PULMONARY EFFECTS OF ACUTE EXPOSURE TO SULFUR TETRAFLUORIDE DURING ELECTRICAL CABLE REPAIR WORK

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ABSTRACT

Six electrical workers were accidentally exposed to sulfur tetrafluoride (SF4) while repairing an electrical cable in an underground confined space. Repairs began 4 days after a burnout at a nearby substation. Symptoms noted approximately 1 hour after beginning work were shortness of breath, chest tightness, productive cough, nose and eye irritation, and headache. Some workers also experienced fatigue, nausea, and vomiting. Partial resolution of symptoms occurred when exposure was interrupted while attempts to identify the cause of the problem were made. Although exposure ended after several hours, 4 workers remained symptomatic for over one week. Chest radiographic abnormalities included, several discrete areas of transitory platelike atelectasis in 1 worker, and soft hazy infiltrates in another. Pulmonary function changes included reversible decrements in FVC and FEV_1.

Sulfur hexafluoride (SF6), an inert gas, used in circuit breakers as an electrical arc-interrupting medium, decomposes to SF4 and other compounds when subjected to intense heat. SF4, an irritant gas, with toxic effects similar to phosgene, was eventually identified by mass spectrometry of worksite air samples, and is the likely cause of the illness developed by these workers. Effects of SF4 exposure on humans have not been reported in the medical literature, although available information indicates that it is a highly irritant compound. Occupational health personnel should be aware that exposure to SF4 is an important health hazard for workers repairing damaged electrical systems containing SF6.

INTRODUCTION

Unpredicted exposures to industrial chemicals place workers at serious risk, as they are both unprepared for the event and may not know the compound's toxic effects. We wish to report the consequences of an unexpected, unpredicted, and unrecognized exposure to the irritant gas, sulfur tetrafluoride (SF4). The exposure occurred after initiation of repairs following a burnout (small explosion) in an electrical substation. During the burnout circuit breakers using sulfur hexafluoride (SF6) as an insulating gas were damaged. When SF6 is subjected to intense heat it decomposes to SF4 and other compounds.[1] Although SF4 has been reported to have toxicity similar to that of phosgene,[2] we could find no published documentation of illnesses in humans caused by this compound.

CIRCUMSTANCES OF EXPOSURE AND ACUTE SYMPTOMS.

On January 12th 1988 approximately 15,000 gallons of polybutene insulating oil was lost from an electrical transmission cable. Concurrently, a burnout occurred in circuit breakers at a substation several miles further down the line. Four days later a team of six gas operators (workers #1-6) began repair work approximately 100 yards from the substation by cutting the surrounding pipe to gain access to the enclosed electrical cable. The worksite was an underground space, 10'×4'×8', with two three foot diameter openings. Four members of the crew (#1-4) worked underground, while the safety officer, (#5), remained on the surface. The foreman, (#6), worked above or below ground as needed. All workers were previously healthy, except for (#5) who had a history of emphysema.

Prior to entering the worksite, routine measurements for natural gas and oxygen concentrations were found to be satisfactory. At approximately 9:00 AM the team began using compressed air powered smith cutters to open the pipe. About one hour later, five underground workers began experiencing burning eyes, tearing, dry and burning throat, and chest tightness. An odor similar to a "burning car battery" was noticed. The crew stopped working and went above ground; symptoms decreased fifteen minutes later.

A fan was obtained to improve air circulation at the worksite. The previously mentioned symptoms, however, recurred shortly after work was resumed. In addition, some workers started experiencing headache, fatigue and cough productive of clear sputum. Concern was raised that the air compressor was the cause of the problems. Work was again halted and a different compressor ordered. Symptoms subsided when the men stopped working underground and went into the fresh air. Nevertheless, the same symptoms recurred one hour after work was resumed with the new compressor.

Due to the persistence and worsening of symptoms a worksite investigation was performed by the company chemist at approximately 3:00 PM. No abnormalities were detected on routine air monitoring and samples from the partially opened pipe were taken for analysis. Although no problems were identified, a second fan was brought to improve the air circulation. Two hours later workers again reported chest tightness and/or shortness of breath. Two complained of headache, fatigue and nose bleeds; two felt nauseous and one worker vomited. Work was again halted and the entire crew waited above ground for the chemist's final report. At 10:00 PM workers were sent home as the report had not yet arrived.

At approximately 1:00 AM all six workers were notified by telephone that SF4, a potentially hazardous material, was identified in the air samples taken from the partially opened pipe at the worksite. In addition they were instructed to immediately go to the nearest hospital emergency room. Five of the workers went to one hospital and the sixth to another. Oxygen was administered by mask in the emergency room of the first hospital. Chest radiographs were not taken until approximately 11:00 AM, approximately 26 hours after the onset of exposure. Five of the workers were discharged a few hours later.

