Environnement Canada Environment Canada

Canadian Electricity Association
Association canadienne de l'électricité

Annex A: SF_6 Emission Estimation and Reporting Protocol for Electric Utilities (Final Version)

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Feb 2008

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Annex

1 Purpose

On March 22, 2007, the Canadian Electricity Association (CEA) and the Greenhouse Gas Division (GHGD) of Environment Canada signed a Memorandum of Understanding (MOU) on SF_6 emissions from electric utilities in Canada. One of the items agreed upon in the MOU was to establish a joint committee to prepare a Sulphur Hexafluoride (SF_6) emission data collection and reporting protocol.

The purpose of the protocol is to provide a guidance document for estimating SF_6 emissions from electric utilities that is consistent with the Intergovernmental Panel on Climate Change (IPCC) Guidelines. The methodology described will be used by all CEA member electric utilities in Canada to estimate their annual SF_6 emissions from in-service electrical equipment and report the results to the GHGD. Non-members of CEA can also use this methodology under the terms of a specific agreement with Environment Canada.

In addition, the document explains the method used for uncertainty assessment and inputs on uncertainty around the emission estimates that need to be collected from utilities, such that international reporting requirements can be fulfilled by the GHGD. It also provides guidelines on quality control checks, and on the documentation and archiving of calculation details that should be performed by utilities to ensure the accuracy of their emission estimates. Moreover, the document gives a summary of the data verification process performed by a third party auditor under the CEA's Environmental Commitment and Responsibility (ECR) Program. Finally, emission data and related information that will be transferred from utilities to the GHGD, as well as the timeframe of the transfer, are described below.

2 Introduction

Sulphur Hexafluoride (SF_6) is a synthetic gas used as an insulating medium and for arc quenching in electrical transmission and distribution equipment and is usually released through switchgear operations. It is a powerful greenhouse gas with a global warming potential of 23,900. Thus, emitting 1 tonne of SF_6 is equivalent to emitting 23,900 tonnes of CO_2. Despite its persistence in the atmosphere and its high GWP, its extraordinary electrical, thermal, physical, and chemical properties have allowed SF_6 to be used successfully by electric power utilities for over 40 years. SF_6 gas is non flammable, non toxic and non corrosive. In addition, its dielectric strength is almost three times that of air and it has powerful arc quenching capabilities. Following arc interruptions, SF_6 gas is able to regenerate itself. Such properties have made SF_6 gas irreplaceable in the electric power industry.

Typical SF_6 equipment includes; gas insulated circuit breakers; gas insulated switchgear; gas insulated buses and compartments and outdoor gas insulated transformers. SF_6 is purchased and used by utilities for topping up or recharging their equipment. As will be discussed later, SF_6 leakages are common with electrical equipment. Therefore, utilities are required to recharge their equipment to make up for the SF_6 gas that has escaped/leaked.

Fugitive SF_6 emissions can potentially occur during/from:

(1) Gas handling and transferring operations
(2) Equipment operation
(3) Equipment mechanical failure

Due to these sources of emissions, there is a need to "top up" equipment or to recharge equipment with SF_6 in order to replace the gas that has leaked and to ensure proper operation. Irrespective of how SF_6 is leaked from equipment, there will be a need for utilities to top up their equipment. Thus, by measuring the amount of SF_6 used for top ups, an accurate estimate can be made for the amount escaped from equipment.

Typically, SF_6 equipment will have low pressure alarms, which are triggered when a 7 - 10 % loss of pressure occurs. This will alert the utility as to when a top-up is required. Under normal operating conditions, minute amounts of gas can be lost annually. There can be loss of up to 0.5 % of the nameplate capacity for newer equipment and up to 5% for older equipment. The newer GIS equipment, however, often does not result in leakages over a 5 to 10 year period. Variability is driven by the quality and age of seal materials and environmental factors. Operating equipment in very cold conditions can lead to minute emissions due to seals being stiff and not sealing tightly. A mechanical failure could cause an immediate release of SF_6 and triggering of an alarm or it could occur more gradually and take up to 1 year until an alarm is triggered.

SF_6 emissions from electrical equipment used within utility transmission systems were first included in Canada's 1990-2003 GHG Inventory, which was submitted in 2005 to the Secretariat of United Nations Framework Convention on Climate Change (UNFCCC). In this instance, Environment Canada applied a top-down IPCC Tier 1 type methodology based on SF_6 sales data. Specifically, it assumed that total SF_6 sold to utilities by gas distributors was equivalent to what was used to refill leaking equipment.

To obtain the annual SF_6 sales data by market segment, gas distributors were surveyed by the GHG Division, but only sales data from 1995–2000 inclusive were collected. Alternative approaches were applied to estimate SF_6 sales for other years of the time series:

- For the 1990-1994 period, sales were assumed to be the same as in 1995.
- For the 2001-2005 period, sales were estimated by subtracting the quantities of SF_6 used in other applications, such as magnesium smelting, from the total SF_6 import data (available at: http://www.statcan.ca/trade/scripts/trade_search.cgi/).

The drawback of this top-down Tier 1 methodology is that it has the potential to overestimate SF_6 emissions from utilities. In order to develop a more robust approach to measuring SF6 releases from the electricity sector, the GHG Division at Environment Canada and the CEA signed a MOU in March 2007. As part of the MOU, a joint committee, consisting of representatives from both the GHGD and the CEA, was created. The main task of the committee is to prepare a protocol that will be used by CEA member electric utilities to estimate SF_6 emissions and to report the estimates to GHGD. The protocol can be used, as appropriate, by non-CEA member utilities for estimating SF_6 emissions.

3 Methodology for Quantification of SF_6 Releases

The Canadian electricity sector will use one method for quantifying SF_6 emissions, which is derived from the basic tier 3 IPCC life cycle equation (see Equation 1). For overview of methodologies recommended in IPCC publications, please refer to the Annex (A3-*Overview of IPCC Methodologies*).

Total Emissions = *Σ Equipment Manufacturing Emissions*
+ Σ Equipment Installation Emissions
+ Σ Equipment Use Emissions
+Σ Equipment Decommissioning and Failure Emissions
+Σ Emissions from SF_6 Recycling and Destruction (1)

The discussion below outlines how the quantification method is derived from Equation 1.

3.1 Equipment Manufacturing Emissions

Since Canadian electric utilities do not manufacture their transmission and distribution equipment, they are not responsible for the SF_6 released during the manufacturing stage. In fact, according to some utilities, electrical equipment purchased by the Canadian electricity sector is manufactured in the United States, Europe or Asia, and hence, emissions associated with manufacturing would have occurred mainly outside of Canada. As such, emissions from equipment manufacturing (i.e. the first term of Equation 1) are assumed to be not applicable to the electricity sector.

3.2 Equipment Installation Emissions

SF_6 equipment is delivered to utilities pre-charged with some SF_6 and it is charged to full capacity at installation. In the Canadian electricity industry, the potential for SF_6 emissions during equipment installation is considered to be extremely rare occurrence. A vacuum hold check is typically performed prior to the installation of new equipment to ensure the equipment is gas tight.

3.3 Equipment Use Emissions

The primary source of SF_6 releases is associated with the cumulative minute releases that occur during normal equipment operation. Gas releases could potentially occur during gas handling and transfer operations although such releases would be significantly smaller in magnitude than emissions that occur during normal operations.

Due to the SF_6 leakage that occurs during the above circumstances, utilities are required to “top up” their equipment to keep their equipment properly charged and operational. By topping up equipment with SF_6 gas, utilities are able to replace the amount of gas that has escaped.

3.4 Equipment Decommissioning and Failure Emissions

During the decommissioning of retired equipment SF_6 gas must be recovered from the retired equipment prior to disposal. As SF_6 gas releases may occur from the way in which the gas is transferred out of the equipment during gas recovery, decommissioning of retired equipment becomes a potential source of SF_6 releases.

