SF_6 GAS EMISSION REDUCTION FROM GAS-INSULATED ELECTRICAL EQUIPMENT IN JAPAN

Mr. Shigeru Maruyama, The Federation of Electric Power Companies (FEPC)
Mr. Masanari Meguro, The Japan Electrical Manufacturers' Association (JEMA)
JAPAN

ABSTRACT

A joint study of technical standards for recycling and handling of SF_6 gas was conducted from 1996 to 1998 by representatives of academia, utilities, equipment manufacturers, and gas producers in Japan, and voluntary actions for SF_6 gas emission reduction from electrical equipment have been taken since 1998. This paper describes the outline of the joint study and voluntary action plan enacted by the concerned parties, as well as the prospects for SF_6 gas emission for the future.

1. BACKGROUND OF SF_6 GAS USAGE IN JAPAN

In recent years, since there has been a significant increase in electricity demand, substation equipment has had to be more reliable and compact, coping with higher voltage and larger capacity ratings. By applying sulfur hexafluoride (SF_6) gas to substation equipment like circuit breakers and switchgear, downsizing and lower maintenance costs can be achieved to greater degrees than in a conventional air-insulated substation because of the excellent performance of SF_6 gas. Therefore, gas-insulated equipment like gas circuit breakers (GCB), gas-insulated switchgears (GIS) and gas-insulated transformers (GIT) are being widely and commonly used. Particularly in Japan, where land acquisition is extremely difficult, there is a large demand for GIS.

On the other hand, because SF_6 gas was identified as a greenhouse gas in recent years, electric power companies and equipment manufacturers in Japan have been studying countermeasures for limiting the release into the atmosphere. Since an alternative gas has not been found yet in spite of great efforts in the concerned fields, we have to continue to use the SF_6 gas with special attention. Therefore, consideration should be taken to keep the SF_6 gas emission to a minimum so that we can make the best use of gas-insulated equipment.

2. SF_6 GAS HOLDINGS AND EMISSIONS IN JAPAN

The world's production of SF_6 gas in 1995 was estimated at being approximately 8,500 tons [1]. Of the total, some 30% was produced in Japan. SF_6 gas is mainly used for electric insulation. From the results of surveys in Japan on the amounts of SF_6 gas handled by gas producers and gas-insulated equipment manufacturers from 1990 to 1995, the amount of SF_6 gas and the quantity of emissions are estimated as shown in Fig. 2-1.

Generally, since SF_6 gas for electric insulation purposes is used in enclosed vessels, the amount of holding gas increases in proportion to the number of facilities. According to the survey, the amount of SF_6 gas possessed by the electric power companies had increased by 400 tons to 500 tons per year, while the amount by the other industries had grown by 100 tons to 150 tons per annum. As of 1995, the total amount of SF_6 gas held in Japan is estimated to have been approximately 8,000 tons.

Emissions from the gas producers are taking place from their production processes and in the course of disposing of residual gas, which remained inside of returned gas cylinders. These emissions are estimated at approximately 8% of the production volume. Emissions at the equipment manufacturers occur in the testing stage both during development and production in their factory, as well as during installation work at the site. These emissions account for approximately 30% of the amount of purchased gas. Emissions at the electric power companies represent the emission during maintenance and removal of equipment as well as leakage. The amount of these annual emissions has been 50 to 80 tons since 1990.

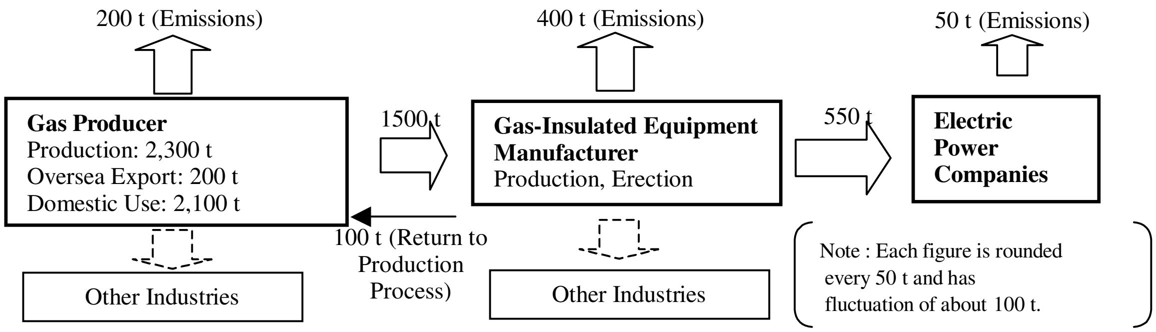

Fig. 2-1: *Outlook of Annual SF_6 Gas Usage and Emission*

3. EMISSIONS FROM GAS-INSULATED EQUIPMENT

3.1 Emissions at Gas-Insulated Equipment Manufacturers

Emissions of SF_6 gas into the atmosphere at equipment manufacturers are categorized as follows. The emitted amounts were roughly proportional to the purchased amount and nearly approximately 30% of the amount of purchase. The ratio of emissions in the factory and at the site stood at nearly 50:50.

