SF_6 EMISSIONS FROM MAGNESIUM

ACKNOWLEDGEMENTS

This paper was written by Bill Palmer (Cheminfo Services, Inc. of Toronto, Canada). The author reviewed various literature sources and contacted various industry participants and government environment departments. Interviews were conducted with 2 SF_6 suppliers, 3 primary magnesium producers, 4 magnesium casters (die and gravity), and the International Magnesium Association in North America. Telephone interviews were conducted with experts in Canada, U.S., Netherlands, Russia and U.K. In addition, e-mail correspondence was obtained from experts in Australia, Denmark, and Norway. Contacts are available upon request.

ABSTRACT

Molten magnesium and its alloys are volatile substances that have a tendency to oxidize explosively in air and require surface protection in casting processes. Work in the late 1960's on the film protection properties of Sulfur Hexafluoride (SF_6) led to the industrial adoption of this gas in protective gas mixtures over salt-based flux melting. Currently available test results indicate that no significant conversion or destruction of SF_6 occurs in magnesium casting processes. For the time being, it is assumed that all SF_6 used as a cover gas is emitted to the atmosphere.

The IPCC methodology calculates SF_6 emissions by assuming they equal consumption. There are no significant issues with emissions calculations at the plant level, since SF_6 consumption is easily measured. The key methodology issue is the availability of appropriate emission factors and activity level data where consumption data is not obtainable. In national inventories of SF_6 emissions from magnesium, the most important issue is likely the completeness of the inventory. Given the segmented nature of SF_6 use within the magnesium industry, it is important to account for all possible uses within the industry in a country. These uses include primary magnesium production, (which is easily accounted for), die casting, gravity casting and secondary magnesium production operations in a country.

Reporting has been problematic for this source. Not only have several countries not reported emissions from magnesium, but also the reports of other Parties have lacked transparency (UNFCCC/SBSTA/1998/7). Another key reporting issue is the preservation of the confidentiality of business data among industry participants. The transparency of reported data could be improved by the rigorous use of standard reporting forms and background notes.

Ensuring the quality of an inventory also requires that countries implement quality assurance and quality control programmes, which will need to occur at several steps in the process. At the plant or company level, key activities include quality control to ensure the accuracy of data (such as plant level measurements, calculations, and data), as well as the provision of sufficient documentation. At the level of the inventory agency, the accuracy of plant or company submissions as well as the compiled inventory must be ensured, and appropriate documentation maintained. One or more different types of external reviews and audits may also be appropriate for these sources.

The desired outputs and key questions related to these three areas have been discussed broadly in the general background paper, and are summarized in a short paper entitled "Outputs and Questions for Breakout Groups".

1 INTRODUCTION

1.1 Nature, magnitude, and distribution of source

1.1.1 SF_6 background

SF_6 is the most potent greenhouse gas of all those defined under the Kyoto Protocol with an estimated atmospheric lifetime of 3,200 years and a 100-year global warming potential of 23,900 relative to CO_2 (Norsko Hydro, 1998). Relatively small quantities emitted have a significant contribution to total greenhouse gas (GHG) emissions. It is an odourless, colourless, non-toxic, non-flammable gas that has a high dielectric strength and a recognized ability to form protective films with molten magnesium.

SF_6 is manufactured as a special gas from fluorine and gaseous sulphur by six major global producers, who account for the majority of global supply. The companies and the locations of their major plants are: Asahi Glass Chemicals (Japan); AlliedSignal Inc. (USA); Air Products & Chemicals (USA); Ausimont (Italy); Kanto Denka Kogya (Japan); and Solvay Fluor und Derivate GMBH (Germany). There are other unidentified Russian and Chinese producers who account for most of the remaining world supply.

Total global sales of SF_6 are estimated at 8,500 tonnes in 1996 and have been increasing at an average annual rate of about 5% per year since 1990. The dominant uses of SF_6 are in gas insulated switch gear (80%) and in blanketing molten magnesium (5-7%). Other SF_6 uses, which are less than 5% each, include: filling pressurized rubber products (e.g. tyres, tennis balls, shoe sole bladders); electronics manufacturing (e.g. plasma etching of tungsten) and filling of sound-insulating windows.

