities is provided in the descriptions of the Tier 3 method above. Gas consumption may be measured by weighing gas cylinders before and after filling or recovery operations or at the beginning and end of the year or by using flow meters (e.g., during equipment manufacturing). At the national level, trade associations for equipment manufacturers and utilities can be very helpful in disseminating knowledge to their members regarding the Tier 3 approach and in helping their members to track and report data consistently and transparently. Trade associations can also act as third parties to aggregate confidential or sensitive data so that it can be released (in aggregate) to the public. Where trade associations are not active, national inventory compilers can facilitate the collection of information at the facility level, as well as the reporting and verification of this information, by developing model emission tracking protocols or by adopting existing industry protocols that embody the Tier 3 approach. These protocols can then be distributed to the manufacturers, users, and disposers of electrical equipment. Electronic protocols such as spreadsheets further facilitate the tracking, documentation, and reporting of emissions and minimize opportunities for arithmetic error.

Because emission rates can vary from region to region and facility to facility, it is *good practice* to survey as many facilities as practical. In addition to manufacturers and utilities, countries should survey industrial sites and other non-utility sites if these contribute substantially to emissions from electrical equipment. If the number of facilities in a country is large (e.g., over 50), it may be difficult to achieve complete reporting. In these cases, countries may estimate emissions from non-reporting facilities by applying the Tier 2 method to these facilities

[3] While the number of pieces of equipment sold each year has generally grown, the average nameplate capacity has generally declined.

or by using alternative activity data as described in Chapter 2 of Volume 1, Approaches to Data Collection. Sector-specific considerations in selecting and using alternative activity data are discussed below.

For sealed pressure equipment (which is widely dispersed among industrial users as well as utilities), manufacturers and distributors are likely to be the best source of complete information on national bank sizes and emission rates. To develop an accurate estimate, inventory compilers should survey manufacturers regarding their sales of equipment between the present and the time when currently retiring equipment was installed, or, if equipment has not yet begun to be retired, between the present and the time when the equipment was introduced into the country.

Sector-specific considerations in selecting and using alternative activity data for Tier 3

As discussed above, even when implementing a Tier 3 method it may not be possible to obtain data from all facilities. To obtain complete coverage of facilities, it is possible to use alternative activity data. For estimating emissions from non-reporting manufacturers, it may be possible to use the manufacturing capacity and/or collective market share (in terms of functional units) of the non-reporting manufacturers. For estimating emissions from non-reporting utilities, possible alternative data sets or drivers include (but are not limited to) the length of transmission lines, the combined length of transmission and distribution lines, or the number of substations of the non-reporting utilities. Transmission kilometres are likely to be a good predictor of emissions where most SF_6 is used in high voltage transmission equipment, as in the U.S. (A discussion of how transmission kilometres are used to estimate emissions in the U.S. can be found in Volume 1, Chapter 2, Approaches to Data Collection.) Where a high percentage of SF_6 is used in medium voltage distribution equipment or in gas-insulated substations, one of the other types of data may be appropriate.

Wherever alternative data sets are used, it is important to derive emission factors from a representative set of facilities to ensure that the resulting estimate of national SF_6 emissions is unbiased. Note that more than one factor may be appropriate, e.g., for different size utilities or for utilities in urban vs. rural locations. Because SF_6 use and emission patterns can change over time, it is *good practice* to update the analysis and emission factor(s) at least every five years. (For example, emission rates may change as compact and leak-tight equipment replaces larger, leakier equipment and as sealed pressure equipment grows in importance.) In some cases, countries may be able to make use of emission factors developed in countries with similar electrical grids. In these cases, it is *good practice* to document the similarities between the grids before applying the emission factor from the other country.

8.2.2.4 COMPLETENESS

Completeness for this source category requires accounting for emissions during the manufacture, use, and disposal of equipment, and during the recycling or destruction of SF_6 recovered from equipment. Where Tier 3 methods are used, completeness requires that all significant SF_6 users (manufacturers and utilities) be identified. When facility-level emissions data are not available from all of these users, emission estimates should be developed for them using one of the extrapolation methods described in Section 8.2.2.3, Choice of Activity Data.

In the manufacturing sector, this requires assessing emissions from:

- Manufacture of gas insulated switchgear (GIS), gas circuit breakers (GCB), high voltage gas-insulated lines (GIL), outdoor gas-insulated instrument transformers, reclosers, switches, and ring main units of both types (sealed and closed pressure systems, respectively up to and above 52 kV), and other equipment including but not limited to cast resin instrument transformers and certain types of bushings using SF_6 either as gas for the casting process or as a blowing agent;
- Manufacturers of gas-insulated power transformers (GIT);
- Minor SF_6 users, including equipment remakers and servicing companies;
- The SF_6 distribution chain from producers and distributors to manufacturing facilities.

In the utility and disposal sector, this requires accounting for all SF_6 losses associated with:

- New electrical equipment installations;
- Leakage, refill, maintenance, and equipment failures;
- Disposal of discarded electrical equipment;
- Recycling or destruction of SF_6 recovered from equipment (but recycling emissions from chemical producers should be counted under chemical production, which is covered in Section 3.10 of this volume).

It is *good practice* to identify and include industrial, military and small-utility applications if these are believed to contribute substantially to total emissions from the electrical equipment source category.

8.2.2.5 DEVELOPING A CONSISTENT TIME SERIES

When estimating emissions from equipment users over a time series, it is necessary to consider SF_6 emissions associated with the full set equipment at users' sites for the years of interest. Thus, when using approaches based on banks and emission-factors (e.g., the Tier 2 approach), countries will require information on the capacity and emission rate of equipment purchased and installed for 30 to 40 years preceding the years of interest.

In the user sector, if historical data are unavailable, *good practice* is to develop estimates using the top-down method, i.e., develop a model based on professional judgement by industry experts and inventory compilers and then calibrate as discussed below. Average leak rates for new equipment and the frequency of refill and routine maintenance all decreased from 1970 to 1995, and this trend has continued to the present. It is *not good practice* to apply current (post-2000) overall loss rates to historical years. Aggregate loss rates estimated from historical sales can be used in this case as well.

