

Evaluation of Exposures and a Potential Hydrogen Sulfide Release Event at an Aircraft Engine Services Facility, West Virginia

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation.

Highlights of this Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a confidential request from employees at an aircraft engine services facility in West Virginia. The requestors were concerned about potential air quality issues, proper ventilation on chemical electroplating tanks, and cleanliness in the blast room. They felt these exposures, which included an incident in July 2013 involving potential exposure to hydrogen sulfide gas, had caused respiratory disease and breathing problems.

What NIOSH Did

- We interviewed employee requestors, current managers, and the facility's former environmental health and safety manager.
- We reviewed documents, including past industrial hygiene reports and medical records.
- In February 2014, we visited the facility.
- During the visit, we met with company management, waste water treatment plant operators, consultant industrial hygienists, and the facility nurse.
- We conducted private, in-person interviews with workers selected from a variety of departments.
- We toured the facility and observed workers performing their tasks.
- We sampled the air for hydrogen sulfide gas, total and respirable dusts, and other gases using real-time monitoring and short-term sampling equipment throughout the facility.
- We reviewed and discussed with management the findings from an internal investigation of the July 2013 incident involving potential exposures to hydrogen sulfide gas.
- We reviewed several breathing test (spirometry) reports done as part of the facility's medical surveillance program for chemists and plate line workers.

We evaluated an aircraft engine services facility for potential respiratory exposures leading to health problems. We learned about an incident in July 2013 in which overgrowth of sulfate-reducing bacteria led to the release of hydrogen sulfide gas in the waste water treatment plant. From existing records of pulmonologist diagnoses, we identified four cases of reactive airways dysfunction syndrome, a form of irritant-induced asthma, that were diagnosed within six months of the incident in workers who were in or near the waste water treatment plant. We reviewed the facility's incident response and actions with the facility management, industrial hygiene consultants, and waste water treatment plant manager. After learning about the incident in July 2013, the facility has taken multiple steps to mitigate exposures to hydrogen sulfide and prevent similar incidents in the future. During informal interviews with workers at the facility, we learned that at the time of the incident there was some confusion about incident reporting channels, which contributed to a delay in the facility's response. In addition, we learned that some workers were concerned about the potential for heat stress during the summer months. On the basis of these findings, we recommended a number of actions focused on engineering and administrative controls.

- We provided our initial findings and recommendations in a closing meeting and an interim letter.

What NIOSH Found

- Management was cooperative and workers were willing to talk with us.
- In July 2013, overgrowth of sulfide-reducing bacteria in a tank in the waste water treatment plant led to the release of hydrogen sulfide gas into the air. However, the hydrogen sulfide monitors located in the basement of the plant did not alarm.
- Due to poor communication between workers and management (which involved confusion about utilizing the company's Near Miss Cards and/or Incident Reports), the problems concerning strong odors and unusual presence of black sludge in the waste water treatment plant were not addressed for at least one week.
- Four workers who worked in or near the waste water treatment plant in July 2013 developed breathing problems following the incident and were diagnosed by a pulmonologist with reactive airways dysfunction syndrome, a form of irritant-induced asthma.
- Facility management performed an internal investigation following the July 2013 incident and organized a number of corrective and preventive actions. The affected workers did not actively participate in the internal investigation.
- Although the facility uses some electroplating chemicals with respiratory toxicity, there are many administrative and engineering controls in place. During the visit, the effectiveness of the engineering controls was confirmed with short-term samples taken directly over the electroplating tanks, which were all below limits of detection.
- During the walk through, the blast room was found to be clean and real time sampling equipment indicated low particulate levels.
- Safety labeling was clear throughout the facility, and workers we spoke with were aware of personal protective equipment and respirator use guidelines.
- A few workers we spoke with were concerned about the potential for heat stress in the electroplating and clean line departments during the summer months. These workers asked us about the feasibility of personal cooling fans.
- The facility has taken steps to address the concerns about heat stress, such as scheduling work/rest cycles and providing workers with a variety of drinks (water and electrolyte drinks).
- Spirometry was conducted at an offsite clinic and had multiple quality problems. The facility's onsite nurse has attended a NIOSH-approved spirometry course, but the facility did not have a functioning spirometer. Following our visit, the facility purchased a new spirometer.

What the Employer Can Do

- Continue to educate workers about the differences between Near Miss Cards and Incident Reports.
- Whenever possible, include the workers involved in an incident in the subsequent internal investigation.
- Before installing or permitting the use of personal fans or cooling devices, perform a review of potential cross ventilation effects to ensure ventilation is not adversely affected.
- Work with health and safety committees, supervisors, and workers to increase awareness about hydrogen sulfide gas.
- When evaluating future process changes, including changes to the waste water system, consider how they may affect occupational health and safety. Continue to examine all scenarios of potential failures in the system, and develop strategies for how these can be avoided.
- Continue to routinely monitor for sulfate-reducing bacterial growth in the waste water treatment plant.
- Continue to track hydrogen sulfide monitoring results from the real time monitors installed in the waste water treatment plant and near the prep room areas.
- Ensure that all spirometry testing conducted on workers is high quality and monitor for changes in lung function over time to identify workers with abnormal declines.

What Workers Can Do

- Report conditions that appear to be unsafe to supervisors, health and safety representatives, or the emergency response team right away.
- Participate in incident investigations if it is possible to do so.
- Check the real time monitors or wear personal sampling badges for hydrogen sulfide gas if unusual odors are detected. Inform a supervisor or health and safety representative if levels greater than 1 ppm are present.