(1) Emissions in the factory

At gas-insulated equipment manufacturers, gas-recovering equipment is installed in their plants and recovered SF_6 gas is being reused. This is done for the enhanced efficiency of SF_6 gas charge/discharge operations performed on equipment under test, the efficient use of SF_6 gas, and the ensuring of safety for workers. On the other hand, to reuse recovered SF_6 gas, it is necessary to remove impurities within the recovered gas. When recovering gas in the negative pressure region, since there is a fear of lubricating oil used in the vacuum pump making its way into the recovery tank as oil mist, it is necessary to evacuate SF_6 gas through an oil mist trap. For this reason, it takes a very long time to recover gas at pressures below atmospheric pressure. This poses a major productivity-enhancement challenge to the gas-insulated equipment manufacturers, and represents the largest factor behind the current emissions of SF_6 gas in factory.

(2) Emissions during installation at the site

As with emissions in the factory, gas recovery is carried out at the site by mobile-type gas handling equipment. In particular for indoor installation, gas recovery is strictly carried out to prevent an oxygen deficiency. However, a nationwide survey of the use of mobile-type gas handling equipment shows that the ownership rate is low and there are still operation-related problems that need to be addressed. What's more, mobile-type gas handling equipment is burdened with problems such as unsatisfactorily long recovery times, just as is the case with the stationary-type gas handling equipment. These factors combine to become a big factor of emissions in th e field.

3.2 Emissions at Electric Power Companies

The release of SF_6 gas at electric power companies consists mainly of emissions during maintenance, emissions during removal of equipment, and leakage from equipment in operation. The results of a survey shows the emissions have ranged between 50 and 80 tons. Table 3-1 gives a breakdown of emissions generated by the above-mentioned causes.

Table 3-1: *Actual conditions of emissions at electric power companies*

	Maintenance	Removal	Leakage
110 kV or higher	Recovery down to 0.05 Mpa· Gage	Fully released	0.1%/year
Lower than 110 kV	Fully released		

(1) Emissions during maintenance
The results of a survey showed that the majority of electric companies in Japan are recovering gas from equipment, rated at 187 kV or higher. Since those companies that possess large quantities of gas are recovering from equipment rated at upwards of 110 kV, it can be said that gas recovery is performed during maintenance of equipment rated at upwards of 110 kV roughly 100% of the time on a nationwide basis.

(2) Emissions during removal of equipment
The results of the survey showed that most of SF_6 gas was presumably released into the atmosphere when removal of GIS, while the number of the case was small.

(3) Leakage of SF_6 gas from equipment in operation
Leakage of SF_6 gas from gas-insulated equipment (GCBs & GISs) in operation refers to gas leakage from gas seals. Table 3-2 shows specifications related to gas-leakage for gas-insulated equipment [2-5].

Table 3-2: *Gas leakage specifications*

Name of standard	Specified leakage rate (%/year)
JEC	1
IEC	1 or 3
ANSI/IEEE	1

Note: JEC: Japan Electro-technical Committee

Gas-insulated equipment, however, has excellent track records in terms of the ability to prevent leakage. According to the SF_6 RECYCLING GUIDE [6] published by the Conférence Internationale des Grands Réseaux Electriques à Haute Tensions (CIGRE), the leakage from first-generation equipment (manufactured before 1985) is rated at 0.5%/year or less, while that from second-generation equipment (manufactured in 1985 or later) is rated at 0.1%/year or less.

3.3 Measurement of Leakage from Equipment
During the aforementioned joint study in Japan, field measurement relating to leakage of SF_6 gas was carried out in order to obtain the conditions of gas-insulated equipment in operation.

(1) Selection of equipment to be subjected to measurement
Measurements were conducted on GISs and GCBs. Equipment for investigation was categorized into two groups as follows: One group consists of equipment manufactured in or after 1981 with low incidence of gas leakage trouble. Another group contains equipment manufactured in or before 1980 with a high incidence of leakage trouble. Measurements were carried out on the occasion of periodical maintenance of each installation.

