Manufacturer's Guaranteed Leak Rate

- Leak rate limit in USA-before Kyoto
- Leak rate limit in Japan
- NEMA SF6 Use Guidelines-after Kyoto
- Continuing work—to establish leak rate limit of less than 0.1% per year as the guaranteed and expected limit (means at least 50 years to first alarm)

Leak rate limit in USA Before Kyoto

Dielectric and interrupting ratings met at moderate pressures of 30 to 70 psig

- Convenient add 10% to 20 % extra gas to allow for leakage and ease of density monitoring
- SF6 gas was inexpensive and readily available
- Limit set at 1% overall, 2% per compartment

IEC Leakage Limits : Pre-Kyoto

3.2 The implications of leakage IEC 1634 - 1995, p.35

Switchgear and controlgear containing SF_6 gas is designed, manufactured and tested to ensure that losses of the gas are kept to a minimum.

Preferred maximum permissible relative leakage rates of 1 % and 3 % of the total initial mass of SF_6 gas per annum are specified in IEC 56, IEC 298 and IEC 517, for closed pressure systems. The lower leakage rate limit of 1 % per annum is readily accepted by manufacturers and is easily achieved using standard materials and sealing techniques.

The gastightness of sealed pressure systems is specified in terms of the expected operating life; preferred values are 10, 20 and 30 years. For equipment using sealed pressure systems, manufacturers report that they are able to achieve relative leak rates of less than 0,1 % per annum. The filling pressure of medium-voltage sealed for life equipment is often just above atmospheric pressure and this reduces the tendency to leak. The combined use, during cumulative leakage measurement, of electron capture detectors and gas collectors, the latter made possible by the small size of the gas enclosures of medium-voltage equipment, allows absolute leakage rates, at room temperature, as low as 10^{-7} atmospheric cm³/second (equivalent to $3{,}15 \cdot 10^{-3}$ litres per year) of SF_6 to be measured.

Leakage was expected and tolerated in USA

- No impact on ozone layer, non-toxic, colorless, odorless—so no reason to notice the leakage
- Less costly to add gas when energized than to take an outage to repair leak
- Difficult to find all leaks in the field (wind, cold)
  - With a 5% to 10% first alarm level, should be 2.5 to 5 years between refilling

Adding SF6 to Energized Equipment

ADDING GAS TO AN ENERGIZED BREAKER

Utilities also take different approaches to how they handle a breaker with reduced gas pressure. When can you add gas to an energized breaker for example? Of the 15 utilities responding to the questionaire, if the pressure was above minimum operating pressure, Nine utilities would add gas to a energized breaker as a standard practice, Four would add gas only if recommended by manufacturer, and two utilities never added gas to an energized breaker. If the pressure had fallen below minimum operating pressure, three utilities would still add gas to an energized breaker, six if only recommended by the manufacturer, and six would never add gas to an energized breaker. One utility commented that this was strictly a judgement call. They felt there was no danger in adding gas if the pressure was near the cutout value but would not add gas if the pressure was near 0 psig.

Manufacturers response to adding gas also varied. Of those responding, Siemens Energy would allow addition of gas if above cutout but not if below. HVB would not recommend adding gas to an energized breaker. W/M Power products allowed adding gas in either case. Sprecher Energie allowed adding gas in either case for live tank breakers but not to dead breakers. Cogenel allowed adding gas above the cutout however below the cutout depended on the circumstances. English Electric allowed adding gas above the cutout but not below. Square D has a sealed interrupter and could not add gas.

Actual Leak Rate in USA

EEI and EPA data—10% per year

Why 10 times the guaranteed level?????

Inadequate seal techniques—pipe threads

Quality of seal materials—"0" Rings

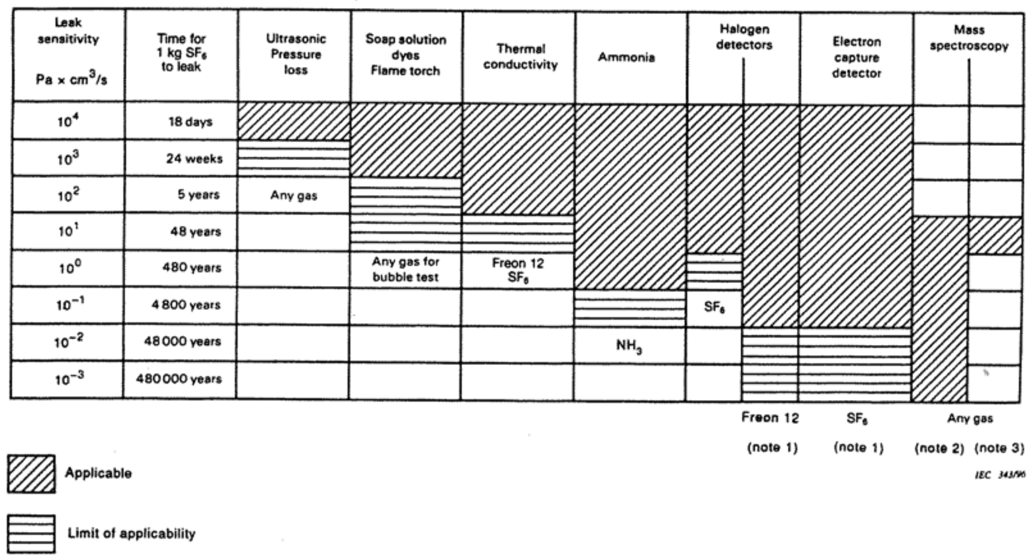
Corrosion—Asbestos Stop Gasket

No enforcement of guarantee

Example of corrosion causing a leak

Leak Checking Techniques

IEC 62271-1 © IEC:2004 – 109 – 17A/688/CD



NOTE 1 Sniffing in good conditions. By integrated leakage measurement, better sensitivity can be achieved.