1.1.2 Nature of SF_6 use in magnesium

Molten magnesium and its alloys are volatile substances that have a tendency to oxidize explosively in air and require surface protection in casting processes. Work in the late 1960's on the film protection properties of SF_6 led to the industrial adoption of this gas in protective gas mixtures over salt-based flux melting. Sulphur dioxide (SO_2) and boron trifluoride (BF_3) also perform the same functions, but are toxic and more corrosive at higher concentrations (International Mag Assoc, 1998). The use of SF_6 in gas mixtures represented a major advance in the safe casting of molten magnesium, since it increased metal yields through reduced formation of impurities as sludge; improved the quality of cast products through reduced contamination; and resulted in a cleaner, non-toxic atmospheric workplace environment.

SF_6 is applied in low concentrations (<1.0% in air or air/CO_2) to the vapour space above the surface of molten magnesium in casting furnaces (melting and holding furnaces) through a distribution tube having multiple nozzles (Norsko, Hydro 1998). A very small portion of the SF_6 applied reacts with magnesium to form a thin molecular film of mostly magnesium oxide (MgO) and some magnesium fluoride (MgF_2) on the surface, which prevents the evaporation of volatile magnesium metal. Currently available test results indicate that no significant conversion or destruction of SF_6 occurs in magnesium casting processes. For the time being, it is assumed that all SF_6 used as a cover gas is emitted to the atmosphere.

1.1.3 Magnitude of SF_6 from magnesium

Total global sales of SF_6 for magnesium were estimated at 437 tonnes and 588 tonnes in 1995 and 1996 respectively (Maiss and Brenninkmeijer,1998). All sales to this end use were assumed to be completely emitted. According to the 1996 U.S. and Canadian GHG inventories], SF_6 from magnesium represents only about 0.2% of the total North American GHG emissions on a CO_2 equivalent basis (Jacques, A et al 1997, EPA, 1990-1997).

Of the 8,500 tonnes of total SF_6 sales in 1996, an estimated 6,100 tonnes were released. Thus, SF_6 emissions from magnesium are approximately 10% of total current SF_6 emissions. The largest source of SF_6 emissions is estimated to be the losses from the large banked quantities in electrical switchgear. Magnesium and electronics are the only SF_6 end uses having direct emissions from consumption.

There are two significant trends occurring in the magnesium industry which will have an effect on future SF_6 emissions from magnesium. The first is the strong growth in magnesium production due to the high demand growth of magnesium die casting for the auto industry. This recent boom in primary production and die casting has been one of the main factors that contributed to the increase of global SF_6 sales for magnesium at an annual average rate of 20% from 1992 to 1996 (Maiss and Brenninkemeijer,1998). An offsetting trend is the increased adoption of best operating practices for reducing SF_6 consumption among producers and casters. The factors behind the increased application of control measures include: the high price of the gas, climate change concerns, and reduction pressures from automobile companies. Some smelters are testing alternative cover gas systems using SO_2 and claim that they will eliminate SF_6 use in the next few years (Cheminfo,1998)

1.1.4 Distribution of SF_6 use in magnesium

There are four distinct segments in the magnesium industry where SF_6 is used for protection of molten magnesium:

- production of primary (pure) magnesium ingots at smelters;
- die casting of magnesium alloys;
- gravity casting of magnesium alloys (permanent molds and sand molds are used), and
- production of secondary magnesium through recycling of magnesium or its alloys.

Other end uses of primary magnesium do not involve melting in a pure state and therefore do not require a protective atmosphere. These uses include: high strength aluminium alloys (such as sheet for beverage cans), wrought products, cathodic protection, production of chemicals, iron and steel desulphurization, and reducing agents for rare metals. Some SF_6 is known to be used in the degassing of primary molten aluminium, but this practice is no longer common.

