TECHNICAL SUPPORT DOCUMENT FOR EMISSIONS FROM ELECTRIC EQUIPMENT MANUFACTURE OR REFURBISHMENT AND MANUFACTURING OF ELECTRICAL COMPONENTS

FINAL RULE FOR MANDATORY REPORTING OF GREENHOUSE GASES

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Office of Air and Radiation
U.S. Environmental Protection Agency

Contents

1. Source Description

Sulfur hexafluoride (SF_6) is most commonly used in the electrical power industry where it acts as an insulator and interrupter in equipment that transmits and distributes electricity (RAND 2004). The electric power industry in the United States has used SF_6 gas since the 1950s because of its superior dielectric strength and arc-quenching characteristics. SF_6 has replaced flammable insulating oils in many applications and allows for more compact substations in dense urban areas. Currently, there are no available or foreseen substitutes for SF_6.

High-voltage circuit breakers account for the majority of SF_6 use in the United States. Other types of electrical equipment that use SF_6 include gas-insulated substations, switches (other than circuit breakers), high-voltage transmission lines, and high-voltage bushings.

Original equipment manufacturers (OEMs) purchase bulk SF_6 gas to:

- install a shipping charge in high-voltage closed-pressure equipment;[1]
- ship alongside closed-pressure equipment for use at electric power system sites;
- fill sealed-pressure equipment with its intended lifetime supply of SF_6;[2] and
- test equipment.

SF_6 emissions from OEMs typically occur during the testing, manufacturing, and installation or commissioning of equipment but can also occur when equipment is decommissioned at a manufacturing facility.

Perfluorocarbons (PFCs) are sometimes 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 some exceptions to this pattern (IPCC, 2006). Throughout this Technical Support Document, "SF_6" will be used to denote SF_6 and/or PFCs.

a. *Total U.S. Emissions*

Emissions of SF_6 from OEMs in the United States were estimated to be 0.8 Tg CO_2 Eq. in 2006 (EPA 2010).

The 1990 to 2006 emission estimates for OEMs were derived by assuming that manufacturing emissions equal 10 percent of the quantity of SF_6 charged into new equipment. The quantity of SF_6 charged into new equipment from 1990 to 2000 was estimated based on statistics compiled by the National Electrical Manufacturers Association (NEMA). The quantities of SF_6 charged into new equipment for 2001 to 2006 were estimated using data reported by participants in EPA's SF_6 Emission Reduction Partnership for Electric Power Systems along with EPA's estimate of the total industry SF_6 nameplate capacity (128.4 Tg CO_2 Eq. in 2006). Specifically, EPA calculated the ratio of new nameplate capacity to total nameplate capacity of a subset of Partners for which new nameplate capacity data was available from 1999 to 2006. EPA then multiplied this ratio by the total industry nameplate capacity estimate to derive the amount of SF_6 charged into new equipment for the entire industry. The 10 percent emission rate is the average of the "ideal" and "realistic" manufacturing emission rates (4 percent and 17 percent, respectively) identified in a paper prepared under the auspices of the International Council on Large Electric Systems (CIGRE) in February 2002 (O'Connell et al. 2002). This method for estimating OEM emissions is the same method used in EPA's *Inventory of Greenhouse Gas Emissions and Sinks:1990-2006* (EPA 2008).

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[1] Closed-pressure equipment requires refilling (topping up) gas during its lifetime and generally contains between five and several hundred kilograms of SF_6 per unit (IPCC 2006).

[2] Sealed-pressure equipment should not require any refilling (topping up) with gas during its lifetime and generally contains less than 5 kilograms of SF_6 per unit (IPCC 2006).

b. Emissions to be Reported

EPA is requiring facilities to report all SF_6 and PFC emissions from testing and manufacturing of new equipment, from refurbishing and decommissioning and disposal of previously manufactured equipment, from storage cylinders and other containers, and from the installation of new equipment unless the title of the equipment has transferred to the electric power system facility.

Additionally, EPA is requiring facilities to report other source categories at the facility for which calculation methods are provided in the rule, as applicable. For example, facilities must report CO_2, CH_4, and N_2O combustion emissions from stationary combustion units by following the requirements of 40 CFR part 98, subpart C (General Stationary Fuel Combustion Sources).

2. Options for Reporting Threshold

EPA evaluated a range of emission and consumption-based thresholds for electrical equipment manufacturing. The emission-based thresholds considered were 1,000; 10,000; 25,000; and 100,000 mt CO_2 Eq. These thresholds translate to consumption-based thresholds of 922; 9,220; 23,061, and 92,244 lbs of SF_6, respectively, assuming an average manufacture emission rate of 10%.

As shown in Table 1 below, EPA estimates that all ten domestic facilities identified as consumers of SF_6 will fall above the 1,000; 10,000; and 25,000 mt CO_2 Eq. thresholds and above the 922; 9,220; 23,061 lbs. of SF_6 thresholds, while only the largest five facilities would be captured by the 100,000 mt CO_2 Eq./92,244 lbs SF_6 threshold. However, while EPA attempted to accurately estimate SF_6 consumption per facility, it is conceivable that OEMs specializing in the production of relatively low-voltage switchgear for the distribution market will fall below both the consumption and emission threshold.