NOTE 2 By integrated leakage measurement.

NOTE 3 By sniffing.

Figure D.2 – Sensitivity and applicability of different leak detection methods for tightness

Laser Leak Check

- Makes leaks visible
- Efficient survey of overall equipment
- Identifies the worst leaks quickly
- Available as a service
- Not sensitive enough for factory testing and not needed for equipment that is not leaking
- Useful for old equipment in the USA

Dealing with high leak rate in USA

- Manual density measurement difficult
- Microprocessor based density monitor predicts when refilling will be needed
- Efficient scheduling of refill crews
- Repair by adding external sealants
- Repair by welding over flange seals
- Automatic refill with pressure regulators

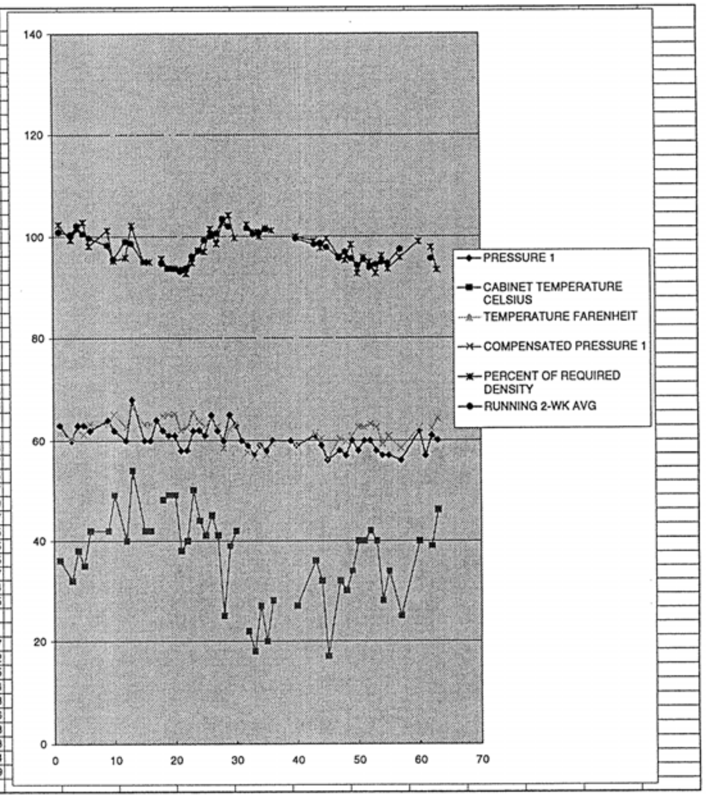
Injection of Sealant to Stop SF6 Leaks

Leak Repair with External Sealant

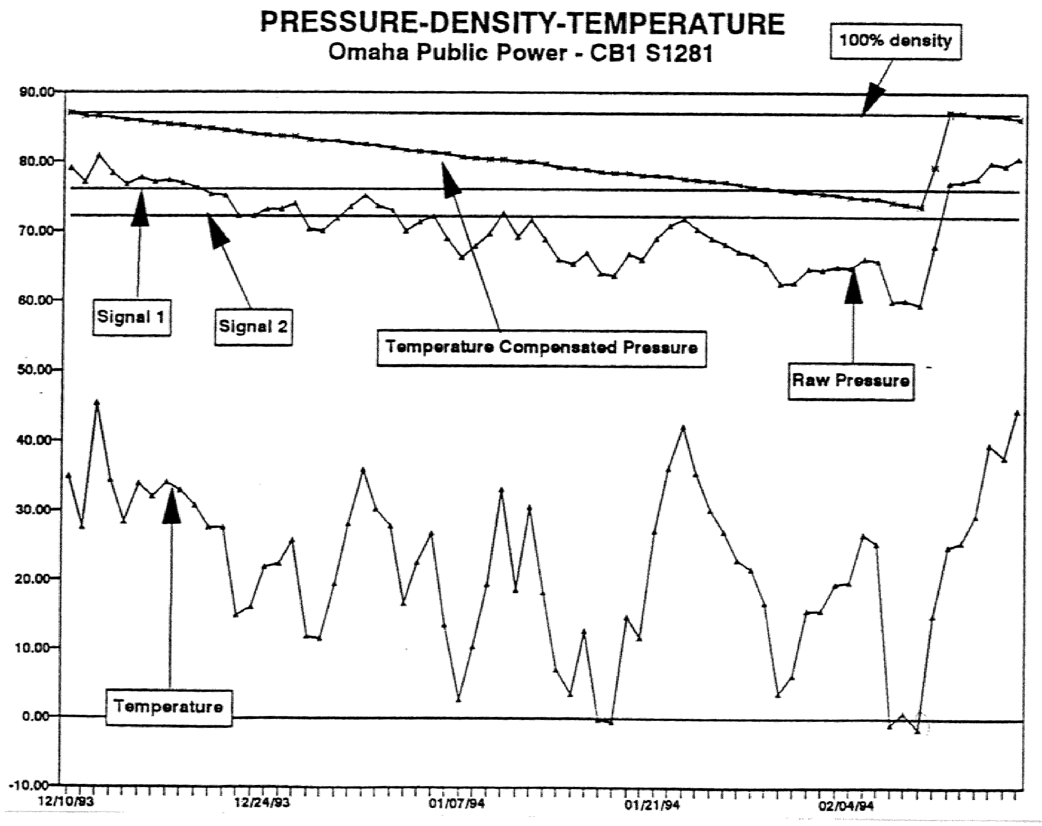
Manual Density Monitoring

MANUAL MONITORING OF SF_6 GAS DENSITY IN A GIS USING PRESSURE GAGE AND AMBIENT TEMPERATURE THERMOMETER

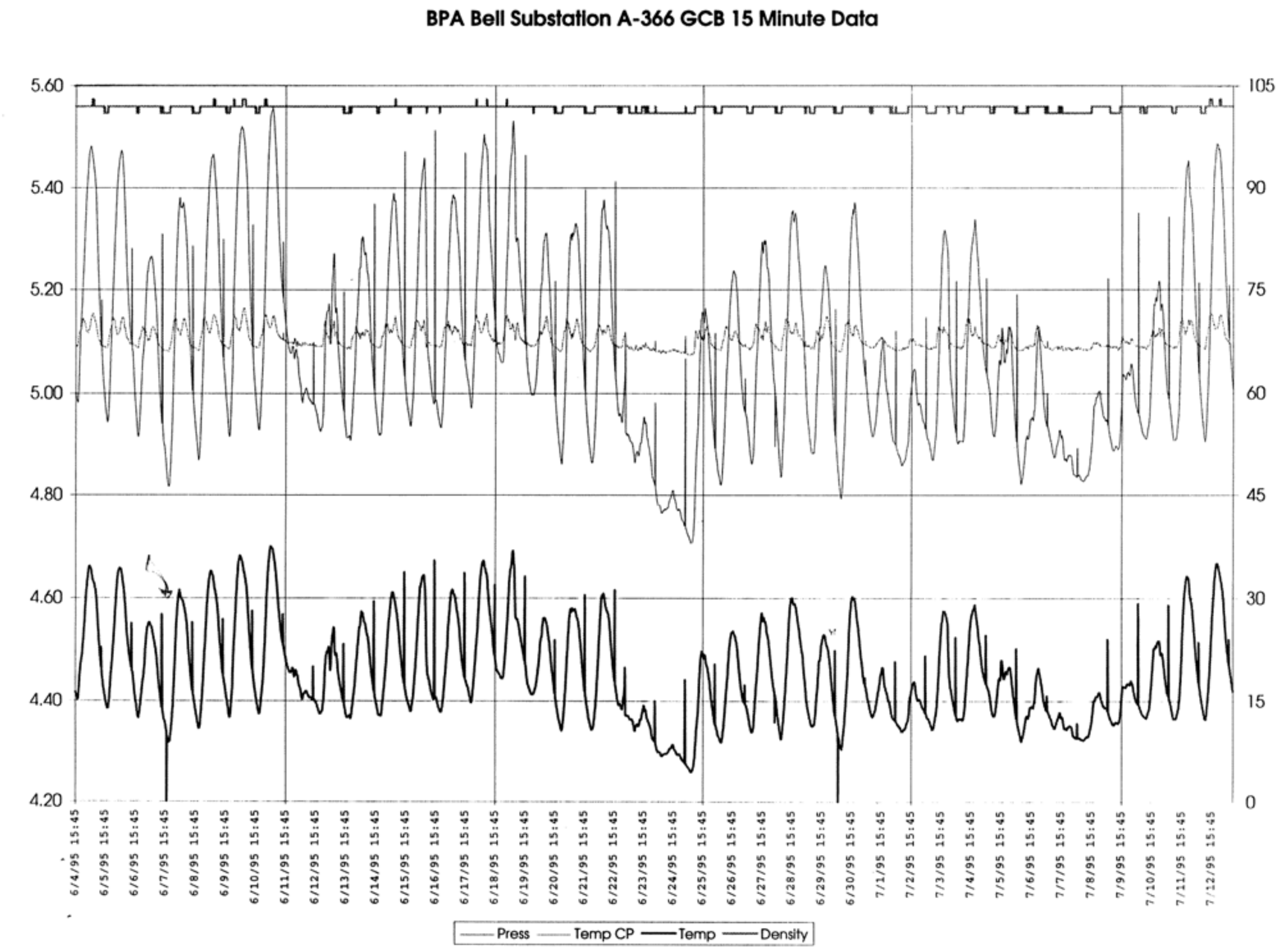
WADDELL GIS GAS ZONE GM7B FILE WADDELL/950710							
DATE	WEEK #	PRESSURE 1	CABINET TEMPERATURE CELSIUS	TEMPERATURE FARENHEIT	COMPENSATED PRESSURE 1	PERCENT OF REQUIRED DENSITY	RUNNING 2-WK AVG
6/22/95	63	60	46	114.8	64.294	93.32	
6/15/95	62	61	39	102.2	62.341	97.85	95.58512
6/8/95	61	57					
6/1/95	60	62	40	104	62.62	99.01	
5/11/95	57	56	25	77	58.435	95.83	97.42144
4/27/95	55	57	34	93.2	60.946	93.53	94.6792
4/20/95	54	57	28	82.4	59.272	96.17	94.84612
4/13/95	53	58	40	104	62.62	92.62	94.39449
4/6/95	52	60	42	107.6	63.178	94.97	93.79597
3/30/95	51	60	40	104	62.62	95.82	95.3929