On the manufacturing side, if historical data for developing base year emissions for 1990/1995 are not available, the top-down method calibrated to more accurate estimates for current years may be applied. Since SF_6 handling practices of equipment manufacturers have changed substantially since 1995 (e.g., more gas is recovered), it is *not good practice* to apply current loss rates to historical estimates. Aggregate loss rates determined from global and regional sales and emission analyses may assist in providing an unbiased estimate for earlier years. It is *good practice* to recalculate emissions according to the guidance provided in Volume 1, Chapter 5, with all assumptions clearly documented.

8.2.3 Uncertainty assessment

When using the Tier 3 method, the resulting emissions estimates will have an accuracy of the order of ± 10 percent, and are likely to be more accurate than estimates developed using Tier 2 or Tier 1 methods.. If surveys are incomplete, the associated uncertainty will be greater. Particular sources of uncertainty may include:

- SF_6 exported by equipment manufacturers (either in equipment or separately in containers);
- SF_6 imported by foreign equipment manufacturers (either in equipment or in containers);
- SF_6 returned to foreign recycling facilities;
- Measurements of mass, density, and pressure (generally accurate to within one or two percent of the total quantity massed, but if emission rates are low, this may be a substantial percentage of those rates);
- Emission factors;
- Time lag between emissions and servicing;[4]
- Lifetime of the equipment;
- Regression error associated with any extrapolative approaches.

The estimated uncertainties in the default emission factors for the Tier 1 method are shown in Table 8.5, Uncertainties for Default Emission Factors for SF_6 Emissions from Electrical Equipment. These values are based on the variation observed in emission factors in Europe. If the factors in Tables 8.2-8.4 are applied outside the countries and/or regions in which they were developed, uncertainties will be greater.

[4] See Chapter 1 of this volume for a discussion of this issue.

TABLE 8.5
UNCERTAINTIES FOR DEFAULT EMISSION FACTORS AND LIFETIME

Phase / Equip-ment Type	Manufacturing	Use (Includes leakage, major failures/arc faults and maintenance losses)	Disposal	
			Lifetime (years)	Fraction of charge remaining at retirement
Sealed-Pressure[a]	±20%	±20%	-20%/+40%	[d]
Closed-Pressure[b]	±30%	±30%	-10%/+40%	[d]
Gas Insulated Transformers[c]	±30%	±30%	-10%/+40%	[d]

[a] Estimated from 'Reductions of SF_6 Emissions from High and Medium Voltage Electrical Equipment in Europe,' Ecofys, June, 2005;no uncertainties available from Japan; not relevant for USA..

[b] Estimated from 'Reductions of SF_6 Emissions from High and Medium Voltage Electrical Equipment in Europe,' Ecofys, June, 2005; U.S. emission factors have higher uncertainty for manufacturing (±70%) and slightly lower uncertainty for use (±15%) (U.S. Inventory of Greenhouse Gases and Sinks (U.S. EPA, 2004)). No uncertainties available from Japan.

[c] Estimated by analogy with closed pressure systems; actual uncertainties may be somewhat higher. No uncertainties available from Japan.

[d] No uncertainties available on fraction of charge remaining at retirement.

8.2.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

8.2.4.1 QUALITY ASSURANCE/QUALITY CONTROL

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. Additional quality control checks as outlined in Volume 1, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

Additional procedures specific to electrical equipment are outlined below:

Comparison of emissions estimates using different approaches

Inventory compilers should sum the facility-level data used as part of a bottom-up, Tier 3 method and cross-check the data against national level emissions calculated using country-level data (the Tier 2 method) and/or country-level data with the IPCC default emission factors (the Tier 1 method). The Tier 2 method may similarly be checked against the Tier 1 method. Countries may also compare their results to those derived using a country-level mass-balance approach, as described in Equations 7.3 and 7.9 of Chapter 7. If countries do not have manufacturing facilities, they may also compare their estimates against potential emissions estimated using national apparent consumption data.

Review of facility-level emissions data

In all instances where site-specific emissions data are obtained through surveys, inventory compilers should compare the emission rates between sites (adjusting for relative size or capacity) to identify significant outliers. They should investigate any outliers to determine if the differences can be explained or if there is an error in the reported emissions. As noted in Section 8.2.2.3, national inventory compilers can facilitate both the collection and verification of information at the facility level by distributing emission tracking protocols that embody the Tier 3 approach. Electronic protocols such as spreadsheets are particularly useful, as they minimize opportunities for arithmetic error. The calculations included in these protocols (whether electronic or not) can then be checked after they are submitted.

Comparison of emission rates with those of other countries

Inventory compilers should compare effective emission factors (loss rates) with values reported by other countries in the region, or with defaults published in the scientific literature for equipment with a similar design and similar level of emissions control. Transparent reporting, as outlined above, is essential for making international comparisons.

8.2.4.2 REPORTING AND DOCUMENTATION

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Section 6.11. It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

Some examples of specific documentation and reporting relevant to this source category ensuring transparency in reported emissions estimates are provided in Table 8.6, Good Practice Reporting Information for SF_6 Emissions from Electrical Equipment by tier.

Confidentiality issues may arise where there are limited numbers of manufacturers or utilities. In these cases, aggregated reporting for the total electrical equipment sector, or even total national SF_6 applications, may be necessary. National or regional associations of users and manufacturers may be willing to collect, check, and aggregate data, particularly when they have collected such data historically. They can then report the aggregated information to the inventory compiler, resolving the problem of confidentiality. If survey responses cannot be released as public information, third party review of survey data may be necessary to support data verification efforts.