When catastrophic failures of equipment occur, a significant amount of SF_6 is leaked out of the equipment. Hence, equipment damages are a potential source of emissions.

Retired equipment and damaged equipment that cannot be repaired are sent off site for disposal.

3.5 Emissions from SF_6 Recycling

When SF_6 gas is recovered from equipment, it is filtered through a gas cart or other filtering equipment to remove moisture and impurities before it is reused. When SF_6 gas has been contaminated with air and impurities, and has a purity of less than a certain level (the acceptable level can vary between 95-99%, depending on utility practices), it cannot be reused and is sent for offsite purification in the U.S. There are no facilities in Canada that perform SF_6 gas purification. One of the methods utilized to purify SF_6 gas is the use of a cryogenic process to separate and remove the air/nitrogen from the SF_6 gas. The purification of SF_6 gas does not produce SF_6 emissions. Hence, emissions from SF_6 recycling are eliminated from the calculation of total emissions.

Given the reasoning above, the Canadian electricity sector will use a <u>modified tier 3 IPCC approach</u> to estimate SF_6 releases. Equation 1 is simplified to include only emissions from equipment use and decommissioning, as shown in Equation 2.

$$\textit{Total Utility } SF_6 \textit{ Emissions} = \Sigma \textit{ Equipment Use Emissions} + \Sigma \textit{ Equipment Decommissioning and Failure Emissions} \quad (2)$$

4 Quantifying Equipment Use Emissions

As mentioned above, emissions that occur during equipment use are a result of leakages during gas transfer and handling operations and leakages during normal operation of the equipment. In order to keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped. This amount is referred to as a "top up".

Leakages of SF_6 are also seen during maintenance/repair activities. When equipment needs to be repaired or sent for maintenance, SF_6 gas is recovered from equipment and once equipment is repaired, they are refilled with the SF_6 gas that was recovered from the equipment. There will be an additional amount needed to refill the equipment, since some gas may have escaped due to normal operations and during the transfer of the recovered gas from the equipment to gas carts (or storage cylinders) and back to the equipment again. It is this additional/incremental amount of SF_6 gas that is referred to as the "top up".

Hence, an accurate estimate of the amount of SF_6 released is the amount used by utilities to top up their equipment during the equipment use stage as shown in Equation 3.

$$\text{Equipment Use Emissions} = \Sigma\ SF_6 \text{ used to top up equipment (kg)} \qquad (3)$$

4.1 Options for Tracking SF_6 Consumed for Top Ups

Based on Equation 3, utilities are able to estimate SF_6 releases from equipment use by tracking the amount of SF_6 used to top up their equipment. The following is a list of options for Canadian electric utilities to track the amount of SF_6 that is used for top up purposes in order to quantify emissions of SF_6 from the equipment use phase. These options are listed in order of most accurate to least accurate. The most accurate method involves directly measuring the amount of gas transferred during top ups and the less accurate methods involve utilities relying on inventory records or purchase receipts to obtain an estimate. **Each utility will have discretion over which method to use.**

For all of the tracking options discussed below, it is assumed that the quantities of the SF_6 gas tracked do not include the gas used to pressurize the new switchgear to their full capacity at time of installation. The latter gas quantities are typically provided by the switchgear vendor at time of installation and hence do not come out of the utility inventory (please also see section 3.2-*Equipment Installation Emissions*).

4.1.1 Mass Flow Meters

Mass flow meters provide the most accurate method for measuring the quantity of SF_6 consumed during each equipment top up operation. The sum of all measured quantities during top-up operations will be used to determine the equipment use emissions.

4.1.2 Weigh Scales

Utilities may choose to weigh their SF_6 cylinders to determine the quantity of SF_6 consumed for top up operations. Weighing of cylinders can be performed every time there is an equipment top-up operation or it can be performed on an inventory basis. When using this method, utilities should ensure that the accuracy of the weigh scale is compatible with the weight of the cylinders to be weighed. For example, utilities should use a scale accurate to ±1 kg, instead of ± 5 kg, to weigh a 50-kg cylinder.

4.1.2.1 Weighing individual cylinders before and after "top ups"

Under this approach, a utility weighs each individual cylinder before and after it is used to top up or refill equipment. The difference in weight then represents the amount that was used to top up the equipment. This procedure can be represented by Equation 4.

$$\text{SF}_6 \text{ Used to top up equipment} = \Sigma \text{ (Weight of Individual SF}_6 \text{ Cylinders before Top up} - \text{Weight of Individual SF}_6 \text{ Cylinders after Top Up)} \qquad (4)$$

4.1.2.2 Weighing SF_6 cylinders on an inventory basis

With this approach, utilities weigh all SF_6 cylinders that are placed in their maintenance inventory at the beginning of the year and the end of the year. They must also account for any purchases or additions to the inventory, weight of SF_6 cylinders returned to suppliers and the quantity of SF_6 sent offsite for recycling or destruction during the year. This method can be represented by Equation 5.

$$\begin{aligned}\text{SF}_6 \text{ Used to top up equipment} =\ & \text{Weight of SF}_6 \text{ Cylinders in Maintenance Inventory at the } \textbf{Beginning of the Year} \\ & - \text{Weight of SF}_6 \text{ Cylinders in Maintenance Inventory at the } \textbf{End of the Year} \\ & + \text{Weight of SF}_6 \text{ Cylinders Purchased/Acquired} \\ & - \text{Weight of SF}_6 \text{ Cylinders Returned to Suppliers} \\ & - \text{Weight of SF}_6 \text{ sent offsite for recycling or destruction}\end{aligned} \qquad (5)$$

4.1.3 Cylinder Count

In the absence of mass flow meters or weigh scales, utilities may choose to rely on information from supplier or inventory records, and purchase receipts to obtain the number and weight of SF_6 cylinders purchased for top up purposes. The mass of SF_6 consumed can generally be calculated in two ways:

1- by obtaining the number of cylinders purchased in a year from purchase records and multiplying this number by the SF_6 weight in a cylinder or;
2- by tracking the number of cylinders entering and leaving the maintenance inventory during the reporting year and multiplying this number by the SF_6 weight in a cylinder.

The weight of SF_6 found in different types of cylinders should be known. Therefore, utilities can simply obtain the weight of SF_6 consumed of top up purposes by performing a cylinder count. If more than one type of cylinder is utilized, utilities must ensure that the number of cylinders of each type is multiplied by the cylinder weight for that type. The products obtained for all cylinder types are then summed together to give the total SF_6 use. More details on these two options are provided in the following subsections.

4.1.3.1 Counting number of cylinders purchased in one year

The amount of SF_6 consumed for top up purposes under this approach is based on purchase or inventory records of each utility or facility. From purchase records, utilities can extract the number of cylinders purchased. The assumption made is that the amount of SF_6 purchased and placed in inventory will eventually be used to replace releases from existing equipment.

When relying on inventory or purchase records, it is important to take into consideration the amount of residual gas left in the cylinders after it is used for top ups. According to information supplied by two major SF_6 gas distributors, approximately 12% of gas is left in cylinders after they are used. This amount should be subtracted from the total amount of SF_6 found in inventory records. Equation 6 represents the SF_6 tracking method based on the central purchasing or inventory records.

$$SF_6 \text{ Used for top up} = \sum_{i=1}^{n} \left[\text{number of cylinder } i \text{ purchased and placed in maintenance inventory} * SF_6 \text{ weigh in cylinder } i * (1\text{-y})\right] \quad (6)$$

where:

i represents different types of cylinders

y represents the percentage of gas left in cylinders when returned to suppliers. *(Note: utilities may choose to directly weigh the residual gas in cylinders and calculate the residual gas in % as y, or may use a default value of 12% for y.)*

4.1.3.2 Tracking cylinder inventory count throughout the year

This approach is similar to the method described in section 4.1.2.2-*Weighing SF_6 cylinders on an inventory basis* except that utilities need only count the number of cylinders purchased and placed in inventory at the beginning of the year and at the end of the year instead of having to directly weigh these cylinders throughout the year. The count of cylinders is then multiplied by the known weight of the SF_6 cylinders.

