Evaluation of a Thermal Drying Process at a Wastewater Treatment Plant

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Contents

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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. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from employees at a wastewater treatment plant. They were concerned about exposures to thermally dried sewage sludge.

What We Did

- We evaluated the facility in March 2014.
- We observed work processes, practices, and workplace conditions, and spoke with managers and employees.
- We conducted confidential health interviews with employees.
- We collected air samples for endotoxins and respirable silica
- We collected bulk samples for endotoxins and silica.

What We Found

- We observed fire hazards in the thermal dryer because of high temperatures and the presence of combustible dust.
- Employees reported eye irritation, coughing, nasal congestion, and headaches that were worse at work.
- Employees reported strong odors inside and outside the wastewater treatment plant.
- Levels of endotoxins and silica in the air were low.
- Respirators were not properly worn, maintained, or stored.
- Employees reported inconsistent use of hearing protection, eye protection, and gloves.

We surveyed employees about work-related symptoms related to working with a new thermal sewer sludge dryer. Employees reported irritation symptoms and headaches. Exposures to endotoxins and silica were low. Dust and odors were detected throughout the facility. We recommended the company address dryer production and safety concerns, improve the respiratory protection program and personal protective equipment use and compliance.

What the Employer Can Do

- Work with the thermal dryer manufacturer to ensure that the equipment is working according to design.
- Make sure all safety mechanisms are operational.
- Ensure that respirators are properly worn, maintained, and stored, and that employees are trained on how to use them.
- Encourage employees to report work-related symptoms or other health problems so steps can be taken to evaluate and control exposures.
- Ensure that all employees working in wastewater treatment are up-to-date on tetanus immunizations following the most current CDC recommendations.

What Employees Can Do

- Report work-related health concerns to your supervisor.
- Seek medical care from a healthcare provider if you have symptoms to determine if your symptoms are related to exposures at work.
- Wear and store respirators properly and consistently wear other personal protective equipment as outlined in standard operating procedures.

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
CFR	Code of Federal Regulations
dBA	Decibels, A-weighted
EPA	Environmental Protection Agency
EU/m^3	Endotoxin units per cubic meter
mg/m^3	Milligrams per cubic meter
ND	Not detected
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
REL	Recommended exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average

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Introduction

The Health Hazard Evaluation Program received a request from employees at a wastewater treatment plant who were concerned about exposures to thermally dried sewage sludge. In particular, employees were concerned about odors, upper airway irritation, and dust exposures from the newly-installed thermal dryer. During our visit in March 2014, we reviewed the process flow and thermal dryer operations. We also collected air samples and bulk samples for endotoxins and silica. We conducted confidential health interviews with employees and reviewed records. We provided a summary of our visit and detailed recommendations in a letter in March 2014. We provided employees with their air sampling results and sent a summary letter with the air sampling results to the facility in June 2014. These sampling results and recommendations are summarized in this report.

Process

The wastewater treatment plant treated, processed, and disposed of municipal sewage with the goals of creating cleaner effluent to release back into the environment and converting sewage solid waste to Class A and B biosolids. The Environmental Protection Agency (EPA) regulates biosolids treatment and reuse [EPA 2003]. Class A biosolids have been treated to eliminate detectable pathogens and Class B biosolids have been treated to reduce pathogens [EPA 1994]. The primary sludge was treated with a dewatering agent that contained about 20% petroleum distillate. During the last step of treatment process, primary sludge from an aerated tank was pumped into either a screw press or thermal dryer, which are both maintained under negative pressure. The thermal dryer was designed to be a continuous flow process that used internal rotors and indirect heating to evaporate water and reduce volume significantly [Figure 1]. During heating, the water vapor from the sludge was collected under slight vacuum by the vapor collection system. Sludge biosolids entered the inlet of the thermal dryer as a sludge cake mixture consisting of water and solids, but were discharged as a dry product that contained greater than 95% solids. Heat drying is an EPA-approved method for treating biosolids to reduce volume and remove pathogens to create Class A biosolids. However, the process can also create a combustible dust hazard that has been associated with fires and explosions [EPA 2006]. Therefore, a cooling auger system is used to help prevent overheating.