The majority of global emissions of SF_6 from magnesium come from primary magnesium smelters. Although there are no known studies in this area, a preliminary review of the North American magnesium industry produces an estimate of over 75% of total SF_6 emissions coming from primary magnesium smelters. These sources are easily identified and contacted. Die casting and gravity casting sources are smaller, more numerous and more difficult to identify. Secondary magnesium producers are also difficult to identify, but currently are limited to only a few countries. A more detailed description of these SF_6 sources is provided in the Completeness section.

1.2 The current state of inventory methodologies

The *IPCC Guidelines* provide one method for calculating SF_6 emissions from magnesium. This method assumes that all SF_6 used as a cover gas is emitted to the atmosphere. Thus, emissions are assumed to equal to consumption.

Current national inventories of SF_6 from magnesium vary from non-existent to reasonably complete and accurate. Some of the developing countries and economies in transition do not have any estimates for SF_6 emissions from magnesium in their countries due to lack of data. The most fully developed inventories combine direct reporting of consumption (bottom-up or point source data) from large point sources with calculations (top-down or area source data) of emissions for the die casting segment using activity level data (such as magnesium castings production) and assumed emission factors. One country is known to cross-check the *actual* emissions calculations with *potential* emissions estimates provided by segmented supplier volume data.

Direct reporting of consumption is the most preferable method for collecting data from large point sources such as primary or secondary smelters. This method can be extended to cover magnesium casters if the participants in the segment are known completely. The US Environment Protection Agency (EPA) has introduced a voluntary direct reporting initiative, as described in the Methodology section. The use of assumed emissions factors provides a reasonable estimate of emissions to cover emissions from smaller sources, as long as the activity level data can be obtained.

2 METHODOLOGICAL ISSUES

2.1 Selection of good practice methods

Within the IPCC methodology are different implementation approaches depending on the availability of data. The following three main methods are listed in descending order of rigour and accuracy. Different methods can be combined in the preparation of a national inventory for different magnesium segments:

- Direct reporting of actual consumption for all companies in all segments;
- Actual activity levels multiplied by emission factor for unidentified sources, and

- Potential national consumption based on supply and trade data.

2.1.1 Direct reporting

Direct reporting of consumption is the most accurate method of actual inventory compilation for those sources gathered, but the key issue is completeness of the sources. It is usually used with primary smelters and large casting companies, and captures information very accurately from the majority of SF_6 emission volume.

At the plant level, all SF_6 emissions are tracked through the measurement of gas consumption. There are different tracking techniques that can be used by the company to record annual consumption. Consumption can be measured by:

- recording delivered purchases and inventory changes (accounting method);
- measuring the difference in cylinder weight for gas used/returned (weight difference method), and
- measuring flow rates and integrating over time (flow measurement method) (EPA,1998)

The first two methods are more accurate because they are both based on total weight used. In the first method, the purchases used must be the actual volumes received in the calendar period and therefore, beginning and end inventories must be taken into account. The gas in the "heels" of any cylinders returned to the supplier must also be considered using this method. The second method is a variation of the first; a weight-based method with the measurement point at the cylinder. If different cylinders are used for different processes, it may be possible to determine different process emission factors with the second method. The use of the third method is better suited for determining different consumption rates for different processes. Most companies will likely use one (or both) of the first two methods.

Emission reporting can be made directly to the government agency or indirectly through a trade association or other neutral third party. In Canada, the two primary smelters report use directly to Environment Canada. In the U.S., the three primary smelters have reported use through the International Magnesium Association (IMA). In Norway, the primary smelter reports directly to the SFT (environment department).