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Abbreviations

LOD	Limit of Detection
MMF	Multi-Media Filter
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
ppm	Parts Per Million
RADs	Reactive Airways Dysfunction Syndrome
STEL	Short Term Exposure Limit

Summary

In December 2013, the National Institute for Occupational Safety and Health received a confidential health hazard evaluation request from employees of an aircraft engine services facility in West Virginia. The requestors were concerned about potential air quality issues, proper ventilation on chemical electroplating tanks, cleanliness in the blast room, and breathing problems. Five NIOSH investigators (two industrial hygienists, one chemist, one physician, and one epidemiologist) visited the facility on February 5 and 12, 2014. During these two visits, we met with workers, medical staff, and facility management. In addition, we toured the facility and performed real-time and short-term industrial hygiene monitoring. The monitoring was performed for screening rather than compliance purposes so that our industrial hygienists could better understand typical levels throughout the facility. We also reviewed documents provided by the company, including the company's environmental health and safety program manual, results of recent industrial hygiene sampling, injury and illness logs, and information about how unsafe conditions are reported.

We learned about an incident that occurred in July 2013 that involved potential exposure to hydrogen sulfide gas, and about the four workers that sought medical attention for respiratory illnesses afterward. The incident occurred when overgrowth of sulfate-reducing bacteria led to the release of hydrogen sulfide gas in the waste water treatment plant. The four workers were diagnosed with Reactive Airways Dysfunction Syndrome (RADs), a form of irritant-induced asthma that is associated with one or more exposures to high levels of chemical irritant(s). We requested and reviewed the pulmonologist diagnoses records for these workers. We reviewed the facility's incident response and actions with the facility management, industrial hygiene consultants, and waste water treatment plant manager. We also confirmed the effectiveness of ventilation over the electroplating tanks by sampling the air above the tanks.

In conversations with workers, we found that most reported they were comfortable speaking to management about health and safety concerns. Several workers were concerned about the potential for heat stress during the summer months in the electroplating and clean line areas.

After the incident occurred in July 2013, the facility management took multiple steps to prevent similar incidents from happening. These steps included elimination of a primary acidic descaler from the waste water treatment system, addition of an agitator to the main media filtration system, scheduling of periodic tests for sulfate-reducing bacteria in the waste water treatment plant, installation of additional hydrogen sulfide monitors, and changes to the ventilation system. We agreed with these steps and recommended additional worker training on hydrogen sulfide gas and incident reporting, as well as inclusion of affected workers in future incident investigations.

Introduction

In December 2013, The National Institute for Occupational Safety and Health (NIOSH) received a confidential health hazard evaluation request from employees of an aircraft engine services facility. The requestors were concerned about potential air quality issues, proper ventilation on chemical electroplating tanks, cleanliness of the blast room, and breathing problems. During the initial phase of our evaluation, we learned of an incident in July 2013 that involved potential exposure to hydrogen sulfide gas. On February 5 and 12, 2014, five NIOSH investigators visited the facility, met with workers and management, toured the facility, and performed real time and short-term industrial hygiene monitoring for screening purposes. In March 2014, we sent an interim letter to the company explaining the visit and stating recommendations made verbally during the visit.

Background

The facility is a 200,000 ft² aircraft engine maintenance, repair, overhaul and assembly facility that first opened in 1971. Several engine models are maintained, repaired and overhauled, and one model is fully assembled and tested onsite.

Process Description

Engines in need of repair or maintenance are either shipped to the facility as freight or flown to a local hangar and disassembled from the aircraft. They are initially processed in the disassembly area of the facility. After disassembly, engines and/or engine parts are evaluated in the inspection area. If an engine has external parts that the facility does not handle, these parts are removed and returned to the customer. Sometimes, in order to identify breakage or abnormalities in engine structure (e.g., metal pitting), the engine part is coated with a fluorescent tracer during inspection. Engineers and technicians will then develop an individual plan for the repair and overhaul of each engine and engine part.

If needed, the engine parts will first be stripped clean of any oils, grease, carbon build-up, grime, or coatings to expose the metal surface. Stripping may be performed physically by abrasive blasting and/or chemically by applying alkali solutions or solvents to the part. The abrasive blasting materials include aluminum oxide and plastic beads, and the process utilizes fully enclosed glove-box blasters. In the clean line area, engine parts may be rinsed, cleaned, or deburred with alkaline rust removers and descaling products.

After the engine is stripped and cleaned, it is again inspected, and a repair criterion is developed. This means the parts may go to the machine shop (for repairs), welding, electroplating, or paint/plasma spray booth areas, as applicable. In the plasma spray booth area, a robot is programmed to apply plasma inside a closed booth. The engine parts may also be recoated with metals or paints. In the electroplating area, the part is submerged in a tank specific to the type of metal or alloy needed for coating.

At the end of the repair process, the engine parts are sent to the build area where they are

reassembled and sent to test cells for performance analysis. Finally, engines are packed and shipped back to the customer. For engines that undergo overhaul and repair the typical turnaround time (back to the customer) is 40-60 days.