Worker #1, complained of headache, cough productive of blood streaked sputum, and wheezing. Three discrete areas of atelectasis were observed on chest radiograph. He was admitted to hospital and treated with bronchodilators and antibiotics. Pulmonary function testing (PFTs) performed January 19th were normal. While in hospital be became febrile. The headache and productive cough persisted for over one week.

All six workers elected to come to the Occupational Medicine Center at the Mount Sinai Hospital for evaluation between January 26 and February 1, 1988. Initial and persistent symptoms are summarized in Table I. Three workers, (#2-4), complained of fatigue at the time of evaluation. Physical examination did not reveal any pertinent abnormalities.

On reviewing the initial radiographs, worker #3 had hazy infiltrates in the lower lung fields, while worker #6 had a slight infiltrate in his left lower lung field. All follow-up radiographs taken between 10-21 days after the accident were normal.

Pulmonary function testing was not performed during the initial emergency room evaluation. PFTs were ordered by the company physician between three and ten days after the event for five of the six workers, the sixth a few days later. Three of these were normal. Workers #5 and 6 had slight

Table I
Symptoms of Workers Exposed to Sulfur Tetrafluoride

	Worker					
Symptom	#1	#2	#3	#4	#5	#6
Burning/ Tearing eyes		*	*	*	*	*
Nasal irritation/ Epistaxis	°		°	°		
Throat irritation	*			*		°
Chest tightness/ Wheezing/ S. O. B.	*	*	°	°		*
Cough	°	*	*			
Nausea/Vomitting	*	*				
Fatigue		°	°	°		
Headache	*		°			

* Symptoms following exposure
° Symptoms lasting longer than one week

decreases in FVC, 75% and 77% percent of predicted, which normalized to 89 and 98% on follow-up testing a few days later. PFT results are summarized in Table II. Interpretation of these findings is limited by the fact that different equipment was used at each location.

Worker #3 had three sets of PFTs, the first set performed on January 19, 1988 was normal. PFTs taken prior to resuming work one week after the event, revealed an obstructive pattern, FVC 109% and FEV_1 67% of predicted. He did not have a history of asthma, but did complain of chest tightness and shortness of breath on exposure to cold air for approximately one week following the exposure. Repeat testing when he was asymptomatic was normal. DLCOs were normal in all workers except for #5 who had a history of asbestos exposure and emphysema.

DISCUSSION

SF6 was first synthesized by Moissen and Lebeau in 1902 by burning sulfur in a fluorine atmosphere.[3] SF6 has been used in electrical equipment in the United States since 1953.[4] It is a heavy, colorless, odorless gas of high chemical stability. By being an effective electron scavenger SF6 can efficiently retard electrical conduction. These properties have led to its use as an electrical insulating material in circuit breakers, cables, capacitors, and transformers.[5] SF6 containing equipment has allowed the creation of compact electrical substations requiring one twentieth the land of previous designs.[6]

The use of SF6 has increased markedly in recent years. The National Occupational Hazard survey initiated in 1971, ap-

Table II
Pulmonary Function Results

Worker ^				
#3	Date FVC FEV1 FVC/FEV1 FEF25-75 DLCO	Jan. 19* 4.15 3.7 89%	Jan. 26 ' 4.40 (109%) 2.08 (67%) 47% 2.00 (62%)	Feb. 1" 4.87 (116%) 3.92 (120%) 80% 2.69 (81%) 38.1 (141%)
#5	Date FVC FEV1 FVC/FEV1 FEF25-75 DLCO	Jan. 19 ' 3.58 (77%) 2.17 (60%) 60% 1.08 (34%)	Jan. 28 " 4.52 (98%) 2.71 (78%) 64% 1.50 (33%) 16.2 (60%)	
#6	Date FVC FEV1 FVC/FEV1 FEF25-75 DLCO	Jan. 21 ' 3.64 (75%) 3.28 (87%) 90% 5.96 (160%)	Jan. 26 " 4.23 (89%) 3.97 (107%) 94% 7.66 (153%) 24.3 (82%)	

* Private Physician's office
' Company medical facility
" Mount Sinai Medical Center
^ Workers #1,2,4 all had unchanged results on repeat testing
Percentages in parenthesis are % perdicted

proximated that 177 American workers were potentially exposed to this compound.[7] Preliminary information from the early 1980's estimates over 9,000 potentially exposed workers, over half repairers of electrical and electronic equipment.[8]