Direct reporting from the casting industry has not been practiced on a broad scale to date. However, in 1998, the US EPA set up the *SF_6 Emission Reduction Partnership for the Magnesium Industry*, a voluntary agreement between the EPA and U.S. magnesium casting companies to directly report total SF_6 emissions and consumption rates. The primary purpose of the agreement is to reduce, and where technically feasible and cost effective, eliminate SF_6 emissions from magnesium casting operations. Participating companies agree to report 1990 and 1995 emissions and commit to report annual emissions and rates each year starting with the 1998 year. Confidentiality is preserved by reporting only usage rates to the EPA and actual emissions through the IMA, who publish industry totals. Best practice and technology information is shared among participants and achievements are recognized. Usage rate targets will be set for hot-chambered, cold-chambered and scrap-remelt processes based on best practice data received.

2.1.2 Actual activity levels and emission factor

This methodology is a top-down calculation made by multiplying appropriate actual activity level data by an average emission factor for the industry, an industry segment or some portion of an industry segment. These methods are considered to produce estimates of *actual* data, because the results are derived from actual activity levels. This method is appropriate for use when direct reporting of actual data is unavailable.

The activity level data is usually derived from national statistics or through market research studies. Emission factors can be obtained from IPCC defaults, international industry estimates, or data from local operations. The selection of the appropriate activity level and emission factor data for a country's magnesium industry is very important to minimize errors. These issues are discussed in the next two sections.

2.1.3 Potential national consumption

Tier 1 methodology defines the potential emissions (consumption) in a country based on overall supply data:

$$\text{Net consumption} = \text{production} + \text{imports} - \text{exports}$$

This may be an effective method of measuring overall use of SF_6 in a country and cross-checking total SF_6 in all end uses. To use this method appropriately for magnesium, the segmentation of end uses (e.g. use in electrical switchgear, magnesium, electronics, etc.) in the country must be determined with reasonable accuracy. Trade data is often not kept in such detail. Suppliers or importers are one possible source of end use segmentation information, but this may be subject to error. Unless the data for SF_6 in magnesium is provided by suppliers who know the segmentation of the market well, this method must be supplemented with some other method of estimating the portion of overall consumption that goes to the magnesium industry. As an example, Denmark obtains its overall SF_6 use data from import data provided by three companies and obtains information on end uses by contacting users.

2.2 Emission factors

Usage rates of SF_6 (and hence emission factors) vary widely between companies and types of processes. As a first approximation, one emission factor can be used for a country's total magnesium industry, but this is prone to high levels of inaccuracy. It is more appropriate to gather emission factors appropriate for each segment of the industry in the country.

A Norsk Hydro survey of 19 die casters worldwide illustrates the variations. It reported that SF_6 consumption ranged from 0.1 to 11 kg/tonne magnesium component produced (Giestland and Magers,1996). The average emission factor calculated from the results was 4.1 kg/t Mg, but this was a simple mean and not weighted for volume of magnesium production. The study results were skewed, since two companies were found to use pure SF_6 as a cover gas (a dangerous practice) and two others reported use at 25% and 50% by volume. The authors have assumed that the weighted average consumption of SF_6 in die casting is much less than 4.1 kg/t (Giestland, Westengen and Plahte, year unknown).

One usage rate estimate used total global SF_6 supply data in 1995 (440 t) and total primary and secondary magnesium production (329 kt) to calculate a mean global consumption rate of 1.3 kg/t Mg(Maiss and Brenninkemejier,1998) This estimate may also be overstated because total SF_6 volume is used in the numerator, but magnesium casting tonnage has not been included in the denominator. The same source reports that the SF_6 usage rate in Norway has decreased from 4 kg/t in the 1980's to 0.7 kg/t in 1996.

Norsk Hydro (Giestland, Westengen and Plahte, year unknown)suggests that in some non-continuous or highly intermittent operations, the application of average emission factors may underestimate the amount of SF_6 actually used. The need for protective gas depends not so much on the throughput, but on the area of the molten metal surface to be protected and the time the metal is molten. Ideally, emission factors for these operations should be given as kg/metal surface area per day, but this data is very difficult to collect.