Additional details on the number of facilities and total emissions that would be captured by each threshold are shown below in Table 1.

Table 1. Emission Threshold Summary

Emission Threshold (Mt CO_2 Eq)	**1,000**	**10,000**	**25,000**	**100,000**
Consumption Threshold (lbs. of SF_6)	**922**	**9,220**	**23,061**	**92,244**
Number of Facilities Above	10	10	10	5
Percent of Facilities Above	100%	100%	100%	50%
Total Emissions of Facilities Above (Mt CO_2 Eq)	814,128	814,128	814,128	569,890
Percent of Emissions Above	100%	100%	100%	70%

a. Data Analysis to Determine Reporting Threshold

The consumption-based threshold offers an important advantage relative to the emission-based threshold because it permits OEMs to quickly determine whether they are covered. It also avoids the scenario in which sources drop in and out of the program based on fluctuating emissions.

EPA performed a threshold analysis to determine how many OEMs would fall above and below the four different consumption thresholds considered. The analysis was performed by:

- Using the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* (EPA 2008) to determine the estimated amount of SF_6 gas purchased by all OEMs, which was estimated as 750,981 lbs in 2006.
- Converting the 750,981 lbs of SF_6 to metric tons of CO_2 equivalent, which is 8,141,281 Mt CO_2 Eq.

- Estimating total U.S. emissions by multiplying total purchases by the 10% emission rate, which is 814,128 Mt CO_2 Eq.

- Identifying the ten OEMs in the U.S. that are responsible for most of the SF_6 consumption in the manufacturing sector.

- Dispersing the total amount of U.S. OEM emissions of SF_6 among each of the ten OEMs based on the estimated market-share of each OEM.

3. Options for Monitoring Methods

For electrical equipment manufacturers, emissions can occur during equipment testing, manufacturing, installation, and decommissioning and refurbishing. EPA evaluated a range of options for estimating emissions that result from these activities. The three primary options reviewed were the Tier 1, Tier 2, and Tier 3 IPCC methods presented in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). Each of these options is described below.

a. IPCC Tier 1 Approach

The Tier 1 method, referred to as the default emission factor method, estimates emissions by multiplying the appropriate default regional emission factor by the amount of SF_6 consumed by each equipment manufacturer. Tier 1 emission factors are usually developed through industry research. However, due to a lack of data availability, IPCC does not provide a default emission factor for the United States. The default emission factors for emissions associated with the manufacture of closed-pressure electrical equipment in Europe and Japan are 8.5% and 29%, respectively.

b. IPCC Tier 2 Approach

The Tier 2 method, referred to as the country-specific emission factor method, also uses emission factors. But these emission factors are more accurate than the Tier 1 factors because they are developed using criteria specific to the country where the manufacturer is located and are usually developed by analyzing actual pure-mass balance emissions that were calculated at the life-cycle level.

While the Tier 1 and Tier 2 approaches are relatively simple, they are likely to result in inaccurate facility emissions estimates because they do not take into account the variation in SF_6 handling and management practices among OEMs as well as variation in production methods associated with the different types of electrical equipment produced. Furthermore, due to lack of data availability, IPCC does not provide emission factors for electrical equipment manufacturing in the United States.

c. IPCC Tier 3 Approach

The Tier 3 method measures SF_6 emissions using mass-balance equations for each life-cycle stage of the SF_6 use. The equations below are based on the Tier 3 mass-balance equations for equipment manufacturing emissions and equipment installation emissions.

The Tier 3 equation for estimating emissions from equipment manufacturing emissions, which includes equipment testing, equipment manufacturing, and equipment decommissioning and refurbishing is the following:

$$\text{Equipment Manufacturing Emissions} = \text{Decrease in } SF_6 \text{ Inventory} + \text{Acquisitions of } SF_6 - \text{Disbursements of } SF_6$$

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 + SF_6 returned to site after offsite 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 sent off-site for destruction destroyed

In addition, emissions may occur when the manufacturer fills the equipment off-site from the manufacturing facility, before transferring custody to the equipment user. These emissions, along with other issues related to the transfer of equipment from manufacturers to users, are discussed further below.

To quantitatively determine disbursements of SF_6 to customers in new equipment (or cylinders), four options were considered:

- Option 1: Disbursements could be estimated by weighing containers before and after gas from the containers was used to fill equipment or cylinders.
- Option 2: Disbursements could be estimated by using flow meters to measure the amount of gas used to fill equipment or cylinders.
- Option 3: Disbursements could be estimated by assuming that the mass of SF_6 or PFCs disbursed to customers in equipment is equal to the nameplate capacity of the equipment or, where the equipment is shipped with a partial charge, equal to the nameplate capacity of the equipment times the ratio of the densities of the partial charge and the full charge.
- Option 4: Disbursements could be estimated by weighing the equipment filled with SF_6 or the PFC from the container before and after filling. The tare weight of the equipment would then be subtracted from the weight of the filled equipment to determine the weight of the gas in the equipment, and therefore, the weight of the actual disbursement.

