SF_6 Emissions Reductions through Recovery/Recycling/Reuse

EPA SF6 Workshop, Phoenix, AZ

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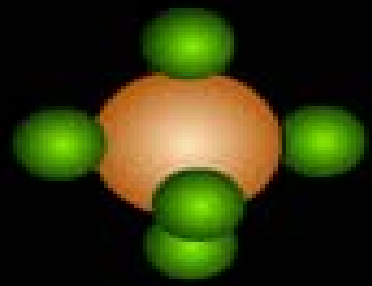
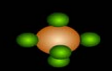


SF_6 Handling - Introduction

- Discussing simple, economical ways to handle and re-use SF_6
  - Processing SF_6 on site for immediate re-use
  - Internationally accepted purity requirements
  - Eliminating SF_6 handling losses
  - Classifying SF_6 for personnel protection
  - Transportation issues
  - Common sense safety issues



Topics of Discussion

- General information
- Contaminants
- DOT/Transportation considerations
- Safety considerations
- SF_6 Handling during breaker maintenance
- Environmental issues

General Information - History

- Discovered in the late 1800's by Henri Moissan
  - Le fluor et ses composes (Fluorine and its compounds) published in 1900
- Used as a dielectric since the 1960's
- Other uses

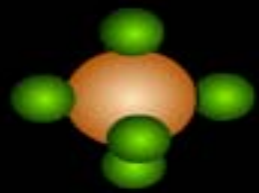
  Electronics, Linear Accelerators, Radar Systems, Sound Insulation, Magnesium casting, Medical uses

General Information – Properties

- Manmade
- Colorless, odorless, non-toxic, non-flammable
- Inert – will not react with other materials
- Thermally stable up to > 350 degrees F
- Excellent thermal transfer characteristics
- Unmatched dielectric strength and arc quenching capabilities
  - Dielectric 2.3 – 2.5 (N2 = 1)
  - Arc quenching 100 x better than air
- Self healing / re-association

General Information - Properties

Reaction of SF_6 when exposed to heat



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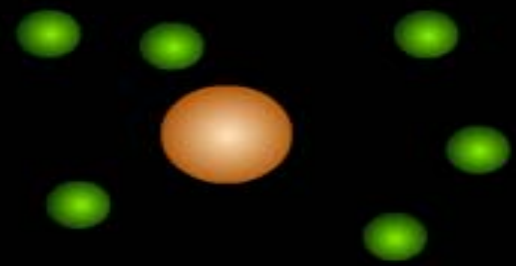

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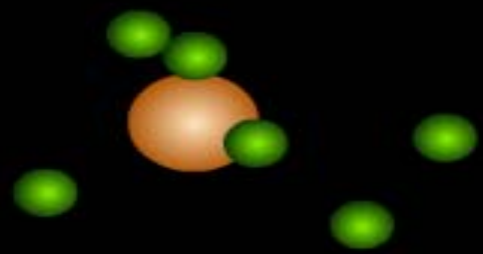

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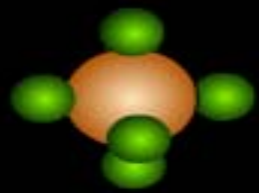
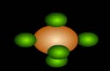


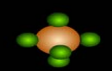
SF_6 Contaminants

- Moisture
  - Formation of by-products
- Decomposition by-products
  - Acidic and highly corrosive
  - Health hazard
- Air
  - Lowers dielectric strength
- Oil
  - Reaction with desiccants



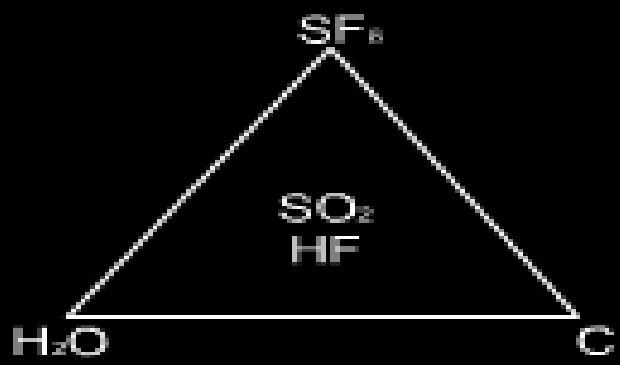
SF_6 Contaminants – Sources

- Moisture / H2O
  - Present due to adsorption, leakage, handling errors
- Decomposition by-products / SO_2, SOF_2, HF
  - Present due to electrical discharges, mechanical generation of particles, reaction with H_2O
- Air
  - Present due to handling errors / faulty handling equipment
- Oil
  - Present due to handling errors / faulty handling equipment



