“Simply safer.”

January 25, 2017

WHITE PAPER:
SF_6 Is *No Longer* a Necessary Evil: The Human Health and Environmental Dangers of SF_6 Gas-Filled Switchgear

By Lisa Sattler Blackburn
Innovative Switchgear Solutions, Inc.

Introduction

In the ordinary course of business, there is a certain level of risk that comes with many activities. And, usually, we will undertake a calculation of sorts before undertaking riskier risks. For example, we weigh *likelihoods* against *less risky alternatives* against *convenience* against *cost*. And, at the end of the analysis, we often resign ourselves to certain things that we don’t like, but simply accept because there are no better, cost effective alternatives available at the present time. These are the “necessary evils” in life. That is the category into which SF_6 in distribution switchgear might properly be placed.

Until now.

Sulfur hexafluoride (commonly referred to as “SF_6”) is an inorganic, colorless, odorless, non-flammable, heavy gas that has been widely-regarded as an excellent electrical insulator.[1] However, although SF_6 is inert during *normal* use, when electrical discharges occur through everyday usage within SF_6-filled equipment, highly toxic by-products are produced that pose a serious health threat to the workers who come into contact with them.[2] Moreover, SF_6 has been identified as the most potent and persistent greenhouse gas in existence. In fact, it has a global warming potential that is approximately 24,000 times greater than carbon dioxide.[3] With these very real health and environmental risks which have been proven to be well-established science, why are we still installing switchgear containing SF_6 gas in applications below 35,000 volts when much safer

[1] W.-T. Tsai, *The Decomposition Products of Sulfur Hexafluoride (SF_6): Review of Environmental and Health Risk Analysis*, Journal of Flourine Chemistry 128 (2007), 1345-1352, at 1346-47.
[2] *Id.*, at 1347; U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexaflouride (SF6) Use in the Electric Power Industry* (2002), at 1.
[3] *Id.*

alternatives actually exist? Are we continuing to treat SF_6 as the "necessary" evil when indeed it is entirely *unnecessary* at certain voltages?

SF_6 Gas in Switchgear

SF_6 was discovered around the turn of the 20th century and, by the 1950's, the U.S. electric power industry widely praised SF_6 as a highly-favorable gaseous dielectric medium in high and medium voltage circuit breakers, switchgear, gas-insulated substations, and other electrical equipment. SF_6 presented some very significant advantages at the time. For one, SF_6 was an excellent replacement for oil-filled circuit breakers and switches that contained what was discovered to be harmful PCBs. In addition, SF_6 is not flammable, and thus took the threat of explosion and fire off the table as well. Moreover, because SF_6 gas under pressure has a much higher dielectric strength than air or dry nitrogen, this very attribute made it possible to significantly reduce the size of switchgear, particularly in the underground environment. Sounds like the perfect solution – that is, until the research decades later would prove otherwise.

In time, it would be discovered that SF_6 chemically decomposes into byproducts of varying mixtures and concentrations when exposed to electric discharges, including (1) switching arcs; (2) failure arcs; and (3) spark discharges.[4] Those byproducts include, among other things, disulfur decafluoride (S_2F_{10}), which is also referred to as sulfur pentafluoride (SF_5). Disulfur decafluoride is a highly toxic gas, its toxicity in some animal species on par with phosgene, the infamous chemical warfare pulmonary agent used in World War I.[5] S_2F_{10} was considered at one time for use as a chemical warfare pulmonary agent during World War II precisely for its insidious nature, as it provided little warning of exposure to the victim.[6]

Leaking SF_6-filled Equipment

The toxicity of both SF_6 and S_2F_{10} would be of less concern but for the documented fact of leakage, as well as uncontrolled releases or discharges that occur during routine development, testing, commissioning, maintenance and repair, and decommissioning of SF_6-filled equipment. These discharges and leakages are the causal connection between SF_6 and legitimate concerns over the health and welfare of utility employees, the community, and the environment. Leakage of SF_6 and its byproducts from equipment in service is the unplanned, usually continuous, emission of gas from a sealed or closed

---

[4] U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexaflouride (SF_6) Use in the Electric Power Industry* (2002), at 1.