TABLE 8.6
GOOD PRACTICE REPORTING INFORMATION FOR SF_6 EMISSIONS FROM ELECTRICAL EQUIPMENT BY TIER

Data	Tier 3	Tier 2	Tier 1
Annual, country-wide consumption of SF_6 by equipment manufacturers		X	X
Nameplate capacity of new equipment	X	X	X
Nameplate capacity of existing equipment	X*	X	X
Nameplate capacity of retiring equipment	X	X	X
SF_6 destroyed	X		
SF_6 in inventory at beginning of year	X		
SF_6 in inventory at end of year	X		
SF_6 purchased by facility	X		
SF_6 sold or returned by facility	X		
SF_6 sent off-site for recycling	X		
SF_6 returned to site after recycling	X		
SF_6 used to fill new equipment	X		
SF_6 used to service equipment	X		
SF_6 recovered from retiring equipment	X		
Emission/recovery factors	X*	X	
Documentation for factors, if country-specific	X*	X	

*Required for some variants of the methods.

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 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., AWACS (Airborne Warning and Control System), 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.

8.3.2 Methodological issues

8.3.2.1 CHOICE OF METHOD

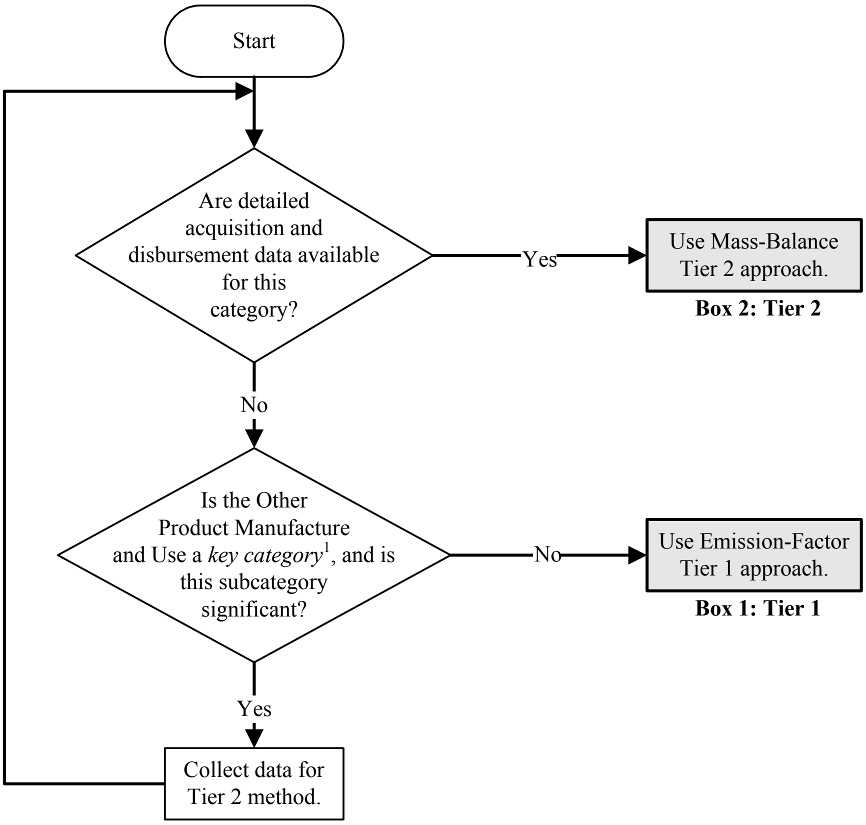
The *good practice* method is to use either consumption data from users of SF_6 or PFCs or top-down import, export and consumption data from national SF_6 producers and distributors, disaggregated by major type of SF_6 or PFC application. Acquiring this data will entail a survey of all producers and 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)

$$\text{User Emissions} = 740 \text{ kg} \bullet \text{Number of planes in AWACS fleet}$$

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 world wide (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 • (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.[5] 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, ECM (Electronic Counter Measures), 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).

[5] 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.

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.