SF_6 Contaminants - Decomposition

- Could be solid (visible powder) or in vapor form
- SF_6 – e- SF_4 / H_2O = SOF_2 + HF



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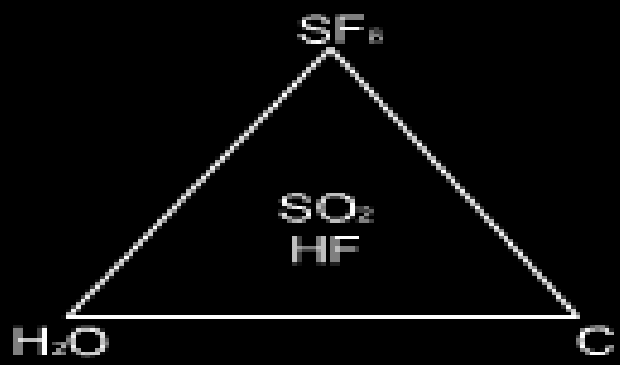

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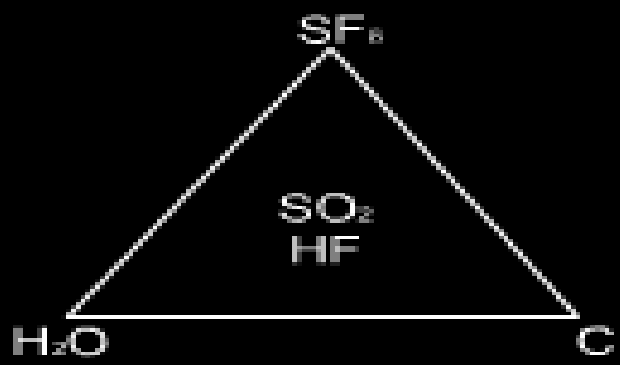


SF_6 Contaminants - Filtration

- Moisture & By-Products
  - Particle filter (powder), drying filter (mixture of aluminum oxide and molecular sieve)
    - On-site removal generally possible
- Non reactive Gases (Air/N_2)
  - Cryogenic process
    - Off-site removal only
- Oil Removal
  - Activated charcoal filtration
    - On-site removal generally possible

Maximum Contaminant Levels

- Established by CIGRE
  - International Council on Large Electrical Systems
  - Publication 234 / TF B3.02.01 / Rev. 2003
- IEC 60480
- Currently reviewed by IEEE and NEMA

Table 1: SF_6 contaminants; main origins, deteriorating effects, maximum tolerable levels in equipment, proposed maximum tolerable impurity levels for reuse of reclaimed SF_6, and practical impurity detection sensitivities.

Contaminant	Main origin	Deteriorating effects	Maximum tolerable impurity levels in equipment	Proposed maximum tolerable impurity levels for reuse	Practical impurity detection sensitivity
Non-reactive gases: Air CF_4	Handling Switching	Reduction of switching performance Reduction of insulation performance	3% vol	**3% vol total**	< 1% vol
Reactive gases or vapours: SF_4, WF_6 SOF_4, SO_2F_2 SOF_2, SO_2, HF	Arcing Partial discharge Follow-up reactions	Toxicity Surface insulation by corrosion	100 ppmv 2000 ppmv	**50 ppmv** total [1]	~ 10 ppmv total
Moisture	Desorption from surfaces and polymers	Surface insulation by liquid condensation	p_{H2O}<400Pa [2]	p_{H2O}< **150 Pa** (T_d < -15 °C) **750 ppmv for p < 200 kPa** [3] **200 ppmv for p < 850 kPa** [3]	< 10 Pa [4]
Oil	Pumps, lubrication, bushings to oil insulated equipment	Surface insulation by carbonisation	not quantified	**10 mg/m³** [5]	< 1 mg/m³
Dust Carbon Dust/particles Switching dust: CuF_2, WO_xF_y,	Arcing, partial discharges Assembling, mechanical wear Contact erosion by arcing	Surface insulation by conducting deposits, gas and surface insulation	Not quantified	Should be removed by dust filter of pore size < 1 µm	