3/23/95	50	58	40	104	62.62	92.62	94.2191
3/16/95	49	60	34	93.2	60.946	98.45	95.53499
3/9/95	48	57	30	86	59.83	95.27	96.85887
3/2/95	47	58	32	89.6	60.388	96.05	95.65775
2/16/95	45	56	17	62.6	56.203	99.64	97.84219
2/9/95	44	59	32	89.6	60.388	97.70	98.67017
2/2/95	43	61	36	96.8	61.504	99.18	98.44104
1/12/95	40	59	27	80.6	58.993	100.01	99.5962
1/5/95	39	60					
12/15/94	36	60	28	82.4	59.272	101.23	
12/8/94	35	58	20	68	57.04	101.68	101.4556
12/1/94	34	59	27	80.6	58.993	100.01	100.8474
11/24/94	33	57	18	64.4	56.482	100.92	100.4645
11/17/94	32	59	22	71.6	57.598	102.43	101.6756
11/10/94	31	60					
11/3/94	30	63	42	107.6	63.178	99.72	
10/27/94	29	65	39	102.2	62.341	104.27	101.9918
10/20/94	28	60	25	77	58.435	102.68	103.4717
10/13/94	27	62	41	105.8	62.899	98.57	100.6245
10/6/94	26	65	45	113	64.015	101.54	100.0547
9/29/94	25	61	41	105.8	62.899	96.98	99.25979
9/22/94	24	62	44	111.2	63.736	97.28	97.12857
9/15/94	23	62	50	122	65.41	94.79	96.0315
9/8/94	22	58	40	104	62.62	92.62	93.70445
9/1/94	21	58	38	100.4	62.062	93.45	93.03855
8/25/94	20	61	49	120.2	65.131	93.66	93.55617
8/18/94	19	61	49	120.2	65.131	93.66	93.6574
8/11/94	18	62	48	118.4	64.852	95.60	94.62985
8/4/94	17	64					
7/28/94	16	60	42	107.6	63.178	94.97	
7/21/94	15	60	42	107.6	63.178	94.97	94.96977
7/9/94	13	68	54	129.2	66.526	102.22	98.59272
6/26/94	12	60	40	104	62.62	95.82	99.01585
6/12/94	10	62	49	120.2	65.131	95.19	95.5044
6/6/94	9	64	42	107.6	63.178	101.30	98.24693
5/15/94	6	62	42	107.6	63.178	98.14	99.71826
5/8/94	5	63	35	95	61.225	102.90	100.5173
5/1/94	4	63	38	100.4	62.062	101.51	102.2053
4/24/94	3	60	32	89.6	60.388	99.36	100.4344
4/10/94	1	63	36	96.8	61.504	102.43	100.8949