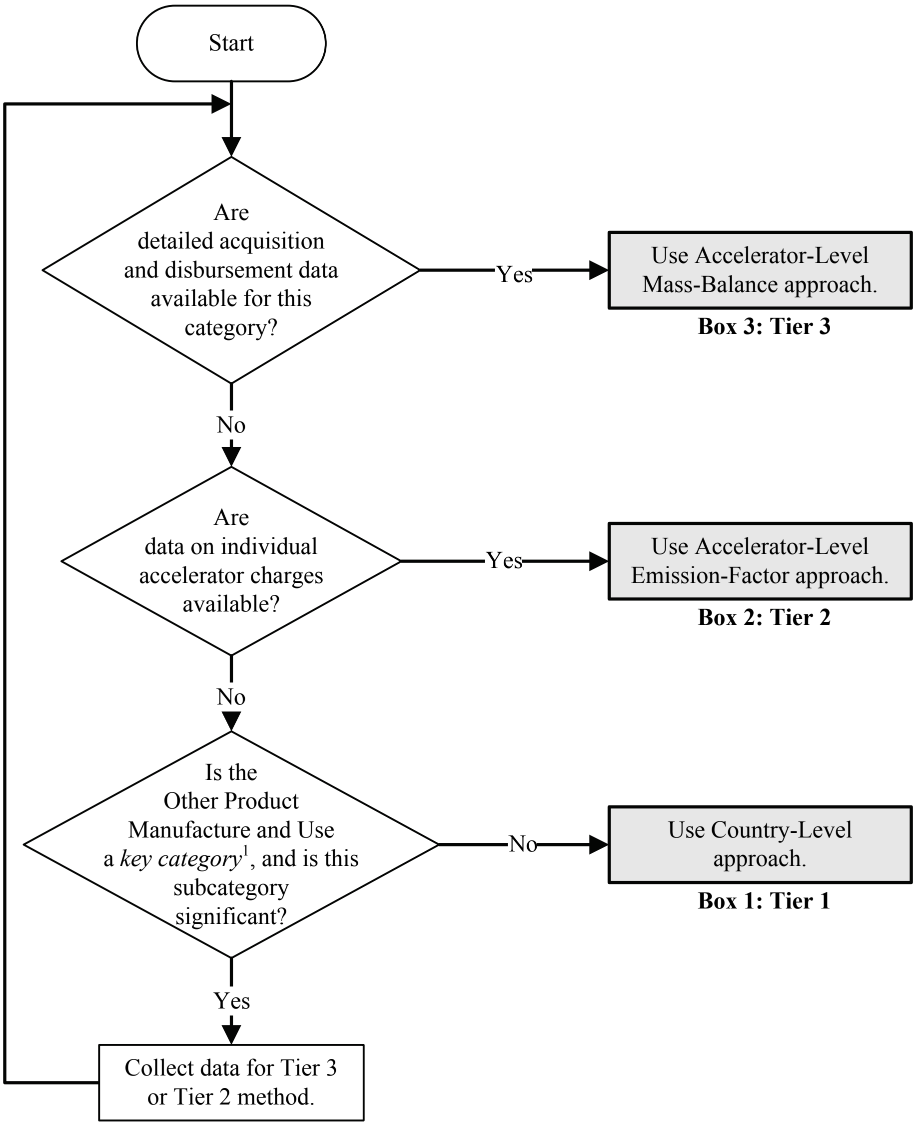
SF_6 EMISSIONS FROM UNIVERSITY AND RESEARCH PARTICLE ACCELERATORS

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.

Figure 8.3 Decision tree for SF_6 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) • (SF_6 Use Factor) • (SF_6 Charge Factor, kg) • (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)

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

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)

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

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

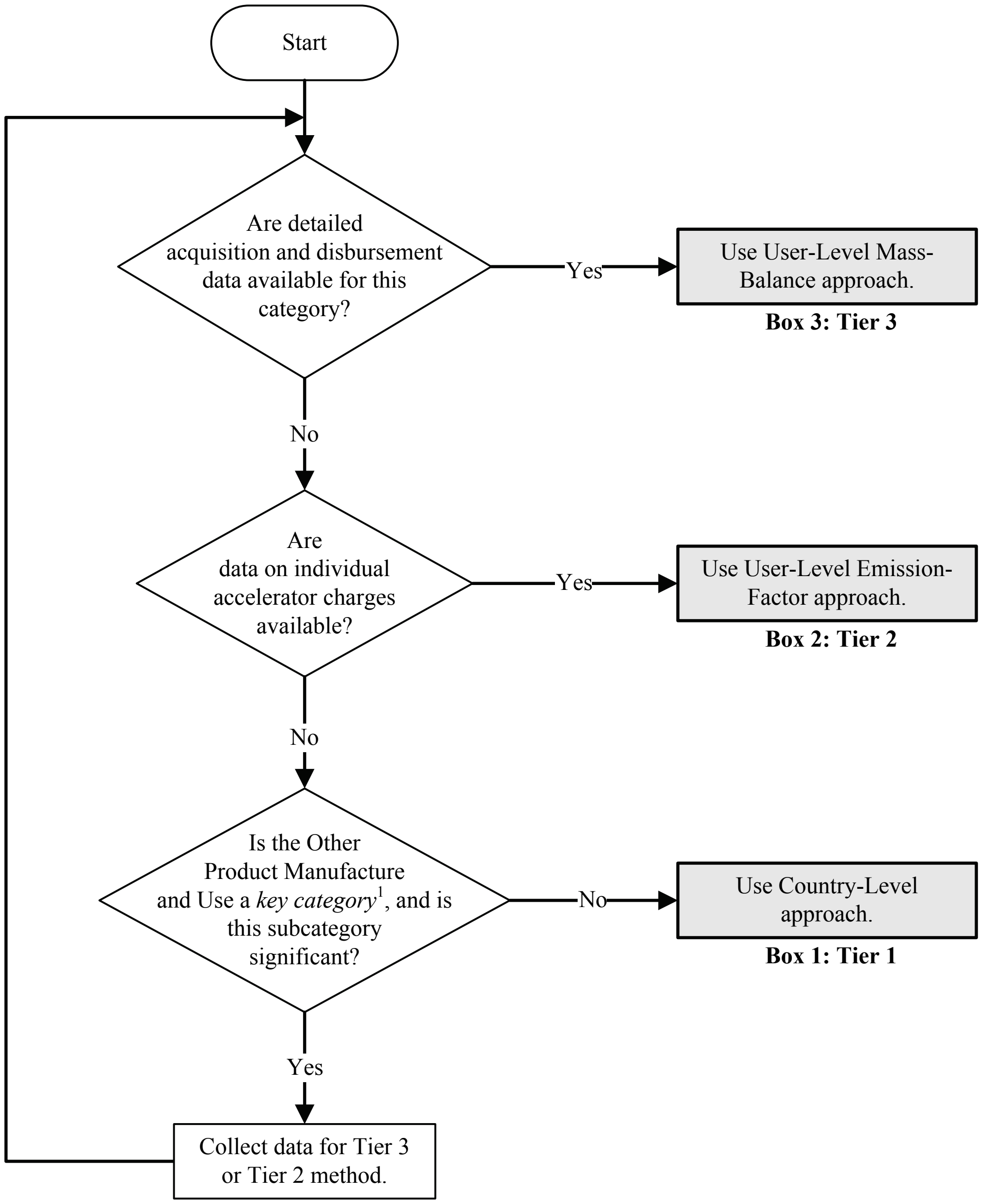
Net Increase in Accelerator Charge = SF_6 Charge of New Components – SF_6 Charge of Retiring Components

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) • (SF_6 Charge Factor, kg) • (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 • SF_6 purchased to fill windows assembled in year t

EQUATION 8.21
DOUBLE-GLAZED WINDOWS: USE

Leakage Emissions in year t = 0.01 • 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 • (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.

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.

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[6]) and use of SF_6 in the production of optical cables (for fluorodoping of glass fibres[7]). 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

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

This equation is similar to the equation for prompt 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, prompt emissive applications and adiabatic applications, including windows.

[6] 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.

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

8.3.2.3 CHOICE OF ACTIVITY DATA

The activity data for these sub-source categories should be consistent with the data used in the calculation of SF_6 emissions from other source categories (e.g., electrical equipment) to ensure that the estimate is complete and there is no double counting. For medical linear accelerators, 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. Guidance regarding possible sources of activity data for other sources is provided under the method for each source category.

