

# Safety and Environmental Evaluation of Insulating Media in MV Distribution Equipment

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# Insulating Media in MV Distribution Equipment

- Introduction
  - Electrical Work Checklists
- Asbestos
  - Regulations
  - Air Circuit Breaker Functions
  - Exposure & Summary
- Oil
  - Oil Circuit Breakers
  - Past Maintenance Practices
  - PCB Contamination, Testing & Labeling
- Sulfur Hexafluoride (SF<sub>6</sub>)
  - Characteristics
  - By-Products
  - EPA Guidelines

# Introduction

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- Electrical Work Checklist
  - Recommended Maintenance Practices
    - Equipment Product Literature
  - Lock-Out / Tag-Out
  - Safe Grounding
  - Site Safety Officer Input
    - MSDS sheet?
      - Not supplied with electrical equipment !!!
  - LONG Life of Electrical Equipment
    - New knowledge regarding health hazards to humans
    - New precautions and work practices

# Asbestos

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- July 12<sup>th</sup>, 1989; EPA ban on “new uses”
  - Carcinogenic to humans
    - Length of exposure
    - Individual smoking habits
  - Exposure to airborne asbestos fibers may not exceed:
    - 0.1 fibers per cubic centimeter of air, averaged over the 8-hour workday **AND**
    - 1 fiber per cubic centimeter of air, averaged over a 30 minute work period

# Asbestos

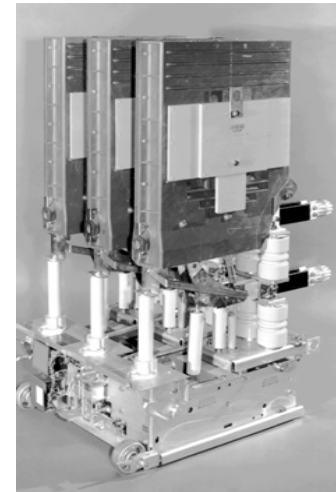
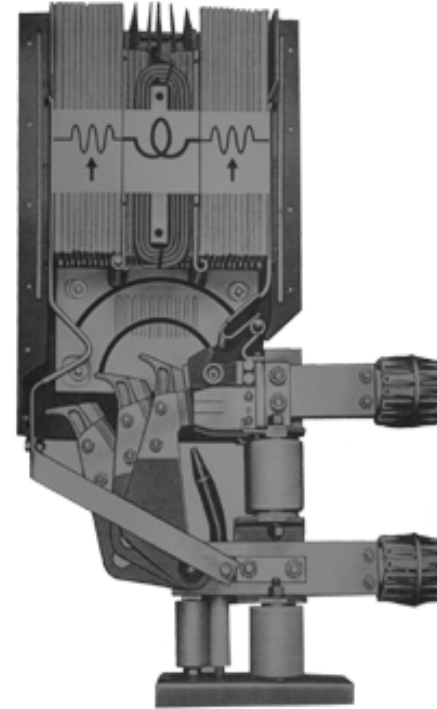
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## Common Past Uses:

- Thermal insulation (e.g. pipe and boiler insulation)
- Fire-proofing materials (e.g.. sprayed insulation, fire door insulation)
- Asbestos cement/fibrocement products (e.g.. roof and wall claddings)
- Decorative and acoustic applications
- Electrical switchboards, insulators and fittings
- Vinyl floor coverings
- Asbestos felts and paper-like products
- Friction materials (e.g.. brake linings)
- Paints, coatings, sealants and adhesives
- Packings and gaskets
- Textiles (e.g.. woven cloths, blankets)
- Miscellaneous and unusual products (e.g.. asbestos socks)

# Air Circuit Breaker Functions

- Isolate Voltage
  - Partial Discharges
  - Tracking / Corona
- Interrupt Fault Current in “Air”
  - Arc Chutes (asbestos)
    - Carbon vs. MVA Rating
    - Moisture Absorption



# Air Circuit Breaker Functions



## Air Circuit Breakers

- Asbestos within arc chute to seal in high temperature arc byproducts
- Carbon build-up with EACH interruption
- The “Interrupting” capability is part of the arc chute design
- Can your circuit breakers interrupt the available fault current?