Microprocessor Density Tracking



Microprocessor Density Monitoring



MITSUBISHI ELECTRIC POWER PRODUCTS, INC.

Japan Task Force on SF6

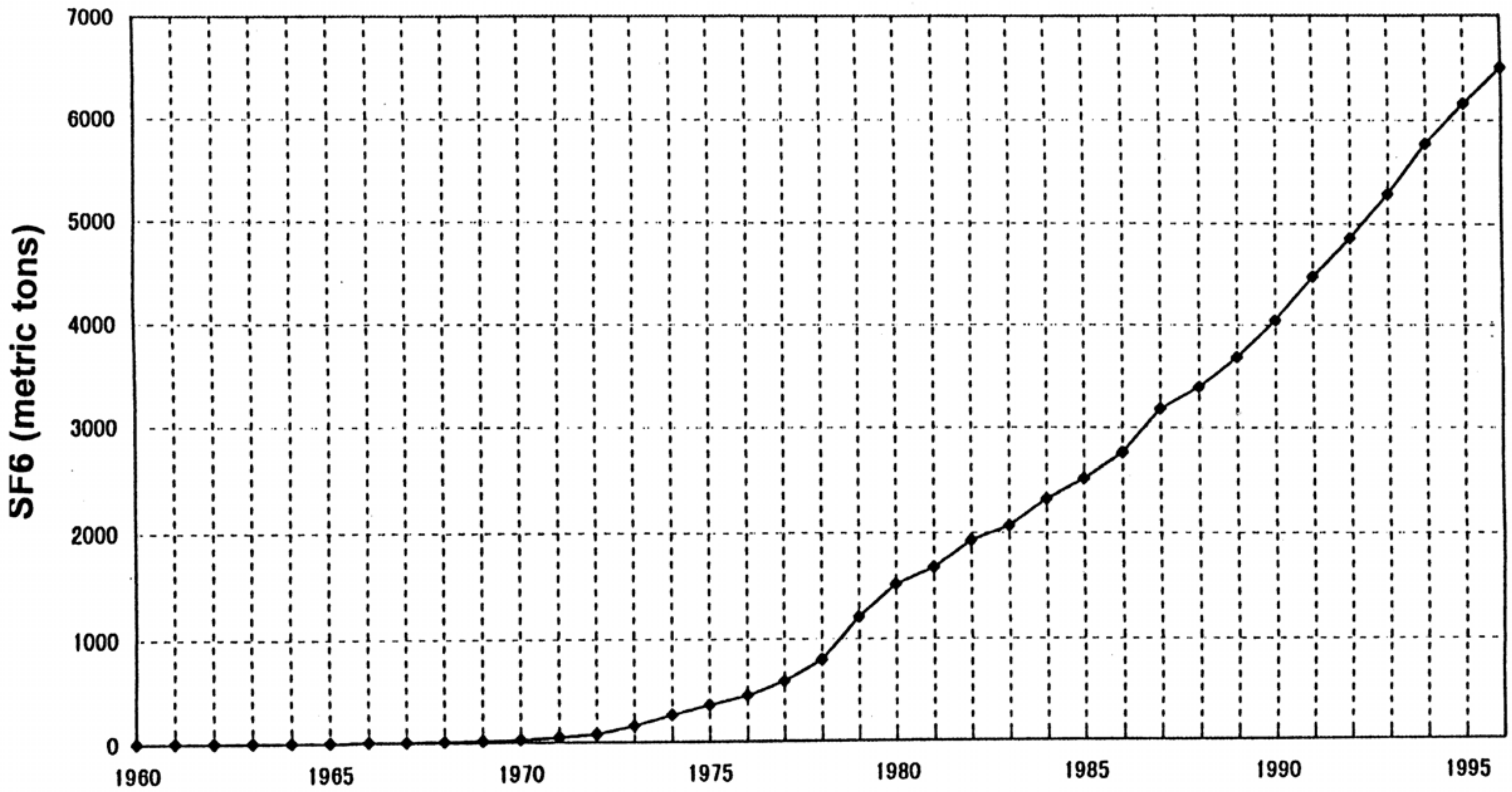
Task Force Committee on Standardization of the Use of SF6 Gas for ElectricaPower Equipment in Japan