2.3 Activity data

The use of emissions factor methodology assumes that activity level data is available in a country to a reasonable level of accuracy. Activity level data is usually production data from different segments of the industry, such as primary and secondary magnesium production or magnesium casting production in a country. In many countries, activity level data may not be available in the appropriate level of detail to use a Tier 2 method properly. One such problem encountered is the lack of segmentation in national statistics between die casting and gravity casting production data. Wrought magnesium products, which do not use SF_6, are sometimes included in published magnesium products data. Ideally, activity level data should be available for each distinctly different type of process, as described in the four segments above. This may have to be obtained through market research if not available through government statistics.

2.4 Uncertainty assessment

Parallel to the IPCC sector-specific workshops on good practice guidance, the IPCC is completing a programme of work on emissions inventory uncertainty. This work will result in recommendations to the United Nations Framework Convention on Climate Change (UNFCCC) on approaches to assessing and managing uncertainty. During the IPCC Inventory Experts Group Meeting in Paris (October 1998), technical experts in the uncertainty subgroup developed a series of questions to be answered in the sector workshops. Specifically, the sector workshops should provide answers to these questions in the individual source context, so as to make known the work on the uncertainty programme in establishing a general methodological approach.

2.5 Completeness

The *IPCC Guidelines*, in section 2.13.8, states that, "SF_6 is used as a cover gas in foundries to prevent oxidation of molten magnesium." It adds that SF_6 is used in the aluminium industry as a cover gas only for special foundry products. No details are provided about the types of foundries or processes in the magnesium or aluminum industries.

A proper segmentation of the magnesium industry is important in preparing a complete and accurate inventory due to different processes, activity levels and emission factors. The four segments of the magnesium industry where SF_6 is used should be considered in a complete inventory. The magnesium segments are described below. Some of these segments may not exist in some countries.

2.5.1 Primary production

Primary magnesium is produced in a molten state from the electrolytic decomposition of magnesium chloride and is cast continuously into ingots under a protective atmosphere. A worldwide total of 395 kt of primary magnesium was produced in 1995. Primary magnesium production is concentrated in only about 10 countries in the world. About two-thirds of production comes from western world smelters, located in six countries: USA (3 smelters), Canada (2), France, Norway, Serbia and Israel (1 each) (Kramer,1997). China and the former Soviet Union (FSU) countries of Russia, Ukraine and Kazakhstan have a large magnesium capacity, some of which is shared with titanium production. China has many, small-capacity magnesium smelters. New magnesium capacity is being added in Canada, Iceland, Australia and the Congo in the next five years, to meet the strong growth in magnesium die casting demand. (Chevalier,1997)

SF_6 for protection of primary magnesium is used mostly in western world smelters. China and the FSU commonly use SO_2 for this purpose. The geographical distribution of the 437 t of SF_6 used in magnesium in 1995 is estimated to be 78% for the U.S. and Canada; 15% for Europe; and 7% for the rest of the world (Maiss and Blenninlenier, 1998) SF_6 consumption rates are estimated to range from 0.5 to 4.0 kg/tonne magnesium produced (Giestland, Westengen and Plahte, year unknown).

2.5.2 Die casting

High pressure die casting is the process of casting magnesium parts by injecting molten magnesium into a mould clamped together by hydraulic force. Generally, one casting furnace supplies molten metal to one mould casting station. Die casting is the most common and economical form of magnesium casting, due to its high casting rates and the long life of the dies. Worldwide, die casting is the second largest end use for magnesium, estimated at over 85 kt in 1997. Magnesium is rapidly displacing steel and aluminum in automotive parts applications, which account for over 85% of die casting demand. Light-weight electronics and tool casings are other end uses. Global growth is estimated at 15% per year (20% in North America) for the next five years. The most common magnesium alloy used for die casting is AZ91 (91% magnesium and about 7-8% aluminum).

Magnesium die casting plants are usually concentrated near automotive manufacturing regions. For example, there are roughly 30-35 magnesium die casters in North America, concentrated mostly in the US Central and Midwest states and the province of Ontario in Canada. This segment operates under multiple year contracts and is highly price competitive, and therefore has the potential for significant operational shifting between plants and countries.