During these processes, waste water discharges from the stripping, cleaning, and plating are treated onsite at a waste water treatment plant that is located next to the plate line. Separate tanks are used to treat cyanide and chromium wastes. Many of the treatment tanks in this area are enclosed and ventilated. Some of the tanks, including the main equalization, multi-media filter (MMF) feed, flocculation, and pre-ion exchange tanks are not enclosed. The large, open equalization tank collects chrome, silver, and other metal wastes after they undergo individual pre-treatment. Typically, the organic acid scaling products that are used for engine cleaning are also treated and added to the main equalization tank. Afterward, this solution is sent to another series of treatment tanks, where the solution is balanced (using sodium metabisulfite and/or sulfuric acid, depending on the pH). During pre-treatment, all of the metals from electroplating processes are precipitated out in solution and a polymer is added to settle out aggregate waste materials. This polymer residue is then discarded as hazardous waste. Finally, the mixture is pressed and the remaining water is flushed through a complex MMF system. In the final treatment tank, sodium hydroxide may be added to rebalance the pH before final discharge from the facility. The waste water treatment process is operated by a contracted environmental services company.

Emergency Response and Incident Investigation

Some hourly employees are assigned to be members of an Emergency Response Team (ERT). This team responds to incidents requiring immediate attention that have been properly reported. The company's definition of such an "incident" can include both near misses (if serious), and actual events like detection of strange odors. In 2013, there were approximately 12 incident investigations at the facility.

Following the incident in July 2013, a team of worker representatives and management performed an incident investigation and organized a number of corrective and preventive actions. The affected workers did not actively participate in the internal investigation. The steps in the investigation were to 1) define the incident and establish the sequence of events; 2) investigate the cause or reason; 3) verify what happened; and 4) insure that a similar incident does not happen again.

Some important actions following the July 2013 internal investigation included the elimination of a primary acidic descaler from the waste water treatment system, the addition of an agitator to the main media filtration system to prevent stagnant conditions which support bacterial growth, scheduling of periodic tests for sulfate-reducing bacteria in the waste water treatment plant, the installation of additional hydrogen sulfide monitors (in the electroplating area and prep room where workers spend a large amount of their time), provision of real time personal hydrogen sulfide monitors for plate line workers to voluntarily monitor their own exposures, reduction of the warning and alarm signal levels on the hydrogen sulfide monitors (to 1 and 5 ppm, respectively), and re-routing the ventilation

system so that make-up air in the electroplating prep room is supplied from the machine shop area instead of the waste water treatment plant and electroplating line area.

Personal Protective Equipment and Respiratory Protection Program

Required personal protective equipment (PPE) in receiving and machine shop areas may include safety glasses, steel toe shoes, and gloves. During tank additions in the electroplating areas, workers typically wear gloves, face shield, apron, and protective sleeves if needed. Additional PPE and respiratory protection may be required in the paint and plasma rooms, including a supplied air respirator, Tyvek or heat-resistant suits, and protective chemical gloves during sprays and applications.

Respiratory protection consists of disposable filtering facepiece respirators, full facepiece respirators with cartridges, and tight-fitting full facepiece masks used with a self-contained breathing apparatus or supplied air. At the facility, the workers involved with handling cadmium compounds are enrolled in the cadmium-related Occupational Safety and Health Administration (OSHA) Medical Surveillance Program (29 CFR 1910.1027). Spirometry is conducted routinely at an off-site clinic for the workers enrolled in this program.

Methods

Prior to Site Visit

Prior to our visit to the facility, we interviewed the requestors to better understand their health concerns, safety practices, and potential exposures at the facility. We also had two telephone conversations with facility management from environmental health and safety and human resources departments.

In addition, we contacted the regional OSHA office in Charleston, WV to learn more about a complaint that was filed concerning an incident on July 16 and 17, 2013 that involved potential exposure to hydrogen sulfide gas in the waste water treatment plant. We learned that the waste water treatment area was located in the same building and next to the plating and clean line areas. At the time of the incident, the waste water treatment plant was being operated by a contracted environmental services company. We learned from the complaint that four workers had experienced sore throat, mucus, cough, irritated eyes, chest congestion, and nausea during the incident. One worker reported having ulcers in his mouth following the incident. We learned that some workers were still seeing an occupational health physician for persisting respiratory symptoms, six months after the incident. We also learned from OSHA that some current workers were requesting facility Safety Data Sheets for chemicals potentially involved in the July incident to provide more information to their occupational physicians.

After our telephone conversation with management, the facility personnel provided us with requested documentation in a timely manner. This included: a labeled map of the facility, internal and external industrial hygiene reports from the last two years, OSHA 300 logs of recordable illness and injury during the past 5 years, a copy of the respiratory protection

program, an environmental health and safety handbook, and the company's environmental, health and safety program manual. We also reviewed existing medical and industrial hygiene literature about known health effects from exposure to hydrogen sulfide gas, as well as the potential for accidental sulfide gas releases during waste water treatment processes. We contacted the four workers who had experienced healthy symptoms following the incident to request and review medical records. We obtained the records from a pulmonologist.

Site Visit

Upon arrival at the site on February 5, 2014, we had an opening meeting, which was attended by local and corporate management, consultant industrial hygienists, the onsite nurse, a worker representative, supervisors from around the facility (including maintenance and engineering), and a representative from the human resources department, to discuss the nature and itinerary for our site visit. During this meeting, we learned about the facility's history of manufacturing and engine repair processes.

We toured the facility to improve our understanding of the facility processes. At our request, the facility's Environmental Health and Safety coordinator took photographs be taken of equipment, tanks, and safety labeling. We learned more about specific requirements for PPE and training in different areas throughout the facility.