# Asbestos Exposure

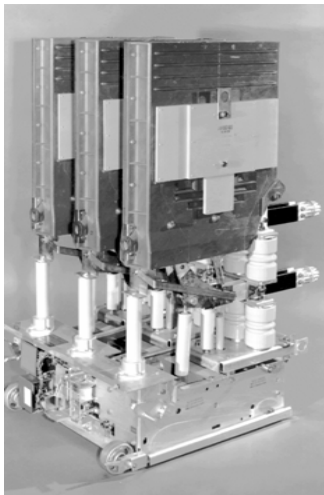
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- Inspections
- Maintenance
- Decommissioning
- Failure investigations
- Upgrading / Modernization

# Equipment Upgrading

- Circuit Breaker Modernization

- Circuit Breakers wrapped and shipped for proper disposal



- Eliminate Asbestos
- Moisture absorbing Bushings



# Equipment Upgrading

- New Metering / Circuit Breaker Controls



- Eliminate Asbestos
- Includes Improved Protection
- Arc Flash Solution

1. Room Base-Line Reading
2. Sealed Enclosure with internal and external monitoring
3. Proper removal & packing
4. Follow-up area clean-up
5. Post Room Base-Line Readings



<http://www.roostercontracts.co.uk/Page%202.html>

# Asbestos Summary

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- Inventory existing asbestos equipment
- Review upgrading / modernization related to potential existing asbestos
  - Manufactured < 1989
- Switching contingencies during work
- Qualified asbestos sub-contractor
  - Certifications, insurance, etc.
- Addition of MSDS sheet on electrical equipment as required

# Oil Circuit Breakers

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- 11kV through 750kV
- Arc Interruption
  - High-pressure oil
- Leakage
  - State Regulations
    - e.g. NJ treatment of oil = PCBs
    - Minor spill at a utility site resulted in \$ 450k clean-up of all past contamination (State EPA notification)
- Catastrophic Failures
  - Flammability → Primarily outdoor use, but many older applications were indoors

# Oil Circuit Breakers

- PCB Contamination (EPA Stopped Mfr in 1977)
- High Flash Point & Excellent insulating and heat transfer characteristics
- Contaminated: > 50 ppm and < 500 ppm
- Very prevalent in transformers
- CONCERN: Past maintenance using similar pumps, filter presses, tubing, etc. between oil-filled transformers and oil circuit breaker
  - Sub-Contractors / Internal lack of knowledge



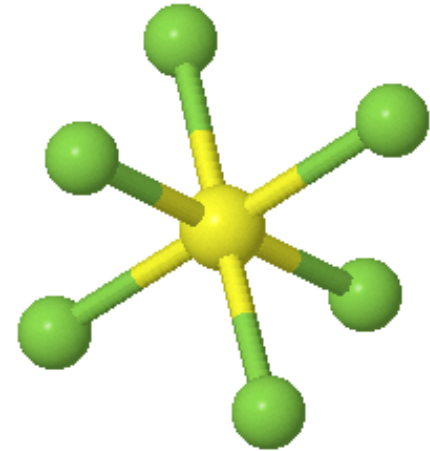
# Oil Circuit Breaker Summary

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- Testing of oil
  - Gas-in-oil analysis
    - Combustible gases content
  - Rogers ratio analysis
    - Potential failure / wear modes
- PCB testing of oil circuit breakers
- Proper labeling
- MSDS sheets
- Long-term resolution

# SULFUR HEXAFLUORIDE (SF<sub>6</sub>)

- SF<sub>6</sub> in its pure state is:
  - Non toxic
  - Odorless
  - Colorless
  - Tasteless
  - Very stable
  - Non flammable
  - Non ozone depleting
- Pure SF<sub>6</sub> possesses good properties from a safety perspective, and from an apparent environmental perspective – more on this later...