1) or, equivalently, 12 ppmv SO_2 + SOF_2, see Appendix 2, Section 2.
2) Based on IEC 60694 and corresponding to a dew point of T_d = -5°C.
3) Within the complete range of reuse pressures p < 850 kPa, covering all possible applications (both HV and MV insulation systems as well as all circuit breakers), the low reuse pressure range p < 200 kPa has been defined to highlight low pressure insulation systems (typically applied in MV distribution).
4) corresponding to a dew point T_d = –45 °C
5) Corresponding to 0.3 ppmw in pure SF_6 at 500 kPa

Transportation Considerations

- Packaging Issues
  - > 25 PSIG @ 68 F classified as HAZMAT by DOT
    - Includes all Class 2.2 gases (SF_6, N_2)
  - Only transport in approved vessels (49CFR173.115(b))
  - Vessel must bear DOT approval stamp
    - DOT3AA2015 (example)
    - Minimal Pressure Rating 1,000 PSIG
    - Within 5 years (10 years with *) of test date

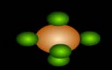
Transportation Considerations

- Weight restrictions / Paperwork requirements

Condition:	Classification:	Limitations:
No single package >220 lbs, and/or combined packages >440 lbs	Materials of Trade (MOT)	None
Single package >220 lbs, and/or combined packages >440 *but <1001 lbs.*	Bulk Hazardous Exempt	Material Safety Data Sheet (MSDS) *and* Shipping Manifest
Combined weight >1000 lbs.	Bulk Hazardous	Same as above, but Class 2.2 (UN1080) placards on all sides of vehicle ***and*** driver must carry HazMat endorsed driver's license

Transportation Considerations

- Common Mistakes
  - DOT weight references are *gross-aggregate*
  - Any class 2.2 gas (N_2, dry air) on vehicle must be included in gross-aggregate weight calculation
  - SF_6 Circuit Breakers (even on mobile substations) are *not* DOT approved vessels
  - Loading a non DOT approved vessel on a flatbed is still illegal
  - Tow vehicle/trailer combination are considered single vehicle
  - Only HAZMAT endorsed drivers may transport vehicles with placards FMCSA383.93(b)



Transportation Considerations

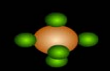
- Cylinder markings

Transportation Considerations

- Cylinder markings

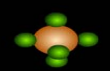
SF_6 Handling - Safety

- Harmless in the presence of air
  - Will displace air / asphyxiation
- Will decompose at temperatures > 350 F
  - Breaker operations
  - Welding
  - Running engines / heaters / open flames
  - Smoking
    - Temperature during drawing up to 700 C (1292 F)
    - Source: http://www.physlink.com/education/askexperts/ae1.cfm



SF_6 Handling – Safety

- Faulted / Arced SF_6
  - Corrosive, highly acidic (SOF/SOF_2, HF)
  - Present as solid (powder) as well as vapor
- Consequences of exposure
  - Respiratory irritant
  - Acid burn / Skin rash
  - Eye irritation
  - Serious health risk