Following the tour, our two industrial hygienists and chemist returned to explore the facility in more depth. We revisited some areas (e.g. blast room, machine shop, electroplating and clean lines, waste water treatment plant) to observe workers performing tasks. We performed real-time and short-term industrial hygiene monitoring for screening rather than compliance purposes, so that we could better understand typical levels of carbon monoxide, hydrogen chloride, nitrous gases, hydrogen sulfide, sulfur dioxide, volatile organic compounds, and total and respirable dust throughout the facility. Additionally, we wore two types of real time monitoring equipment on our persons and brought a number of direct reading, colorimetric tubes for air sampling. These devices measure an array of different particles and gases, as described in Table 1. We took samples from both general work areas and directly over plating tanks and waste water tanks. We also spoke with the industrial hygiene consultant about the facility's ongoing industrial hygiene monitoring strategy, as well as how the monitoring strategy was adjusted following the July 2013 incident.

Our physician and epidemiologist informally interviewed workers from all over the facility. These confidential interviews were intended to provide us with a better understanding of individual safety practices and PPE use, and to identify any health and safety concerns that might exist in the workforce. We also talked to workers about the July 2013 incident, if they were present at the time. We provided copies of an informational handout regarding the NIOSH visit, and offered pamphlets on the NIOSH health hazard evaluation program [CDC 2009]. Lastly, we reviewed medical records (e.g., spirometry test reports) and spoke with the facility nurse about health and safety issues and medical surveillance procedures and capabilities.

At the end of first day, we scheduled a second visit for February 12, 2014 in order to accommodate the participation of the contracted waste water treatment facilities manager who was unable to make the initial meeting.

During the second visit on February 12, 2014, our physician and epidemiologist interviewed more workers and collected additional spirometry test reports for review. Our industrial hygienists and chemist met with the facility management, the worker representative, and the contracted waste water treatment facilities manager, to specifically review the root cause of the July 2013 incident and the company's investigation and response. At this time, management provided us with a report documenting the company's investigation. The waste water treatment plant manager provided us with information on the semi-quantitative test for visual determination of sulfate-reducing bacteria (visual determination, SRB-BART™) and sulfates in water solutions or produced waters (USEPA Method 8051). At the end of the visit, we requested a picture documenting the visual test and a full description of a hydrogen sulfide verification test performed in the waste water treatment plant following the incident. These were provided to us on February 25, 2014.

At the end of the second visit, we held a closing meeting to discuss our preliminary recommendations and the future course of the evaluation.

After the Site Visit

We prepared an interim letter summarizing our findings and initial recommendations. This was sent to the company, confidential requestors, OSHA, and the state health department in March 2014.

Results

Incident Description

On July 9 2013, some workers filed Near Miss Cards referencing strong and unusual "rotten egg-like" odors in the electroplating and waste water treatment work areas. At this time, some workers began experiencing respiratory irritation, headache, and nausea associated with the strong odors. An atypical "black sludge" floating in some of the waste water treatment plant tanks was noted at this time. During the time period of July 9-16, high outdoor temperatures ranged from 82-95 °F (28-35°C) [NOAA, 2013], although temperatures may have been higher indoors near the electroplating tank lines, as these lines involve hot processes. Seven days passed until, on July 16, 2013, one of the electroplating line workers directly contacted the environmental health and safety coordinator and again reported strong, unusual odors and some health symptoms that included scratchy/sore throat, cough, and phlegm. Workers in the area reported losing the ability to smell the odor over the course of the day. After management learned about the situation, the five workers who were experiencing symptoms were relieved from work duties in the electroplating line on the same day. Five days later, these workers returned and were stationed in other work locations of the facility. This included four electroplating line technicians and one maintenance technician. In the waste

water treatment plant, the hydrogen sulfide monitoring device located in the basement that had a warning signal at 5 ppm and an alarm signal at 10 ppm did not activate. Although the basement was open to the wastewater and electroplating areas, the hydrogen sulfide monitoring device was not in the same location as where the electroplating workers were regularly performing job tasks.

The waste water treatment plant manager explained that the specific incident had not been anticipated because hydrogen sulfide gas releases were not a common phenomenon in treatment plants dealing with such low levels of organic compounds. We confirmed both with company management and workers that the unusual odors and sludge build-up began when a specific organic acidic descaling product (which is used to remove metallic heat scales from jet engines) began to be treated regularly in the plant. In addition, the new MMF system had been recently installed, and the sludge first became visible at the bottom of the MMF feed tank. At the time, this tank was not being agitated, allowing the water to become stagnant.

Document Review

Our review of both the OSHA 300 logs and medical records revealed that four workers were diagnosed with Reactive Airways Dysfunction Syndrome (RADS) following the July 2013 incident. Respiratory symptoms including shortness of breath, cough, and wheeze persisted for months despite cessation of exposure and use of breathing medications. Three of the four workers received temporary worker's compensation for the RADS diagnosis. The OSHA log also described four workers in the electroplating and repair areas who had experienced respiratory and gastrointestinal symptoms stemming from a potential exposure to a freshly applied floor coating in May 2010. After examining the safety data sheet for the floor coating product, we learned that the gloss was a polyester resin that contained small amounts of xylene, ethyl-benzene, and dibutyltin dilaurate. One of the workers diagnosed with RADS in 2013 was involved in both chemical exposure incidents.

The facility contracts with industrial hygiene consultants to perform an array of routine air monitoring. We reviewed all industrial hygiene reports of monitoring done at the facility from years 2011 to 2013. In the electroplating and clean line areas, sampling included monitoring for hexavalent chromium, hydrogen cyanide, and ethanolamine to ensure that ventilation and capture systems are performing. Other industrial hygiene sampling included monitoring for airborne metal exposures (e.g., aluminum, molybdenum, and nickel) in the plasma area, welding fumes in the welding shop, and volatile organic compounds in the paint shop.