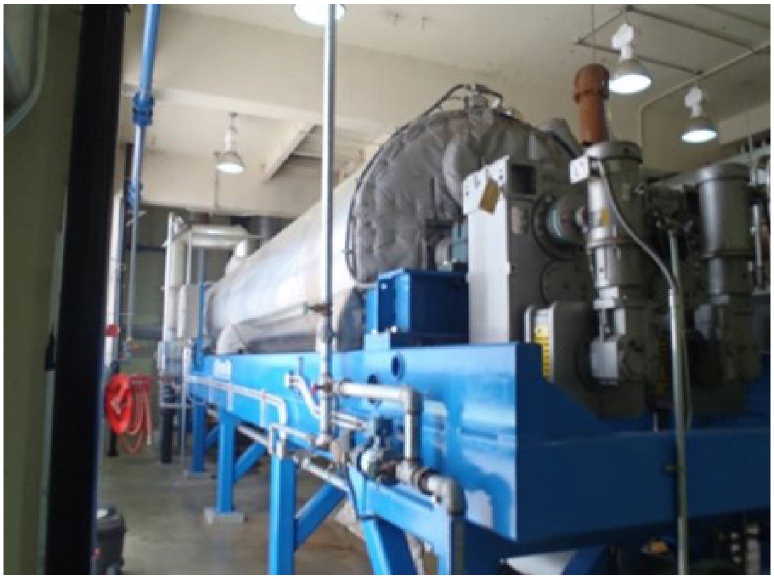
Figure 1. Thermal dryer. Photo by NIOSH.

At the time of our visit, the processed sludge was emptied into either large bags (dried) [Figure 2] or an open dumpster (wet). The longer the discharge spout was open the higher the probability of an exothermic reaction due to the introduction of air to the dried sludge/biosolids. Such a reaction could lead to fire or explosion. Therefore, workers would cool down the mixture by opening or evacuating the mixture at the discharge hopper into a bag or injecting the mixture with a nitrogen/bicarbonate compound. At the time of the site visit, exhaust air from the thermal dryer room was directly exhausted out of the roof. Ten employees worked first and second shifts in the thermal dryer area of the water treatment plant.

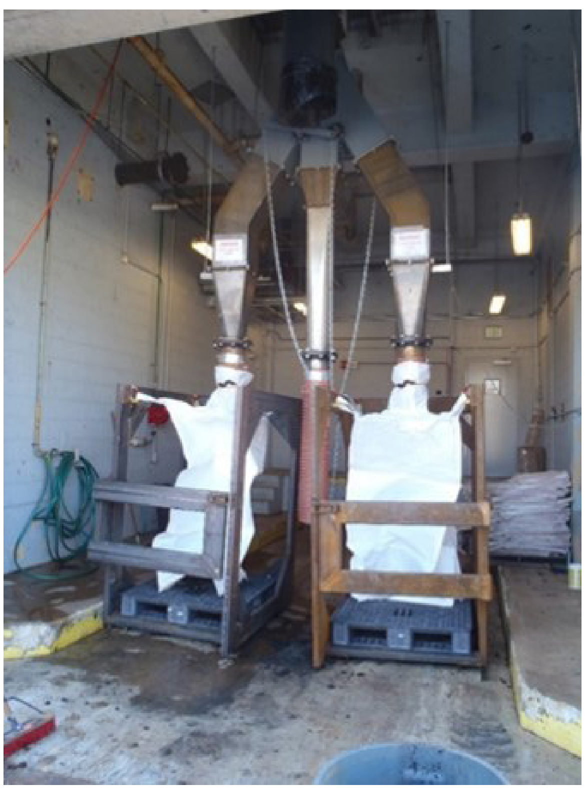
Figure 2. Dust collection bags on the ground floor underneath the thermal dryer area. Photo by NIOSH.

Methods

We focused our evaluation on health and safety concerns during the use of the thermal dryer. Our primary objectives were to evaluate employees' exposures to endotoxins and silica and evaluate whether employees had potential work-related symptoms. We observed workplace conditions and work processes and practices. We reviewed consultant reports and the Occupational Safety and Health Administration (OSHA) Form 300 Log of Work-related Injuries and Illnesses. We also held confidential health interviews with employees.

We collected two personal and two area air samples for endotoxins. One additional area endotoxin sample from the inlet of the thermal dryer was not reported due to post-calibration flow rate problems. We also collected two bulk sludge samples to determine its endotoxin concentration.