The committee consists of members from major utilities, power manufactures, gas manufactures as well as universities in Japan.

- **WG 1** : Current volume of use and emission of SF6 gas in Japan. Measured the leak rate from flanges, fittings and sealed parts for 40 GISs in service. The leak rates were below 0.1% per year.
- **WG 2** : SF6 decomposition products and their properties were measured for operating GISs. No significant decomposition products were detected.
- **WG 3**:Standards for recycled gas quality control and recycling effectiveness.

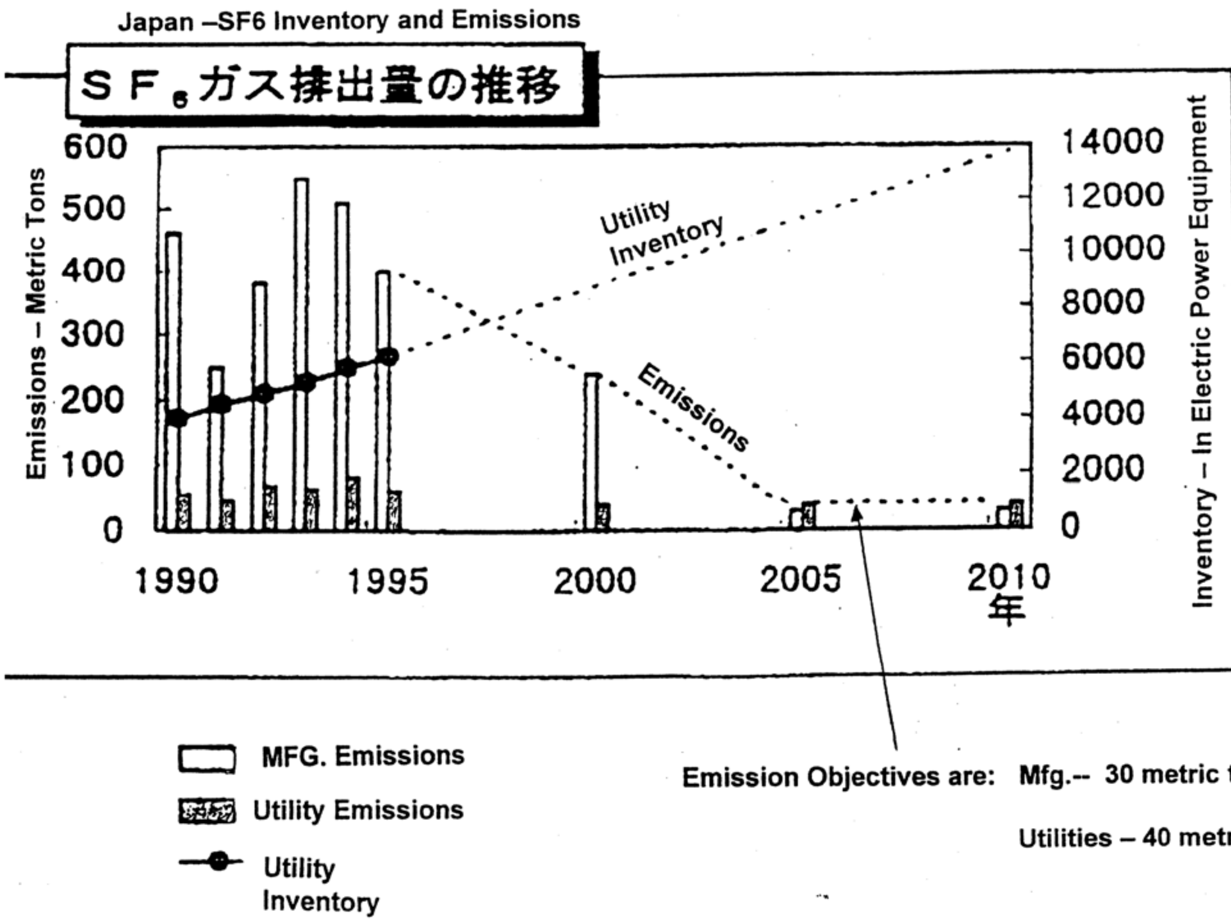
year	1996	1997	1998
Committee held on	10/30	3/17 , 10/1	3/31
Activity	□ Questionnaires for power utilities and manufacturers □ Research for technical papers	□ Measurements in a field Technical Studies Interim report	Summary Final report – In Japanese-249 pages