These options and their advantages and disadvantages are discussed, in turn, below.

- **Option 1** appears to be a practice currently employed at some manufacturing facilities. A digital scale is used to weigh the containers storing the gas before and after the equipment is filled (MEPPI 2010). In this regard, this option does not present new costs or changes to current procedures (at least for some facilities). However, EPA recognizes that emissions can occur downstream of the container to the equipment being filled. These emissions can occur through leaks in the hose or line connecting the container to the equipment, during coupling and decoupling activities, as well as through general mishandling (e.g., a faulty connection). To accurately estimate disbursements, these emissions should be estimated separately and subtracted from the disbursement total.

  Emissions could be calculated by the following method:

  i) Determine annual disbursements by summing individual disbursements as summarized in the equation below. Individual disbursements are denoted as "Q_p" and are summed to determine annual disbursements.

$$D_{GHG} = \sum_{p=1}^{n} Q_p$$

Where:

D_{GHG} = The annual disbursement of SF_6 or PFCs sent to customers in new equipment or cylinders or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers.

Q_p = The mass of the SF_6 or PFCs charged into equipment or containers over the period p sent to customers or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers.

n = The number of periods in the year.

ii) Determine Q_p, the mass of the SF_6 or PFCs charged into equipment or containers over the period p sent to customers or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers, by weighing containers before and after gas from containers is used to fill equipment or cylinders and subtracting emissions that occur during the filling. This calculation is summarized in the equation below.

$$Q_p = M_B - M_E - E_L$$

Where:

Q_p = The mass of SF_6 or the PFC charged into equipment or containers over the period p sent to customers or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers.

M_B = The mass of the contents of the containers used to fill equipment or cylinders at the beginning of period p.

M_E = The mass of the contents of the containers used to fill equipment or cylinders at the end of period p.

E_L = The mass of SF_6 or the PFC emitted during the period p downstream of the containers used to fill equipment or cylinders and in cases where a flowmeter is used, downstream of the flowmeter during the period p (e.g., emissions from hoses or other flow lines that connect the container to the equipment that is being filled).

iii) Determine the mass of SF_6 or PFC emitted downstream of the containers used to fill equipment or cylinders. These emissions could originate from hoses or other flow lines that connect the container to the equipment or cylinder that is being filled. This calculation is summarized in the equation below. To estimate losses from filling events, sum the emissions losses for each of the different valve-hose combinations during the period p.

$$E_L = \sum_{i=1}^{n} F_{Ci} \times EF_{Ci}$$

Where:

E_L = The mass of SF6 or the PFC emitted during the period p downstream of the containers used to fill equipment or cylinders and in cases where a flowmeter is used, downstream of the flowmeter during the period p (e.g., emissions from hoses or other flow lines that connect the container to the equipment that is being filled).

F_{ci} = The total number of fill operations over the period p for the valve-hose combination.

EF_{ci} = The emission factor for the valve-hose combination.

n = The number of different valve-hose combinations used during the period p.

The emission factor for a given valve-hose combination could be estimated using measurements and/or engineering assessments or calculations based on chemical engineering principles or physical or chemical laws or properties. Such assessments or calculations could be based on, as applicable, the internal volume of the hose or line that is open to the atmosphere during coupling and decoupling activities, the internal pressure of the hose or line, the time the hose or line is open to the atmosphere during coupling and decoupling activities, the frequency with which the hose or line is purged and the flow rate during purges. Such methods could also include the use of leak detection methods (e.g., EPA Method 21 and the Protocol for Equipment Leak Emission Estimates) to determine a loss factor appropriate to calculate emissions; however, bagging techniques as described in these methods may introduce feasibility concerns (e.g., user/operator error, bag damage) (Dilo 2010a). Unexpected or accidental emissions from the filling lines or hoses should be included in the total. EPA's understanding is that electrical equipment is at a vacuum and is sealed prior to being filled with SF_6 or PFCs (MEPPI 2010, NEMA Task Force 2001a). However, if any air or nitrogen is in the equipment and is purged during the filling process, then the method should also account for SF_6 and PFC emissions that occur during such purging.