(2) Measurement results
By the measurement, it was found that the great majority of equipment leakage was small beyond the limits of detection. All measured data were below 0.1%/year, and the average value was smaller than 0.001%/year -- even in consideration of a small sample quantity (of 40 units) and

measurement errors. Accordingly, it is understood that original seal performance as measured at the time of installation remains within the tolerable range after the years of operation, and that gas-insulated equipment has a sufficient gas tight performance of less than 0.1%/year in leakage. This result enables us to use 0.1%/year for an emission factor for the inventory of gas emissions.

3.4 Processing of Disused SF_6 Gas

(1) Processing of recovered gas

In many cases, before maintenance work on equipment, its SF_6 gas is once recovered into gas handling equipment. After maintenance work, the gas is refilled into the equipment for reuse. According to the results of surveys, small amounts of gas are released into the atmosphere in many cases, while recovery is carried out, as a rule, in cases where the gas amount is large as mentioned above. Then, the recovered gas is reused for development testing at gas-insulated equipment manufacturers or refined at gas producers. As for the refining process, the components of recovered SF_6 gas are checked and the gas is introduced into the refining process of production plants to become new gas. Furthermore, efforts are also underway to develop a destruction process.

(2) SF_6 gas destruction

When SF_6 gas is heated, destruction begins at about 500°C, then some 30% of the gas decomposes at about 800°C, and then 100% of the gas breaks up at temperatures over 1000°C. Thermal destruction equipment is commercially available. It is designed to pass SF_6 gas through a layer impregnated with special chemicals and heated to a certain high temperature to convert the gas into silicon tetrafluoride (SiF_4) and sulfur dioxide (SO_2). However, since the capability of such equipment is only limited at present, and thermal destruction needs large amounts of energy, we understand that the destruction of SF_6 gas should be avoided as much as possible and that recycling should be pursued instead.

4. VOLUNTARY ACTION PLANS

In April 1998, the Federation of Electric Power Companies (FEPC) and the Japan Electric Manufacturers' Association (JEMA) announced a voluntary action plan for the reduction of SF_6 gas emissions from electric equipment. The voluntary action plan was issued based on the understanding that electric power companies and electric equipment manufacturers must make every effort to keep their SF_6 gas emissions to a minimum in order to make use of gas-insulated equipment, since an alternative gas has not been found yet in spite of great efforts in the concerned field.

The actions to be addressed are as follows:

(1) Suppression of SF_6 gas emissions during maintenance work
(2) Suppression of SF_6 gas emissions at the removal of gas-insulated equipment
(3) Establishment of a gas recycling system
(4) Brush up the current SF_6 gas inventory system
(5) Development of new technology to minimize the use of SF_6 gas in equipment

At the same time, gas recovery guidelines (target values) for SF_6 gas emission was presented and the required actions have been taken since then. Needless to say, joint and close work by the respective parties are indispensable.

5. SF_6 GAS QUALITY CRITERIA

For decreasing the emissions of SF_6 gas, it is essential not to emit SF_6 gas and to recover it for recycling at the time of maintenance or removal of the gas-insulated equipment. For such recycling, a new SF_6 gas quality control standard is indispensable.

In establishing the purity control criteria for SF_6 gas, the following conditions are considered jointly by the representatives of academia, utilities, equipment manufactures, and gas producers together.

1. Since breaking performance is mostly influenced by the inclusion of the impurity, the allowable value of the impurity is determined based on the breaking performance. The breaking performance of the circuit breaker is said to be statistically dispersed. When an experimentally allowable value including such statistical dispersion is considered to be about 3%, the amount of mixed N_2, by which the breaking performance declines by 3% compared with that where the purity is 100%, is 5 vol.%. Therefore, the allowable value is 95 vol.% by deducting 5 vol.% from 100 %.

2. The margin of error, 1 vol.%, of the purity measuring instrument of the SF_6 gas needs to be taken into consideration. Besides such an error, it is considered that there are some errors including one deriving from the linear approximation of the experimental data. Therefore, 97 vol.%, the sum of the error of the purity measuring instrument (1 vol.%), another error and allowance (1 vol.%) and the allowable value (95 vol.%), is taken as the purity control value.

In addition, the results of studies conducted on air, moisture, decomposed gases, products, and oil content are shown in Table 5-1.