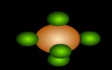


SF_6 Handling - Safety

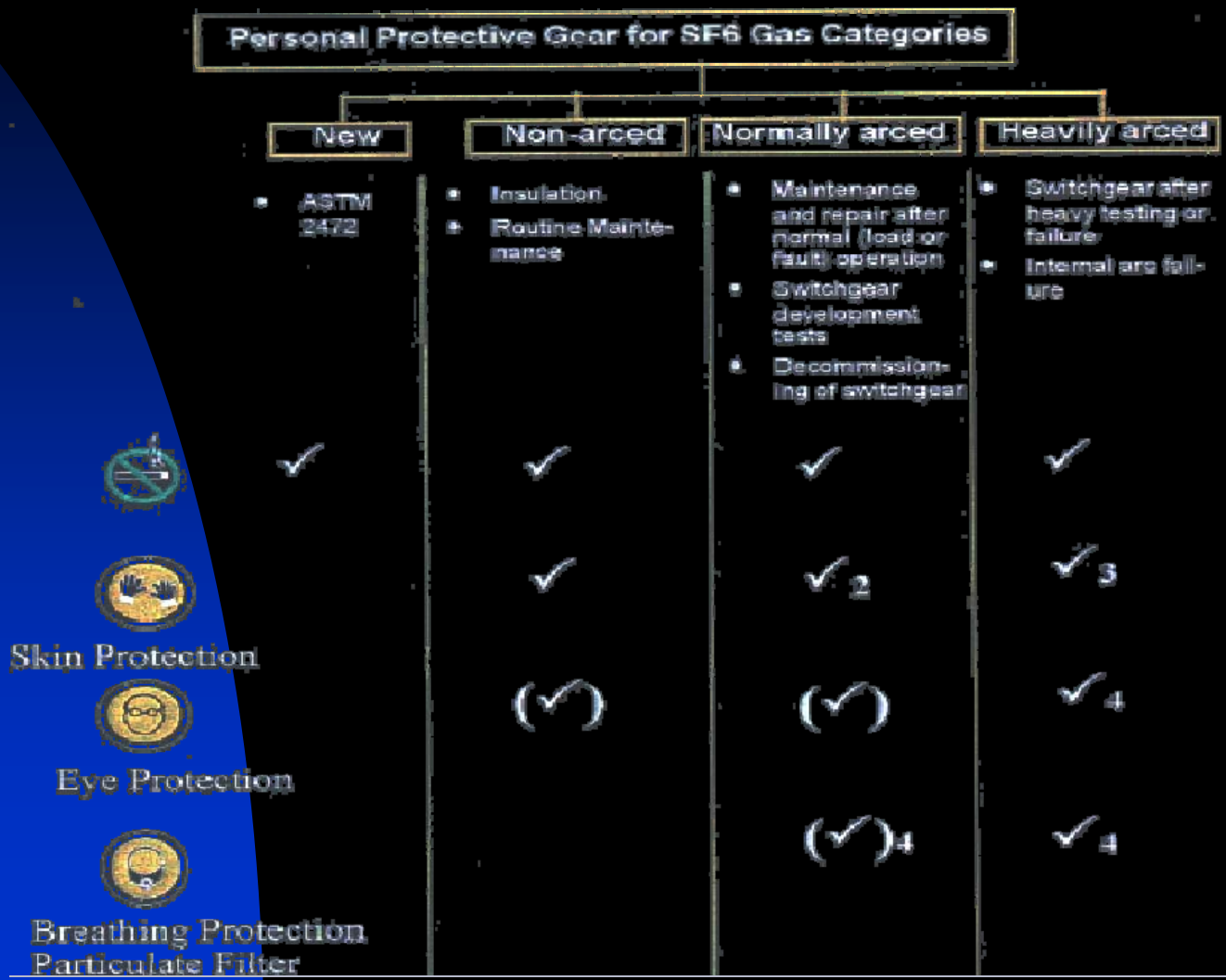
- Exposure Limits / TLV / PEL
  - SF_6 = 1,000 ppmV
  - SO_2/SOF_2 = 5 ppmV
  - HF = 3 ppmV
    - All levels per OR-OSHA / airborne concentrations
    - Additional information available at www.cdc.gov/niosh

SF_6 Handling - Safety

- Dealing with decomposition by-products
- Test and classify SF_6 *before* degassing GIE
  - New SF_6
    - Gas in original cylinder
  - Non Arced
    - < 100 ppmV SO_2 + SOF_2
  - Normally Arced
    - > 100 ppmV SO_2 + SOF_2 < 1%
  - Heavily Arced
    - > 1% ppmV SO_2 + SOF_2



SF_6 Handling – Safety
PPE – What to wear, when to wear it



SF_6 Handling - Safety

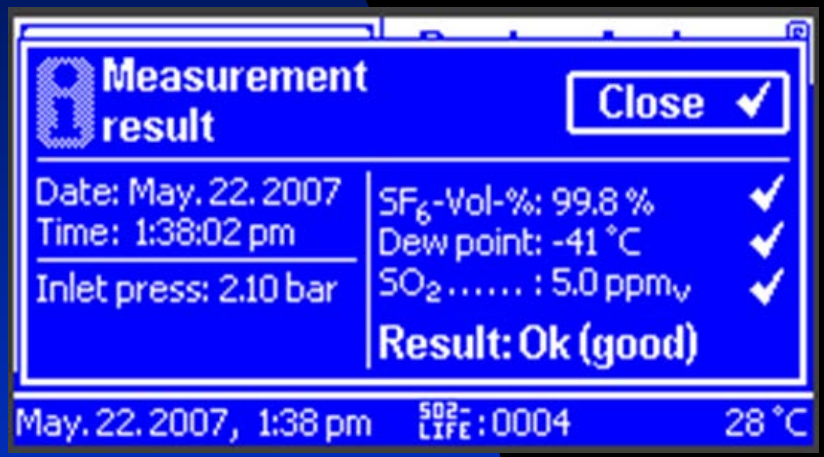
- Handling heavily arced SF_6
- Heavily arced SF_6 generally a result of catastrophic equipment failure
- GIE will need extensive repairs or need to be replaced
- No urgency to clean / repair GIE
- Use specialized Hazmat contractor
- USE COMMON SENSE