Following the July 2013 incident, the facility management requested that the consultants perform real time air monitoring for hydrogen sulfide gas at various locations throughout the facility, including the electroplating and clean line areas, as well as in the waste water treatment plant. The facility also collected a large amount of real time data with a MultiRAE Photoionization Gas Detector (RAE Systems, San Jose, CA) inside the prep room from July 23 to November 20, 2013. Overall, hydrogen gas levels were low, ranging from below the

Limit of Detection (LOD) to 0.3 ppm. On July 24-31, 2013 the monitor reported some levels of 0.1 to 0.2 ppm. The industrial hygiene consultants noted that these levels decreased after the facility cleaned the MMF tanks.

Industrial Hygiene Screening Results During Site Visit

We did not notice any unusual odors during the site visit. Table 1 provides a description of industrial hygiene monitoring that was conducted on February 5, 2014 during the facility visit. All of the chemical and dust sampling results collected using real-time instruments were below applicable occupational exposure limits. Real time monitoring for total and respirable dust with a Dustrak DRX Aerosol Monitor (Model 8534) indicated total dust levels less than 1 mg/m³ and respirable dust levels less than 0.4 mg/m³ throughout areas including the electroplating line, clean line, blast room, machine shop, shipping/receiving, and office areas. When real time monitoring for total and respirable dust was performed in the blast room, a worker was operating a fully enclosed glove-box blaster. The short-term sampling results collected for carbon monoxide, hydrogen chloride, nitrous gases, hydrogen sulfide, and sulfur dioxide were below the LOD. In addition, our industrial hygienists observed that visible mist from the electroplating tanks was being pulled away from the breathing zone into local exhaust directly above the tank. We also learned that some of the electroplating tanks without similar local exhaust systems (e.g., nickel tanks) had an added surfactant to help prevent the release of mists.

Worker Interviews

Everyone at the facility was friendly, welcoming, and generally willing to discuss jobs and processes, their personal sense of overall health and safety, and the July 2013 incident with us. We informally interviewed 11 workers from the repair line, machine shop, maintenance, electroplating line, clean line, paint shop, assembly line, and plasma departments. The tenure for these workers ranged from 1 to 28 years. Most workers felt safe at work and did not report many symptoms that they attributed to the workplace. Many informed us that they were comfortable notifying and speaking with supervisors if they had a health and safety concern. Two workers were concerned about the potential for heat stress during the summer months in the electroplating and clean line areas. We learned that there is no air-conditioning in these areas due to high ventilation rates of processes. The workers informed us that since some processes are heated, during the summer these areas of the facility can reach near or above 100°F (38°C).

Although a few of these workers were present at the facility during the July 2013 event, they informed us that they currently felt safe working at the facility. One worker told us that he frequently checks the readings on the new hydrogen sulfide monitors and has not seen elevated levels in the time since the event occurred. A few workers had noticed some reoccurring rotten egg smells in the past, but they reported that it was not bothersome and did not cause symptoms. Another worker informed us that when a smell is detected, he checks the hydrogen sulfide monitors and sometimes chooses to put on one of the personal monitors that are available to electroplating and clean line workers in the plate line room.

On-site interviews with health professionals

The facility contracts with a local clinic to have a nurse onsite full-time. The nurse oversees medical surveillance, including hearing conservation for about 120 workers and annual medical evaluations including spirometry for less than a dozen chemists and electroplating line technicians, as per the OSHA standards for cadmium and chromium. The facility's nurse took a NIOSH-approved spirometry course and was conducting spirometry onsite until about a year prior to our visit. At that time, the spirometer she was using stopped functioning, and she began sending workers to an off-site clinic for spirometry.

Our review of reports of spirometry tests done at the off-site clinic revealed multiple quality issues. These issues included outdated reference equations, outdated interpretation algorithms, and technical errors that could lead to inaccurate estimations of lung function. After our first visit, we reported these issues to the facility nurse, who obtained permission from plant management to purchase a new spirometer for use at the plant. We later provided feedback on the spirometer settings and reviewed a report prepared using the new device. The testing met recommended quality criteria.

Incident Response

The facility took several corrective actions after the incident was reported to the environmental health and safety coordinator. The addition of sulfuric acid into the ion tanks was immediately halted and all scrubbers were rinsed with clean water. The contracted waste water treatment facilities manager arrived that evening to collect waste water from a few different tanks for sulfide testing. Eventually, the bacterial source of the hydrogen sulfide off-gassing was identified at the MMF feeding tank. This was confirmed with a semi-quantitative test for visual determination (white precipitate) of sulfate-reducing bacteria (visual determination, SRB-BART™) and sulfates in water solutions or produced waters (USEPA Method 8051). The organic acid descaler product was no longer added to the waste water system. Instead, it was collected, packaged, and disposed of as hazardous waste offsite.

Within 1 month of the incident, the facility made additional changes. The MMF tanks were completely drained, cleaned, and all filters were replaced. An agitating device was added to the MMF feed tank to ensure that sludge would not accumulate in stagnant water conditions. In addition, the facility installed new ductwork to pull in a mix of outdoor air and machine shop air instead of recirculating air in the waste water treatment plant and electroplating area.