Since utilities are not weighing their cylinders, an estimate of the amount of residual gas left in the cylinders when returned to suppliers must be estimated. Utilities may choose to weigh this amount or utilize the suggested 12% explained above. This methodology is represented by equation 7.

$$SF_6 \text{ Used for top up} = \left\{ \sum_{i=1}^{n} \left[C_i \text{ at beginning of year} + C_i \text{ of purchases} - C_i \text{ at end of year} \right] * SF_6 \text{ weigh in cylinder } i * (1\text{-y}) \right\} - \text{outflows} \quad (7)$$

where:

i represents different types of cylinders
C_i represents the number of cylinders of type *i*
y represents the amount (in %) of residual gas left in cylinders when returned to suppliers. *(Note: utilities may choose to directly weigh the residual gas in cylinders and calculate the residual gas in % as y, or may use a default value of 12% for y.)*
outflows include the amount (in weight units) of SF_6 sent offsite for recycling or destruction

5 Quantifying Equipment Disposal and Failure Emissions

Equipment disposal and failure emissions include emissions from decommissioning of retired equipment and emissions that result from the rare event of catastrophic equipment failures.

In the decommissioning of retired equipment, SF_6 losses occur as gas is being recovered from the retired equipment. Emissions can be estimated by taking the difference between the nameplate capacity of the equipment and the recovered amount of SF_6 (see Equation 8). It should be noted that this equation is also found in the 2006 IPCC guidelines.

$$\text{Equipment decommissioning emissions} = \textit{Nameplate capacity of retired equipment} - \textit{SF}_6 \textit{ recovered from retired equipment} \quad (8)$$

The value of nameplate capacity (in mass units) can be obtained from equipment specifications provided by the equipment manufacturer or from sound engineering estimates. The amount of recovered SF_6 gas is weighed.

When equipment failures or damages occur to the point where they cannot be repaired, the nameplate capacity of the equipment can provide a reasonable estimate of emissions that have taken place as a result of equipment failures (see Equation 9).

$$\text{Emissions from damaged equipment} = \textit{Nameplate capacity of damaged equipment} \quad (9)$$

It is important to note that Equation 9 only applies to equipment that has been damaged to the point where they cannot be repaired. If the equipment is taken for repair then emissions are captured using Equation 3. Similar to Equation 8, the nameplate capacity value (in mass units) used in Equation 9 can be obtained from equipment specifications provided by the equipment manufacturer or a calculation can be made based on sound engineering estimates.

6 Data Uncertainty

Uncertainty estimates are essential for a complete emission inventory. As per the emission reporting requirements set out by the United Nations Framework Convention on Climate Change (UNFCCC), Canada must report its emission estimates along with the associated uncertainty values. These uncertainty values are not intended to dispute the validity of the emission estimates, but to help prioritize efforts to improve the accuracy of the estimates, and guide decisions on methodological choice. Before applying an equation to quantify uncertainty of a given emission source, it is important to identify the reasons for which actual emissions differ from the estimated number. Some sources of uncertainty may generate well-defined estimates of the range of potential errors, while some others are much more difficult to characterize and require expert judgment. Examples of uncertainty sources for each of the SF_6 tracking methods are provided in the Annex (A4-*Sources of Uncertainty*).

The IPCC Good Practice Guidance provides two types of methods for estimating uncertainty: Tier 1 method using the error propagation equation and Tier 2 method using the Monte Carlo analysis. *To respond to the international GHG reporting requirements, a Tier-1 type uncertainty assessment on the total SF_6 emission estimate for the electric utility sector will be performed by the GHGD and inputs to be gathered from utilities via a questionnaire. The questionnaire will be developed by the GHGD in consultation with utilities in the first year of official data transfer.* It is understood that utilities may not be able to provide some of the actual data required for the uncertainty assessment, but the best available information which may be based on the field expert judgment will be sought. Also, to simplify the uncertainty quantification process and to decrease the reporting burden of utilities, it will be assumed that the overall uncertainty associated with the national total SF_6 emission estimate for the electricity sector in the first year of official data transfer stays the same in subsequent years as long as the methods applied by utilities stay the same. Any changes in methods used by major SF_6 users would necessitate an update in the overall uncertainty; a questionnaire will be sent to utilities again to collect the data needed for the update. Described in subsection 6.1-*Tier 1 Uncertainty Quantification* is the Tier 1 uncertainty quantification for all levels (i.e., equipment, utility or company, and national). The types of data that needs to be collected from utilities by the GHGD in order to perform the uncertainty assessment are summarized in Table A5-1 found in the Annex.

6.1 Tier 1 Uncertainty Quantification

As per the Tier 1 approach recommended in the IPCC Good Practice Guidance (IPCC, 2000), there are two rules that can be applied, depending on whether the uncertain quantities are combined by addition or multiplication.

Rule A: Where uncertain quantities are to be combined by addition, the relative uncertainty of the sum will be the square root of the sum of the squares of the uncertainties of the quantities that are added, divided by the sum of the quantities (this rule is exact for uncorrelated variables). Using this interpretation, a simple equation can be derived for the relative uncertainty of the sum, when expressed in percentage (%) terms becomes:

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 + \cdots + (U_n * x_n)^2}}{x_1 + x_2 + \cdots + x_n} \qquad (10)$$

Where:

U_{total} is the relative uncertainty (in %) of the sum of quantities
x_i are uncertain quantities
U_i are the relative uncertainty values (in %) associated with the quantities x_i.

Rule B: Where uncertain quantities are to be combined by multiplication, the overall relative uncertainty will be the square root of the sum of squares of the relative uncertainties. A simple equation can be derived for the relative uncertainty of the product, expressed in percentage (%) terms:

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2} \qquad (11)$$

Where:

U_{total} is the relative uncertainty (in %) of the product of the quantities
Ui are the percentage uncertainties associated with each of the quantities.

These two rules have been utilized as basis to derive equations that can be used to estimate uncertainties associated with estimates of SF_6 emissions at all levels (equipment, utilities and national). Since estimates of emissions coming from equipment use can be developed using different methods (as discussed in Section 4-*Quantifying Equipment Use Emissions*), equations for quantifying uncertainty around these estimates are also different. Also to be noted is that the U_{total} described in equations 10 and 11 is the relative uncertainty, which is the uncertainty (in physical units, e.g., kg) divided by the mean of the quantity multiplied by 100. The uncertainty in physical units, which is the multiplication of the relative uncertainty by the mean, is indicated by "**u**" in the equations below.

6.1.1 Uncertainty Assessment for the Method of "Mass Flow Meters"

When a facility uses mass flow meters to track the amount of SF_6 used for top-ups, the uncertainty (u_m) in ± kg associated with the estimate of SF_6 can be determined by the following equation:

$$u_m = \pm\sqrt{n} * u_s \quad [\pm \text{kg}] \qquad (12)$$

where:

n is the number of times the mass flow meter is used
u_s is uncertainty of the mass flow meter (±kg)

6.1.2 Uncertainty Assessment for the Method of "Direct Weighing of Cylinders Before and After Top-Ups"

When a facility weighs its cylinders right before and after use, Equation 13 can be applied to calculate the uncertainty (u_m) in ± kg associated with the estimate of SF_6 use emissions.

$$u_m = \pm\sqrt{n} * u \quad [\pm \text{kg}] \tag{13}$$

where:

n is the number of times that "top-ups" have occurred
u is the uncertainty value of the weight scale in ± kg

The application of Equation 13 is valid as long as the same weight scale is used to measure the cylinders, or as long as the uncertainties of the different weight scales are the same. In the event where multiple weight scales are used, the value of u could be the largest uncertainty of all weight scales. However, this would give an overestimation of the uncertainty.