8.3.2.4 COMPLETENESS

Data per application on import, export and consumption from national SF_6 and PFC producers and distributors will suffice, provided that (i) all SF_6 and PFC producers and distributors are identified, (ii) domestic consumers only purchase SF_6 and PFCs from national suppliers, and (iii) imports and exports in products (e.g., sport attributes) are negligible. It is *good practice* to check regularly for additional distributors to ensure that no gas is imported directly (in bulk) by end-users and that identified products containing SF_6 or PFCs are not imported in sizeable amounts.

Alternatively, if top-down data on chemical consumption is not available, countries may use information on the number of accelerators, AWACS, windows, etc. in use in the country, applying the emission factors that are supplied in the method for each source category.

8.3.2.5 DEVELOPING A CONSISTENT TIME SERIES

For base year estimates, data may be needed for a few years prior to the base year; one year for prompt emissions and more years for delayed emission applications. It is *good practice* to calculate emissions using the same method for every year in the time series. Where data are unavailable to support a more rigorous method for all years in the time series, it is *good practice* to recalculate according to the guidance provided in Volume 1, Chapter 5.

8.3.3 Uncertainty assessment

If the survey of domestic sales per application by national gas producers and distributors is complete, then the accuracy of annual apparent consumption data will be high. The uncertainty in emissions estimates will be similarly small when the uses are all prompt emissions. In case of delayed emission applications, the uncertainties are:

- Default delay times in adiabatic property applications: 3±1 year;
- Defaults for soundproof windows: 50±10% filling emissions and 1±0.5% leakage/breach emissions.

If gas consumption data are not available, uncertainties regarding the numbers and usage of accelerators and AWACS, etc. become important.

- For accelerators, the total SF_6 charge and leak rate determine emissions and associated uncertainty
- For use of SF_6 in AWACS, the number of sorties per plane has a significant impact on emissions and uncertainty.

8.3.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

8.3.4.1 QUALITY ASSURANCE/QUALITY CONTROL

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. Additional quality control checks as outlined in Volume 1, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

Additional procedures specific to other sources of SF_6 are outlined below:

Comparison of emissions estimates using different approaches

Inventory compilers should compare total national potential SF_6 and PFC emissions (minus the amount allocated to the source categories as per chapters 3.10, 4, 6 and 8.2) to the estimated SF_6 and PFC emissions from other uses. These adjusted potential national emissions can be used as an upper bound on emissions.

Activity data check

Inventory compilers should compare the activity data submitted by different producers and distributors, and, adjusting for relative size or capacity of the companies, identify significant outliers. Any outliers should be investigated to determine if the differences can be explained or if there is an error in the reported activity.

Comparison of emission rates with those of other countries

Inventory compilers should compare the emissions from other SF_6 and PFC end-uses included in the national inventory with information submitted by other similar countries. For each source, emissions per capita or per unit of GDP should be compared with the corresponding emission rates of other countries. If national figures appear to be relatively very high or very small, a justification should be provided.

8.3.4.2 REPORTING AND DOCUMENTATION

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Section 6.11. It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

For transparency, it is *good practice* to report both actual and potential emissions from the source category 'other uses' separately from other SF_6 and PFC emissions. In addition, providing information on the specific applications that are included in this source category is useful for comparing (estimates of) national practices with other countries, regionally, or globally. In addition, the methods applied and references should be documented. For delayed emission sub-source categories, annual emissions, delay times and emission factors per type of sub-source category should be reported.

8.4 N_2O FROM PRODUCT USES

8.4.1 Introduction

Evaporative emissions of nitrous oxide (N_2O) can arise from various types of product use, including:

- Medical applications (anaesthetic use, analgesic use and veterinary use);
- Use as a propellant in aerosol products, primarily in food industry (pressure-packaged whipped cream, etc);
- Oxidising agent and etchant used in semiconductor manufacturing;
- Oxidising agent used, with acetylene, in atomic absorption spectrometry;
- Production of sodium azide, which is used to inflate airbags;
- Fuel oxidant in auto racing; and
- Oxidising agent in blowtorches used by jewelers and others.

In general, medical applications and use as a propellant in aerosol products are likely to be larger sources than others. It is *good practice* to estimate and report N_2O emissions from these sources. Inventory compilers are encouraged to estimate and report N_2O emissions from the other sources as well, if data are available.

MEDICAL APPLICATIONS

Anaesthetic use of N_2O

N_2O for anaesthetic use is supplied in steel cylinders containing a minimum of 98 percent N_2O. N_2O is used during anaesthesia for two reasons: a) as an anaesthetic and analgesic and as b) a carrier gas for volatile fluorinated hydrocarbon anaesthetics such as isoflurane, sevoflurane and desflurane. The anaesthetic effect of N_2O is additive to that of the fluorinated hydrocarbon agents.

Not all anaesthetics require the use of N_2O, and the use of N_2O is contra-indicated in a small number of medical situations. The carrier gas during anaesthesia may be either N_2O and oxygen or a mixture of air and oxygen, in which case N_2O is avoided.

Inhaled anaesthetic agents are increasingly administered via breathing systems which re-circulate the exhaled breath of the patient through a canister of carbon dioxide absorbent before directing the gases back to the patient. Using this method the flow of carrier gas can be reduced considerably after the first few minutes of anaesthesia when uptake by the patient is high. This technique is known as Low Flow Anaesthesia. Low Flow Anaesthesia has the advantage of reducing emissions as well as reducing cost.
Some anaesthetics may avoid both N_2O and the fluorinated hydrocarbon agents completely by employing a technique in which an anaesthetic drug is continuously infused into a vein throughout the surgical procedure. This technique is known as Total Intravenous Anaesthesia.