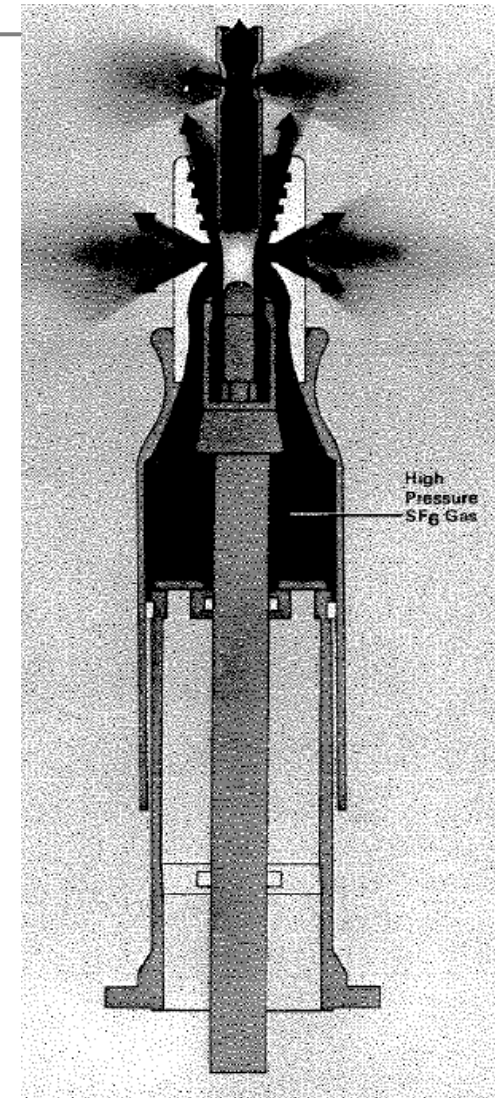


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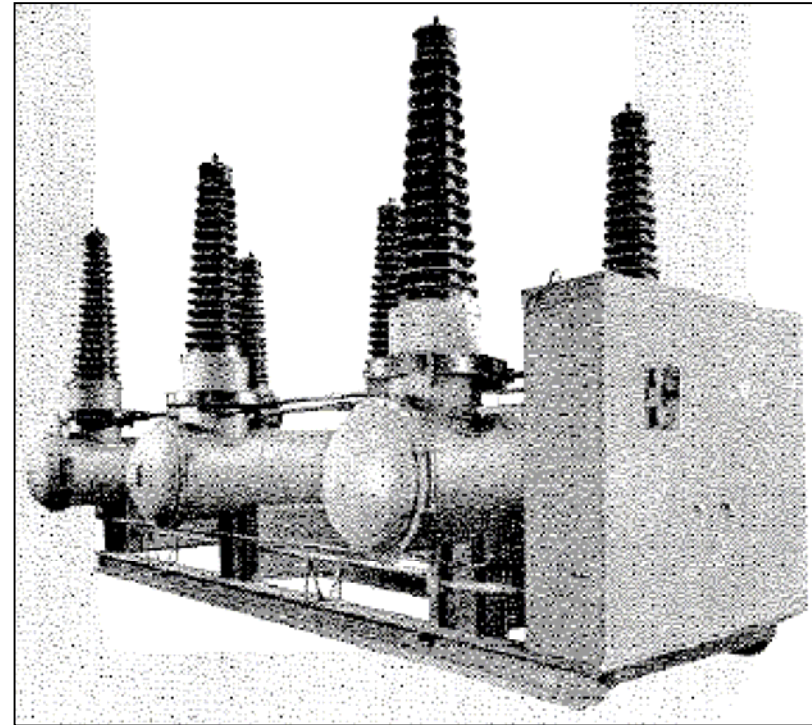
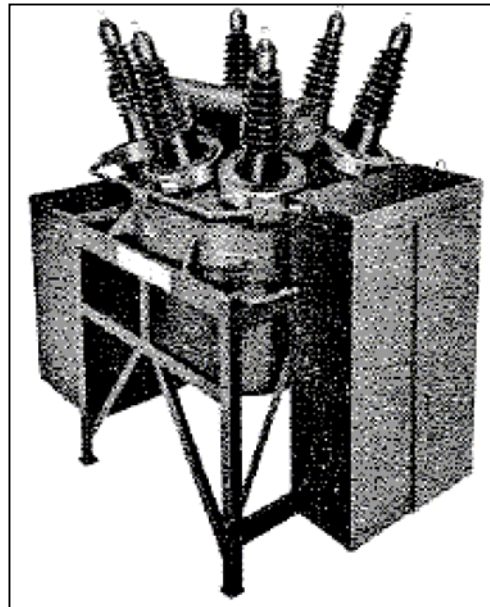
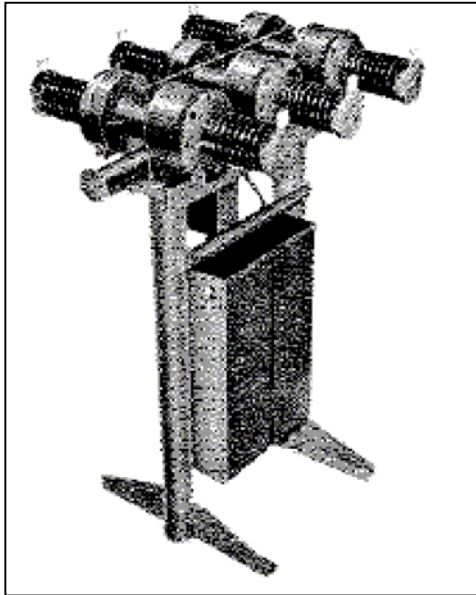
- SF<sub>6</sub> usage has displaced oil in most applications above 38kV
- SF<sub>6</sub> can be utilized for two purposes in switchgear
  - The medium for circuit breaker arc interruption
  - The medium for insulating conductors from each other and ground
- For circuit breakers, SF<sub>6</sub> possesses good dielectric and heat transfer properties and is “self-healing” after arc interruption.