[5] Animal toxicology studies were undertaken to evaluate the toxicity and effects of S_2F_{10}; obviously, such studies could not be conducted on humans. It was observed that in some animal species, S_2F_{10} demonstrated a *stronger* toxicity than phosgene, while in the case of one species, S_2F_{10} was *less* toxic than phosgene. Griffin, G.D., *et al.*, *Disulfur Decafluoride (S_2F_{10}): A Review of the Biological Properties And Our Experimental Studies of This Breakdown Product of SF_6*, Health and Safety Research Division, Oak Ridge National Laboratory (1991), 545-552, at 547.

[6] *Id.* at 546.

system.[7] This generally occurs at seals and joints, and sometimes by molecular diffusion through certain enclosure materials.[8] "Under ideal conditions, SF_6 would remain contained within . . . [the] equipment. In reality, however, SF_6 is inadvertently emitted into the atmosphere as leaks during various stages of the equipment's lifecycle. SF_6 can also be accidentally released during equipment installation, servicing, or de-commissioning."[9]

SF_6 *and Byproducts are Difficult to Detect*

The Environmental Protection Agency (EPA) has referred to S_2F_{10} as "the byproduct of greatest concern due to its relatively high toxicity,"[10] and has concluded that "SF_6 byproducts are difficult to detect chemically under normal working conditions . . . SF_6 byproducts such as SOF_3 and SF_4 (sulfur tetrafluoride) have a strong 'rotten egg' odor at low concentrations, and, at high concentrations, are irritating to the eyes, nose, throat, and lungs (U.S. EPA 2001; National Library of Medicine (NLM) 2001). Solid byproducts (i.e., metal fluoride byproducts) are white, gray, or tan powders that often can be observed when present and are irritating to exposed skin (Edison Technical Center 1997; U.S. EPA 2001a; NLM 2001). *However, these gross physical indicators of the presence of byproducts should not be relied upon as safety mechanisms due to the possibility of severe injury, especially given that the most toxic byproduct,* S_2F_{10}*, is generally odorless in pure form at typical environmental temperature.*"[11]

Health Hazards of SF_6 *and* S_2F_{10}

While SF_6 is regarded as a non-toxic gas, experts agree that it can displace oxygen in the lungs, and therefore cause asphyxia if too much is inhaled. SF_6 gas is approximately five times heavier than air and, if released or leaked in sufficient quantity, tends to accumulate initially in low-lying areas where there is no natural ventilation and may cause asphyxiation.[12] Under normal circumstances, it might be considered rare to be exposed to SF_6 without sufficient oxygen dilution; however, for utility employees, this type of exposure is well within the normal course of duties when installing, servicing, recycling, monitoring, and decommissioning SF_6-filled switchgear in vaults, basements, buildings, and other enclosed spaces. Indeed, if a substantial quantity of SF_6 gas leaks in

---

[7] *Guide to Safe Use of* SF_6 *in Gas Insulated Electrical Equipment*, Unipede/Eurelectric (1998), at 2; retrieved on Sept. 1, 2015.

[8] *Id.*

[9] Blackman J., Kantamaneni R., *EPA's* SF_6 *Emission Reduction Partnership: Maximizing the Benefits of* SF_6 *Emission Reduction for Electric Utilities*, Gaseous Dielectrics X, edited by Christophorou, *et al. (2002),* Springer, New York.

[10] U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexaflouride* (SF_6) *Use in the Electric Power Industry* (2002), at 2.

[11] U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexaflouride* (SF_6) *Use in the Electric Power Industry* (2002), at 4 (emphasis added); Griffin, G.D., et al., *Disulfur Decafluoride* (S_2F_{10})*: A Review of the Biological Properties And Our Experimental Studies of This Breakdown Product of* SF_6, Health and Safety Research Division, Oak Ridge National Laboratory (1991), at 546.