SF6 in Electrical Equipment in Japan



SF6 In Electrical Power Equipment in Japan By Year

Emission of SF6 in Japan



Emission Objectives are: Mfg.-- 30 metric tons / year

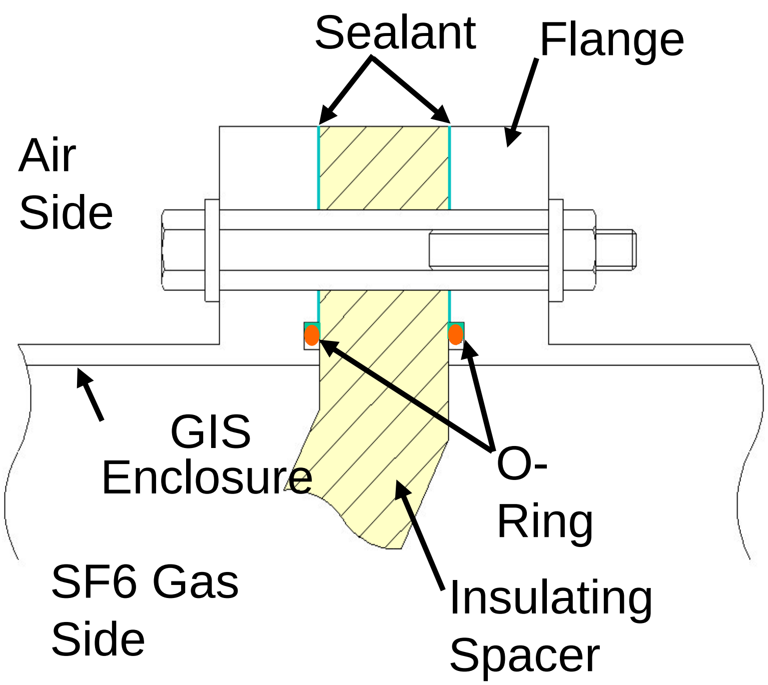
Utilities – 40 metric tons / year

MITSUBISHI ELECTRIC POWER PRODUCTS, INC.

March 2004

TM T&D

SF_6 Gas Seal of Mitsubishi GIS



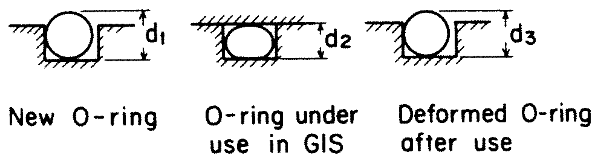
- O-RING
  - GAS SEALING
- LIQUID SILICONE SEALANT
  - GAS SEALING

+

PROTECTION AGAINST

- WATER INGRESS FROM AIR SIDE
- RUSTING OF FLANGE

Deformation of “O” Rings in Use



$$\text{Deformation Rate} = \frac{d_1 - d_3}{d_1 - d_2} \times 100 \quad (\%)$$

Fig. 7. Definition of deformation rate of O-rings.

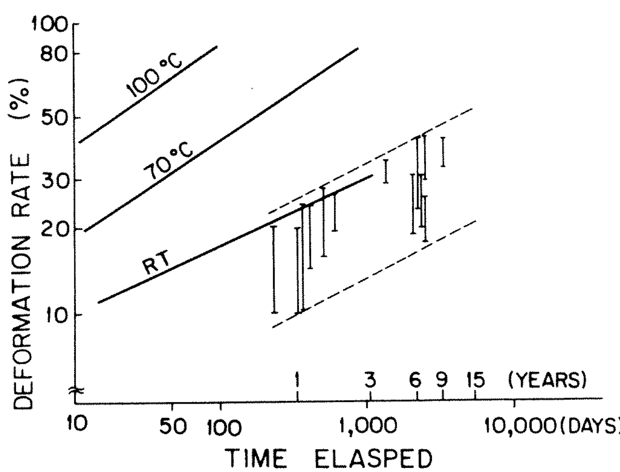


Fig. 8. Deformation characteristics of O-rings.

Aging of "O" Rings

Table 3. Hardness and tensile strength of O-rings after six years in use.

Samples			Hardness (Hs)		Tensile Strength (kg/cm^2)	
Equipment		Kind of O-ring	Measured Value	Specification	Measured Value	Specification
84kV GIS	Phase A	JIS· G 290	68.5	70±5	197	＞140
	Phase B		68.5		—	
	Phase C		72.0		179	
168kV GIS	Phase A	JIS· G 290	67.0	70±5	155	＞140
	Phase B		68.0		—	

Japan-Leak Rate Witness Test

MITSUBISHI ELECTRIC CORPORATION
TRANSMISSION & DISTRIBUTION, TRANSPORTATION SYSTEMS CENTER
1-1, TSUKAGUCHI-HONMACHI 8-CHOME, AMAGASAKI-CITY, JAPAN
TELEPHONE : +81-(6)-6497-8753 FACSIMILE : +81-(6)-6497-8378

DATE : Oct.19 , 2000
REF.No. : HKT-65408

TECHNICAL CORRESPONDENCE SHEET

Subject ; SF6 Gas Leakage Calculation (Conversion from ppm to wt%)
(Customer: SCE SERRANO 550kV GIS 2nd. Lot [Bay2] Witness Test)

According to gas leakage measurement in the acceptance test of above GIS, the value "ppm" ,obtained by SF6 gas leakage detector, is converted to the value "leakage %" and compared with the customer's specified criteria " less than 0.1% per year" as follows.

1. Calculation of total SF6 gas volume of GIS

In the attached drawing "H1L6183", SF6 gas weight of GIS is indicated.
In the case of 2nd. Lot [Bay2], total gas weight is calculated,
(Phase A) 89+23+120+23+147 = 402kg
(Phase B) 89+23+120+23+152 = 407kg
(Phase C) 89+23+120+23+157 = 412kg
Among three phases, phase A is the most sever phase because of its minimum gas volume.
Total gas volume of phase A is calculated,
(Phase C) 402×10^3 (g) ／ 6.14 (g/l) = 65400 (l)
, Where 6.14 (g/l) is SF6 gas density at atmospheric pressure.