Endotoxins are lipopolysaccharide compounds that may be released by the outer cell walls of Gram-negative bacteria when the bacteria die or multiply. Gram-negative bacteria are commonly associated with the human digestive tract. Additional information on endotoxins can be found in Appendix A. We used personal air-sampling pumps calibrated at 2 liters per minute to collect the samples onto 0.45-micrometer-pore-size polycarbonate filters in an endotoxin-free three-piece 37-millimeter closed-face cassette. We analyzed the samples for endotoxin content with the kinetic-chromogenic procedure using the *Limulus amebocyte* lysate assay [Cambrex 2005]. The limit of detection was 0.50 endotoxin units (EU) per sample.

Silica is the most abundant inorganic material in dried biosolids [Skoglund et al. 2014]. We collected two personal and three area air samples for silica (quartz) using a tared 5-micron 37-millimeter polyvinyl chloride filter with a 10-millimeter nylon cyclone at a flow rate of 1.7 liters per minute. The samples were analyzed according to National Institute for Occupational Safety and Health (NIOSH) Method 7500 [NIOSH 2018]. Additional information on silica can be found in Appendix A. A bulk sludge sample was also analyzed for percent silica (quartz) according to NIOSH Method 7500 [NIOSH 2018].

Results and Discussion

Health Interviews

The ten interviewed employees had worked in the wastewater treatment plant for an average 2.3 years (range: 1 month – 4 years). Three of the employees reported they were current smokers. Most of the employees (90%) reported respiratory symptoms such as sinus congestion, nasal and throat irritation, and coughing that were worse at work when the thermal dryer was running. Some of these employees (50%) reported conditions in the plant were dusty when the dryer was running and a frequent need to "blow their nose", resulting in a black discharge. Forty percent of employees reported frequent headaches and fatigue at work that improved on days off. Most of the employees (80%) reported strong odors at work that a few employees (30%) associated with headaches and nausea with most reporting the odor lingered on clothing after leaving the treatment plant.

Some of the employees (30%) reported voluntary use of disposable filtering facepiece respirators when the dryer was running, but reported inconsistent training on proper use. Approximately 40% of employees reported inconsistent use of ear and eye protection, and glove use while at work. Some of the employees reported concerns about fire hazards when working with the thermal dryer. Employees reported a lack of guidance and insufficient training on what job tasks required respirators and what type to wear. The only two entries on the OSHA logs from 2011–2013 were one orthopedic injury from a slip/fall and one allergic reaction from hornet stings.

Symptoms reported by these workers are similar to those reported previously in sewage treatment employee studies. Rylander found a higher prevalence of nose irritation, tiredness, and diarrhea among sewage treatment plant employees when compared to municipal employees with no wastewater exposure; there was also an increase in airway responsiveness [Rylander 1999]. Thorn and Kerekes conducted a literature survey on reported health effected for sewage treatment plant employees. They found that three major types of symptoms were reported – airway symptoms, fatigue and headache, and gastrointestinal symptoms [Thorn and Kerekes 2001]. Other studies found an increase in airway symptoms including irritation and breathlessness after gas/fume exposure, and central nervous system symptoms including headaches, tiredness, and difficulty concentrating when compared to municipal employees [Thorn et al. 2002]. Heldal and associates found that nose irritation, cough and headache were more prevalent in employees handling dry sludge when compared to other sewage employees [Heldal et al. 2010]. Since employees are at risk of soil-contaminated injuries at wastewater treatment plants, it is routine practice to offer vaccinations for tetanus [NIOSH 2002b].

Odors

Odors are organic or inorganic compounds that trigger the sense of smell and can be perceived as pleasant or unpleasant. Some, but not all, compounds that cause odors can be health hazards. Some odorless substances are very hazardous to health, for example, carbon monoxide. The presence of odors can cause some people to suspect harmful exposures. Some chemicals or compounds have a very low odor threshold, which means people can smell them even at very low levels.

Odors may produce health symptoms by three mechanisms. First, symptoms can be induced by exposure to odorants at levels that also cause irritation. Therefore, irritation, rather than the odorant, is the cause of the symptoms. Second, health symptoms from odorants at nonirritant concentrations, such as hydrogen sulfide, can be due to innate or learned aversions. Third, symptoms may be due to a co-pollutant, such as endotoxin, that is part of an odorant mixture [Schiffman and Williams 2005]. It is possible that symptoms reported by facility employees could be associated with all three mechanisms but also could be associated with non-occupational factors. In persons with existing health problems, such as asthma or chronic respiratory problems, odors can also worsen pre-existing symptoms. For example, odors have been found to affect the physiological and psychological responses of individuals with asthma [Beach et al. 1997].