Plants typically operate 5-20 casting furnaces in a variety of sizes. All furnaces must be supplied with SF_6 from a central mixing station through a distribution piping network. Three distinct processes are: hot-chambered die casting, cold-chambered die casting and scrap re-melting. Each of these processes have different operating conditions and may have different SF_6 consumption rates.

The SF_6 concentration for a die caster is recommended to be in the range of 0.2 to 0.3 % by volume in air or CO_2. This will likely result in SF_6 consumption rates of about 1 kg/t. Under ideal conditions, which are difficult to attain, a minimum rate of 0.04% SF_6 by volume is recommended. The total volume of SF_6 used in die casting operations is much lower than in primary smelting operations due to the lower volumes of molten magnesium processed.

2.5.3 Gravity casting

Gravity casting is a manual process where molten magnesium is usually poured manually into moulds composed of resin-bound sand. It is used for highly complex castings requiring precision and close tolerance. One example is the production of aircraft engine parts requiring very small cores for internal oil flow. One central furnace may supply several moulding stations. The furnaces are usually more open to the atmosphere than die casting furnaces and there is more re-work of cast products.

Gravity casting requires as much as ten times the SF_6 usage rate per tonne product than die casting. For gravity casting, the recommended concentration of SF_6 in a CO_2 protective atmosphere ranges from 1.7 to 2.0%. This is six or seven times that recommended for die casting. SF_6 consumption rates can be as high as 10 kg/tonne of finished product. Compared to die casting, the finished product tonnage is much lower and there is more rework. A small number of gravity casting operations have the potential to account for a significant share of the SF_6 used in all types of casting operations, despite accounting for a low percentage of tonnage output.

2.5.4 Secondary production

While some primary smelters operate their own recycling processes for returned used cast alloy materials, there are a number of independent magnesium recyclers who also use SF_6 for protection of molten magnesium. A variety of recycling processes are in current use, based on the use of refining fluxes as well as flux-free methods using SF_6. Recycled alloys are often first remelted under salt-based flux protection because they are usually received in an impure or dirty state. There is some yield loss of magnesium, but the salt-flux is effective in binding and removing the impurities into a sludge which can be separated for disposal. Later, the material can be refined under SF_6 protection in the same type of refining and casting furnace used for primary metal, depending on the market requirement for the secondary metal.

The United States and Japan have over 90% of the estimated 100 kt of secondary magnesium production in the world (1996) (Kramer, 1997). In the U.S., which has the largest share of secondary magnesium production, there are about 4 or 5 major independent magnesium recyclers, some of which use SF_6. These include: Emco, Spectrolite, Garfield Alloys (Magretech division), and Remacor.

2.5.5 Other areas for review

In the preparation of a national inventory, a review should also be made to determine whether any SF_6 is used at all in a country's aluminium industry. Aluminium companies report that SF_6 is not used for melting of alloys containing magnesium, because the magnesium ingots can be immersed in molten aluminium with special baskets. Although SF_6 has been used in the past for the degassing process of molten aluminium, most companies have discontinued this practice, using chlorine or argon gas instead.

Magnesium parts can be made using thixotropic injection moulding processes, which create a semi-solid "slush" for pressure injection. SF_6 is generally not required in these processes because the magnesium is not fully melted. One plant reports that argon gas is used in the injection system.

2.6 Under-estimation/over-estimation

A review of the four magnesium segments will help to minimize Type 1 errors (i.e., not reporting SF_6 which is being used in some unidentified locations). A programme of direct reporting by magnesium casters may not record the complete SF_6 use in that segment if all companies do not participate or if minimum reporting thresholds are applied. The market should be known well enough so that a Tier 2 estimation can be applied to the portion covered by smaller or non-participating companies. If this is done, an estimation of what portion of the segment is not covered by the direct reporting method should be made.