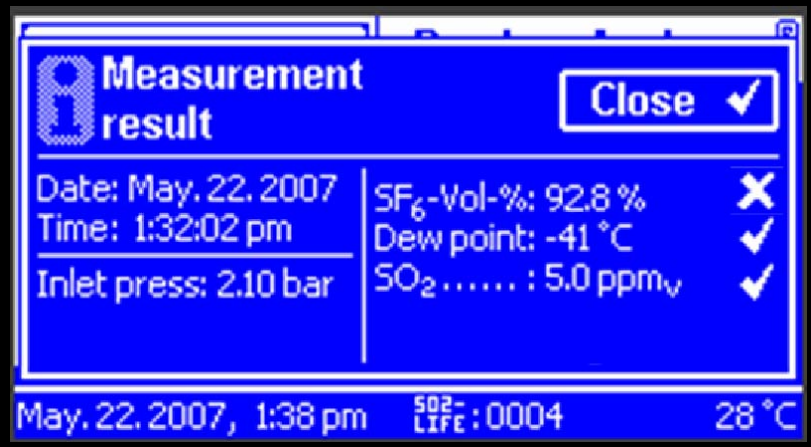
SF6 Handling – Quality Check

- Testing SF_6 prior to degassing GIE
  - SO_2/SOF_2
    - Personnel safety
    - Filter selection
  - Volume % / Purity
    - Required Storage
    - Ability to bring replacement SF_6
  - Moisture
    - Filter selection

SF_6 Handling – Quality Check

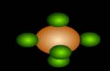
- Gas analysis test result





SF_6 Handling – Recovery Preparation

- Provide adequate storage
  - Enough in-date cylinders on hand
- Use Pre-Filter as needed
  - Normally or heavily arced SF_6
  - High moisture levels
- Leak check hoses / fittings (vacuum raise test)



SF_6 Handling – Gas Recovery

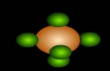
- Determining how much SF_6 has been recovered:

$$\left(\frac{P_I - P_F}{P_I}\right) \times 100 = \%recovered$$

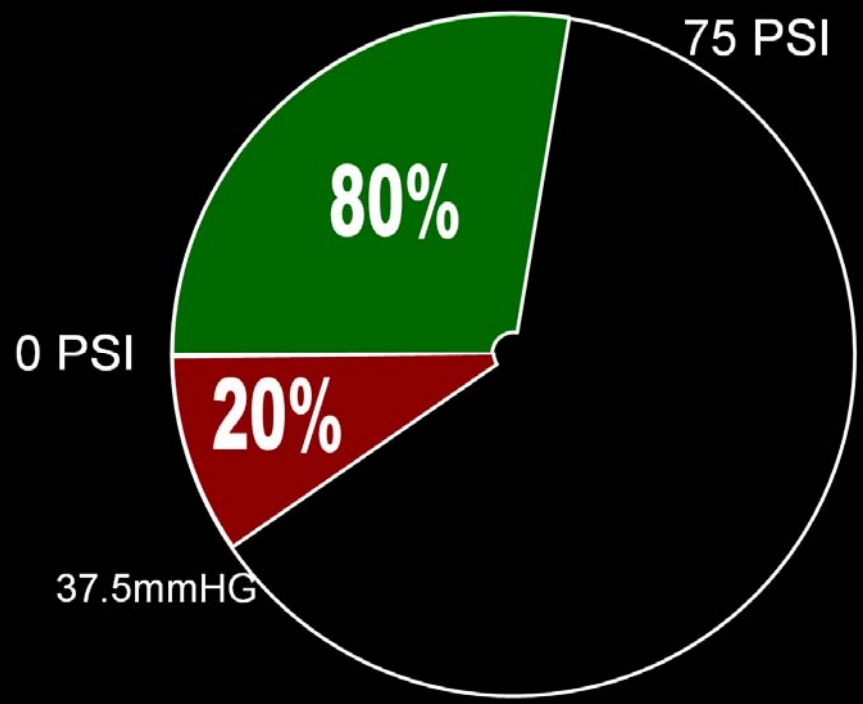
P_I = Initial breaker pressure in mmHg(absolute)
P_F = Final breaker pressure in mmHg(absolute)