Table 5-1: *Quality control criteria for SF_6 gas*

		Permissible limits	Criteria
SF_6 gas purity		95 vol.%	97 vol.%
Air		(5 vol.%)	(3 vol.%) including CF_4
Moisture content	Equipment without current interruption	1000 ppm (vol.)	500 ppm (vol.)
	Equipment with current interruption	300 ppm (vol.)	150 ppm (vol.)
Dissolved gases/decomposition products		–	No color reaction in detecting tube

6. SF_6 GAS RECYCLING FLOW

A recycling flow for SF_6 gas, which is shown in Fig. 6-1, has been established based on the above SF_6 gas handling criteria. In each phase of the flow, recycling should be promoted when handling SF_6 gas. Note that SF_6 gas should not be released into the atmosphere even when it fails to measure up to the required quality level; the gas should be recovered for refining (or destruction). Provision shall be made to enable the use of not only new gas but also recycled gas at every step of the flow.

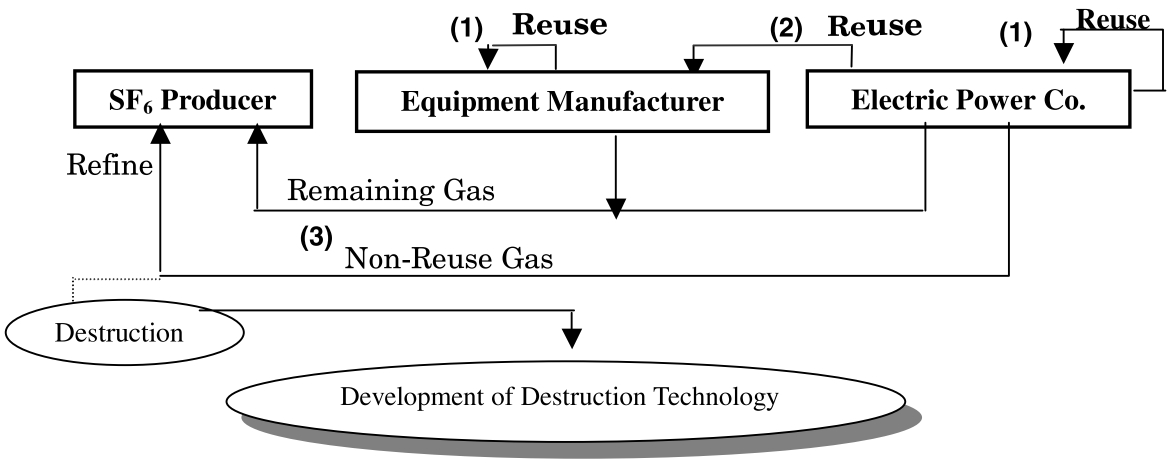

Fig.6-1: *SF_6 Gas Recycling Flow*

To make efficient gas recovery operations possible, the following principles should be observed:

1. Recovered SF_6 gas that meets the required quality control level should be reused by electric power companies and gas-insulated equipment manufacturers.
2. Even when SF_6 gas recovered from removed equipment satisfies the required quality control level, its reuse in electric power companies is not efficient if the gas is available in large quantities. If this is the case, recovered gas should be brought in to gas-insulated equipment manufacturers.
3. If recovered SF_6 gas fails to reach the required quality control level, the gas should be returned to its producers for refining or destruction.

7. ESTIMATES OF EMISSIONS

7.1 Recovery Targets for SF_6 Gas

Table 7-1 shows the current gas recovery rates and target values in the future of gas recovery guidelines.

(1) During development stage of equipment

In cases of interrupted tests or switching tests during the development stage, SF_6 gas used to be not recovered in many cases because such tests generate dissolved gases. However, in the future, it is necessary to promote recovery even during the development stage through the use of filters and the like, so as to remove dissolved gases to a sufficient degree. In this sense, a standardized procedure for recycling under development stage is required.

Terminal pressure of 0.015 MPa abs (corresponding to a recovery rate of 97% for equipment whose rated gas pressure stands at 0.4 MPa gage) or lower shall be adopted from the year 2005 onward as a target.