Environmental Assessment

Air Sampling

The endotoxin concentrations in personal air samples, shown in Table 1, ranged from not detected (ND) to 1.7 endotoxin units per cubic meter (EU/m^3). No samples exceeded the Dutch Expert Committee on Occupational Safety recommended limit of 90 EU/m^3 [DECOS 2010] as a no effect level for an 8-hr exposure. No occupational exposure limits (OELs) for endotoxin have been established in the United States. The airborne concentrations of endotoxin detected were at or below the range of concentrations reported in published studies. Endotoxin concentrations reported for sewage treatment workers in published studies ranged from 0.7 EU/m^3 to 214 EU/m^3 [Cyprowski et al. 2015]; ND to 1630 EU/m^3 [Krajewski et al. 2004]; 38 EU/m^3 to 322, 000 EU/m^3 [Rylander 1999]; and 0.6 EU/m^3 to 2093 EU/m^3 [Smit et al. 2005]. The area air sampling results for endotoxin collected in two locations (near the bag loading of the final product and at the end of the thermal drying machine) were not detectable at a minimum detectable concentration of 1 EU/m^3.

Table 1. Personal air sampling results for endotoxins, in EU/m^3 (March 2014)

Job/Activity	Sample duration (minutes)	Concentration
Operator 1	262	1.7
Operator 2	75	ND*
DECOS		90

*ND = not detected; sample result was below the minimum detectable concentration of 1 EU/m^3. Concentrations were calculated using sample duration.

The silica concentrations in personal air samples (Table 2) were ND.

Table 2. Personal air sampling results for crystalline silica in mg/m^3 (March 2014)

Job/Activity	Sample duration (minutes)	Concentration (mg/m^3)*
Operator 1	106	ND
Operator 2	229	ND
NIOSH REL		0.05
OSHA PEL		0.05 (final rule)
ACGIH TLV		0.025

ACGIH = American Conference of Governmental Industrial Hygienists

PEL = Permissible exposure limit

REL = Recommended exposure limit

TLV = Threshold limit value

*The minimum detectable concentrations were 0.02 for the sample collected on operator 1 and 0.01 mg/m^3 for the sample collected on operator 2. Concentrations were calculated using sample duration.

The area air sampling results for crystalline silica collected in three locations (near the bag loading of the final product; at the inlet of thermal drying machine; and at the end of the thermal drying machine) were not detectable at a minimum detectable concentration of 0.01 mg/m^3.

Bulk Samples

One bulk sample, analyzed for crystalline silica, had 4.5% crystalline silica (quartz) by weight. The two bulk samples for endotoxins contained 140 endotoxin units per milligram and 518 endotoxin units per milligram by weight.

Review of Consultant Industrial Hygiene Reports

The company provided us with two industrial hygiene reports from May 2014 for environmental sampling conducted in March and April 2014. In March 2014, the industrial hygiene consultant collected personal and area air samples for endotoxins. Endotoxin concentrations were low. The highest concentration of endotoxins detected was 2.3 EU/m^3. The consultant also collected air samples for carboxylic acids, amines, and reduced sulfur compounds because these compounds can cause odors. Low concentrations of acetic acid, butyric acid, 2-methylpropanoic acid, methyl mercaptan, trimethylamines, dimethyl sulfide, and hydrogen sulfide were detected and did not exceed any OELs. However, these compounds were found at levels that exceeded their odor thresholds.

In April 2014, the consultant collected area air samples for silica (quartz) and total dust for about 6 hours in the thermal drying room. Respirable silica (quartz) concentrations ranged from 0.005 to 0.01 mg/m^3. Total dust levels ranged from 0.27 to 0.42 mg/m^3. According to the report, additional air sampling for odor causing chemicals found methyl mercaptan, hydrogen sulfide, acetic acid, 2-methylpropanoic acid, and dimethyl sulfide levels above their respective odor thresholds, but below current OELs. Odors generated by thermally treated biosolids are a well-recognized issue [EPA 2006]. The chemical compounds detected by air sampling have been associated with processed sewage sludge in wastewater treatment plants [Lehtinen and Veijanen 2011; Lewkowska et al. 2016; Sharma et al. 2012].

Full-shift personal noise dosimetry measurements were taken on two employees in the thermal drying room. These employees' noise exposures were 84.6 decibels, A-weighted (dBA) and 83.4 dBA, which was slightly below the OSHA action limit of 85 dBA. However, on some days exposures may exceed the OSHA action level. Their exposures are most likely above the NIOSH REL because NIOSH measures noise using more sensitive noise measurement criteria.