6.1.3 Uncertainty Assessment for the Method of "Weighing of Cylinders on an Inventory Basis"

When a facility weighs its cylinders on an inventory basis to track its SF_6 use/emissions, the following equation is used to calculate the uncertainty (u_m) in ± kg associated with the emission estimate:

$$u_m = \pm\sqrt{n_B + n_E + n_P + n_R} * u_s \quad [\pm \text{kg}] \tag{14}$$

where:

n_B is the number of cylinders at the beginning of year
n_E is the number of cylinders at the end of the year
n_P is the number of cylinders purchased/acquired
n_R is the number of times SF_6 gets extracted from equipment (during maintenance operations only) and sent off-site for recycling/destruction
u_s is uncertainty of the weight scale (±kg)

Like in the previous case, the application of Equation 14 is valid as long as the same weigh scale is used to measure the cylinders, or as long as the uncertainties of the different weight scales are the same. When multiple weight scales are used, the u would be the largest uncertainty of all weight scales.

6.1.4 Uncertainty Assessment for the method of "Counting Number of Cylinders Purchased in One Year"

When a facility or utility relies on the number of cylinders purchased shown on purchase or inventory records to estimate its SF_6 used for top-ups in a year, the uncertainty (u_m) in ± kg associated with the emission estimate can be calculated as follows:

$$u_m = \pm\sqrt{\sum_i^l n_i * \left((1+y^2)u_c^2 + (y * U_y)^2 * x_i^2\right)} \quad [\pm \text{ kg}] \tag{15}$$

where:

i is the type of SF_6 cylinders used
n_i is the number of cylinders of type i purchased in the calendar year
y is the percentage of gas left in cylinders when returned to suppliers
u_c is the uncertainty of the stated amount of SF_6 in the cylinder (in ±kg; according to unofficial information provided by a gas distributor, the uncertainty for the stated mass of a bottle of 52.2 kg SF_6 is about ±1 kg. (This value can be used as a default value; however, preference would be given to values based on gas suppliers' data.)
U_y is the relative uncertainty of y (±%)
x_i is the amount of SF_6 (kg) in the type i cylinder

6.1.5 Uncertainty Assessment for the method of "Tracking Cylinder Count throughout the Year"

To evaluate the uncertainty (u_m) in ± kg around the emission estimate developed by tracking the cylinder count throughout the year, the equation below can be used:

$$u_m = \pm\sqrt{\sum_i^l (n_{Bi} - n_{Ei} + n_{Pi}) * \left((1+y^2)u_c^2 + (y * U_y)^2 * x_i^2\right) + k * u_s^2} \quad [\pm \text{ kg}] \tag{16}$$

where:

i is the type of SF_6 cylinders used
n_{Bi} is the number of cylinders of type i at the beginning of the calendar year
n_{Ei} is the number of cylinders of type i at the end of the calendar year
n_{Pi} is the number of cylinders of type i purchased/acquired during the calendar year
y is the percentage of gas left in cylinders when returned to suppliers
u_c is the uncertainty of the stated amount of SF_6 in the cylinder (in ±kg; see section 6.1.4-*Uncertainty Assessment for the method of "Counting Number of Cylinders Purchased in One Year"*)
U_y is the relative uncertainty of y (±%)
x_i is the amount of SF_6 (kg) in the type i cylinder
k is the number of SF_6 cylinders sent out for recycling/destruction
u_s is uncertainty (in ± kg) of the weight scale used to measure the gas sent off-site for recycling/destruction

6.1.6 Uncertainty Assessment for "Equipment Decommissioning and Failure Emission Estimate"

To determine the uncertainty (u_{df}) in ± kg around the estimate of emissions coming from equipment decommissioning/failure, Equation 17 is used.

$$u_{df} = \pm\sqrt{\sum_{i}^{m} u^2_{np(i)} + n \bullet u^2_{rec}} \quad [\pm \text{kg}] \tag{17}$$

where:

m is the number of decommissioned/failed equipment in a facility
$u_{np(i)}$ is the uncertainty (in ± kg) of the nameplate capacity value of equipment i
n is the number of pieces of decommissioned equipment from which SF_6 gas is recovered
u_{rec} is the uncertainty (± kg) of the weight scale used to measure the recovered gas

It should be noted that the way the uncertainty of the nameplate capacity value ($u_{np(i)}$) is determined, depends on how the nameplate capacity value (in mass units) is obtained. For example, if the nameplate capacity value (in mass units) used by a utility in its calculations is obtained from equipment specifications, the uncertainty of this value can be requested from the equipment manufacturer. If the nameplate capacity is estimated by an operator based on the operating pressure of the equipment, the uncertainty of the capacity value would have to be determined by the operator using his/her best judgment.

6.1.7 Uncertainty Assessment for "SF_6 Emissions at Utility or Administrative Division Level"

Summing all emissions resulting from maintenance and from decommissioning/failure that occur in a utility (or administrative division) gives the total emissions of the utility (or administrative division). The uncertainty (u_f) in ± kg around the total SF_6 emission estimate of a utility can be determined by using Equation 18.

$$u_u = \pm\sqrt{u^2_m + u^2_{df}} \quad [\pm \text{kg}] \tag{18}$$

where:

u_m is the uncertainty associated with the emission estimate for equipment use
u_{df} is the uncertainty associated with the emission estimate for equipment failure and decommissioning.

6.1.8 Uncertainty Assessment for "SF_6 Emissions at National Level"

Similarly, to calculate the uncertainty (u_{nat}) associated with the national total estimate of SF_6 emissions from electric utilities, Equation 19 is used.

$$u_{nat} = \pm\sqrt{u^2_{u(1)} + u^2_{u2)} + \cdots + u^2_{u(n)}} \quad [\pm \text{kg}] \tag{19}$$

where:

$u_{u(n)}$ represents the uncertainty associated with SF_6 emission estimate of each of the utilities.

Not only uncertainty can be expressed in physical units (e.g., in ± kg) as described in Equation 19, but it can also be shown as a relative value to the mean. For example, if the national total SF_6 estimate is A kg with an uncertainty of ± B kg, the relative uncertainty, U_{nat} (in %), can be calculated by Equation 20.

$$U_{nat} = \frac{\text{B kg}}{\text{A kg}} \bullet 100\% \qquad (20)$$

7 Data Quality Control

According to the IPCC Good Practice Guidance (IPCC, 2000), it is good practice to implement quality control (QC) procedures during the development of emission estimates as these would result in improvements in estimates and ensure data accuracy. QC can be defined as a system of routine and consistent checks that ensures data integrity, correctness and completeness. It is performed by personnel who develop estimates to identify and address errors and omissions. Generally, QC activities include accuracy checks on data acquisition, calculations, measurements, uncertainty estimation, and documentation and archiving of information and data.

To ensure the quality of SF_6 data transferred to and used by the GHGD for national GHG inventory purposes, it is recommended that the following QC activities, adopted from the IPCC GPG and the 2006 IPCC Guidelines, be carried out by utilities and CEA.