SF_6 Handling – Gas Recovery

- SF_6 recovery comparison
- GIE containing 2,200 lbs @ 87 PSIG operating pressure
  - Recovery to 0 PSIG = 85.71% SF_6 removal
    - 315 lbs of SF_6 lost
  - Recovery to 200 mmHg = 96.21% SF_6 removal
    - 86 lbs of SF_6 lost
  - BLANK OFF PRESSURE AT THE END OF RECOVERY PROCESS SHOULD BE < 50 mbar / 37.5 mmHg (Torr)



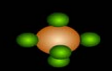
SF_6 Handling – Gas Recovery



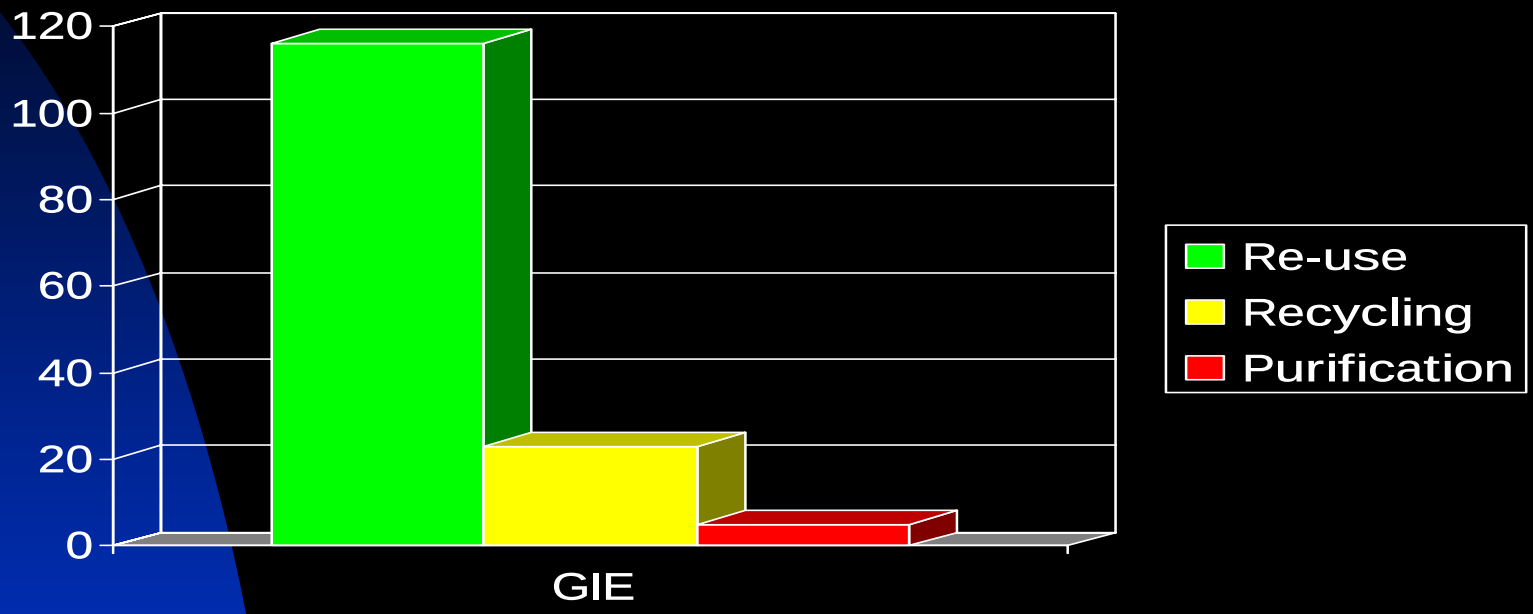
- Breakers with known leakage
  - Initially stop recovery process at 2 PSIG
  - Recover and store residual SF_6 into separate cylinders

SF_6 Handling – Gas Recovery

- Suggestions / Avoiding mistakes
  - Always analyze/test gas before recovery
  - Standardize GIE fittings
  - Use properly sized recovery system/compressor
    - No replacement for displacement
  - Complete SF_6 recovery from GIE
    - Understand residual / blank-off pressure
    - Do not purposely release SF_6 to avoid air intrusion during recovery process (GIE leakage)