Observations

During the site visit, we observed an incident in which the temperature of dried sludge in the thermal dryer was not sufficiently reduced by the cooling auger system and exceeded the recommended maximum temperature of 280° Fahrenheit. As a result, hot sludge was pushed into the discharge chute, triggering an alarm, and signaling for an automatic shutdown of the system. However, the company had previously disabled this automatic shutdown safety mechanism. Therefore, the discharge chute with overheated sludge was flooded with nitrogen and bicarbonate to rapidly reduce the temperature and prevent overheated sludge from continuing down the discharge chute into the large collection sacks. Large amounts of smoke and steam filled the workspace during this incident. During our site visit and in our May 2014 post site visit summary letter to the company we recommended that the employer enable the automatic safety shutdown immediately and that they work with the manufacturer to improve thermal dryer function to prevent future overheating incidents.

When the thermal dryer was in use, we observed exhaust entering other areas of the building, which spread strong odors throughout the building, including the quality control laboratory. Some areas of the plant were very dusty, specifically, along the walls and ledges and discharge bay, and other areas near the entrance to the thermal dryer room. Excess dust can build-up can increase the risk for fires and explosions from combustible dust. We also observed fluid leaking onto the floor in the condensation area of the thermal dryer, which could cause a slip hazard.

Management representatives reported to us that employee respirator use was voluntary; however, we noted that the standard operating procedures for removal of dryer blockages required employees to use disposable P99 filtering facepiece respirators. The company written respiratory protection program included the procedures for voluntary respirator use, but did not have procedures, such as medical evaluation and fit-testing, for mandatory respiratory use.

We observed some employees with facial hair wearing disposable filtering facepiece respirators. Additionally, we observed respirators that had visible dirt on the inside and outside, respirators stored uncovered next to used gloves, and respirators that were not stored inside sealed storage containers. The company provided a laundry service, which not all employees were using. We also observed that employees were not always washing their hands before going into the breakroom.

Conclusions

We observed potential fire hazards in the thermal dryer area because dryer conditions led to overheating of sludge and the presence of combustible dust. Endotoxin and silica exposures were below OELs. Strong odors were reported by employees during the treatment process and several compounds associated with unpleasant odors were identified by the company's consultant. The most common health symptoms reported by employees were eye irritation, coughing, nasal congestion, and headaches. These symptoms are similar to those reported previously in sewage treatment employee studies. Although it is possible that symptoms could be associated with odors, the symptoms could also could be associated with non-occupational factors. Potential overexposures to noise in the thermal dryer area were identified by the company's consultant. We observed that respirators were not always used, maintained, or stored correctly. In addition, correct use of other PPE such as gloves and safety glasses was inconsistent.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage your facility to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the wastewater treatment plant.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix A). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Elimination and Substitution

Eliminating or substituting hazardous processes or materials reduces hazards and protects employees 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. Ensure operation of the thermal dryer is free of potential fire hazards and that combustible dust hazards are eliminated. Maryland Occupational Safety & Health Consultation Services can also be contacted for additional information in evaluating and providing recommendations related to fire and combustible dust hazards in the thermal dryer process (https://www.dllr.state.md.us/labor/mosh/volc.shtml).

Engineering Controls

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

1. Return the automatic safety shutdown mechanism on the thermal dryer to proper function. Do not override the manufacturers' safety precautions.
2. Continue to work with the thermal dryer system manufacturer to get assistance with proper dryer functioning, including decreasing the fire hazard risks, and reducing generation of strong odors.
3. Consult with a qualified engineer to determine if the ventilation system for the quality control laboratory is functioning properly and there is not re-entrainment of exhaust into the laboratory.

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. Encourage employees to promptly report odor-related concerns and respiratory and other symptoms to their supervisor or safety manager. Employees with persistent

symptoms should be evaluated by an occupational medicine physician or a medical provider specializing in workplace diseases and illnesses. The Association of Occupational and Environmental Clinics has an online directory of such providers at http://www.aoec.org/directory.htm.