7.1 QC activities to be performed by utilities:

- Check that SF_6 data has been obtained from all district offices, field locations, etc. as appropriate. Archive source records. *SF_6 raw data and calculation records can be requested by the GHG Division as necessary (e.g., in a major international review).*
- Check that any assumptions made on the data are documented and archived.
- If the SF_6 tracking method used involves any weighing, ensure that the scale is functioning properly.
- Check for transcription and calculation errors
- Investigate and explain probable cause of any significantly different values from previous years.
- Check that all SF_6 data fields of the CEA ECR data submission templates have been accurately recorded and submitted to CEA. *(This check is only applicable to CEA members)*
- Check that the SF6 tracking method noted on ECR data template reflects the method that was used to record the current year's data. *(This check is only applicable to CEA members)*
- Check that the SF6 tracking method, along with the SF_6 estimate, is accurately reported to the GHGD. *(This check is applicable to non-CEA members)*

7.2 QC activities to be performed by CEA:

- Check for completeness. Confirm that all data needed for the aggregated calculations have been collected from CEA members with SF_6 releases. *Archive data and other documentation received from CEA members with SF_6 releases at least for three years. Records can be requested by the GHG Division as necessary (e.g., in a major international review).*
- Check that the SF_6 tracking method used, along with the data, is reported by CEA members with SF_6 releases.

- Check that data are correctly transcribed from files supplied by members to CEA's master copy of calculation file.
- Check that units are correctly labelled in the calculation file, and that appropriate conversion factors are used (if necessary).
- Check that aggregated calculations are correctly done.
- Compare current data to previous years' data. If there are significant departures from expected trends and fluctuations, investigate and explain cause of discrepancies.

To fulfill the IPCC requirement for the recording and archiving of QC activities performed, two QC checklist templates, specific to utilities and CEA, have been prepared. These are found in the Annex. They should be filled out by utilities and CEA for each year's emission estimation and reporting. *Electronic copies of the completed templates should also be archived by utilities and CEA for a period of at least three years, so that they can be made available to GHGD upon request (e.g., in the case of an in-country review).*

8 Data Verification by Third Party

CEA ECR Program members are required to report their total aggregate SF_6 releases in kilograms for the calendar year as part of their annual Utility Progress Reporting (UPR). SF_6 reporting is to be based on actual kilograms of gas released as opposed to utilizing an emission factor. Releases are defined as the amount of gas used to top up or replace lost gas. Different methods may be used to obtain this number, as long as they are defendable and based on established industry knowledge. A description of the method used is also required in the UPR.

UPR information is subject to an external verification process. This process is an established component of the ECR Program and is conducted by an independent, qualified reviewer. The verification reviews comprise a 'desktop' review of UPR data and information submitted by the utility, along with a site visit that test-checks the content of the UPR and gains assurance as the effectiveness of environmental management system (EMS) implementation. Verification reviews are conducted of all utilities in the ECR Program on a three-year rotating basis.

For SF_6, the verification review examines the amount disclosed in the context of the utility's profile of SF_6 containing equipment, and reviews the documentation supporting the amounts presented. The amounts are test-checked to supporting databases, calculations are re-performed, and conversion factors (if any are used) are reviewed for appropriateness. The EMS procedures that govern the handling, storage and reporting of SF_6 are also reviewed, and the implications for UPR SF_6 information assessed. The methodology used to calculate the amount is also confirmed and reviewed for acceptability vis-à-vis UPR requirements. Any issues or exceptions are noted for follow-up in the Verification Report, which is communicated to the utility and back to the ECR Program Manager.

In addition to the verification reviews, the UPR data and information is also reviewed for reasonableness each year by the technical coordinator who manages the collection and compilation of the UPRs. Any significant noted anomalies or information gaps are followed up by the coordinator.

9 Transfer of Information and Data to GHGD

9.1 For members of CEA:

Under the terms of the MOU between the GHGD and CEA, SF_6 emission estimates aggregated at provincial/territorial and national levels are to be transferred from CEA to GHGD on an annual basis. To increase the transparency of the SF_6 estimates prepared by utilities, other pieces of information or data also need to be forwarded by CEA to GHGD. These include:

1. Specification on SF_6 tracking methods used by each utility;
2. Indication that QC checks have been performed and;
3. Statement(s) for the verification performed by a third party on emission estimates from utilities. There should be one statement, prepared by the third party verifier(s), for each utility that has undergone verification. This statement should:
    - Describe whether or not the SF_6 emission estimate was correctly developed by the utility in accordance with the protocol;
    - Describe whether or not the method reported to CEA and GHGD concurs with the method used;
    - Describe what has been done by the verifier(s) to obtain evidence that support his opinion (i.e. provide a summary of what have been verified);
    - State the data year coverage of the verification and;
    - State who performed the verification
    - Signature(s) of the verifier(s)

Information and data of the previous calendar year are to be transferred to the GHGD ***no later than the end of the second week of October of every year***. The following template (put either in MS Word or MS Excel format) can be used to transfer the required data and information to GHGD:

Table 9.1:SF_6 Data Transfer Template

Province	SF_6 Emissions Estimate (kg)	SF_6 Tracking Method(s) Used	Completed QC Checks (Yes/No)	Verification Done* (Yes/No)
British Columbia				
Alberta				
…				
Total SF_6 Emissions for CEA-member utilities: ____________ kg				

* If the answer is yes, please also provide a copy of the utility-specific verification statement to GHGD.

Finally, a questionnaire requesting inputs for the Tier 1 Uncertainty Assessment will be sent to utilities in the first year of official data transfer. They will be asked to complete the questionnaire with their best knowledge and members of CEA will send their response to the GHGD via CEA. As mentioned in section 6-*Data Uncertainty*, such questionnaire does not need to be completed by utilities on an annual basis. Utilities will only be resurveyed when an update to the uncertainty assessment is necessary.

9.2 For non-CEA members

SF_6 estimates for the previous calendar year aggregated at utility-level, and items 1 and 2 stated in 9.1-*For members of CEA:* are to be submitted by non-CEA members to the GHGD ***no later than the end of the second week of October of every year***. If a third-party verification statement is not available for a utility, item 3 above can be replaced by a similar statement prepared and signed by the manager that is in charge of the development of SF_6 emission estimates. Finally, a questionnaire requesting inputs for the Tier 1 Uncertainty Assessment will be sent to non-members of the CEA in the first year of official data transfer. They will be asked to complete the questionnaire with their best knowledge and send their response directly to the GHGD. As mentioned in section 6-*Data Uncertainty*, such questionnaire does not need to be completed by utilities on an annual basis. Utilities will only be resurveyed when an update to the uncertainty assessment is necessary.

10 Documentation and Archiving

As recommended by the IPCC, it is good practice to document and archive all information relating to the preparation and management of data used for inventory activities. Documentation should be prepared in such a way that calculations made can be reproduced and that ambiguity in records is avoided. Elements to be documented and archived by utilities, CEA or GHGD include, as a minimum, the following:

- Original records of raw data used and assumptions made;
- SF_6 gas inventory and purchase records;
- Information on the uncertainty associated with activity data (e.g., how uncertainty is determined, identification and qualification of individuals providing expert judgment for uncertainty estimates, etc.);
- Choice of tracking method and the rationale for it;
- Changes in data inputs for previous years (if any);
- Calculation worksheets;
- Records of QC checklists and its outcomes (e.g., any corrections or modifications) and;
- Records of verification process (e.g., verification process manual and verification statements);

Due to the large number of utilities in Canada and the vast amount of information to be managed, it was agreed upon by the GHGD-CEA joint committee that details of the calculations made will be documented and archived by utilities. The CEA will also hold records of the SF_6 data transfer from CEA member utilities to the program. However, utilities (either members or non-members of CEA) and CEA will give to the GHGD full access to the archived information, including calculation details and the items mentioned above, when needed (e.g., in the case of a UNFCCC review). The GHGD will archive the transferred data and verification statements received from CEA and non-members of CEA.

To be sure that the required information is available when a review takes place, it is recommended that utilities and CEA keep, for a period of at least THREE years, records (preferably electronically) of all calculation details, raw data used, uncertainty estimates, QC checks performed and verifications made.