Also within 1 month of the incident, all plate line workers were provided with GX-2009 RKI Four Gas Confined Spaces Monitor (Union City, CA) personal monitors for continuous hydrogen sulfide monitoring. The workers were trained on how to use the personal monitors to voluntarily monitor their own exposures. These monitors were stored in the prep room. Within 6 months, the contracted industrial hygiene team performed air monitoring and conducted air flow studies to determine the placement of two additional real time hydrogen sulfide monitors. After installing the monitors, the facility began to conduct more frequent calibration of the monitor sensors. The sensors were set to lower warning and alarm signals, at 1 ppm and 5 ppm, respectively. The facility required that an onsite sulfates analysis be

performed once per shift to check on potential bacteria growth to prevent incidents in the future.

Finally, the facility revised its system for reporting incidents, and has begun to train workers about the differences between Near Miss Cards and Incident Reports. Currently, there are future plans to construct a wall entirely separating and enclosing the waste water treatment plant from the electroplating and clean lines. The RKI Four Gas Confined Space personal monitors for continuous hydrogen sulfide monitoring have been replaced with the newer GX-2012 model.

Field Observations

During our visit, we observed that the facility was clean. Specific locations and department areas were labeled. At the entrance of many specific areas of the facility, there were clearly labeled health and safety guidelines, specifying the types of PPE, surveillance, and training that was required prior to entering the area. Many typically-hazardous processes, like abrasive blasting, painting, and plasma application were enclosed or automated. There were many ventilated areas throughout the facility. In the electroplating and clean line areas, there were local and general exhaust systems operating to pull electroplating mists or fumes away from the worker's breathing zone. The local exhaust consisted of nearby slots over the electroplating tanks pulling evaporation at the source. Some surfactants were also used in tanks to prevent misting. We confirmed that exposures were low over these plating and clean line areas by taking some short-term Drager tube samples in the electroplating and clean line aisles, as well as directly over some of the electroplating and clean line tanks (see results, Table 1).

In the electroplating department, we informally spoke with workers and learned that approximately 80% of their time during the work shift is spent in the prep room, and that many workers from the clean line department also enter this room for periodic breaks. We learned that during the incident, this room was receiving make-up air through the air-conditioning unit from the electroplating and waste water treatment areas. After a brief discussion with the facility's industrial hygiene consultant, we learned that some air flow studies were conducted after the incident, and these studies revealed that the general air flow direction was from the waste water treatment plant to the electroplating line. Since the July 2013 incident, the facility has installed new ductwork to pull make-up air from the machine shop area through the air conditioning unit instead of recirculating the air from the waste water treatment plant and electroplating line areas.

In the waste water treatment plant, many of the tanks (e.g., chromium, cadmium) were enclosed. However, some of the tanks were open, which may be necessary for proper chemical and physical reactions during the treatment process.

Discussion

Industrial Hygiene Monitoring

Hydrogen sulfide exposures are often associated with municipal sewers, sewage treatment plants, and oil drilling operations, which are characterized by high levels of organic materials. This is because bacteria and fungi can release hydrogen sulfide during the decomposition of sulfur-containing proteins and by the direct reduction of sulfate. OSHA has established an acceptable ceiling concentration of 20 ppm for hydrogen sulfide in the workplace, with a short term exposure limit (STEL) of 50 ppm over a 10 minute duration if no other measurable exposure occurs during the 8-hour work shift. NIOSH has set a Recommended Exposure Limit 10-minute ceiling value of 10 ppm. The ACGIH recommended exposure limits are much lower, with a time weighed average of 1 ppm over the course of an 8 hour work shift, and a STEL of 5 ppm over 15 minutes.

We took air samples during the walk through visit in February 2014 to determine if there were current exposures to hydrogen sulfide, sulfur dioxide, nitrous gases, hydrogen cyanide, volatile organic compounds, carbon monoxide, and total and respirable dust. We did not detect current exposures at the facility at concerning levels, and most of the air monitoring samples were below instrument detection limits. It should be noted that the measurements taken by our industrial hygiene team occurred several months after the time of the incident, after clean-up had occurred and the sulfate-reducing bacteria had been cleared. Although the hydrogen sulfide monitors in the waste water treatment basement area did not alarm during the July 2013 incident, it is unknown if the monitor was measuring the same levels experienced in the mezzanine above, which included the electroplating line, clean line, and prep room. The industrial hygiene reports generated by external consultants (which began within one week of the incident) also demonstrated low levels, which were all ≤ 0.3 ppm. Since hydrogen sulfide has such a low odor threshold, it is possible that slight odors may have still been detected by workers even after the incident occurred, despite documented levels in the prep room ≤ 0.3 ppm. In addition, some of the levels measured (0.1-0.3 ppm) in these reports could have been due to instrument calibration issues with the Photoionization Detector. After the facility re-calibrated the instrument on September 3, 2013, most of the gas levels were all below the LOD.

Health Effects

Exposure to hydrogen sulfide can result in a wide range of short-term health effects, from mucous membrane irritation to loss of consciousness, respiratory paralysis, and death. Health effects vary with the concentration of hydrogen sulfide in the air. At 50 ppm, eye, nose, and throat irritation occur [Reiffenstein et al. 1992; Knight and Presnell 2005; ATSDR 2006]. At 250-300 ppm, pulmonary edema, in which the lungs fill with fluid, occurs. At 500 ppm and higher, loss of consciousness, respiratory paralysis, cardiac arrhythmias and death result. Other possible effects of hydrogen sulfide exposure include headache and nausea. Some individuals may be more sensitive to hydrogen sulfide exposure. In one study, people with asthma who were exposed to low concentrations of hydrogen sulfide (2 ppm) for 30

minutes suffered impairment in lung function with the exposure [Jappinen et al. 1990].