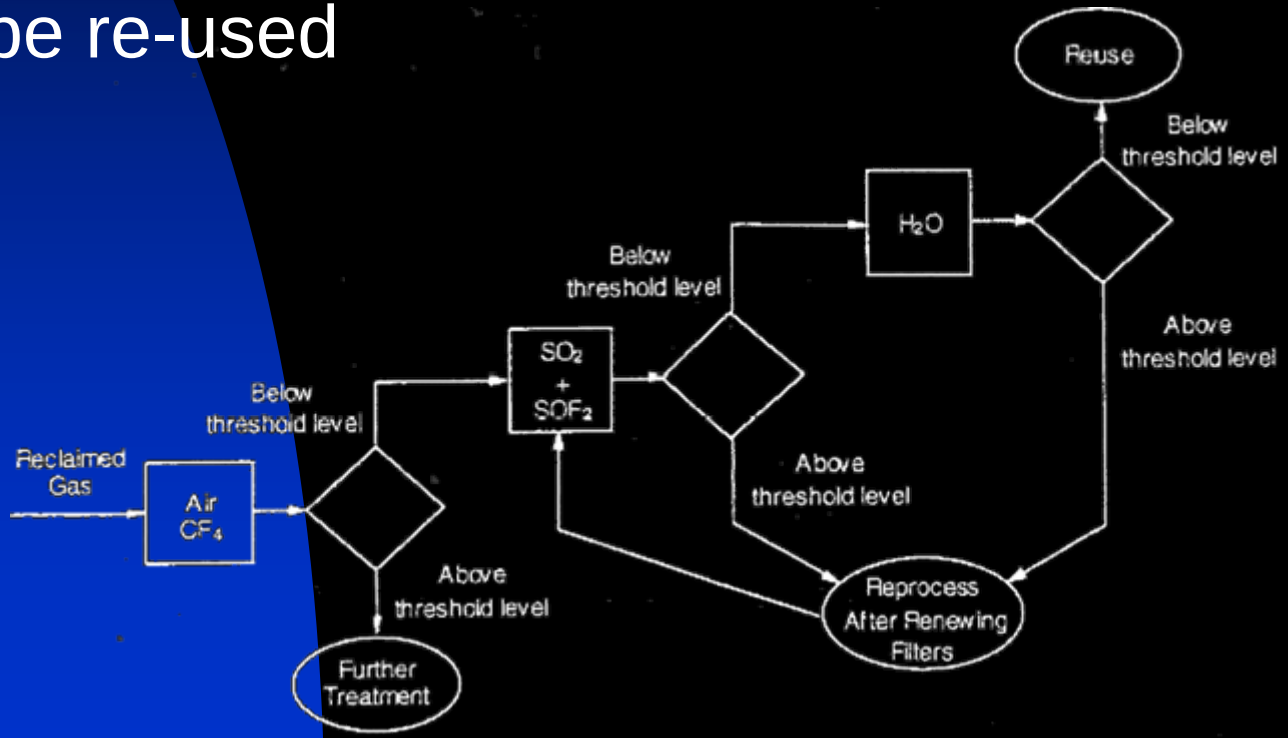
Real Life – In GIE SF_6 Quality



- 144 pieces of GIE recently tested by DILO
- 116 (80.6%) qualified for immediate re-use
- 23 (16%) required recycling due to high H_20 or decomposition
- 5 (3.4%) required purification due to non-reactive gases

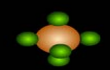
SF_6 Handling - Testing

- Following the standard check will allow field personnel to determine if the recovered SF_6 can be re-used



SF_6 Handling – Breaker Entry

- After SF_6 recovery, GIE will be in substantial vacuum
  - Whenever possible, purge vacuum with N_2/dry air
  - Wear proper PPE
  - If powder present, clean surfaces with HEPA vacuum
  - Clean surfaces with OEM approved solvents only