11 New Information or Data Updates

11.1 For CEA members:

In the event a utility discovers new information, missed data, or corrections related to previously reported values, a correction notification must be made. The corrected data will be included within the next CEA ECR report submission, accompanied with a note to explain the nature of the revision and the data year for which correction has been made.

Since corrections made by a utility affect the national and provincial total estimates of a given year, the revised provincial and national data, the data year for which correction has been made and a note explaining the nature of correction must also be provided to the GHGD by CEA within the next CEA-GHGD data transfer.

11.2 For Non-CEA members:

In the event a utility discovers new information, missed data, or corrections related to previously reported values, a correction notification must be sent to the GHGD. The notification, including the corrected data, the data year for which correction has been made and explanation on the nature of the revision made, will be provided to the GHGD in the next data submission to the GHGD.

12 Protocol Review and Amendments

The Protocol will be reviewed on a five-year cycle starting from 2007, the year in which is the MOU signatory dated. The objective of the review is to ensure that the Protocol remains effective and is still appropriate to the requirements of Environment Canada and Canadian Electricity Association. The review will be undertaken by a committee composed of Environment Canada, CEA and utility representatives.

However, amendments to the Protocol may be made prior to the five-year review by mutual agreement to accommodate changing circumstances or to provide for additional clarity.

ANNEX

A1. Overview of the Greenhouse Gas Inventory

As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), Canada, as one of the Annex 1 parties, is obliged to submit a greenhouse gas (GHG) emission inventory to the Secretariat of the UNFCCC on a yearly basis. The national GHG inventory has two components: 1- the National Inventory Report (NIR) and 2- Common Reporting Format (CRF) tables. It is the key tool for monitoring and reporting on emissions from sources and removals by sinks and, with respect to the Kyoto Protocol, is the ultimate measure for assessing compliance with the national emission target.

The Greenhouse Gas Division (GHGD) of Environment Canada (EC), on behalf of the Government of Canada, is responsible for preparing, publishing and submitting the annual national inventory that complies with the UNFCCC Reporting Guidelines. These Guidelines have a number of implications on reporting and review requirements. For example, the GHGD is expected to estimate GHG emissions by sources and removals by sinks using agreed-upon methodologies, as outlined in the *Revised 1996IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA, 1997), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000), and *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC, 2003). The UNFCCC also requires that uncertainty of estimates be identified, quantified, and reduced as far as practicable. Therefore, to ensure that internationally agreed upon standards are met, the GHGD has to have in place a system for estimating GHG emissions and removals, continuous evaluation and improvement of methods, QA/QC of estimates, and documentation and archiving.

The current NIR includes estimates of anthropogenic (human-induced) emissions by sources, and removals by sinks, of the six main GHGs not controlled by the Montreal Protocol. They are:

- Carbon dioxide (CO_2);
- Methane (CH_4);
- Nitrous oxide (N_2O);
- ***Sulphur hexafluoride (SF_6)***;
- Perfluorocarbons (PFCs) and;
- Hydrofluorocarbons (HFCs).

Estimates of emissions and removals of these gases (for all the years between 1990 and the year of submission minus two) are presented at national and provincial/territorial levels. They are further grouped into six sectors: Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land Use, Land-Use Change and Forestry, and Waste. In addition to estimates, the NIR also provides detailed descriptions of the methodologies used to develop the estimates, a framework of a Quality Assurance and Quality Control Plan for the GHG inventory, and analyses of the factors underlying the trends in emissions/removals since 1990, and presents uncertainty estimates for each category and the overall inventory.

Between 1990 and 2005, CO_2 emissions have represented more than 75% of the total GHG emissions. Also, the majority of the total GHG emissions have been coming from the sector of Energy. However, emissions of HFCs, PFCs and SF_6 only occur in the sector of Industrial Processes. For example, manufacturing and operation of refrigeration and air conditioning equipment are responsible for most of the HFC emissions. PFC emissions mostly come from anode effects that may happen during aluminum production. SF_6, which has a GWP of 23 900 (meaning that emission of 1 kg of SF_6 has a warming effect that is 23 900 times stronger than that of 1 kg of CO_2), can be emitted from magnesium production and casting, ***electric utilities***, semiconductor manufacturing and other minor sources (e.g., in laboratory).

Since even small quantities of SF_6 can contribute significantly to global warming, it is important for the GHGD to keep good track of Canada's SF_6 emissions. To be able to do so, the GHGD has been working closely with magnesium producers and casting facilities. As a result, SF_6 use/emission data and the estimation methods used by casting facilities have been collected at company level. In addition, the MOU between CEA and GHGD, and the development of a SF_6 emission estimation protocol are important steps taken by the GHGD, in collaboration with industry, to ensure the completeness and accuracy of the SF_6 component of the overall GHG inventory.

A2. Overview of the Environmental Commitment and Responsibility (ECR) Program of the Canadian Electricity Association (CEA)

ECR Program

CEA utility members recognize that the industry and individual companies have to conduct their business with due respect and care for the natural environment and societal expectations in order to remain accountable to stakeholders. In 1997 the ECR program was established as a means for the electricity industry to collaboratively demonstrate its commitment to improve environmental performance through better environmental management.

The ECR Program adopts four environmental performance principles:

1. To be more efficient in our use of resources.
2. To reduce the adverse environmental impact of our business.
3. To be accountable to our constituents.
4. To ensure that our employees understand the environmental implications of their actions and have the knowledge and skills and to make the right decisions.

Key Elements of the ECR Program

The ECR program requires all utility members to implement an environmental management system based on the *ISO 14001:2004 Environmental Management Systems* (EMS) standard. Annually, each utility reports key environmental performance data and initiatives to CEA. The aggregated results are compiled into an Annual ECR Report on the electricity industry, which is shared with utility customers, government, business partners and other stakeholders.

The ECR program incorporates a third party verification process to ensure the integrity and accuracy of ECR reports. The ECR Program also utilizes a Public Advisory Panel to provide an independent assessment of the Programs and suggestions for improvement.

A3. Overview of IPCC Methodologies

To estimate SF_6 emissions from electrical equipment, methods of different levels of complexity are suggested in the Intergovernmental Panel on Climate Change (IPCC) publications. For example, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* published in 1997 suggest one simple estimation method that relies on the provided default emission rates. The *IPCC Good Practice Guidance* published in 2000 provides three approaches that can be used depending on data availability. Finally, the *2006 IPCC Guidelines* introduce a new Hybrid Approach, combining the use of mass balance and emission factor, and two types of emission factors for estimating SF_6 emissions from electrical equipment.

The following sections provide descriptions on the methods recommended by the IPCC publications.

Revised 1996 IPCC Guidelines (published in 1996)
The Revised 1996 IPCC Guidelines recommends one simple emission factor method, as shown in Equation A3-1:

SF_6 emissions in year t =
1% of total SF_6 charge in existing equipment in year t
+ 70% of the original charge of equipment that is being disposing of (A3-1)

However, recent studies indicate that the default rate of 70% suggested in the Guidelines underestimates retiring emissions, because equipment does not function below 90% capacity and will be refilled during its lifetime. Thus, inventory agencies using this approach are encouraged to review the applicability of the emissions factors in Equation A3-1 and use country-specific emission factors if appropriate.

IPCC Good Practice Guidance (published in 2000)
The IPCC Good Practice Guidance (IPCC GPG) describes three types of methods that can be applied to estimate emissions of SF_6 from electrical equipment. They are: Tier 1 Potential Emission Approach; Tier 2 Emission Factor Approach; and Tier 3 Mass Balance Approach (the most complex and accurate).

In a Tier 1 method, the total SF_6 sold to utilities and equipment manufacturers has to be determined. This can be done directly by obtaining data on sales to utilities and equipment manufacturers, or indirectly by obtaining data on sales for other uses.

