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WHITE PAPER:

SF₆ Is *No Longer* a Necessary Evil: The Human Health and Environmental Dangers of SF₆ Gas-Filled Switchgear

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In life, in business, in the ordinary course of doing things, there is a certain level of risk that comes with just existing. Granted, as individuals or as business people, we will do 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 SF₆ might properly be placed . . . until now.

Sulfur hexafluoride (commonly referred to as “SF₆”) is an inorganic, colorless, odorless, non-flammable, heavy gas that has been widely-regarded as an excellent electrical insulator.¹ However, although SF₆ is inert during *normal* use, when electrical discharges occur through everyday usage within SF₆-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, SF₆ 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 SF₆ gas in applications below 35,000 volts when much safer

¹ W.-T. Tsai, *The Decomposition Products of Sulfur Hexafluoride (SF₆): Review of Environmental and Health Risk Analysis*, *Journal of Fluorine 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 Hexafluoride (SF₆) Use in the Electric Power Industry* (2002), at 1.

³ *Id.*

alternatives actually exist? Are we continuing to treat SF₆ as the “necessary” evil when indeed it is entirely *unnecessary* at certain voltages?

SF₆ Gas in Switchgear

SF₆ was discovered around the turn of the century and, by the 1950’s, the U.S. electric power industry widely praised SF₆ as a highly favorable gaseous dielectric medium in high and medium voltage circuit breakers, switchgear, gas-insulated substations, and other electrical equipment. SF₆ presented some very significant advantages at the time. For one, SF₆ was an excellent replacement for oil-filled circuit breakers and switches that contained what we discovered were harmful PCBs. In addition, SF₆ is not flammable, and thus took the threat of explosion and fire off the table as well. Moreover, because SF₆ 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 SF₆ 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 (S₂F₁₀), which is also referred to as sulfur pentafluoride (SF₅). 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 S₂F₁₀ 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

The toxicity of both SF₆ and S₂F₁₀ 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 SF₆-filled equipment. These discharges and leakages are the causal connection between SF₆ and legitimate concerns over the health and welfare of utility employees, the community, and the environment. Leakage of SF₆ and its byproducts, including S₂F₁₀, from equipment in service is the unplanned,

⁴ U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexafluoride (SF₆) Use in the Electric Power Industry* (2002), at 1.

⁵ Animal toxicology studies were undertaken to evaluate the toxicity and effects of S₂F₁₀; obviously, such studies could not be conducted on humans. It was observed that in some animal species, S₂F₁₀ demonstrated a *stronger* toxicity than phosgene, while in the case of one species, S₂F₁₀ was *less* toxic than phosgene. Griffin, G.D., *et al.*, *Disulfur Decafluoride (S₂F₁₀): A Review of the Biological Properties And Our Experimental Studies of This Breakdown Product of SF₆*, Health and Safety Research Division, Oak Ridge National Laboratory (1991), 545-552, at 547.

⁶ *Id.* at 546.

usually continuous, emission of gas from a sealed or closed system.⁷ This generally occurs at seals and joints, and sometimes by molecular diffusion through certain enclosure materials.⁸ “Under ideal conditions, SF₆ would remain contained within . . . [the] equipment. In reality, however, SF₆ is inadvertently emitted into the atmosphere as leaks during various stages of the equipment’s lifecycle. SF₆ can also be accidentally released during equipment installation, servicing, or de-commissioning.”⁹

SF₆ and Byproducts are Difficult to Detect

The Environmental Protection Agency has referred to S₂F₁₀ as “the byproduct of greatest concern due to its relatively high toxicity,”¹⁰ and has concluded that “SF₆ byproducts are difficult to detect chemically under normal working conditions . . . SF₆ byproducts such as SOF₃ and SF₄ (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, S₂F₁₀, is generally odorless in pure form at typical environmental temperature.*”¹¹

Health Hazards of SF₆ and S₂F₁₀

While SF₆ 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. SF₆ 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 SF₆ without sufficient oxygen dilution;

⁷ *Guide to Safe Use of SF₆ in Gas Insulated Electrical Equipment*, Unipede/Eurelectric (1998), at 2; retrieved on Sept. 1, 2015.