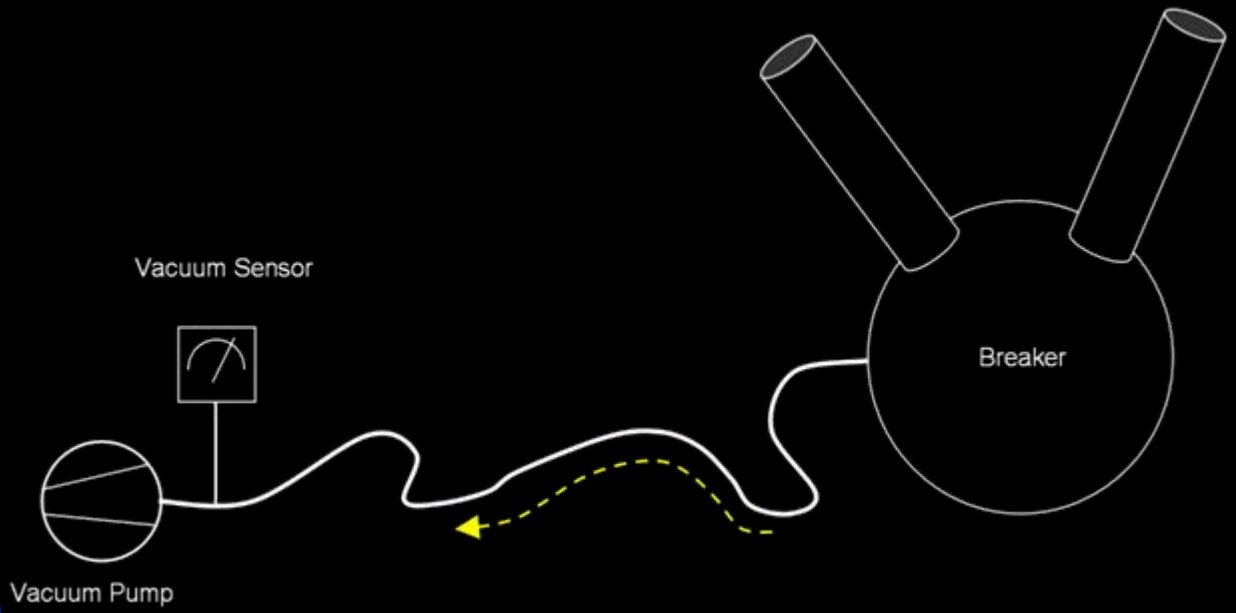


SF_6 Handling – Desiccant Disposal

- Spent desiccant / cleaning supplies need to be neutralized for disposal
  - Place in metal or plastic container
  - Add water and baking soda
    - Will produce heat / caustic steam
  - Test PH to ensure solution is neutralized
  - Dispose in accordance with Local/State/Federal Regulations

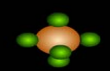
SF_6 Handling - Vacuuming

- Vacuum pump setup



SF_6 Handling – Vacuuming

- Before closing breaker add new desiccant
- Immediate air and moisture removal once GIE has been sealed
- Vacuum reading only accurate at static pressure
- Proper vacuuming instructions *must* include level (example: 1 Torr) *and* hold time (example: 1 hour)
  - This requires that after having the pump stopped for 1 hour, vacuum level is = < 1 Torr
- Gas-scavenging will speed up the process

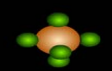


SF_6 Handling - Vacuuming

- Suggestions / avoiding mistakes
  - Use gas-scavenging whenever possible
  - Use properly sized vacuum pump
    - No replacement for displacement
  - Use least restrictive hose/fitting/connection
  - Properly perform vacuum raise test

SF_6 Handling - Filling

- Fill GIE using regulators only
- Fill from upright cylinders only
  - Exception: Using filling equipment with integrated evaporator and filter
- Apply heat to cylinders before filling
  - Use only thermostatically controlled heating blankets
  - Limit heat to < 120 F
- Test SF_6 again before energizing equipment



SF_6 Cylinder Handling

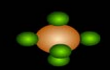
- Only use weight to determine SF_6 content in cylinders
- As SF_6 is liquefied in cylinder, static vapor pressure cannot be used to determine SF_6 content
- Cylinders in storage should be separated
  - Full
  - Partial
  - Empty

Environmental Considerations

- SF_6 is *not* an ozone depleting
- One of (6) gases listed under Kyoto Protocol
- GWP 24,000 times higher than CO2
- Estimated atmospheric lifespan 3,200 years
- EPA SF6 Emission Reduction Partnership
  - www.epa.gov/electricpower-sf6
- As of 2006 approximately 85 US Utility Partners

Summary

- Indefinite re-use of recovered SF_6 generally possible
- Immediate re-use (using CIGRE / IEC standards) of recovered SF_6 even in new GIE generally possible
- Properly trained personnel will be able to minimize/eliminate handling losses and exposure to harmful by-products
- Provide specialized training for personnel involved in SF6 handling



SF_6 Handling – Questions

- **QUESTIONS?**

- Contact:

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