# SF<sub>6</sub> Circuit Breaker

- SF<sub>6</sub> + moisture + high temperatures = toxic byproducts
- Arc interruption in sealed circuit breakers with low moisture content does not pose a great concern.
- Circuit breakers can be a problem if:
  - Desiccant becomes ineffective
  - Moisture enters during maintenance
  - SF<sub>6</sub> becomes contaminated
  - Leaks occur (moisture drawn into gas chamber)



# Vintage HV SF<sub>6</sub> Circuit Breakers



# Modern MV SF<sub>6</sub> Circuit Breakers



# SF<sub>6</sub> Insulated Switchgear

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- SF<sub>6</sub> insulated switchgear – gas insulated switchgear (GIS) – is another application for SF<sub>6</sub>
- Arc interruption typically occurs inside vacuum interrupters sealed in an SF<sub>6</sub> chamber – but not exclusively.
- Bare switchgear conductors are contained in sealed chambers with SF<sub>6</sub> surrounding the conductors for insulation.

# SF<sub>6</sub> Insulated Switchgear

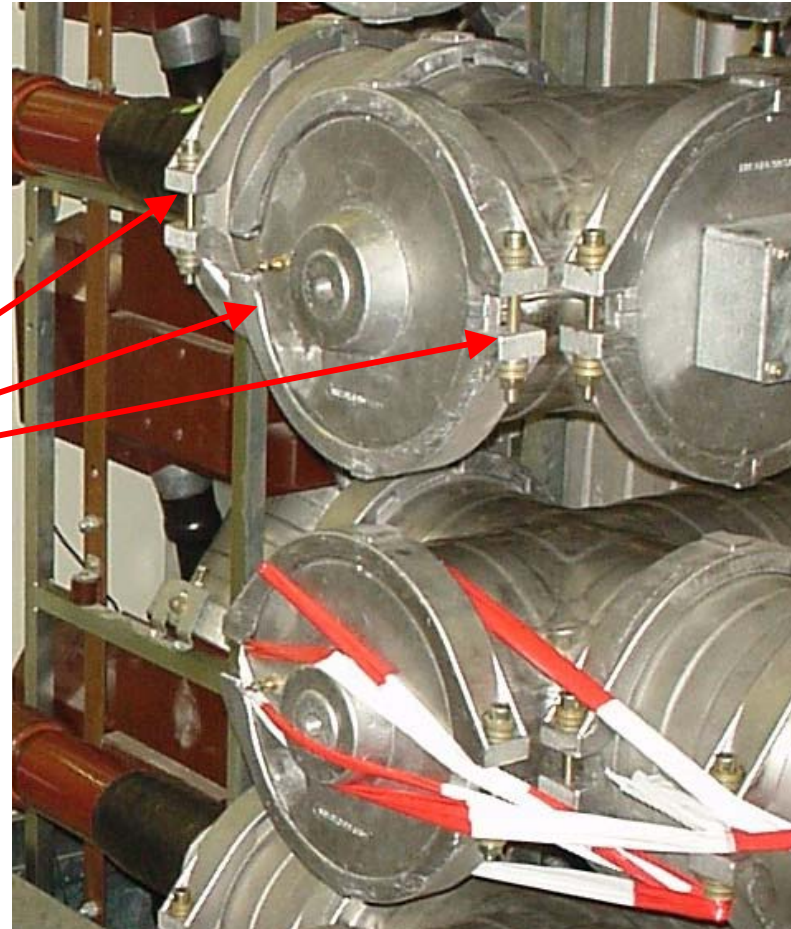


# SF<sub>6</sub> Insulated Switchgear



# SF<sub>6</sub> Insulated Switchgear

Mechanical gas  
seals



# Arced SF<sub>6</sub> Byproducts

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- SF<sub>6</sub> + moisture + high temperatures = toxic byproducts
- GIS equipment failures due to:
  - Lightning strikes
  - SF<sub>6</sub> leaks
  - Contaminated SF<sub>6</sub>
  - Moisture + HV = PD = insulation degradation = failure
- Rotten egg smell
- White powdery residue

# Arced SF<sub>6</sub> Byproducts

Table 1. Gaseous SF<sub>6</sub> Decomposition Byproducts and Typical Concentrations During Repeated Sparking

Chemical Formula	Chemical Name	Chemical Abstracts Service Registry Number	Experimental Concentration (percent by volume) <sup>a</sup>
HF	Hydrogen fluoride	7664-39-3	1.0
SOF <sub>2</sub> (SF <sub>4</sub> ) <sup>b</sup>	Thionyl sulfide (sulfur tetrafluoride)	7783-42-8 (7783-60-0)	0.5
SOF <sub>4</sub>	Sulfur tetrafluoride oxide	13709-54-1	0.085
SiF <sub>4</sub>	Silicon tetrafluoride	7783-61-1	0.085
S <sub>2</sub> F <sub>10</sub> (SF <sub>5</sub> ) <sup>c</sup>	Disulfur decafluoride	5714-22-7	0.025