⁸ *Id.*

⁹ Blackman J., Kantamaneni R., *EPA’s SF₆ Emission Reduction Partnership: Maximizing the Benefits of SF₆ 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 Hexafluoride (SF₆) Use in the Electric Power Industry* (2002), at 2.

¹¹ U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexafluoride (SF₆) Use in the Electric Power Industry* (2002), at 4 (emphasis added); Griffin, G.D., et al., *Disulfur Decafluoride (S₂F₁₀): A Review of the Biological Properties And Our Experimental Studies of This Breakdown Product of SF₆*, Health and Safety Research Division, Oak Ridge National Laboratory (1991), at 546.

¹² *Guide to Safe Use of SF₆ in Gas Insulated Electrical Equipment*, Unipede/Eurelectric (1998), at 3, 5; retrieved on Sept. 1, 2015.

however, for utility employees, this type of exposure is well within the normal course of duties when installing, servicing, recycling, monitoring, and de-commissioning SF₆-filled switchgear in vaults, basements, buildings, and other enclosed spaces. Indeed, if a substantial quantity of SF₆ gas leaks in 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 SF₆ in the form of fine powders such as aluminum fluoride (AlF₃), copper fluoride (CuF₂), and wolfram (tungsten) oxide (WO₃) 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 S₂F₁₀, 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 S₂F₁₀ 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 S₂F₁₀ is "literally orders of magnitude more toxic than other SF₆ breakdown products ... in our cell culture systems."¹⁵ Extensive animal toxicology studies were conducted in order to evaluate S₂F₁₀ 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

¹³ *Id.*

¹⁴ Averyt, Mollie, *U.S. EPA's International Conference on SF₆ and the Environment: SF₆ Byproducts: Safety, Cleaning, and Disposal Concerns* (November 29, 2006), at slide 5.

¹⁵ Griffin, G.D., et al., *Disulfur Decafluoride (S₂F₁₀): A Review of the Biological Properties and Our Experimental Studies of This Breakdown Product of SF₆*, 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 Hexafluoride (SF₆) 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 (S₂F₁₀): A Review of the Biological Properties And Our Experimental Studies of This Breakdown Product of SF₆*, Health and Safety Research Division, Oak Ridge National Laboratory (1991), at 548.

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 SF₆, including thionyl sulfide (SOF₂) or sulfur tetrafluoride (SF₄), silicon tetrafluoride (SiF₄), sulfuryl fluoride (SO₂F₂), and hydrogen fluoride (HF) 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

SF₆ Gas Is a Greenhouse Gas

In or about 1997, SF₆ was identified by the Intergovernmental Panel on Climate Change (IPCC) as a highly potent greenhouse gas that contributes to climate change. SF₆ 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 SF₆ 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, SF₆ 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 CO₂ and non-CO₂ greenhouse gas emissions from U.S. industrial processes.²³ Although SF₆ is emitted in smaller quantities than other greenhouse gases, it has a significant long term impact on global climate change.²⁴

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

¹⁸ *Id.* at 546.

¹⁹ U.S. Environmental Protection Agency, Office of Air and Radiation, *Byproducts of Sulfur Hexafluoride (SF₆) 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 SF₆ Emission Reduction Partnership: Maximizing the Benefits of SF₆ Emission Reduction for Electric Utilities*, *Gaseous Dielectrics X*, edited by Christophorou, *et al.* (2002), Springer, New York.

²³ *Id.*

²⁴ *Id.*

SF₆ in high and medium voltage circuit breakers, switchgear, and other electrical equipment. From a corporate utility and risk management perspective, SF₆-filled equipment is *no longer* a necessary evil. Indeed, it is entirely *unnecessary*, and jeopardizes both human health and the environment.

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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 25kV 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.Innovative-Switchgear.com.

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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.

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