SF$_6$ By-products: Safety, Cleaning, and Disposal Concerns

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SF₆ Gas Properties

- Slow reacting with a relatively high molecular weight and extremely stable molecular structure.
- Excellent insulation properties, strong arc quenching abilities, and high dielectric strength
- Non-flammable and non-toxic to humans
- Colorless and Odorless
- Under high temperature conditions (> 350° F), SF₆ decomposes into products that are toxic and corrosive
SF₆ Decomposition and Contamination

• Reactive decomposition byproducts form when SF₆ is exposed to:
  1. spark discharges,
  2. partial discharges,
  3. switching arcs, and
  4. failure arcing

• Decomposition byproducts can take the form of gas or powders

• Other types of contaminants can include moisture and air (from handling or leakage), dust and particles (mechanical generation)
# SF$_6$ Decomposition Byproducts

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gaseous Byproducts</strong></td>
<td></td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>SO$_2$</td>
</tr>
<tr>
<td>Thionyl Sulfide (sulfur tetrafluoride)</td>
<td>SOF$_2$ (SF$_4$)</td>
</tr>
<tr>
<td>Hydrogen Fluoride</td>
<td>HF</td>
</tr>
<tr>
<td>Disulfur Decafluoride (sulfur pentafluoride)</td>
<td>S$<em>2$F$</em>{10}$ (SF$_5$)</td>
</tr>
<tr>
<td>Sulfuryl Fluoride</td>
<td>SO$_2$F$_2$</td>
</tr>
<tr>
<td>Sulfur Tetrafluoride Oxide</td>
<td>SOF$_4$ (SF$_4$) a</td>
</tr>
<tr>
<td><em>SF$_4$ is readily hydrolyzed to SOF$_2$.</em></td>
<td></td>
</tr>
<tr>
<td><strong>Powder Byproducts</strong></td>
<td></td>
</tr>
<tr>
<td>Tungsten, aluminum, copper fluorides</td>
<td>WF$_6$, WO$_3$, AlF$_3$, CuF$_2$</td>
</tr>
</tbody>
</table>
Human Health Concerns

• Irritating to the eyes, nose, and throat, pulmonary edema and other lung damage, skin and eye burns, nasal congestion, bronchitis; powders may cause rashes

• Physical Indicators can include:
  – strong irritating “rotten egg” odor at low concentrations
  – Eyes, nose, throat and lung irritation at high concentrations
  – Presence of white, gray, or tan powders

• Toxic
  – Cell toxicity tests indicate $S_2F_{10}$ is significantly more toxic to cell cultures than other byproducts
## Occupational Exposure Limits

<table>
<thead>
<tr>
<th>Substance</th>
<th>PEL-TWA</th>
<th>PEL-Ceiling</th>
<th>TLV-TWA</th>
<th>TLV-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>3 ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOF₄ (SF₄)</td>
<td></td>
<td>0.1 ppm</td>
<td></td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>S₂F₁₀ (SF₅)</td>
<td>0.025 ppm*</td>
<td>0.01 ppm</td>
<td></td>
<td>0.01 ppm</td>
</tr>
<tr>
<td>SO₂F₂</td>
<td>5 ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>2 ppm</td>
<td></td>
<td>2 ppm</td>
<td></td>
</tr>
<tr>
<td>SF₆</td>
<td>1,000 ppm</td>
<td></td>
<td>1,000 ppm</td>
<td></td>
</tr>
</tbody>
</table>

*Revised in 1989 to a PEL-ceiling value of 0.01 ppm; enforcement of the new limit stayed by OSHA, until available sampling and analytical technique is published a notice in the Federal Register.
SF₆ Gas Categories

- New (Gas In Cylinders)
- Non-arced
- Normally Arced
- Heavily Arced

Degree of Contamination Risk:
- Low
- High
Safe Handling Procedures

• Low Risk (new, non-arced SF$_6$)
  – Work in well-ventilated areas
  – No smoking, refrain from welding, avoid open flame or outdoor heaters

• Intermediate Risk (normally arced SF$_6$)
  – Same as above

• High Risk (heavily arced SF$_6$)
  – Use of personal protective equipment (i.e., respiratory device, protective clothing such as rubber gloves, footwear, goggles) for removal/handling of solid SF$_6$ byproducts
  – Ventilate and test enclosed areas for adequate O$_2$ prior to initiating clean up
Safeguarding the Work Area