[12] *Guide to Safe Use of* SF_6 *in Gas Insulated Electrical Equipment*, Unipede/Eurelectric (1998), at 3, 5; retrieved on Sept. 1, 2015.

an enclosed area, it can present a real and present danger of asphyxiation to personnel due to oxygen deficiency.[13]

In addition, toxic solid byproducts of SF_6 in the form of fine powders such as aluminum fluoride (AlF_3), copper fluoride (CuF_2), and wolfram (tungsten) oxide (WO_3) can be present as a result of interaction with Teflon, copper and tungsten contacts and aluminum from shields. These are toxic if ingested or inhaled, causing eye, nose, and throat irritation, pulmonary edema (fluid in the lungs), and other lung damage, skin and eye burns, nasal congestion, bronchitis, and rashes.[14]

With respect to S_2F_{10}, as noted above, it is routinely referred to in the literature as being highly toxic. The Centers for Disease Control's National Institute for Occupational Safety and Health Pocket Guide (NIOSH) indicates that one can be exposed to S_2F_{10} by inhalation, ingestion, skin and/or eye contact. The symptoms include irritation of the eyes, skin, and respiratory system, and the target organs are the eyes, skin, respiratory system, and central nervous system. Cell culture toxicity tests indicate that S_2F_{10} is "literally orders of magnitude more toxic than other SF_6 breakdown products … in our cell culture systems."[15] Extensive animal toxicology studies were conducted in order to evaluate S_2F_{10} as a candidate warfare agent. Exposure to 5% concentrations resulted in animal death within a few minutes.[16] Exposure to lower concentrations produced death within an hour of exposure, and exposure to various low concentrations still resulted in lung damage. Longer term exposure (18 hours or more) at various concentrations were studied. Those exposed to higher concentrations died within 16 hours; those at lower concentrations survived. All were autopsied, revealing lung damage ranging from significant to generalized lung irritation, as well as lung lesions, edema, and lung hemorrhages.[17] And, once again, the subjects gave no initial indication of exposure. Once symptoms did appear, however, they included respiratory distress, which progressed to convulsions and death. Death was determined to result from anoxia (lack of oxygen) due to a vigorous pulmonary edema (lungs filled with liquid) and hyperemia (blood in the lungs).[18]

Finally, other byproducts of SF_6, including thionyl sulfide (SOF_2) or sulfur tetrafluoride (SF_4), silicon tetrafluoride (SiF_4), sulfuryl fluoride (SO_2F_2), and hydrogen fluoride (HF)

---

[13] *Id.*

[14] Averyt, Mollie, *U.S. EPA's International Conference on SF_6 and the Environment: SF_6 Byproducts: Safety, Cleaning, and Disposal Concerns* (November 29, 2006), at slide 5.

[15] Griffin, G.D., et al., *Disulfur Decafluoride (S_2F_{10}): A Review of the Biological Properties and Our Experimental Studies of This Breakdown Product of SF_6*, Health and Safety Research Division, Oak Ridge National Laboratory (1991), at 548.

[16] *Id.*

[17] U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexaflouride (SF_6) Use in the Electric Power Industry* (2002), at 3, citing Dervos and Vassiliou 2000; Hazard Substances Data Bank (HSDB) 2001; Griffin, G.D., et al., *Disulfur Decafluoride (S_2F_{10}): A Review of the Biological Properties And Our Experimental Studies of This Breakdown Product of SF_6*, Health and Safety Research Division, Oak Ridge National Laboratory (1991), at 548.

[18] *Id* at 546.

are extremely irritating to the eyes, nose, and throat. Other health effects include pulmonary edema, skin and eye burns, nasal congestion and bronchitis due to corrosive properties.[19] "Sulfur tetrafluoride exposure in an underground enclosed space for six hours causes shortness of breath, chest tightness, productive cough, nose and eye irritation, headache, fatigue, nausea, and vomiting. Physical abnormalities in tissues of the lung were observed, and tests showed obstruction of lung function."[20]