Table 7-1: *Current Gas Recovery Rates and Future Gas Recovery Guidelines (The indicated recovery rates apply to cases where recovery is performed on equipment/facilities with a rated gas pressure of 0.4 MPa· Gage.)*

		Recovery terminal pressure		Recovery rate	
		Lower than 110 kV	110 kV or higher	Lower than 110 kV	110kV or higher
Before 1995	During testing	No recovery		No recovery	
	During manufacture	0 - 0.05 MPa· gage		Approx. 70%	
	During installation/ maintenance	No recovery	0 - 0.05 MPa· gage	No recovery	Approx. 70%
	During removal	No recovery		No recovery	
In future (from 2005 onward)	During testing/ manufacture/ installation/ maintenance	0.015 MPa· abs (114 Torr) or lower		97% or higher	
	During removal	0.005 MPa abs (38 Torr) or lower		99% or higher	

(2) During equipment manufacturing
Product testing during equipment manufacturing is only the work related to SF_6 gas handling. Since recovery is virtually performed almost 100% of the time in the course of equipment manufacture, further efforts shall be made to increase the rate of recovery in the future. The same recovery terminal pressures of 0.015 MPa abs or lower at 0.4Mpa gage shall be adopted as a target from the year 2005 onward as indicated in Table 7-1.

(3) During equipment installation
In this case, it is important that work process adjustments shall be considered in related cases because the duration of gas recovery time during the installation generally becomes longer. Target terminal pressure is the same as above.

(4) During maintenance work
During internal inspection of gas-insulated equipment, recovery of SF_6 is necessary at first in order to open the SF_6 gas sealing section. After the completion of the inspection, the section is to be vacuumed up and then is refilled with the gas just like at the time of the installation. When SF_6 gas has to be recovered, issues such as the elongation of the out-of-service time are expected to occur in cases where that voltage class is 110kV or lower, from which the gas has not been recovered actively. In urban areas, it is difficult to secure the required out-of-service time. Therefore, SF_6 gas recovery equipment with higher efficiency is required from now on. Considering the constraint like that, we are aiming at attaining the terminal pressure of 0.015 MPa·abs or lower at the time of the recovery from the year of 2005 onward.

(5) During equipment removal
When removing SF_6 gas-insulated equipment, as when conducting maintenance, the SF_6 gas sealing section has to be opened, and so, the dismounting should be carried out after recovering the SF_6 gas. So far, we do not have many experiences in the removal of the equipment and have less experience in the recovery of gas. Concerning the equipment units to be removed from now on, we are required to attain a higher recovery rate of gas due to the reasons that there are no constraints for outage, and a larger amount of gas has to be recovered as a consequence. Therefore, 0.005 MPa abs or lower (corresponding to a recovery rate of 99% for equipment whose

rated gas pressure stands at 0.4 Mpa·Gage) is set to a target of the recovery terminal pressure.

7.2 Estimates of SF_6 Gas Emissions

Based on the aforementioned targets, the amounts of SF_6 gas emissions by gas-insulated equipment were estimated as follows.

(1) Estimates of SF_6 gas holdings

In recent years, the amount of SF_6 gas holdings of the electric power companies has been increasing by 400 to 500 tons per year. Since demand for electric power is growing steadily, the amount of electrical equipment is also expected to grow correspondingly. On the other hand, the amount of SF_6 gas in newly developed equipment becomes smaller. In this sense, the quantity of gas possessed in Japan is expected to grow at the current pace (of 400 to 500 tons annually) into the future because growing demand would be offset to some extent by decreasing amounts of charged gas per unit.

Furthermore, in the field of non-utility-use equipment, the SF_6 gas holdings have been on the increase at an annual rate of 100 to 150 tons in recent years. In future years, capital investment is expected to be nearly the same level as in the past and therefore, the annual amount of SF_6 gas handled by gas-insulated equipment manufacturers is considered to remain roughly at the current level.

(2) Estimates of SF_6 gas emissions

Through the implementation of said measures, the Japan Electrical Manufacturers' Association (JEMA) presumes that it may be possible to reduce the amount of discharge from gas-insulated equipment manufacturers to less than one-tenth of the current emissions of approximately 400 tons.

On the other hand, it is expected that the amount of leakage from the equipment in operation will increase because of the growing number of facilities. As a result, the amount of equipment to be inspected and replaced increases, which, in turn, creates new factors for increasing gas emissions. Even under such a situation, it is considered possible to maintain the electric power companies' current emission level in the future by increasing the recovery rate, namely by improving the performance of gas-recovery equipment, and increasing the number of such equipment to offset increases in the amount of leakage. Through the implementation of these measures, it becomes possible to reduce the total amount of emissions from both gas-insulated equipment manufacturers and electric power companies down to approximately 15% of the current level. Estimates of SF_6 gas emissions are shown in Fig. 7-1.