There exist two kinds of Tier 2 approaches: Tier 2a – lifecycle emission factor approach and Tier 2b – IPCC default emission factor approach. Emission factors for the Tier 2a method can be developed based on data collected from representative manufacturers and utilities that track emissions by lifecycle stage. Essentially, emissions from these facilities are calculated for one year using the Tier 3a method. Explanations for the Tier 3a method will be provided further ahead. Total emissions from the surveyed manufacturers/facilities are summed and then divided by their purchase or nameplate capacity data to yield emission factors that can be applied across the sector. If emission factors cannot be developed, the IPCC default lifecycle emission factors can be used. If only national-level data on the total charges of installed and retiring equipment is available, emission factors can be applied to these data in a Tier 2b equation. The first term of the equation estimates leakage and maintenance losses as a fixed percentage of the total charge (e.g. 2%). The existing stock of equipment in each year includes all equipment installed in that year in addition to previously installed equipment that is still in use. The second term calculates emissions from retiring equipment and assumes that the minimum charge is 90%.

The Tier 3 method is the most accurate approach for estimating actual emissions of SF_6 from electrical equipment. It is a mass balance approach that tracks the amount of new SF_6 introduced into the industry each year. Industry uses some of this newly purchased SF_6 to replace leaked gas that escaped to the atmosphere the previous year(s). The remainder of the new SF_6 is used to fill the new equipment. The latter amount, while increasing the total equipment capacity, does not replace leaked gas and therefore is not considered as emission. In other words, the Tier 3 approach distinguishes between the SF_6 used to replace emitted gas and SF_6 used to increase total equipment capacity. It can be further broken down into: tier 3a – lifecycle approach; tier 3b – manufacturer and utility-level mass balance approach; and tier 3c – country-level mass balance approach. The Tier 3a method looks after emissions from each phase of the lifecycle of equipment, including equipment manufacture, installation, usage, and disposal. Data are obtained for every equipment manufacturer and utility in the country, and the emissions of all manufacturers and utilities are summed to yield the national estimate. If data for estimating emissions from lifecycle stages (Tier 3a) are unavailable, emissions can be estimated by tracking overall consumption and disposal of SF_6 for all utilities and manufacturers in a Tier 3b approach. In the latter approach, the stages covering installation, use and disposal are included in the utility emission estimates. It may be impossible for inventory agencies to obtain emissions data from all equipment manufacturers and utilities, or such data may be incomplete. In such cases, a Tier 3c national level estimate can be developed based on annual national sales of SF_6 into the electrical sector, equipment imports and exports, and SF_6 destruction.

2006 IPCC Guidelines (published in 2006)

Like the IPCC GPG, the 2006 IPCC Guidelines also provides three level Tiered approaches for estimating SF_6 emissions. Two of the options rely on the use of emission factors (either IPCC default or country-specific) derived for each lifecycle stage. A new Tier 3 approach called the "Hybrid Method – Emissions by Lifecycle Stage of Equipment," combining the application of emission factors and mass balance, is introduced in the 2006 IPCC Guidelines. It is implemented at the facility level and includes separate equations for each stage 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, one can choose to use either a mass-balance approach ***or*** country- (or facility-) specific emission factors.

A4. Sources of Uncertainty

As shown in Equation 2 in section 3.5-*Emissions from SF6 Recycling*, the total SF_6 emissions from a utility is calculated by adding together emissions from equipment use, and those arising from equipment decommissioning and failures. There are uncertainties associated with each term of the equation. Because there exist different ways to develop estimates of equipment use emissions, the sources of uncertainty also vary depending on the SF_6 tracking method used.

Mass Flow Meters

Mass flow meters provide the most accurate method for tracking the amount of SF_6 used for each top up operation. To ensure that the total equipment use emission estimate during a year is accurately calculated, utilities using this method must keep adequate records of measurements taken at each top up, otherwise missing records can give rise to uncertainty in the estimate. However, the uncertainty related to human errors is not reflected in the quantification method explained in section 6, because it is considered to be negligible and difficult to be quantified. Another source of uncertainty can be the mass flow meter itself. An uncertainty value of $\pm x$ unit of mass is provided by the mass flow meter manufacturers, but this should be small compared to the measured quantity.

Weighing individual cylinders before and after "top ups"

If the direct weighing of SF_6 cylinders before and after top-ups is performed to track the amount of SF_6 used/emitted, scale calibration and weight increments of the scale will influence the accuracy of the reported value (typically expressed as $\pm x$ unit of mass). That is, outside of human errors, reported data accuracy will be contingent on weight scale calibration and weight measurement increments. Scales used by utilities, when calibrated, would have an uncertainty value of $\pm x$ unit of mass provided by the scale manufacturers.

Weighing SF_6 cylinders on an inventory basis

When the weighing method on an inventory basis is used to track emissions coming from equipment use, the uncertainty of the emission estimates, like in the case of direct weighing of SF_6 cylinders before and after top-ups, is mainly driven by the accuracy of the scale.

Counting number of cylinders purchased in one year

When the amount of SF_6 used/emitted is determined based on the number of cylinders purchased in a year (shown in purchase or inventory records), uncertainty around the emission estimate could be coming from purchase or inventory records. According to anecdotal information provided by a gas distributor, the uncertainty around the stated net SF_6 mass (of 52.2 kg) of a cylinder would be ± 1 kg. Additional data inaccuracy can be introduced by the estimation of the amount of residual gas. 12 % of the gas will typically be left in a cylinder after use according to a gas distributor. Nonetheless, depending on how facilities use and handle SF_6, the residual amount of 12% can vary. This variation would cause some uncertainties in the estimates developed using purchase record method. Finally, the method assumes that all amounts of SF_6 shown on the records gets released within the year of purchase, whereas in practice it may take 3-4 years for that gas to be used. Since the uncertainty introduced by this drawback cannot be easily quantified and the SF_6 estimate from the central purchase record method is very accurate over a range of years, this uncertainty is not considered in the uncertainty quantification equations in section 6-*Data Uncertainty*.

Tracking cylinder count at the beginning and end of each year
If a utility tracks its SF_6 equipment use emissions based on inventory records at the beginning and at the end of a year, a source of uncertainty for the emission estimate is the record itself. As explained above, there can be an uncertainty of ± 1 kg around the stated SF_6 weight. The percentage estimate of residual gas (default value, 12%) found in cylinders that are returned to distributors is another source of uncertainty. In addition, if the utility takes into account, in its calculations, additional cylinders acquired during the year and the amount of SF_6 that is sent offsite for recycling, the purchase records that show the number of additional cylinders and the scale that measures the amount sent to recycling sites can contribute to the overall uncertainty in the emission estimate as well. Similar to the previous SF_6 tracking option, this method assumes that all amounts of SF_6 shown on the records of a year gets released within that year, whereas in practice it may take 3-4 years for that gas to be used. Since the uncertainty introduced by this drawback cannot be easily quantified and the SF_6 estimate from the central purchase record method is very accurate over a range of years, this uncertainty is not considered in the uncertainty quantification equations in section 6-*Data Uncertainty*.

Equipment decommissioning and failure
To estimate emissions from equipment decommissioning and failure, the values of nameplate capacity of equipment (retired or damaged) and of SF_6 recovered are used. Each of these values would have uncertainty associated with it. For instance, for older equipment for which the nameplate capacity may not be known, an approximation (i.e., a value with uncertainty) would have to be generated by expert judgment. For the amount of recovered SF_6, if utilities evacuate the gas from retired equipment into cylinders and then weigh the cylinders, the uncertainty associated with the SF_6 recovery estimate would be the uncertainty provided by the scale manufacturer.

Other sources of uncertainty
In addition to the sources of uncertainty mentioned above, there are also some sources that are much more difficult to numerically characterize. An example of a cause of uncertainty that is not easy to quantify is human error that results in loss of track of some SF_6 cylinders. Furthermore, the timeliness of reported data is another important aspect of uncertainty that cannot be easily quantified. Depending on the reporting method, there can be a fairly significant time displacement between the year for which release is reported and the actual time period that the SF_6 was released to the atmosphere.