Facilities could calculate the emission factor or use an industry-developed value for each combination of hose and valve fitting. No such values have been established by the industry to-date; however, valve manufacturers, in collaboration with equipment manufacturers could establish industry-wide factors. EPA inquired with one company that manufactures valves about developing such values (Dilo 2010a). Their calculations, for two standard fitting sizes—an 8 MM (DN8) and 20 MM (DN20), indicate the following:

Under normal breaker pressure (75 PSI) and at 20 degrees Celsius:

- 8 MM valve –80 milligrams; and
- 20 MM valve –265 milligrams (Dilo 2011).[3]

- **Option 2** presents the same issue as in option 1 in that emissions downstream of the containers would be required to be estimated separately and subtracted from the disbursement total. One disadvantage in this approach is that flowmeters may not already be used by the OEM, in which case, the OEM would need to purchase these devices (Dilo 2010a). OEMs commonly rely only on the pressure rise to monitor the transfer of the gas from a container to a breaker or other piece of equipment (MEPPI 2010).

Emissions could be calculated by the following method:

i) Determine annual disbursements by summing individual disbursements as summarized in the equation below. Individual disbursements are denoted as "Q_p" and are summed to determine annual disbursements. This calculation uses the same equation as in option 1, and is shown again below.

$$D_{GHG} = \sum_{p=1}^{n} Q_p$$

Where:

D_{GHG} = The annual disbursement of SF_6 or PFCs sent to customers in new equipment or cylinders or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers.

Q_p = The mass of the SF_6 or PFCs charged into equipment or containers over the period p sent to customers or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers.

n = The number of periods in the year.

ii) Determine Q_p, the mass of the SF_6 or PFCs charged into equipment or containers over the period p sent to customers or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers, using a flowmeter and the following equation:

[3] In a November 2011 revision to this Technical Support Document, EPA updated the value for the 8 MM valve from 10 grams to 80 milligrams and the value for 20 MM valve from 50 grams to 235 milligrams.

$$Q_p = M_{mr} - E_L$$

Where:

Q_p = The mass of SF_6or the PFC charged into equipment or containers over the period p sent to customers or sent off-site for other purposes including for recycling, for destruction or to be returned to suppliers.

M_{mr} = The mass of the SF_6 or the PFC that has flowed through the flowmeter during the period p.

E_L = The mass of SF_6 or the PFC emitted during the period p downstream of the containers used to fill equipment or cylinders and in cases where a flowmeter is used, downstream of the flowmeter during the period p (e.g., emissions from hoses or other flow lines that connect the container to the equipment that is being filled).

iii) Determine the mass of SF_6 or PFC emitted downstream of the containers used to fill equipment or cylinders. These emissions could originate from hoses or other flow lines that connect the container to the equipment or cylinder that is being filled. This calculation uses the same equation as in option 1, and is shown again below. To estimate losses from filling events, sum the emissions losses for each of the different valve-hose combinations during the period p.

$$E_L = \sum_{i=1}^{n} F_{Ci} \times EF_{Ci}$$

Where:

E_L = The mass of SF_6 or the PFC emitted during the period p downstream of the containers used to fill equipment or cylinders

F_{ci} = The total number of fill operations over the period p for the valve-hose combination.

EF_{ci} = The emission factor for the valve-hose combination.

n = The number of different valve-hose combinations used during the period p.

As explained in Option 1, above, facilities could calculate the emission factor or use an industry-developed value for each combination of hose and valve fitting. No such values have been established by the industry to-date; however, valve manufacturers, in collaboration with equipment manufacturers could establish industry-wide factors.

- **Option 3** equates the mass of SF_6 or PFCs disbursed to customers in equipment to the nameplate capacity of the equipment or, where the equipment is shipped with a partial charge, equal to the nameplate capacity of the equipment times the ratio of the densities of the partial charge and the full charge. The nameplate capacity could be based on the manufacturer's current estimate (i.e., the one that appears on the nameplate) or it could be measured. One disadvantage of assuming that the mass of SF_6 or PFCs disbursed to customers in equipment is equal to the current estimate of the nameplate capacity is that the current estimate may never have been measured with good precision and accuracy. Even if the nameplate capacity has previously been carefully measured, the internal volume of the equipment or density to which the equipment is charged might have changed since the original measurement. Because the mass-balance approach requires precise inputs, inaccuracies of even two or three percent could lead to very large inaccuracies in the facility's emissions estimate.

  One way of developing a more precise estimate of the nameplate capacity of equipment would be to fill the equipment with a fluid and then to carefully recover the fluid, measuring what was recovered. This fluid could be SF_6, another gas, or a liquid. If SF_6 was used, the equipment would be charged to its operational or shipping SF_6 density using the facility's usual methods and then emptied. The mass of the SF_6 recovered, adjusted slightly for the residual pressure of the SF_6 that would remain in the equipment even at a deep vacuum, could be equated to the full or shipping charge, as applicable. One advantage of this approach is that it would reflect the actual SF_6 charging practices of the facility; one disadvantage is that it could result in small SF_6 emissions during the charging and recovery steps.

If a liquid was used, the equipment would be filled carefully, ensuring that the full volume was filled, and then emptied. The volume of the liquid recovered would be equated to the internal volume of the equipment. The temperature of the liquid would need to be kept constant throughout this exercise to obtain an accurate measurement of the volume. This volume multiplied by the SF_6 density at the full charge would yield the nameplate capacity of the equipment.