8. SF_6 Gas Emissions in the Other Industry

With the implementation of measures, the SF_6 gas production industry has set a quantitative reduction target for emissions of SF_6 gas as follows:

- Actual 1995 emissions: 82.2 kg/ton
- Target for the year 2010: 43 kg/ton or less (down 48% from the above figure)

In addition, it is reported that SF_6 gas is applied to the magnesium casting process and approximately 20 tons of SF_6 gas was used in 1999 by the magnesium industry. However, from the standing point of environmental protection, substitute gas is now being researched and therefore, the quantity of SF_6 gas used in the magnesium industry will be reduced, thanks to the substitute gas and other measures.

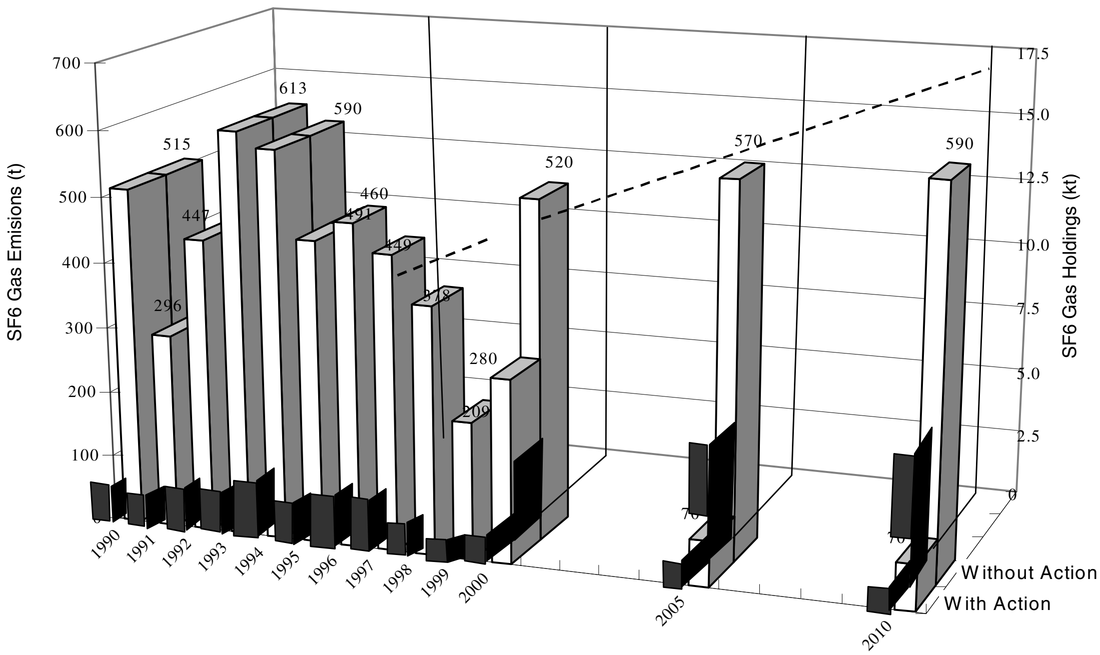

Fig. 7-1: *Estimates of Future SF_6 Gas Emissions*

9. CLOSE/FUTURE PERSPECTIVE FOR SF_6 GAS EMISSIONS

With the prime purpose of controlling emissions of SF_6 gas, the Joint Study Committee has conducted studies of handling guidelines. The studies of the present state of affairs have shown that the amount of SF_6 gas leakage occurring from equipment in operation is low—on the order of 0.1% or less per year. Furthermore, where future handling of gas is concerned, the committee was able to devise conditions for the continued use of SF_6 gas by establishing measures and an SF_6 gas recycling system that can adequately contribute to the reduction of emissions of greenhouse gases. As indicated in Fig. 7-1, SF_6 gas emission from 1996 to 1999 was gradually reduced as expected.

In the future, we are confident that further efforts and continued cooperation of relevant parties will reduce SF_6 gas emissions in accordance with the guidelines established by th is joint study.

REFERENCE

1) U.H. Bartell et al. ”SF_6 und die Atmosphare – eine energietechnische Bilanz” (1997)

2) IEC. “High-voltage alternating-current circuit-breakers,” Publication 56 (1987)

3) IEC. “Gas insulated metal-enclosed switchgear for rated voltage of 72.5kV and above,” Publication 517 (1990)

4) IEEE. “IEEE Standard for Gas-Insulated Substations,” IEEE Std C37. 122-1993 (1993)

5) Institute of Electrical Engineers of Japan. “Gas-Insulated Switchgear,” JEC-2350-1994 (1994)

6) CIGRE. “SF_6 Recycling Guide Electra”, No. 173 (1997)