Analgesic use of N_2O

Inhaled N_2O is used to provide pain relief in certain situations. For example, it is supplied in steel cylinders containing pre-mixed N_2O 50 percent and oxygen 50 percent as premixed nitrous oxide and oxygen mixtures in the UK. Premixed nitrous oxide and oxygen mixtures are used to provide pain relief in childbirth, and for painful procedures of short duration, e.g. for dressings to be changed in burns patients. Premixed nitrous oxide and oxygen mixtures are not used in countries with a very cold climate because the mixture can separate if the cylinders are stored below –6 degrees centigrade, with the consequent risk of administering pure nitrous oxide to patients with no oxygen.

Veterinary use of N_2O

N_2O is also used during animal anaesthesia. Administration methods are similar to those used in human anaesthesia.

USE AS A PROPELLANT IN AEROSOL PRODUCTS, PRIMARILY IN FOOD INDUSTRY

N_2O is also used as a propellant in aerosol products primarily in food industry. Typical usage is to make whipped cream, where cartridges filled with N_2O are used to blow the cream into foam.

8.4.2 Methodological issues

8.4.2.1 CHOICE OF METHOD

It is *good practice* to estimate N_2O emissions from data of quantity of N_2O supplied that are obtained from manufacturers and distributors of N_2O products according to Equation 8.24 below. There will be a time delay between manufacture, delivery and use but this is probably small in the case of medical applications because hospitals normally receive frequent deliveries to avoid maintaining large stores. Therefore, it is reasonable to assume that the N_2O products supplied will be used in one year. In the case of use as a propellant in aerosol products, there is no reliable data that prove there is a significant time delay between manufacture, delivery and use. Such being the case, it is considered practical to assume that the N_2O products supplied will be used in one year. Equation 8.24 covers more than one year because both supply and use are assumed to be continuous over the year; that is, N_2O supplied in the middle of year t–1 is not fully used and emitted until the middle of year t.

Different tiers could not be defined for this source category, because there is no other reliable estimation method. For example, in the case of medical applications, estimations from numbers of anaesthetics given, number of surgical beds or hours of anaesthesia could be considered but these methods are likely to be inaccurate. (See Section 8.4.2.3, Choice of Activity Data.)

EQUATION 8.24
N_2O EMISSIONS FROM OTHER PRODUCT USES

$$E_{N2O}(t) = \sum_i \left\{ \left[0.5 \bullet A_i(t) + 0.5 \bullet A_i(t-1)\right] \bullet EF_i \right\}$$

Where:

$E_{N2O}(t)$ = emissions of N_2O in year *t*, tonnes

A_i (t) = total quantity of N_2O supplied in year *t* in application type *i*, tonnes

A_i (t-1) = total quantity of N_2O supplied in year *t*-1 in application type *i*, tonnes

EF_i = emission factor for application type *i*, fraction

8.4.2.2 CHOICE OF EMISSION FACTORS

MEDICAL APPLICATIONS

It is assumed that none of the administered N_2O is chemically changed by the body, and all is returned to the atmosphere. It is reasonable to assume an emission factor of 1.0.

USE AS A PROPELLANT IN AEROSOL PRODUCTS, PRIMARILY IN FOOD INDUSTRY

For N_2O used as a propellant in pressurized and aerosol food products, none of the N_2O is reacted during the process and all of the N_2O is emitted to the atmosphere resulting in an emissions factor of 1.0 for this source.

OTHERS

For the other types of product use, it may not be appropriate to assume an emissions factor of 1.0. In case the inventory compilers estimate and report N_2O emissions arising from product use other than medical applications and use as a propellant in aerosol products, they are encouraged to derive reasonable emission factors for that source from literature or measurements.

8.4.2.3 CHOICE OF ACTIVITY DATA

MEDICAL APPLICATIONS

Total quantity of N_2O supplied by application type should be obtained from manufacturers and distributors of N_2O products. Alternatively, for medical applications, quantity of N_2O usage may be obtained from the pharmacy department in individual hospitals that usually have records of the number and capacity of nitrous oxide cylinders purchased per annum.

The duration of hospital stay following a surgical procedure varies considerably from less than one day to several days or weeks. Estimates of the number of anaesthetics administered which are calculated from the surgical bed occupancy are likely to be inaccurate.

Because N_2O is used in only a proportion of anaesthetics its use cannot be estimated reliably from the number of anaesthetics given.

The flow of N_2O (L/min) delivered by the anaesthetic apparatus may be varied by the anaesthetist during the course of surgery, typically between zero and 6 L/min. Because of this considerable variability, estimates of consumption based on duration of anaesthesia are likely to be inaccurate.

The proportion of anaesthetics in which N_2O is used varies between countries and between individual anaesthetists in a given country. Over the recent years there appears to be a general reduction in the proportion of anaesthetics which incorporate N_2O but data are sparse.

USE AS A PROPELLANT IN AEROSOL PRODUCTS, PRIMARILY IN FOOD INDUSTRY

Total quantity of N_2O supplied by application type should be obtained from manufacturers and distributors of N_2O products.

8.4.2.4 COMPLETENESS

Data per application on import, export and consumption from national N_2O manufacturers and distributors will suffice, provided that (i) all N_2O manufacturers and distributors are identified, (ii) domestic consumers only purchase N_2O from national suppliers, and (iii) imports and exports in products (e.g. sport attributes) are negligible. It is *good practice* to check regularly for additional distributors to ensure that no N_2O is imported directly (in bulk) by end users and that identified products containing N_2O are not imported in sizeable amounts.

8.4.2.5 DEVELOPING A CONSISTENT TIME SERIES

It is *good practice* to calculate emissions of N_2O using the same method for every year in the time series. Where data are unavailable to support a more rigorous method for all years in the time series, it is *good practice* to recalculate according to the guidance provided in Volume 1, Chapter 5.

8.4.3 Uncertainty assessment

8.4.3.1 EMISSION FACTOR UNCERTAINTIES

In the published literature it is widely assumed that none of the N_2O inhaled by a patient during anaesthesia is metabolised. N_2O is taken up continuously from the lungs as dissolved N_2O in blood. The portion which is not taken up is exhaled in the next breath. Uptake by the patient is high initially and falls progressively in a near-exponential fashion over time. It is reasonable to assume that all the administered N_2O is eventually returned to the atmosphere and the emission factor is 1.0. This is a pragmatic assumption because there are no reliable data. Any error in the emission factor is likely to be extremely small in comparison with other uncertainties.