2. Calculation of SF6 leakage % per year

Calculation status
Average vinyl-sheet volume of leakage measuring point : 10 (l)
Leakage measuring point numbers per one phase : 50 (points)
Leaving period for the leakage measurement : 12 (hr)

If it is assumed that the SF6 density inside of every vinyl sheet is "0.5ppm", detective sensitivity of SF6 gas leakage detector, SF6 leakage % per year is calculated as follows.

(SF6 leakage % per year)

$$\frac{0.5 \times 10^{-6} \times 10\ (l) \times 50\ (points)}{65400\ (l)} \cdot \frac{24 \times 365\ (hr)}{12\ (hr)} \times 100(\%) = 0.0003\ (\%/year)$$

That satisfies Customer's specification " less than 0.1 %/year "

Switchgear Quality Control Section Switchgear Department	
Approved by	[signature]
Checked by	[signature]
Designed by	[signature]

Routine Factory Test for Leakage

Calculation status

Average vinyl-sheet volume of leakage measuring point : 10 (l)
Leakage measuring point numbers per one phase : 50 (points)
Leaving period for the leakage measurement : 12 (hr)

If it is assumed that the SF6 density inside of every vinyl sheet is "0.5ppm", detective sensitivity of SF6 gas leakage detector, SF6 leakage % per year is calculated as follows.

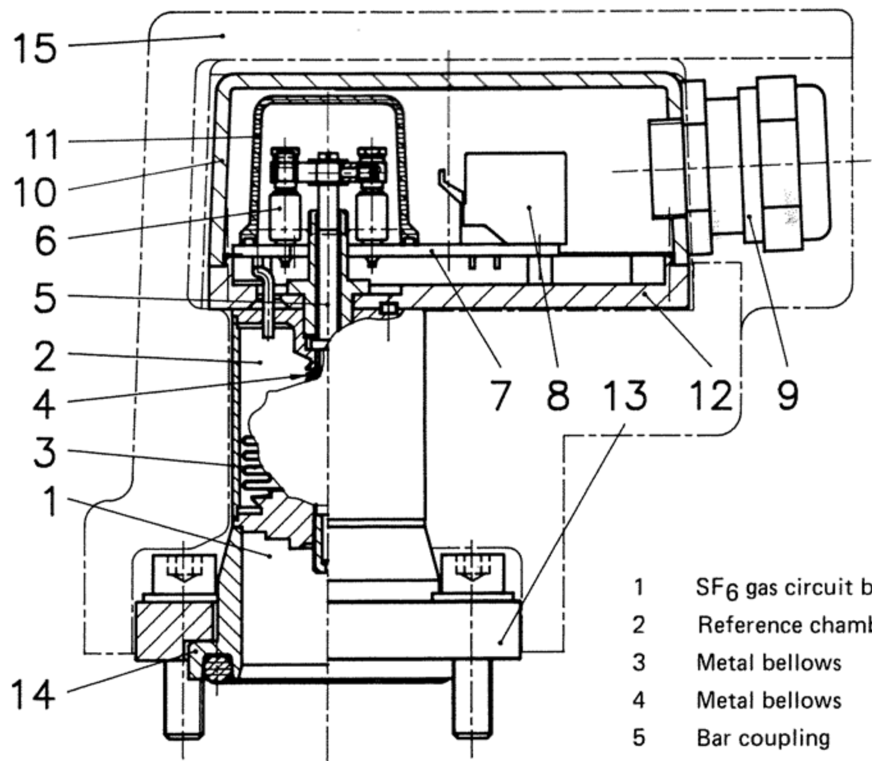
(SF6 leakage % per year)

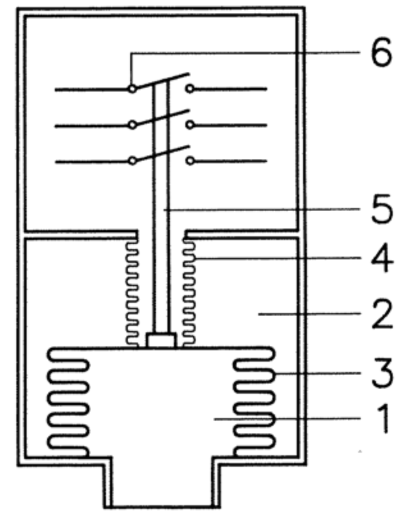
$$\frac{0.5 \times 10^{-6} \times 10\ (l) \times 50\ (points)}{65400\ (l)} \quad \frac{24 \times 365\ (hr)}{12\ (hr)} \times 100(\%) = 0.0003\ (\%/year)$$

That satisfies Customer's specification " less than 0.1 %/year "

Enclosure Mounted Temperature Compensated Pressure Switch

Functional drawing





1	SF_6 gas circuit breaker	8	Plugable screw terminals
2	Reference chamber	9	Cable gland
3	Metal bellows	10	Cast aluminium cover
4	Metal bellows	11	Microswitch cover
5	Bar coupling	12	Base plate
6	Microswitch	13	Pressure connection
7	Circuit board	14	Pressure connection
		15	outdoor cover

Enclosure Mounted Gas Density Monitor

Continuing Work

- As a manufacturer, back up guarantee of less than 0.1% annual leak rate by effective action—fix any detected leak
- Continue to emphasize best practices for containment of SF6
- Support tighter leak rate limits in standards (IEEE, IEC) and user specifications
- Cooperate with US EPA in reductions in SF6 emissions from electric power equipment

IEC SF6 Leakage Limits : Post-Kyoto

5.15.2 Closed pressure systems for gas IEC 62271-1-2004 p 55

The tightness characteristic of a closed pressure system and the time between replenishment under normal service condition shall be stated by the manufacturer and shall be consistent with a minimum maintenance and inspection philosophy.