At the same time, it is important to minimize Type 2 errors (i.e. attributing SF_6 use to operations where it is not used). This can occur when the emissions factor methodology is used to estimate emissions for a segment. A magnesium parts company may use thixotropic moulding for some or all of its production, or may use SO_2 cover gas instead of SF_6. (There are a few die casters in Europe who use SO_2 instead of SF_6). Some secondary magnesium producers use flux instead of SF_6. Since a company's production data is included in the national activity level statistics, the application of average SF_6 emission factors to the industry or segment may overstate SF_6 use for this company.

3 REPORTING ISSUES

The IPCC reported in October 1998, that only 21 Parties of 34 reported emissions of HFCs, PFCs and SF_6 in 1995, with varying levels of completeness. Some countries are known to have not submitted information due to lack of data and resources.

3.1 Current IPCC reporting guidelines

In an effort to improve completeness and comparability across inventories, the UNFCCC encouraged Parties to use the formal reporting instructions as outlined in the *IPCC Guidelines*. The intent is to make national inventories as transparent as possible to allow external parties to reproduce the results. This requires sufficiently detailed information to be provided on activity data, emission factors, model parameters, and assumptions. The Guidelines establish:

- Standard tables, definitions, units and time intervals for reporting all types of emissions;
- Necessary documentation to enable comparison of national inventories, including worksheets, major assumptions, methodological descriptions, and enough data to allow a third party to reconstruct the inventory from national activity data and assumptions, and
- An uncertainty assessment.

SF_6 emissions from magnesium are reported in Table 2: Sectoral Report for Industrial Processes. The results appear in IPCC category 2C4, which refers to Industrial Processes (2), in the Metal Production category (C), under the specific title, SF_6 Used in Aluminum and Magnesium Foundries (4). A single quantity represents the total SF_6 emissions and there is no further segmentation of this source. The value is reported in units of gigagrams (Gg equivalent to kilotonnes) of gas, which for SF_6 inventories is usually less than 1.0 for any country.

The reporting format does not provide the detail necessary to accommodate different methods of emission reporting. For example, if direct reporting of emissions from large sources is combined with Tier 2 calculations using activity level data and emission factors for unidentified smaller sources, the data is not fully transparent unless explanatory notes are provided. Ideally, there should be several segments within the source category to add reporting detail, but this may add too much complexity to the reporting format for such a small category. Additionally, the units for SF_6 should be reported in tonnes of SF_6 gas, not kilotonnes (Gg), since the tonne is the most commonly used measure for SF_6.

3.2 Current reporting practices

There was considerable variation in the second national greenhouse gas inventory submissions to IPCC for the year 1996 (IPCC, 1998). For the “new” gases (HFCs, PFCs, and SF_6), only 21 of 34 Parties provided data, and not all reported emissions of all 3 gases. Of the 13 Parties which did not report these emissions at all, some indicated that emissions of one or more of these gases are negligible. The results had varying degrees of completeness and quality.

With regards to documentation and transparency, only 18 of 34 Parties provided the IPCC standard data tables, only 15 Parties provided the Overview tables and only 5 Parties provided their worksheets, as requested by the *IPCC Guidelines*. Most Parties did not identify the tier of the method used to make their emission estimate. These poor reporting practices make it difficult to reproduce or compare national results.

The use of actual and potential approaches varied considerably among Parties, but the methods used for SF_6 are not known. Many countries, especially economies in transition, reported that they do not have systems in place to estimate these emissions. Only some indicated that they would provide these data in future inventories. One example is Russia, where SF_6 emissions are not yet estimated at all and the inventory process is just beginning. A greenhouse gas monitoring system does not exist currently, but the intention is to start one in 1999. The difficulties include: a lack of inventory specialists and a shortage of funds. In such a situation, the two best options would be to apply default SF_6 emission factors to primary magnesium capacity data (activity data) or to conduct a supply study with the help of global SF_6 suppliers.