To account for variability, a certain number of these measurements would need to be performed to develop a robust and representative average nameplate capacity (or shipping charge) for each make and model. Equipment samples should be selected so as to reflect predictable variability in the facility's filling practices and conditions.[4] In addition, within a particular set of conditions, equipment should be selected at random. The specific number of samples would depend on the variability of the nameplate capacity within each make and model and on the desired level of precision of the estimated mean nameplate capacity of each make and model. As discussed below, the desired level of precision of the mean would depend on the level of precision of the emissions estimate as a whole.

A Student T distribution calculation is the appropriate statistical procedure for determining when additional samples should be taken to achieve a tolerable error for the average nameplate capacity of a certain make and model of SF_6-containing electrical equipment.[5] The calculation presumes an approximately normal, bell-shaped distribution of the underlying parameter, which implies that the distribution of the average is the Student's t distribution. In principle, the mean of the samples taken approaches the true mean as more samples are taken; this procedure determines how many samples are needed as a function of the relative standard deviation of the sample measurements. The following matrix demonstrates this concept using a 95 percent confidence level and an assumed initial sample size of ten. On the left is the relative standard deviation of the sample population; an initial sample size of ten was chosen for this computation.[6] For example, an equipment manufacturer conducts a minimum of ten tests to determine the nominal nameplate capacity of ten samples from a given make and model of a high voltage circuit breaker. In this hypothetical example, the resulting standard deviation of those samples is 1.5 percent. If the tolerable error is one percent of the true mean, the manufacturer must increase its sample size to twelve, i.e., conduct two more tests, according to the chart below. If the standard deviation of the sample population tested was larger, the number of samples that would need to be taken would also increase.[7]

[4] For example, if equipment is filled to a particular pressure, and the temperature of the facility varies during the day or seasonally, then the density to which the equipment is filled will vary as well (with higher densities at lower temperatures). In this case, samples should be taken to reflect the typical range of temperatures at which equipment is filled.

[5] See the Technical Support Document for Fluorinated Gas Production for more discussion of the Student's t test.

[6] Table 2 is provided as an example; a manufacturer would apply the Student T distribution to determine the appropriate number of samples based on the variability of the quantity of gas charged into equipment of a given make and model.

[7] It is important to note that the reliability of the mean nameplate capacity estimate depends on the accuracy and precision of the individual measurements as well as on the number of times they are repeated. Accuracy is a measure of the bias (systematic error) of a measurement; precision is a measure of the random error. The precision includes the random errors from the measuring devices such as the scales used and the variation in the nameplate capacity for a single make and model. Repeated measurements using the same measurement device improve the precision of the mean, but they do not improve accuracy because each measurement has the same systematic error. For example, if the scale used to weigh the SF_6 shipping charges is only guaranteed to be accurate within one percent, and it happens to be biased upward by 0.75 percent, the mean of even 2,000 weight measurements of the same device will be biased upward by 0.75 percent.

Table 2. Example Lookup Table of Total Sample Size required to meet Precisions, given Initial Sample Size of 10

Relative Standard Deviation of Sample	Precision 0.25%	0.50%	1.00%	5.00%
0.5%	18	10	10	10
1.0%	64	18	10	10
1.5%	141	38	12	10
2.0%	249	64	18	10
2.5%	389	99	27	10
3.0%	560	141	38	10
3.5%	763	191	50	10
4.0%	996	249	64	10
4.5%	1260	315	81	10
5.0%	1556	389	99	10

The actual precision with which the mean nameplate capacity would need to be measured would depend on (1) the desired level of precision for the emissions estimate for the facility, (2) the precision with which the other quantities in the mass-balance equation were monitored, (3) the share of the facility's SF_6 disbursements accounted for by a particular make and model, (4) the number of makes and models whose nameplate capacities were measured,[8] and (5) the level of emissions. Example calculations indicate that a facility that measured gas acquisitions with a precision and accuracy of one percent and that had an emission rate of 10 percent might need to estimate the mean nameplate capacity (or shipping charge) to a precision of two percent to achieve a precision in its emissions estimate of about 20 percent (expressed as a 95-percent confidence interval). A facility that measured gas acquisitions with a precision and accuracy of one percent and that had an emission rate of 5 percent might need to estimate the mean nameplate capacity to a precision of one half of one percent to achieve a precision in its emission estimate of about 25 percent. (The accuracy of the device used for the nameplate capacity measurement would also need to be one half of one percent or better.)

For other sources (e.g., fluorinated GHG production processes using the mass-balance approach), EPA is proposing a maximum error of 30 percent. However, in general, the tolerable level of error in an estimate depends in part on the size of the emissions. For smaller emission sources, errors larger than 30 percent might be tolerable.

To reflect subtle changes in manufacturing methods and conditions over time, it may be appropriate to require re-measurement of nameplate capacities at some interval, e.g., every five or ten years.