A5. Summary of Data Requirements For a Tier 1 Uncertainty Assessment

As mentioned in section 6, the GHGD will perform a Tier 1 uncertainty assessment on the 2007 SF_6 emission estimates provided by utilities. Results generated from this are assumed to be applicable to emission estimates of subsequent years. Summarized in Table A5-1 are the data needed from utilities and equipment manufacturers and gas distributors.

Table A5-1: Data needed from utilities and equipment manufacturers

Method Used:	**For Uncertainty Assessment**	
	Data from Utilities	**Data from Equipment Manufacturers/Gas Distributors**
Mass flow meters	• Number of times meter is used • Uncertainty range of the meter	None
Weighing cylinders before and after top-ups	• Number of top-up operations • Uncertainty range of the scale	None
Weighing cylinders on a inventory basis	• Number of cylinders in inventory at the beginning of a year • Number of cylinders in inventory at the end of a year • Number of cylinders purchased during the year • Number of times the SF_6 gas is extracted from equipment and sent off-site for recycling/destruction • Uncertainty range of the scale used	None
Counting the number of cylinders purchased in a year	• Type(s) of cylinders purchased • Number of cylinders purchased (for each type)	• Weight of SF_6 per cylinder (for each reported cylinder type) • Uncertainty of the stated SF_6 weight

Method Used:	**For Uncertainty Assessment**	
	Data from Utilities	**Data from Equipment Manufacturers/Gas Distributors**
Tracking cylinder count throughout the year	• Type(s) of cylinders purchased <u>For each type of cylinder:</u> • Number of cylinders in inventory at the beginning of the year • Number of cylinders in inventory at the end of the year • Number of cylinders purchased during the year • Number of SF_6 cylinders sent off-site for recycling/destruction • Uncertainty range of the scale used	• Weight of SF_6 per cylinder (for each reported cylinder type) • Uncertainty of the stated SF_6 weight
Calculating Emissions from Equipment Decommissioning and Failure	• Number of pieces of decommissioned equipment • Uncertainty estimate of the nameplate capacity value* • Number of SF_6 recovery operations • Uncertainty range of the scale used to weigh recovered gas	• Uncertainty estimate of the nameplate capacity value*

* Depending on how the nameplate capacity of decommissioned or failed equipment is determined, the uncertainty estimate is obtained either from utilities or equipment manufacturers.

A6. QC Checklist Templates

As mentioned in Section 7-*Data Quality Control*, utilities and CEA should implement quality control (QC) procedures during the development of emission estimates, since these would result in improvements in estimates and ensure data accuracy. Provided below are checklist templates that are to be filled out by utilities and CEA for each year's emission estimation and reporting. Electronic copies of the completed templates should also be properly archived by utilities and CEA for a period of at least THREE years. They are to be made available to GHGD upon request (e.g., in the case of an in-country review).

QC Checklist – Utility

This checklist is to be completed by the utility during the development of SF_6 emission estimate. Please also fill in the space below each check if you have any additional comments/remarks, reference for supporting documents or suggestions that are relevant to the check.

(a)	**Utility Name**		
(b)	**Submission Year**		
(c)	**Completed by:**	**Name:**	
		Title:	

QC activities to be performed by utilities

	QC Activity	**Complete?**	**Errors detected?**			**Completion Date**
		Yes	**Yes**	**Date Corrected**	**No**	
1	Check that SF_6 data has been obtained from all district offices, field locations, etc. as appropriate. Archive source records. *SF_6 raw data and calculation records can be requested by the GHG Division as necessary (e.g., in a major international review).*	☐	☐		☐	
	Notes and supporting documents:					
2	Check that any assumptions made on the data are documented and archived.	☐	☐		☐	
	Notes and supporting documents:					
3	If the SF_6 tracking method used involves any weighing, ensure that the scale is functioning properly.	☐	☐		☐	
	Notes and supporting documents:					

4	Check for transcription and calculation errors	☐	☐		☐	
	Notes and supporting documents:					
5	Investigate and explain probable cause of any significantly different values from previous year's	☐	☐		☐	
	Notes and supporting documents:					
6	Check that all SF_6 data fields of the CEA ECR data submission templates have been accurately recorded and submitted to CEA. *(This check is only applicable to CEA members)*	☐	☐		☐	
	Notes and supporting documents:					
7	Check that the SF6 tracking method noted on ECR data template reflects the method that was used to record the current year's data. *(This check is only applicable to CEA members)*	☐	☐		☐	
	Notes and supporting documents:					
8	Check that the SF6 tracking method, along with the SF_6 estimate, is accurately reported to the GHGD. *(This check is only applicable to non-CEA members)*	☐	☐		☐	
	Notes and supporting documents:					

Sign-off

I have completed the above checklist

____

Name:

Title:

Signature:

Date:

QC Checklist – CEA

This checklist is to be completed by CEA during the development of SF_6 emission estimates. Please also fill in the space below each check if you have any additional comments/remarks, reference for supporting documents or suggestions that are relevant to the check.

(a)	**Organization Name**		**Canadian Electricity Association**
(b)	**Submission Year**		
(c)	**Completed by:**	**Name:**	
		Title:	

QC activities to be performed by CEA

	QC Activity	Complete?	Errors detected?			Completion Date
		Yes	Yes	Date Corrected	No	
1	Check for completeness. Confirm that all data needed for the aggregated calculations have been collected from CEA members with SF_6 releases. Archive data and other documentation received from CEA members with SF_6 releases. *Records can be requested by the GHG Division as necessary (e.g., in a major international review)*	☐	☐		☐	
	Notes and supporting documents:					
2	Check that the SF_6 tracking method used, along with the data, is reported by CEA members with SF_6 releases.	☐	☐		☐	
	Notes and supporting documents:					
3	Check that data are correctly transcribed from files supplied by members to CEA's master copy of calculation file.	☐	☐		☐	
	Notes and supporting documents:					
4	Check that units are correctly labeled in the calculation file, and that appropriate conversion factors are used (if necessary).	☐	☐		☐	
	Notes and supporting documents:					
5	Check that aggregated calculations are correctly done.	☐	☐		☐	

	Notes and supporting documents:					
6	Compare current data to previous years' data. If there are significant departures from expected trends and fluctuations, investigate and explain cause of discrepancies.	☐	☐		☐	
	Notes and supporting documents:					

Sign-off

I have completed the above checklist

____

Name:

Title:

Signature:

Date:

A7. Estimation of SF_6 Emissions for 1990-2003

As a result of discussions between the GHGD and CEA, SF_6 emission data will be provided to the GHGD by CEA for the years 2004 onwards. SF_6 emission data will also be sought from non-members of CEA. These data would represent considerable improvements for the category of SF_6 emissions from electrical equipment in the national GHG inventory. However, to complete the time series as required by the UNFCCC, emission values for 1990 to 2003 also need to be recalculated.

To recalculate 1990-2003 SF_6 emissions from electrical equipment, the 2004 emission data of utilities (either members or non-members of CEA) and the 1990-2004 estimates of total sales of SF_6 to Canadian utilities are used. Also, it is assumed that the actual SF_6 use or emissions for utilities follow essentially the same trend as the SF_6 sales to utilities. Specifically, the total sales of SF_6 of any given year are divided by the total sales of SF_6 in 2004. The ratio obtained from the division is then multiplied by the 2004 SF_6 emission data provided by CEA to give an estimate of the SF_6 emissions of that year. The advantage of this recalculation method is that it takes into account the fact that not all SF_6 quantities sold to utilities are emitted to the atmosphere, since some of them may be used to fill up new equipment.

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