SO <sub>2</sub> F <sub>2</sub>	Sulfuryl fluoride	2699-79-8	0.006
SO <sub>2</sub>	Sulfur dioxide	7446-09-5	0.002

Table a dapted from Dervos and Vassiliou (2000).

# Arced SF<sub>6</sub> Byproducts

In the U.S., six workers were exposed during repair work on electrical equipment (Kraut and Lilis 1990). The workers experienced symptoms including burning/watering eyes, nasal irritation/epistaxis, throat irritation, chest tightness/wheezing/shortness of breath, coughing (in one case producing blood), nausea/vomiting, fatigue, and headaches. Most symptoms occurred immediately following or up to one week after the exposure event. Some workers' symptoms did not resolve until a month later or (in one case) a year later. No long-term physical effects were observed. Chemical evaluation at the site qualitatively identified the presence of SF<sub>4</sub>.

In the U.K., two workers collapsed after entering an SF<sub>6</sub> storage tower (James et al. 1993). One of the workers suffered pulmonary edema for the three days following exposure. No long term effects were reported for either worker. Following the incident, both SF<sub>6</sub> and SO<sub>2</sub>F<sub>2</sub> were detected at levels that exceeded occupational exposure limits.

# Arced SF<sub>6</sub> Byproducts

In the Netherlands in 1989, an accident was reported involving two people who were exposed to unidentified substances resulting from a switchgear equipment failure (Mauthe and Pettersson 1991). The equipment contained SF<sub>6</sub>; upon failure, a small amount of powder was observed (likely solid metal fluorides). Both people recovered within two weeks.

A case of serious injury was reported to CIGRE in which an electrician repairing a circuit breaker was exposed to SF<sub>6</sub> decomposition products released by the equipment (Mauthe and Pettersson 1991). The worker lost consciousness and then awakened with a burning sensation in his chest. The worker's lung capacity was reduced by 45 percent. (CIGRE reports that had oxygen been administered more quickly, the damage would have been greatly reduced.)