According to industry, equipment manufacturers are filling breakers with SF_6 gas to a full charge as part of their testing procedures; the equipment is then evacuated and filled to a partial charge for shipment at a later stage in the process (MEPPI 2010). Therefore, an advantage to Option 3 is that it appears that it could be integrated into normal facility procedures without introducing any significant filling and recovering related activities. However, if the test charge were used to estimate the nameplate capacity, equipment manufacturers would need to account for possible variations between the density to which the equipment was charged during the test and that to which it was charged for shipping.

- Lastly, **Option 4** would require the weighing of the equipment filled with SF_6 or the PFC before and after the equipment is charged. The tare weight of the equipment would then be subtracted from the weight of the filled equipment to determine the weight of the gas in the equipment, and therefore, the weight of the actual disbursement. Although, in theory this option is advantageous because it shifts the emphasis to the

[8] If the nameplate capacities of multiple models were measured independently, using multiple measurement devices, then the "error" (more precisely, the relative standard deviation) of their summed or averaged nameplate capacities would be smaller than the errors of their individual nameplate capacities. However, if the nameplate capacities were measured using the same measuring device (with the same systematic error), then the error of the summed nameplate capacities would not be reduced below the systematic error of the individual nameplate capacity measurements.

equipment that is being disbursed (rather than weighing the containers at the intermediary step), this option is not practical for two reasons. First, the mass of the SF_6 or PFC charged into the equipment is likely to be low relative to the mass of the equipment; thus, it may be difficult to obtain a precise measurement of the mass of the SF_6 or PFC using this method (i.e., within 1 percent) even if the scale is precise and accurate to within 1 percent of full scale. Second, it would be very difficult and impractical to weigh the shipping unit, which can be large and difficult to maneuver onto a scale (MEPPI 2010).

Based upon a close examination of these options and review of comments received during the public comment period, EPA decided to require either Options 1 or 2. Additionally, to increase flexibility, EPA also incorporated Option 3 into the final rule. For this option, the number of measurements that is required for each make and model to determine a sufficiently precise estimate of shipping charge or nameplate capacity must be calculated to achieve a precision of one percent of the true mean, using a 95 percent confidence interval.

4. Issues Related to the Transfer of Equipment from Equipment Manufacturers to Equipment Users

As noted above, emissions may occur when the manufacturer fills the equipment off-site from the manufacturing facility, before transferring custody to the equipment user. Such emissions could be estimated using the following equation:

$$EI = M_F + M_C - N_I$$

Where:

EI	=	Total annual SF_6 or PFC emissions from equipment installation at electric transmission or distribution facilities.
M_F	=	The total annual mass of the SF_6 or PFCs used to fill equipment off-site from the OEM facility.
M_C	=	The total annual mass of the SF_6 or PFCs used to charge the equipment prior to leaving the electrical equipment manufacturer facility.
N_I	=	The total annual nameplate capacity of the equipment installed at electric transmission or distribution facilities.

These emissions could be attributed to the equipment manufacturer. Through EPA's SF_6 Emission Reduction Partnership for Electric Power Systems, a conference call was organized between representatives from the National Electrical Manufacturers Association (NEMA) and EPS Partners. Participants agreed that the responsibility of installation emissions varies and discussed points at which the reporting requirement for installation emissions would transfer from the manufacturer to the user (NEMA representatives 2010b). The final rule delineates the reporting boundary between the electric equipment manufacturer under this subpart and the electric transmission or distribution facility (under subpart DD) with respect to emissions during equipment installation. The final rule specifies that the responsibility of reporting emissions from installation practices is dependent upon the point at which the title is transferred to the electric power transmission or distribution facility by the electrical equipment manufacturer or third-party contracted by the manufacturer. The OEM must estimate and report emissions from equipment installation using the equipment installation mass balance equation if:

1) the electrical equipment manufacturer holds the title; or
2) the title temporarily passes from the OEM to a third party contractor.

In addition, any emissions from equipment that was filled (partially or completely) at the OEM's facility but whose charge leaked out before being delivered to and installed for the customer should also be the manufacturer's responsibility to report.

EPA understands that in some cases, manufacturers may exceed the nameplate capacity of equipment when charging it, either intentionally, to postpone the re-fill of the equipment in the event that the equipment develops a leak, or unintentionally due to adiabatic cooling that occurs during filling (NEMA Representatives 2010a). If there is an overcharge, then the actual initial charge of the equipment should be conveyed clearly to the equipment user. If it is not, the user will underestimate emissions. The underestimate will occur because the user will underestimate the quantity of gas "purchased with or inside of equipment." Effectively, an extra supply of gas is hidden inside the equipment rather than conveyed alongside it in a container.