SF6 is an inert gas; in experimental studies no ill effects were found in mice breathing a mixture of 80% SF6 and 20% O_2 for 12–16 hours.[2] SF6 will break down to toxic sulfur oxyfluorides during electrical arcing in the presence of oxygen.[1,9] Worker exposure to these gases can be significantly reduced by the presence of properly maintained absorptive filters. In experiments specifically designed to identify the decomposition products of SF6, SF4 was only generated by higher energy arcs after the consumption of available oxygen.[1] Temperatures above 150°C have been reported to lead to the decomposition of SF6 to SF4 and other compounds.[10]

SF4, a highly reactive, colorless gas which fumes in moist air, has an irritating odor similar to sulfur dioxide.[11] No comprehensive studies of this compound's toxicity could be found in the medical literature. The material safety data sheet on this compound reports it to be extremely irritating and corrosive to the upper and lower respiratory tracts, skin, and eyes.[9] SF4 hydrolyses in air to form hydrofluoric acid. Thus skin and mucous membranes lesions similar to those caused by this acid can be expected in workers exposed to SF4. SF4 may cause chemical pneumonitis and pulmonary edema.[4] Animals exposed to 10 ppm SF4 for one hour developed rapid labored breathing, weakness, and cyanosis.[12] The manufacturer has reported that animals exposed to 50 ppm for 4 hours died from pulmonary edema.[13] Ten repeated exposures of 4 ppm for 4 hours produced signs of respiratory effects in rats. Pulmonary damage was observed in rats sacrificed immediately after the tenth exposure. Those subsequently unexposed for 14 days recovered clinically and showed no anatomical lesions.[14] In 1959 investigators for E.I. Du Pont de Nemours & Company recommended that SF4 should be treated with extreme caution as it has an inhalation toxicity comparable to phosgene.[2] Consistent with this high level of toxicity the ACGIH has set a ceiling exposure limit of 0.01 ppm for this compound.[15]

Electrical substations contain switches, circuit breakers, conductors, and transformers to switch power circuits and transform power from one voltage to another or from one system to another. At the station in question three circuit breakers were connected to the damaged cable. Each of these were approximately the size of a 55 gallon drum and filled with SF6.

Although the exact sequence of events leading to the SF4 exposure has not been determined, a likely sequence is as follows. Due to damage at a distant site insulating oil was lost from the cable. This, or the following burnout led to a disruption of the valve separating the circuit breakers from the cable. Due to the intense heat of the burnout SF6 decomposed and all oxygen in the system was consumed. Further breakdown of SF6 occurred leading to the production of SF4 and possibly other compounds. As the circuit breakers were not externally damaged the SF4 was forced into the pipe containing the cable and was released when the pipe was cut at the worksite. Although other breakdown products may have been present, SF4 was the only one qualitatively identified. The level of exposure was not quantified. Repeat testing the following day revealed barely detectable levels.

Workers were exposed to SF4 for about 6 hours over a 12 hour period while repairing the cable. Chest radiographs were not taken until 26 hours after the start of exposure. In addition any early PFT changes may have been missed as testing was not performed until a few days after the event when the majority of acute symptoms had already subsided.

Radiographic evidence of multilobar atelectasis was present in one worker. In addition a second worker, who did not have a previous history of asthma, complained of chest tightness on exposure to cold air and developed a transitory obstructive pattern on pulmonary function testing. His chest radiograph revealed hazy infiltrates in his lower lung fields. These findings are consistent with known toxic effects of irritant gas exposure.

All five underground workers had respiratory tract symptoms, the sixth worker who remained above ground, experienced only eye irritation. The intermittent nature of the exposure most probably prevented the development of more severe effects such as chemical pneumonitis or toxic pulmonary edema.

These workers were unaware that their job could lead to exposure to SF4. Although they had worked for many, some for over twenty years in this field, none had heard of SF4 before or were aware that their job may lead to exposure to irritating chemicals in general and to SF4 in particular. Had they, or the company management, physician, chemist, or industrial hygienists been aware of the potential for this exposure, it is likely that the exposure would have been of much shorter duration. The potential for toxic exposures, however, is documented in the material safety data sheet describing SF6.[9] Proper education may have prevented the adverse health effects suffered by these workers.

Although the presence or absence of odor should not in general be relied upon to identify toxic exposures, odors present in areas containing heated SF6 must be considered to be coming from decomposition products and be a signal for the use of proper safety procedures.[1,4] An odor similar to a "burning car battery" was identified by workers, but no one involved in the initial investigation recognized this to be a warning signal. Fortunately, no worker developed severe complications and all have been able to return to work.

In order to limit the potential adverse effects of a similar event in the future, the following recommendations were given to both workers and management:

1. Comprehensive air tests be conducted before work is begun after accidents.
2. Knowledgeable individuals should be available for immediate on sit consultation if needed.
3. If a problem is presumed to exist work should not be resumed until the evaluation has been completed.
4. Proper respiratory protective equipment should be available at the worksite.

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