# Arced SF<sub>6</sub> Byproducts

- Clean-up after a GIS failure requires use of proper PPE.
  - Eye, skin, nose, and throat irritation
  - Pulmonary edema, bronchitis and other lung damage
  - Hydrogen fluoride (HF) can cause severe, deep, and disfiguring burns.
  - Absorption of HF into the body can cause the heart to beat irregularly, leading to death.



# Other SF<sub>6</sub> Precautions...

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- SF<sub>6</sub> is heavier than air
  - SF<sub>6</sub> seepage will settle
  - Use caution working under GIS, especially when filling with gas.
  - Remove personnel from cable trenches and sub floors when filling.
- Environmental concern
  - SF<sub>6</sub> is non-ozone depleting, **but**.....

# SF<sub>6</sub> Environmental Impact

- SF<sub>6</sub> is the most potent greenhouse gas (GHG) the US EPA has ever evaluated
- GHGs do not deplete the earth's ozone layer – they trap the earth's heat, contributing to global climate change.
- With a global warming potential 23,900 times greater than CO<sub>2</sub>, and an atmospheric life of 3,200 years, one pound of SF<sub>6</sub> has the same global warming impact as 11 tons of CO<sub>2</sub>!

# SF<sub>6</sub> Environmental Impact

- Do not permanently attach SF<sub>6</sub> “make-up” cylinders to equipment.
  - Topping off is not environmentally responsible
- Rectify leaks immediately
- Utilize approved hoses, fittings, and gas carts to purify and replace SF<sub>6</sub>
- Never defeat pressure alarms
- EPA document: *Catalog of Guidelines and Standards for the Handling and Management of Sulfur Hexafluoride*
- IEC 62271-303 High-voltage switchgear and controlgear – Part 303: *Use and handling of sulphur hexafluoride (SF<sub>6</sub>)*

# SF<sub>6</sub> Proliferation

- Historically GIS and SF<sub>6</sub> circuit breakers in the US were relegated to outdoor utility usage.
  - Only viable alternative above 38kV
  - Utilities have developed good environmental and safety practices for handling SF<sub>6</sub> and dealing with SF<sub>6</sub> related failures.
- GIS at 38kV and below is common outside the US.
- A few cases have been seen of the acceptance of GIS at lower voltage classes for indoor use in the US.
  - Be aware of what engineering is specifying and what Supply Chain is purchasing for your facility.

# Summary

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- De-energized switchgear and circuit breakers are assumed to be “safe”.
- Vintage switchgear and circuit breakers have higher potential for containing hazardous materials.
- Asbestos and oil exist in vintage switchgear and circuit breakers.

# Summary

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- Oil filled equipment originally free from PCBs can develop PCBs from contaminated oil filling equipment
- PCB contaminated oil and asbestos must be disposed of properly.
- Have MSD Sheets available for hazardous materials.

# Summary

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- SF<sub>6</sub> has replaced the use of oil at voltages > 38kV
- SF<sub>6</sub> is finding its way into the US in lower voltage classes of indoor equipment.
- Pure SF<sub>6</sub> is non-toxic
- Arced SF<sub>6</sub> produces hazardous byproducts
- Clean-up after SF<sub>6</sub> equipment failures requires use of appropriate PPE.

# Summary

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- SF<sub>6</sub> is non-ozone depleting
- SF<sub>6</sub> is the most highly potent greenhouse gas (23,900 times the global warming potential of CO<sub>2</sub>)
- Use approved hoses, fittings, and gas carts when handling

# Conclusions

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- Safety procedures and check lists need to force operators to confirm the existence of hazardous materials before work begins
- Outside professionals that specialize in handling of asbestos, PCB-contaminated oil, and SF<sub>6</sub> are available

# Parting Thoughts

- Original equipment was designed to satisfy end-user requirements using available, safe materials
- Electrical equipment “lasts a long-time!”
- New knowledge identifies new safety and environmental issues, not previously known
- New precautions are required for employees and the environment
- Asbestos: Equipment < 1989
- PCBs: Equipment < 1977
- SF<sub>6</sub> : Equipment manufactured today
- Be safe, be legal, be proactive, be environmentally conscious

# Questions

## Safety and Environmental Evaluation of Insulating Media in MV Distribution Equipment

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