• Post warning signs provided with emergency instructions strategically
• Post evacuation maps and plans
• Provide personnel with written instructions for safe handling of SF₆-filled equipment, including:
  – Procedures for low, intermediate, and high risk situations
• Train personnel on cleaning procedures
Cleaning Procedures

• Contaminated Work Area
  – Use of Personal Protective Equipment
  – Removal of powdery deposits with vacuum cleaner equipment (HEPA filters), wipes
  – Removal of disposable protective equipment and waste bags into a properly labeled hazardous waste drum

• Contaminated SF$_6$ Gas
  – Onsite purification unit for acceptable levels
  – Off-site reclamation methods for non-acceptable levels (i.e., heavily arced gas)
Cleaning Contaminated SF₆ Gas On-Site

- Determine gas category
- Select appropriate filters
- Purify gas by filtering
- Perform quality checks
- Handle gas that results as non-reusable
## Select Appropriate Filters

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>Function</th>
<th>SF$_6$ Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle Filter</td>
<td>Removes solid decomposition products and other particles</td>
<td>Non-arced, normally arced, heavily arced</td>
</tr>
<tr>
<td>Gas/Moisture Filter</td>
<td>Removes gaseous decomposition products and moisture</td>
<td>Non-arced, normally arced, heavily arced</td>
</tr>
<tr>
<td>Prefilter</td>
<td>Reduces concentrations of solid and gaseous decomposition products</td>
<td>Heavily arced</td>
</tr>
<tr>
<td>Detoxification Filter</td>
<td>Reduces reactive gaseous decomposition products to below 200 ppmv for transport</td>
<td>Heavily arced</td>
</tr>
</tbody>
</table>
Purify Gas by Filtering

- 50 ppmv - maximum tolerable impurity level for reuse

  which translates into a reading of

- 12 ppmv if the sum concentration of \( \text{SO}_2 \) and \( \text{SOF}_2 \) is measured

(IEC 60480 and CIGRE TFB3.01.01/2004)
Perform Quality Checks

Methods include:

- Portable Analyzers
  - Electrochemical sensors
  - Spectrometer
  - Tester using reactive tubes

- Gas chromatograph (not suitable for field testing and expensive)
Portable Analyzer
Used SF₆ Storage and Transportation

• Generally need to store and transport used SF₆ gas for
  – disposal of non-reusable gas
  – off-site purification

• Procedures include:
  – Clearly label cylinder as used gas (Apply danger labels and/or use a different color)
  – Follow local transport regulations
  – Arrange for disposal of waste that complies with federal and state regulations
SULPHUR HEXAFLUORIDE USED

C - Corrosive

R 26/27/28 - Very toxic by inhalation, in contact with skin and if swallowed
S 7/9 - keep container tightly closed and in a well-ventilated place
S 38 - in case of insufficient ventilation, wear suitable respiratory equipment
S 45 - in case of accident or if you feel unwell, seek medical advice immediately
(show the label where possible)

UN 3308 : Toxic, corrosive liquefied gas, N.O.S
Contains : Sulfur hexafluoride - class 2

Source: Bessede, Huet, Montillet - AREVA T&D
and Barbier and Micozzi, - AVANTEC
Used $\text{SF}_6$ Disposal Procedures

- Incineration plants offer destruction services for used $\text{SF}_6$ gas
- $\text{SF}_6$ gas can be destroyed at a thermal process operating at 2100 degrees F
  - Dissociates into reaction products that are passed through wet scrubbers to form gypsum, fluospar minerals
  - Gypsum $\text{CaSO}_2$ used in construction
  - Fluorospar $\text{CAF}_2$ used as an additive in toothpaste
Resources

- IEC TR 61634 (SF₆ Handling)
- IEC TR 60480 (Used SF₆)
- EPA’s EPS Partnership Web site
  - Byproducts of SF₆ Use in the Electric Power Industry, January, 2002
  - Partner SF₆ Handling Procedures
  - Service Provider Directory
  - Catalog of Guidelines and Standards for the Handling and Management of SF₆