Long-term health effects of hydrogen sulfide exposure also have been described and respiratory health effects are notable. Shortness of breath was the complaint of 23% of workers in Alberta, Canada seeking compensation after hydrogen sulfide exposure [Arnold et al., 1985]. Among oil and gas workers, those who had experienced loss of consciousness from hydrogen sulfide exposure were more likely to later report shortness of breath, wheeze with chest tightness, and attacks of wheeze [Hessel et al. 1997]. A study of sewer workers found lower lung function related to hydrogen sulfide exposure [Richardson 1995]. These symptoms and abnormalities are consistent with airways diseases including asthma and/or scarring of the small airways. In addition, pulmonary fibrosis, a scarring lung disease, has also been described after hydrogen sulfide exposure [Parra 1991; Duong et al. 2001].

In addition, long-term neurological problems have been reported after hydrogen sulfide exposure. These include persistent headaches, lack of concentration, poor attention span, impaired short-term memory, and impaired motor function [ATSDR 2006 Doujaiji et al. 2010; Nam et al. 2004].

The odor threshold for hydrogen sulfide ranges from 0.0005 to 0.3 ppm [Reiffenstein et al. 1992; Knight and Presnell 2005; ATSDR 2006]. At 10 ppm, an unpleasant odor is obvious and at 30 ppm, the odor is described as strong or intense. At higher concentrations (100-150 ppm), sense of smell is impaired. Therefore, it is important not to rely on smell to determine if an exposure has ended. The disappearance of a hydrogen sulfide odor could mean that the concentration is high enough to cause loss of the sense of smell.

During the July 2013 incident, workers reported a sulfurous odor and associated symptoms (e.g., scratchy/sore throat, cough, phlegm, headache, and nausea). Olfactory fatigue (loss of sense of smell) was also noted. These observations suggest that hydrogen sulfide concentrations may have been as high as 100 ppm. However, without proper monitoring data, we are unable to verify that such levels were present.

Following the incident, four workers had persistent respiratory symptoms, consistent with previous reports of long-term respiratory impairment following hydrogen sulfide exposure. These workers were diagnosed with RADS, a form of irritant-induced asthma that is associated with one or more exposures to high levels of chemical irritant(s) [Tarlo and Lemiere 2014]. Once RADS develops, symptoms such as cough and shortness of breath can persist for years. In one study of 35 workers who developed RADS after exposure to chlorine gas or other agents, all still had asthma symptoms and two-thirds were still using inhalers four or more years after the exposure [Malo et al. 2009].

Workers who perform the majority of their work in hot environments may be at risk for heat stress. Exposure to extreme heat can result in occupational illnesses and injuries. Heat stress can result in heat stroke, heat exhaustion, heat cramps, or heat rashes. After our visit, we are aware the facility is looking into many potential ways to solve this issue. The company does have some programs in place to prevent heat stress. Overall, the workers that we interviewed

were aware of work/rest cycles and they informed us that they take breaks in the Prep Room, which is air conditioned. A supply of electrolyte beverages and water is provided by the facility for workers.

We learned that the facility management responded quickly to the incident upon learning about the problem on July 16, 2013. However, we also learned from some of the workers that the smells and dark sludge were detected a week earlier. It is likely that poor communication between workers and management contributed to the delayed response. At the closing meeting, we discussed the importance for workers to be trained on and understand the proper communication channels for reporting incidents like the one that occurred in July 2013.

Conclusions

We evaluated an aircraft engine services facility for potential respiratory exposures leading to health problems. We learned about an incident in July 2013 that involved overgrowth of sulfate-reducing bacteria that led to the release of hydrogen sulfide gas in the waste water treatment plant, and reviewed the incident response and actions taken by facility management, industrial hygiene consultants, and the contracted environmental services company. We identified four cases of RADS that had been diagnosed by a pulmonologist in workers within six months of the incident who were in or near the waste water treatment plant. In order to determine if there were any current exposures to hydrogen sulfide, we measured for airborne sulfur dioxide and hydrogen sulfide gas. We also sampled for nitrous gases, hydrogen cyanide, volatile organic compounds, carbon monoxide, and total and respirable dust during a visit to the facility on February 5, 2014. We did not detect current exposures at the facility at concerning levels and most of the samples were below instrument detection limits. During informal interviews with workers at the facility, we learned that at the time of the incident there had been some confusion among reporting channels for Near Miss Cards and Incident Reports, and that approximately one week had passed between when sulfur-containing odors were initially filed on a Near Miss card to when the workers formally informed a supervisor.

We also learned during our interviews with workers at the plant that some were concerned about the potential for heat stress during the summer months. On the basis of these findings, we recommended a number of actions focused on primarily engineering and administrative controls.

Recommendations

On the basis of our findings, we recommend the actions listed below. These recommendations are based on an approach known as the hierarchy of controls.

Elimination and Substitution

Eliminating or substituting hazardous processes or materials reduces hazards and protects workers more effectively than other approaches. Prevention through design, considering elimination or substitution when designing or developing a project, reduces the need for additional controls in the future.

1. Continue to treat the descaling product as a potential hazardous waste and have the product treated off site.
2. Work with the waste water treatment plant manager to continue assessing the potential for similar incidents for other jet engine cleaners and descaling products by flagging new products that have similar acidic components and chemical properties.