SF_6 *Gas Is a Greenhouse Gas*

In or about 1997, SF_6 was identified by the Intergovernmental Panel on Climate Change (IPCC) as a highly potent greenhouse gas that contributes to climate change. SF_6 is 22,000 times more effective at trapping infrared radiation (i.e., creating the greenhouse effect) than an equivalent amount of carbon dioxide over a 100-year period.[21] Additionally, it has an atmospheric life of 3,200 years, and its accumulation in the atmosphere is virtually irreversible.[22] SF_6 world production was at 7,000 tons in 1993, and was expected to reach 10,000 metric tons per year by 2010. The electrical industry uses approximately *80%* of that amount. In 2002, SF_6 emissions from the U.S. electric power industry totaled 589 metric tons. From a greenhouse gas perspective, that equates to 14.1 million tons of CO2, or five percent of total CO_2 and non-CO_2 greenhouse gas emissions from U.S. industrial processes.[23] Although SF_6 is emitted in smaller quantities than other greenhouse gases, it has a significant long term impact on global climate change.[24]

<u>2017 UPDATE</u>:

Federal and State Regulations Regarding SF_6

By 2008, the EPA had mandated the Greenhouse Gas Reporting Program (GHGRP) which appeared to be addressing the tracking and reporting of greenhouse gas data from large emission sources. The underlying intent, however, was the reduction, if not elimination, of SF_6 emissions into the environment either by managing leakage, or elimination of SF_6 altogether. By 2011, the State of California had joined such efforts to reduce SF_6 emissions, but in a much more specific and targeted fashion. Through the California Air Resources Board (CARB) regulations, the State of California became the

---

[19] U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexaflouride (SF_6) Use in the Electric Power Industry* (2002), at 2.
[20] Kraut, A., Lilis, R., *Pulmonary Effects of Acute Exposure to Degradation Products of Sulfur Hexafluoride During Electrical Cable Repair Work*, British Journal of Industrial Medicine (1990), 47:829-832 at 830.
[21] IPCC Fourth Assessment Report: Climate Change 2007: Working Group I: The Physical Science Basis; Section 2.10.1 Direct Global Warming Potentials, Table 2.14; retrieved Sept. 2, 2015.
[22] Blackman J., Kantamaneni R., *EPA's SF_6 Emission Reduction Partnership: Maximizing the Benefits of SF_6 Emission Reduction for Electric Utilities*, Gaseous Dielectrics X, edited by Christophorou, *et al.* (2002), Springer, New York.
[23] *Id.*
[24] *Id.*

first state to enact mandatory reductions in SF_6 emissions. California's regulation mandates emission reduction to 1% by 2020.[25]

Conclusion

For the protection of human health and of the environmental quality, it is imperative to mitigate and control – *if not entirely eliminate* – the discharges of these toxic and corrosive decomposition substances which are the result of using SF_6 in high and medium voltage circuit breakers, switchgear, and other electrical equipment. From a corporate utility and risk management perspective, SF_6-filled equipment is *no longer* a necessary evil. Indeed, it is entirely *unnecessary*, and jeopardizes both human health and the environment.

About Innovative Switchgear Solutions. Innovative Switchgear is the pioneer in designing and building premium quality, feature-rich, medium voltage solid dielectric-in-air switchgear for applications ranging from 4kV to 27kV that include a remarkable patent pending visible open isolation point design. Our products represent the new industry standard for safety, environmental responsibility and are entirely maintenance free. We deliver a total solution which solves a multitude of engineering, functionality, operations, and space utilization challenges. Our maintenance-free products for both switch and interrupter applications are based upon patent-pending insulating and safety innovations, eliminating the many risks associated with oil or SF6 gas in conventional switchgear. Our engineering and sales personnel are available to help you with your power distribution needs. Additional information about Innovative Switchgear Solutions can be found at www.InnovativeSwitchgear.com.

Author Bio:
Lisa Sattler Blackburn has been Innovative Switchgear's President and General Counsel since its inception. Prior to joining Innovation Switchgear, she was an intellectual property trial attorney and partner in a major international law firm. Lisa earned a Juris Doctorate from Santa Clara University School of Law, and a Bachelor of Science degree in Economics from Mills College. Contact: lblackburn@innovative-switchgear.com

Innovative Switchgear Solutions, Inc.
5073 Silver Peaks Avenue, Suite 101, Dacono, CO 80514 • 720-440-9404
www.innovative-switchgear.com

[25] Cal. Code Regs., Title 17, Sections 95350 to 95359, administered by CARB.