Also in the case of use as a propellant in aerosol products, N_2O is not likely to be reacted during the process. Therefore, it is a pragmatic assumption that emission factor is 1.0, and any error in the emission factor is likely to be extremely small in comparison with other uncertainties.

In case the inventory compilers estimate and report N_2O emissions arising from product use other than medical applications and use as a propellant in aerosol products, emission factor uncertainties may need to be carefully considered.

8.4.3.2 ACTIVITY DATA UNCERTAINTIES

The uncertainties in quantity of N_2O supplied by application type obtained from manufacturers and distributors of N_2O products may vary widely from country to country. If the uncertainty estimates are obtainable from the manufacturers and distributors, those estimates should be used. Otherwise, activity data uncertainties should be estimated by expert judgement.

8.4.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Chapter 6. It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

For transparency, providing information on the specific applications that are included in this source category is useful for comparing (estimates of) national practices with other countries, regionally, or globally. In addition, the methods applied and references should be documented.

It is *good practice* to conduct quality control checks and quality assurance procedures as outlined in Volume 1, Chapter 6. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

Additional procedures specific to this source category are outlined below:

Activity data check

Inventory compilers should compare the activity data submitted by different manufacturers and distributors of N_2O, and, adjusting for relative size or capacity of the companies, to identify significant outliers. Any outliers should be investigated to determine if the differences can be explained or if there is an error in the reported activity.

Comparison of emissions with other countries

Inventory compilers should compare the N_2O emissions from types of product use included in the national inventory with information submitted by other similar countries. For each source, emissions per capita or per unit of GDP with other countries should be compared. If national figures appear to be relatively very high or very small, a justification should be provided.

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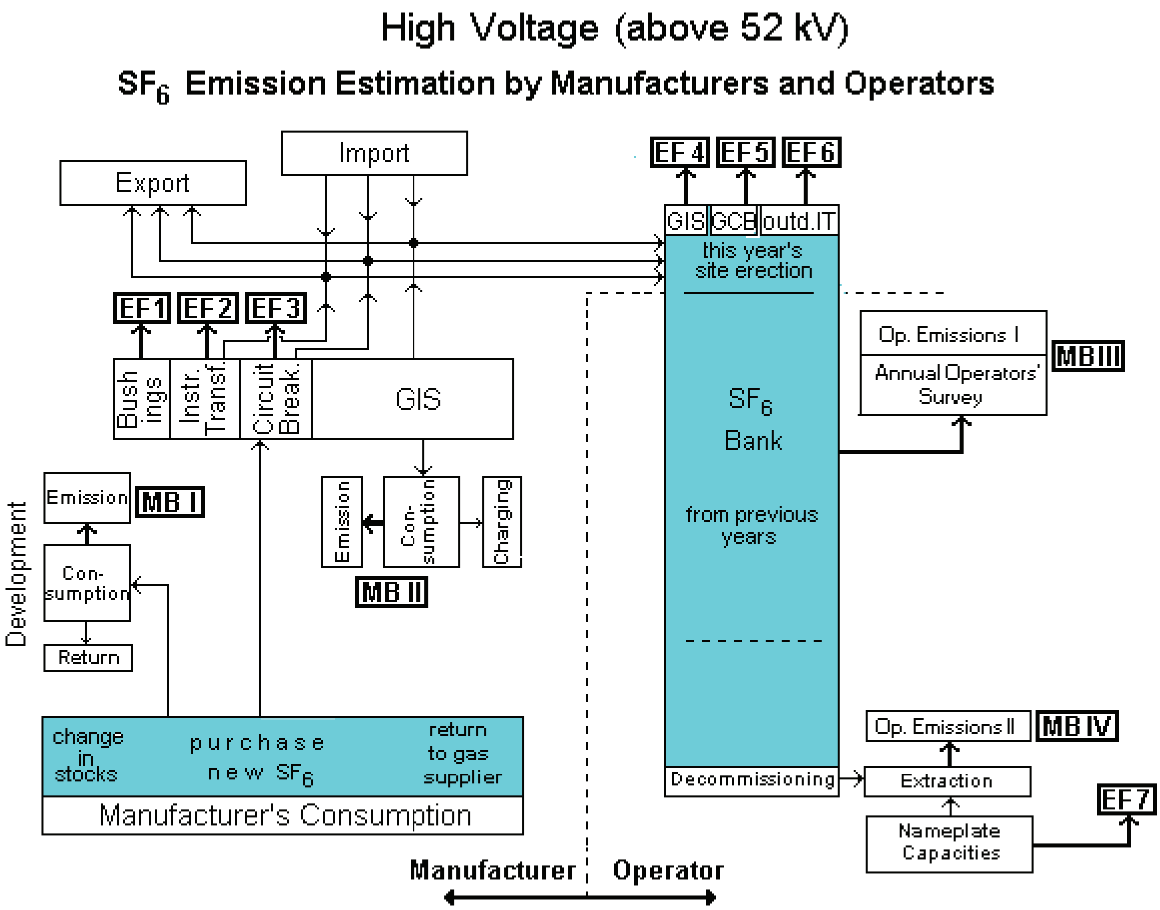
Annex 8A Examples of Tier 3 national SF_6 inventory systems

Figures 8A.1 and 8A.2 illustrate the Tier 3 Hybrid approach as it is currently applied in Germany for closed pressure (high voltage) and sealed-pressure (medium voltage) equipment (Schwarz, 2006). In the diagram, 'MB' indicates processes or life cycle stages for which the mass-balance approach is used, while 'EF' indicates processes and life cycle stages for which emission factors are used. For example, in manufacturing, the mass-balance approach is used to estimate emissions from the filling of gas-insulated switchgear, while emission factors are used to estimate emissions from the filling of bushings, instrument transformers, and circuit breakers. In Germany, the latter processes have emission rates of 1 percent or less, making emissions difficult to measure using mass-balance methods. Note that this diagram is intended to be an example only; when implementing the Tier 3 approach, countries are encouraged to choose approaches and emission factors appropriate to their national circumstances.