The value for the time between replenishment is at least 10 years and should be consistent with the tightness values.

The tightness of closed pressure systems for gas is specified by the relative leakage rate F_{rel} of each compartment; standardised values are:

- For SF_6 and SF_6-mixtures the standardised values are 0,5 % and 1% per year.
- For other gases the standardised values are 0,5%, 1 % and 3 % per year.

The possible leakages between sub-assemblies having different pressures are also to be taken into account. In the particular case of maintenance in a compartment when adjacent compartments contain gas under pressure, the permissible gas leakage rate across partitions should also be stated by the manufacturer, and the time between replenishments shall be not less than one month.

Means shall be provided to enable gas systems to be safely replenished whilst the equipment is in service.

NEMA SF6 Management Guidelines

NEMA
Setting Standards for Excellence

Management of SF_6 Gas for Use in Electrical Power Equipment

SF_6 is a powerful greenhouse gas so it should never be deliberately released to the atmosphere. However, it is not an ozone depletion gas. Maintain control of SF_6 by an inventory program that tracks:

a) SF_6 purchased
b) SF_6 received inside of and with electrical equipment
c) SF_6 in service in electrical equipment
d) SF_6 in storage
e) SF_6 in gas handling equipment
f) SF_6 returned to SF_6 supplier or equipment manufacturer

Use gas checking and handling equipment to approach the following target levels:

1) Evacuate air to 1 mbar (100 Pa or 0.8 mmHg) from equipment, hoses and fittings that are to be filled with SF_6. This keeps air contamination of SF6 to acceptable levels (less than 0.02% per filling to a typical pressure of 5 bar (500 kPa or 60 psig), and is important since air cannot be removed by ordinary filters and separation is difficult and does not recover all the SF_6.

2) Remove SF_6 from equipment being tested, produced or maintained to a vacuum of 1.3 mbar (130 Pa or 1 mmHg). This will keep handling losses for electrical equipment (typically filled at 5 bar or more (500 kPa or 60 psig) to below 0.02% per handling cycle. It will also, through subsequent dilution of any toxic SF_6 decomposition products in the equipment with the backfilled air, ensure that personnel are not exposed above tolerable limits.

3) Filter SF_6 being handled to remove moisture, decomposition products and other possible filterable contaminants using molecular sieve, activated alumina and 1 micron or smaller particle filters. This will keep the SF_6 in good condition and also help ensure that personnel are never exposed to toxic decomposition products in SF_6.

4) Check quality of SF_6 intended for re-use in electrical equipment using:
a) percentage SF_6 instrument (2% air limit)
b) hygrometer or dew point instrument for moisture (120 ppmv limit)
c) chemical reagent tube for decomposition products (50 ppmv total or 12 ppmv SO_2 limit).

5) Leak check all equipment containing SF_6 with special attention to gas fittings, moving seals, gas handling equipment and storage facilities. Eliminate leaks to keep overall SF_6 emission rate from leakage below 0.1% per year.

Over a 50 year service life the emission of SF_6 gas due to its use in electrical equipment will not exceed 10% (5% equipment leakage, 2% manufacturing and decommissioning, 1% maintenance, checking, filtering and storage losses plus a 2% allowance for accidents). For detailed information on the technical reasons for the above target levels see CIGRE Report #117, "SF_6 Recycling Guide - Re-use of SF_6 Gas in Electrical Equipment and Final Disposal", August, 1997.

Switchgear Section (8-SG) 48
Ad Hoc Task Group on SF_6 February 23, 1998

NEMA Leakage Limit : Post-Kyoto

5) Leak check all equipment containing SF_6 with special attention to gas fittings, moving seals, gas handling equipment and storage facilities. Eliminate leaks to keep overall SF_6 emission rate from leakage below 0.1% per year.

Over a 50 year service life the emission of SF_6 gas due to its use in electrical equipment will not exceed 10% (5% equipment leakage, 2% manufacturing and decommissioning, 1% maintenance, checking, filtering and storage losses plus a 2% allowance for accidents). For detailed information on the technical reasons for the above target levels see CIGRE Report #117, "SF_6 Recycling Guide - Re-use of SF_6 Gas in Electrical Equipment and Final Disposal", August, 1997.

Switchgear Section (8-SG)
Ad Hoc Task Group on SF_6

February 23, 1998

NEMA

ABB World Leak Rate Data

 ENVIRONMENTAL CHCRC.V3 1.96-7

Local loss rates

balance region	year	SF$_6$ quantity installed [t]	SF$_6$ quantity fill-up [t/y]	average loss rate [%/y]	source, comments
World	95	26 000	3 200	12	CAPIEL 3/97 SF6 producers 3/97
US	95	2 700	350 3 250	13 120	ABB estimate NEMA / EEI Ausimont tart (?)
Germany	95	1 000	9	0.9	Umweltministerium
Brasilia	93	207	1.8	0.9	SNPTEE
RWE (D)	97	120.5	0.63	0.55	ABB internal
NOK (CH)	90-95	7	0,014	0.2	NOK (Guerig)

Average leakage rate = fill-up/ installed

Transmission & Distribution Segment

Rec'd 6 Apr 1998

ABB