3.3 Confidential business issues

Confidentiality of SF_6 data is a very important issue to companies in the magnesium industry because SF_6 use can be directly linked to production. The magnesium industry, especially the die casting segment, is highly competitive and companies tend to be very cautious about revealing data. When multiple smelters or die casting companies exist in a country, any direct reporting should be conducted through a neutral third-party (e.g. consultant), a trade association, or government agency to preserve confidentiality.

4 INVENTORY QUALITY

4.1 QA/QC systems

A thorough quality assurance/quality control (QA/QC) system ensures that the multi-stage process of preparing a national inventory results in the best possible estimates which have the confidence of all stakeholders. The four main stages of good inventory preparation are:

- Plant Level: data measurement, reporting of data to government;
- Government/agency: input review, inventory compilation, reporting to UNFCCC;
- External Parties: audits, peer and public review of results, and
- UNFCCC: input review for consistency with other submissions in a standard format

Internal quality control (QC), a system of routine activities used to verify inventories as they are being prepared, minimizes procedural and technical errors associated with developing emission estimates. QC is applied at any stage where data is being measured, assembled, calculated and totaled from the plant level to the UNFCCC. The second component of a QA/QC system is external quality assurance (QA), the systems of review and audit activities conducted by personnel who are not directly involved in the inventory preparation process. QA includes the review of input submissions at each stage for transparency and external peer and public reviews of results. The proper documentation of data and methods used for submission of results at any stage is critical to achieve the desired transparency of results.

4.2 Informational and organizational requirements

The QC system for the direct reporting of SF_6 use for magnesium by a plant should include the choice and description of measurement method (e.g. purchases, use, flows), the raw data measurements and the calculations for the results. Ideally, SF_6 usage rates corresponding to the SF_6 use data should be reported for different processes within a plant. Additional information should include: a summary of inventory QC procedures, equipment calibration procedures, and estimates of accuracy.

At the government/agency level, QA should be done on input data submissions to ensure accuracy and transparency. When preparing inventories, some important QC practices include: cross-checking aggregated results with industry, supplier or national totals; ensuring all plants are included; and analysing calculated average national emission factors and trends. Inventory preparation data, assumptions and methods should be well documented to facilitate an external review.

External reviews may be performed on inventories by independent third-parties, industry experts (peers), other industry stakeholders, or the public. Reviews by industry experts or stakeholders are quite useful in establishing good plant and national inventory procedures in the early stages of development. They ensure that the methods and factors used are the most rigorous and accurate, and that the data reflects the best available information. Confidential third-party reviews may be more appropriate to improve procedures to ensure transparency. The U.S. EPA Partnership is based on recent review efforts with the U.S. die casting industry. The International Magnesium Association can also play an important role in helping to review procedures to ensure consistency. In the U.K., the SF_6 inventory is reviewed by one SF_6 producer (Air Product PLC), industrial gas distributors, and trade associations. The U.K. and the Netherlands follow ISO 9000 standards for inventory preparation, while others are putting measures in place to do the same.

5 CONCLUSIONS

SF_6 is a greenhouse gas having a very high global warming potential. It is used as a component of a cover gas to protect the surfaces of molten magnesium from igniting explosively in air. SF_6 emissions are assumed to equal consumption. SF_6 is used in various casting operations at primary and secondary magnesium smelters, die casting plants and gravity casting plants.

The 3 general types of methodologies for estimating national SF_6 emissions are, in decreasing order of certainty: direct reporting, calculation from emission factors, and national mass balances. SF_6 emission factors used for calculations vary from 0.1 to 11 kg/tonne magnesium component produced, depending on type of operation and containment, cover gas flow rates, SF_6 concentration in the cover gas and degree of gas feed process control. Best practices at primary smelters and die casting operations have indicated SF_6 emission rates below 1.0 kg/tonne magnesium.

National inventories should be complete, accounting for all magnesium casting operations in a country. The reporting of inventories should be transparent, detailing methodologies used, activity levels and emission factors assumed and data sources. An uncertainty analysis should be provided to show the degree of potential error.

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