Engineering Controls

Engineering controls reduce worker's exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect workers effectively without placing primary responsibility of implementation on the employee.

1. Prior to installing any personal cooling fans to address heat stress concerns, investigate the potential effects of fan operation on important ventilation systems in the electroplating and clean lines.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Continue communication with potentially affected workers after an incident and involve them in the incident investigation if possible.
2. Consider potential occupational health and safety impacts of process changes, such as installation of the MMF filters. Continue to examine and prepare for scenarios in case of system failure and develop strategies for how these can be avoided in advance.
3. Continue to periodically perform industrial hygiene monitoring for hydrogen sulfide, sulfur dioxide, and sulfuric acid on workers who perform work in areas where sulfuric acid and inorganic sulfides are used. If workers are wearing the GX-2012 RKI Four Gas Confined Space personal monitors for continuous hydrogen sulfide monitoring, develop a plan to track their monitoring results. This also allows facility management

to gain insight about who wears the monitors, and how often. This includes workers who are employed by the contracted environmental services company that operates the waste water treatment plant.

4. Continue to use the warning signal at 1 ppm (ACGIH TWA for hydrogen sulfide during an 8-hour work shift) and the alarm signal of 5 ppm (ACGIH STEL for hydrogen sulfide) on all area monitors.
5. Educate workers about the nature of hydrogen sulfide exposures during employee health and safety training. Some training topics may include: Information on how the gas is generated biologically and how the odor detection level differs from recommended exposure limits.
 - a. Prevention of conditions for bacterial growth.
 - b. Locations and instructions for reading the current hydrogen sulfide monitors (e.g., monitor limits of detection, alarms, frequency of sensor calibration).
 - c. How to wear and operate personal sampling devices if odors are detected.
 - d. Types of health effects (signs and symptoms) that are associated with different levels of hydrogen sulfide exposures. Discuss how the detection via smell may differ from the concentration at which health effects are initially observed.
6. Continue to train workers on how to readily differentiate a Near Miss from an accident or incident requiring immediate notification to a supervisor or the Emergency Response Team.
7. Spirometry should be conducted onsite by the facility nurse, as she has taken a NIOSH-approved course in spirometry; this change is now underway. We also provided information about SPIROLA, a software program that can be used to track lung function over time. SPIROLA is available free on the NIOSH website (<http://www.cdc.gov/niosh/topics/spirometry/spirola-software.html>).
8. Continue to educate workers about work/rest cycles, hydration, and cooling centers during summer months.

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Table

Table 1: A description of industrial hygiene monitoring that was conducted during the plant visit, February 5, 2014.

Particles/Gases Type	Monitoring Equipment	Sample Time Period	N Samples	LOD	Result (Range)	NIOSH REL (or OSHA PEL)	Locations Monitored
Hydrogen Sulfide (H ₂ S)			5	0.2 ppm	All samples <LOD	10 ppm [10-minute]	Electroplating line, clean line, waste water treatment plant.
Sulfur Dioxide (SO ₂)	Draeger Tubes	Short Term (1-5 minutes)	1	1 ppm	All samples <LOD	TWA 2 ppm	Waste water treatment plant.
Nitrous Gases (NO _x)			4	2 ppm	All samples <LOD	TWA 25 ppm (Nitric Oxide)	Electroplating line, clean line, waste water treatment plant.
Hydrogen Cyanide Gases (HCN)			1	2 ppm	All samples <LOD	ST 4.7 ppm	Electroplating line.
H ₂ S			2*	1 ppm	All samples <LOD	10 ppm [10-minute]	All throughout the plant (electroplating line, clean line, blasting room, machine shop, shipping/receiving, office areas). The sampling wand was extended directly over electroplating tanks and hung from the mezzanine directly into open waste water treatment tanks.
Volatile Organic Compounds (VOCs)	MultiRAE Plus, with sampling wand (extended coil tubing).	Real Time Sampling (15 second intervals)	2*	0.1 ppm	<LOD-0.5 ppm	NA, varies by compound	
Carbon Monoxide (CO)			2*	0.1 ppm	<LOD-0.2 ppm	TWA 35 ppm	
Total Dust	Dustrak DRX Aerosol Monitor	Real Time Sampling	2*	0.001mg/ m ³	0.001 – 0.939 mg/ m ³	15 mg/m ³	All throughout the plant (electroplating line, clean line, blasting room, machine shop, shipping/receiving, office areas).
Respirable Dust	Model 8534 Handheld	(15 second intervals)		0.001mg/ m ³	0.001 – 0.334 mg/ m ³	5 mg/m ³	

TWA = Time Weighted Average; ST = Short Term; *These samples were real time monitoring equipment continuously measuring over 15 second intervals. These devices were taken in to the plant on two occasions. The first sampling occurred during the initial walk through tour and the second sample occurred during the industrial hygienist's return visit (both sampling periods were ~1½ hours). †There is no NIOSH REL for total and respirable dust, these values are the OSHA permissible exposure limit.

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Keywords: NAICS 336412 (Aircraft Engine and Engine Parts Manufacturing) Hydrogen Sulfide; Gas; Reactive Airways Dysfunction Syndrome (RADS); Wastewater; Electroplating.

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Availability of Report

Copies of this report have been sent to the employer, employees, and union at the facility. The state and local health department and the Occupational Safety and Health Administration Regional Office have also received a copy. This report is not copyrighted and may be freely reproduced.

This report is available at <http://www.cdc.gov/niosh/hhe/reports/pdfs/2014-0042-3216.pdf>.

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