For example, suppose that a piece of equipment is charged to 105 percent of its proper charge (nameplate capacity) when it is first installed, but that its initial charge is recorded as 100 percent of the proper charge. Suppose further that the equipment slowly leaks over its lifetime so that it has 90 percent of its proper charge left upon retirement. When the equipment is retired, only the difference between the proper charge (100 percent) and the actual charge (90 percent) will be noticed. The loss of the extra five percent will not be recorded because the initial gain of that five percent was not recorded. In the event that the equipment never leaks during its lifetime and is retired with 105 percent of its charge, the five-percent overcharge, when recovered along with the rest of the SF_6 inside the equipment, will register as an addition to the SF_6 in storage that is five percent above the retired nameplate capacity. Again, this will result in emissions being underestimated by the quantity of the overcharge.

To avoid the underestimate, electrical equipment manufacturers would need to provide equipment users with an accurate estimate of the quantity of SF_6 actually charged into newly commissioned equipment. The user would then record this as additional gas "purchased with or inside of equipment." Using the standard mass-balance approach, this extra gas would register as an emission during the first year. This is because the extra gas would be recorded as part of the total amount of gas purchased during the year, but would not be canceled out by a corresponding increase to cylinder inventory (since the extra gas is inside the equipment) or by the increase to nameplate capacity (since the extra gas is by definition the amount of gas remaining once the nameplate capacity of the equipment is subtracted from the amount of gas actually inside the equipment). Since it would not be accounted for as an addition to inventory or as part of the new nameplate capacity, it would seem to have been emitted or used to replace emitted gas. However, this apparent loss would be made up for when the equipment was retired, as discussed above.

An alternative approach to tracking the overcharge would be to record it as stored inside the particular piece(s) of equipment that is (are) overcharged. Effectively, this extra charge would be tracked as if it were stored inside a cylinder that happened to be attached to the equipment. The equipment would be checked annually to see whether and how much of its charge had leaked during the year; if the overcharge had not leaked out, then the overcharge would still be considered to be in storage and would not be recorded as an emission. Although this approach would avoid indicating an emission before any occurred, the need for annual checks of overcharged equipment would make it relatively burdensome to carry out.

Given the potential for an overcharge as well as general data accuracy of inputs required to estimate emissions of SF_6 from electrical equipment use, EPA decided to require in the final rule that the quantity of gas charged into delivered equipment and added during installation by the manufacturer be certified by the manufacturer and expressed in pounds of SF_6 or PFC. Electrical equipment manufacturers must keep records of certifications of the quantity of gas, in pounds, charged into equipment at the electrical equipment manufacturer or refurbishment facility as well as the actual quantity of gas, in pounds, charged into equipment at installation.

5. Review of Existing Relevant Reporting Programs/Methodologies

In addition to the *2006 IPCC Guidelines*, EPA also reviewed the protocols and guidance in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, the Technical Guidelines for the Voluntary Reporting of Greenhouse Gases (1605(b)) Program, EPA's Climate Leaders Program, and The Climate Registry. These protocols and guidance coalesce around the IPCC 2006 Tier 3 guidelines.

6. Procedures for Estimating Missing Data

It is expected that equipment manufacturers should be able to obtain 100 percent of the data needed to perform the mass balance calculations for both SF_6 and PFCs. The use of the mass-balance approach requires measured values for all inputs. However, if needed, replace missing data using data from similar manufacturing operations, and from similar equipment testing and decommissioning activities for which data are available.

7. QA/QC Requirements

QA/QC methods for reviewing completeness and accuracy of reporting include the following:

- Review inputs to the mass balance equation to ensure inputs and outputs to the manufacturer's system are all accounted for in all appropriate sections.
- Ensure no negative inputs are entered and negative emissions are not calculated. However, the *change* in storage inventory may be calculated as a negative number.
- Ensure that beginning of year inventory matches end of year inventory from previous year.
- Ensure that in addition to SF_6 purchased from bulk gas distributors, SF_6 returned from utilities and received from offsite recycling are properly accounted as additions to inventory.

QA/QC methods should be employed throughout the year. Important checks/procedures include the following:

- Ensure that cylinders returned to the vendor are weighed in a consistent manner.
- Ensure that gas suppliers measure the amount of gas remaining in cylinders/tanks returned (residual gas).
- Adopt practices such as tracking cylinders leaving and entering storage with check-out sheets and weigh-in procedures.

a. Analysis to Determine Scale Accuracy Requirements

A ±1 percent (of true weight) relative accuracy requirement for scales was originally proposed; however, based on comments EPA received during the public comment period indicating that the proposed requirement was too stringent, EPA reexamined the appropriate level of accuracy and precision for scales used to weigh cylinders.