Figure 8A.1 Example of Tier 3 approach: Germany, High-Voltage equipment

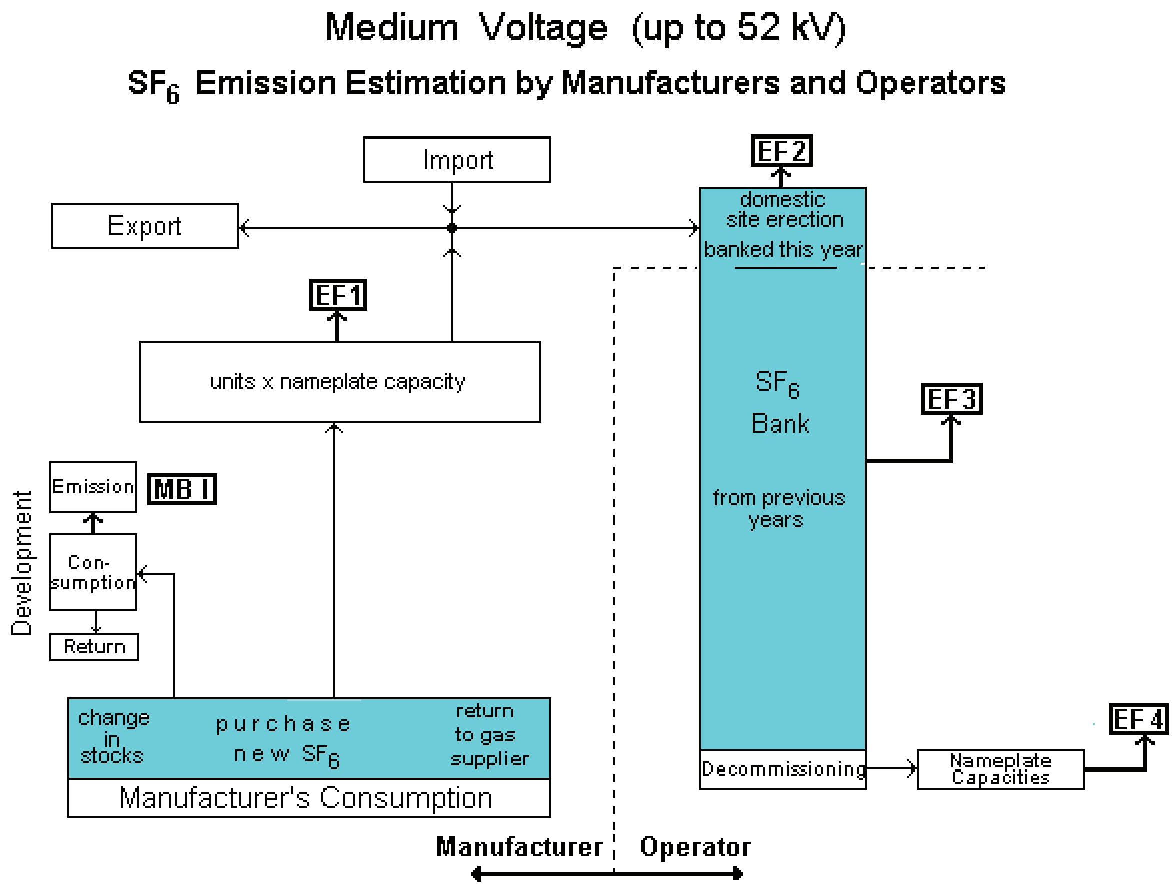


Legend for Emissions Estimation in HV		
Mass Balance Approach		
Symbol	Equation	
MB I	Development Emissions = Consumption for Developing minus Return from Development Department	
MB II	GIS Charging Emissions = Consumption for Charging minus Charge (nameplate capacities); also applicable to Gas insulated Lines (GIL's)	
MB III	Operating Emissions I = Annually surveyed topping up by equipment operators	
MB IV	Operating Emissions II = Nameplate capacity of decommissioned equipment minus gas recovered from this equipment	
Emission Factor (EF) Approach		
Symbol	**Kind of Emission Factor (EF)**	**Multiplied by**
EF 1	Factory Filling EF Bushings*	NC** of bushings filled in factory
EF 2	Factory Filling EF Outdoor Instrument Transformers (ITs)	NC of ITs filled in factory
EF 3	Factory Filling EF Gas Circuit Breakers (GCBs)	NC of GCBs filled in factory
EF 4	Site Erection EF GIS and GIL	NC of GIS and GIL filled on site
EF 5	Site Erection EF GCBs	NC of GCBs filled on site
EF 6	Site Erection EF Outdoor ITs	NC of Outdoor ITs filled on site
EF 7	Disposal EF	NC of decommissioned equipment

* Bushings are treated as integral parts of GIS as of Site erection.

**NC = Total nameplate capacity of equipment undergoing a given process

Figure 8A.2 Example of Tier 3 approach: Germany, Medium-Voltage equipment



Legend for Emissions Estimation in MV		
Mass Balance Approach		
Symbol	Equation	
MB I	Development Emissions = Consumption for Developing minus Return from Development Department*	
Emission Factor (EF) Approach		
Symbol	**Kind of Emission Factor (EF)**	**Multiplied by**
EF 1	Factory Filling EF	NC** filled in factory
EF 2	Site Erection EF	NC*** filled on site
EF 3	Operating EF	NC of operating equipment (total bank from this and previous years)
EF 4	Disposal EF	NC decommissioned

* This mass balance approach also applies to manufacturing of Cast Resin Instrument Transformers (ITs).

**NC = Total nameplate capacity of equipment undergoing a given process.

*** In countries where MV equipment is already gas-filled in factories, site erection emissions are negligible.