The first steps undertaken by EPA to reassess scale accuracy requirements were to research scale manufacturer Web sites and to contact scale manufacturers and electrical equipment users to better understand what scales are available on the market and the typical specifications of scales designed to weigh cylinders. [9]

Subsequently, EPA performed a sensitivity analysis using a variety of scale accuracies to analyze what effect changes in scale accuracies would have on the relative uncertainty of emission estimates. The analysis was performed using assumptions for two hypothetical electrical equipment manufacturers—a switch manufacturer manufacturing low and medium voltage equipment ("OEM 1" in Table 3, below) and a high voltage electrical equipment manufacturer manufacturing 138 kV circuit breakers ("OEM 2" in Table 3, below). Since the price of scales tends to increase as scale accuracy increases (all else being equal), EPA's goal was to determine which scale accuracy requirement would result in the least cost burden while still providing emission estimates with reasonable uncertainty levels. The summary results from the sensitivity analysis are provided in Table 3 below.[10]

Table 3. Relative Uncertainties of Emission Estimates for Various Scale Accuracies (95% Confidence Interval)

Level of accuracy applied to mass-balance inputs	OEM 1	OEM 2	Average
± 1% (relative)	1%	8%	5%
± 5% (relative)	5%	42%	24%
± 1 pound (absolute)	1%	8%	5%
± 2 pound (absolute)	2%	16%	9%
± 1% of full scale (absolute)[a]	3%	26%	15%

[a]Assuming full scale is equivalent to a scale capacity of 330 pounds.

EPA concluded that the incremental increase in relative uncertainty from a scale accuracy requirement of ± 1

[9] Documentation of the internet research and correspondence with scale manufacturers can be found in the docket for this rule (Docket ID No. EPA-HQ-OAR-2009-0927).
[10] The analysis, in its entirety, is provided in the docket for this rule (Docket ID No. EPA-HQ-OAR-2009-0927).

percent of true mass or weight to ± 2 pounds absolute scale accuracy was not enough to justify maintaining the proposed accuracy of ± 1 percent of true mass or weight and its associated burden. Additionally, EPA understands that some electrical equipment manufacturers draw SF_6 from large vessels such as ISO containers to fill equipment at their facilities (Dilo 2010b). After reviewing the results of the sensitivity analysis as well as public comments submitted by electrical equipment manufacturers and information received from industry correspondence, EPA eased the proposed requirement as well as differentiated between flowmeters and scales as follows:

- For flowmeters, the final rule requires a scale accuracy of ±1 percent of full scale;
- For scales, the final rule requires a ±1 percent of the maximum weight of the containers (i.e., gas plus tare) typically weighed on the scale.[11]

This final requirement was designed taking into consideration that some electrical equipment manufacturers use large containers to fill equipment. A requirement such as ±2 pounds absolute scale accuracy would be exceedingly stringent when applied to scales with very large capacities used to weigh very large containers. EPA believes that the final accuracy requirements will lower the burden on reporters without significant compromise to data quality.

8. Reporting Procedures

The following supplemental data would aid in verifying facilities' emissions estimates, in pounds unless otherwise specified:

- SF_6 and PFC stored in containers at the beginning and end of the year
- SF_6 and PFCs sent off-site for destruction;
- SF_6 and PFCs sent off-site to be recycled;
- SF_6 and PFCs purchased in bulk, in pounds;
- SF_6 and PFCs returned by equipment users with or inside equipment;
- SF_6 and PFCs returned from off site after recycling
- SF_6 and PFCs stored in containers at the beginning and end of the year;
- SF_6 and PFCs inside new equipment delivered to customers;
- SF_6 and PFCs inside containers delivered to customers;
- SF_6 and PFCs returned to suppliers;
- The nameplate capacity of the equipment delivered to customers with SF_6 or PFCs inside, if different from the quantity of SF6 and PFCs in equipment delivered to customers inside equipment;
- A description of the engineering methods and calculations used to determine emissions from hoses or other flow lines that connect the container to the equipment that is being filled;
- The emission factors used for each hose and valve combination and the associated valve fitting sizes and hose diameters;
- The total number of fill operations for each hose and valve combination used to fill equipment or container disbursements;
- The mean value for each make, model, and group of conditions if the mass of SF_6 or the PFC disbursed to customers in new equipment is determined by assuming that it is equal to the equipment's nameplate capacity or, in cases where equipment is shipped with a partial charge, equal to its partial shipping charge;
- The number of samples and the upper and lower bounds on the 95 percent confidence interval for each make, model, and group of conditions if the mass of SF_6 or the PFC disbursed to customers in new equipment is determined by assuming that it is equal to the equipment's nameplate capacity or, in cases where equipment is shipped with a partial charge, equal to its partial shipping charge;
- SF_6 and PFCs, in pounds, used to fill equipment at off-site electric power transmission or distribution locations;
- SF_6 and PFCs, in pounds, used to charge the equipment prior to leaving the electrical equipment manufacturer or refurbishment facility;
- The nameplate capacity of the equipment, in pounds, installed at off-site electric power transmission or distribution locations used to determine emissions from installation; and

[11] For scales that are used to weigh cylinders containing 115 pounds of gas when full, this equates to ±1 percent of the sum of 115 pounds and approximately 120 pounds tare, or slightly more than ±2 pounds absolute accuracy.

- For any missing data, the reason the data were missing, the parameter for which the data were missing, the substitute parameters used to estimate emissions in their absence, and the quantity of emissions thereby estimated.

9. References

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