2. Conduct in-person training that includes demonstrations of proper donning and doffing of respirators.
3. Include wastewater treatment operators as members of the plant's safety committee.
4. Continue to train employees to wash hands and arms before entering the breakroom and going home and to change work uniforms before going home to reduce the spread of dust and potential microbial contamination.
5. Establish a housekeeping schedule and standard operating procedures that outline employee responsibilities for each area of the plant.
6. Keep floors and steps as dry as possible to prevent slips, trips, and falls in accordance with OSHA's general industry walking-working surfaces and fall protection standard [https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9714].
7. Ensure that all employees who work in the wastewater treatment plant are up-to-date on tetanus immunizations following current recommendations [Kim et al. 2018] because employees are at risk of soil-contaminated injuries. More information can be found in this CDC guidance document on controlling potential risks to workers exposed to Class B biosolids: http://www.cdc.gov/niosh/docs/2002-149/pdfs/2002-149.pdf. Currently, no additional immunizations (such as Hepatitis A and B) are advised for workers in contact with wastewater [NIOSH 2002b].
8. Measure thermal dryer employees' full-shift noise exposures to determine if exposures are above the NIOSH REL. Include these employees in a hearing loss prevention program. The program should include annual audiometric exams, providing hearing protection, training on hearing loss and use of hearing protection, and include periodic noise exposure assessments. For additional information on noise and guidance on developing a hearing loss prevention program, refer to the NIOSH document, Occupational Noise Exposure, at https://www.cdc.gov/niosh/docs/98-126/default.html.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

1. Institute a respiratory protection program for all employees who are required to wear respirators. The program must include and meet all the required elements in

the OSHA respiratory protection standard (29 CFR 1910.134). Employees required to wear respirators and employees voluntarily using respirators, except for filtering facepiece respirators, must be medically cleared by an occupational health professional for each type of respirator that they may use. Provide employees voluntarily using respirators with a copy of Appendix D from the OSHA respiratory protection standard (Information for Employees Using Respirators When Not Required Under Standard) [https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9784]. Employees with facial hair are not permitted to wear any tight fitting respirator (including filtering facepiece respirators), because facial hair can interfere in the facepiece to face seal. Ensure employees are trained on proper respirator cleaning, storage, use, and maintenance procedures.

2. Provide disposable protective clothing, such as Tyvek coveralls and nitrile gloves to employees working in the thermal dryer area. For all employees, provide laundering services for their work clothing or contract with a service for laundering the work uniforms.

3. Provide hearing protection to employees.

Appendix A: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limit or ceiling values. Unless otherwise noted, the short-term exposure limit is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Another set of OELs commonly used and cited in the United States is the ACGIH TLVs. The TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2018].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Endotoxin

Endotoxins are lipopolysaccharide complexes found in the outer cell wall of Gram-negative bacteria. Endotoxin is released when bacteria die [Hagmar et al. 1990; Olenchock 1997]. Gram-negative bacteria are ubiquitous in the environment. Endotoxins produce a wide range of biological responses including blood vessel changes, inflammation, and allergic reactions. Airborne endotoxin exposures between 45 and 400 EU/m^3 have been associated with symptoms of cough, wheeze, shortness of breath, chest tightness, and mucous membrane irritation, and signs of acute airflow obstruction [Castellan et al. 1987; Farokhi et al. 2018; Milton et al. 1996; Smid et al. 1994]. Chronic health effects that have been associated with airborne endotoxin exposures include chronic bronchitis, bronchial hyperreactivity, chronic airways obstruction, hypersensitivity pneumonitis, and emphysema [Castellan 1995; Liebers et al. 2008]. A permanent decrease in pulmonary function, along with respiratory symptoms, has been reported in epidemiologic studies [DECOS 2010]. Endotoxin exposure has also been associated with skin itch and rash [Manfreda et al. 1986], but these associations have not been well documented. Endotoxin exposures have been associated with decreased lung function and airway inflammation with sewage workers [Cyprowski et al. 2015]. Although scientists agree that endotoxins can cause human health effects, no universally accepted OELs have been developed because of the variability in sampling and analytical methods and a lack of data showing a consistent dose-response relationship [Paba et al. 2013]. The Limulus amebocyte lysate assay is the most commonly used method of analyzing endotoxin [Milton 1999].

In the Netherlands, the Dutch Expert Committee on Occupational Standards has recommended a health-based exposure limit of 90 EU/m^3 for airborne endotoxin in the working environment, averaged over an 8-hour working day. This exposure level is regarded as a no-observed-effect level [DECOS 2010]. This proposed OEL is based on epidemiologic studies showing evidence of respiratory health effects at concentrations near this level [Castellan et al. 1987; DECOS 2010].

Respirable Crystalline Silica

Silica, or silicon dioxide, occurs in a crystalline or noncrystalline (amorphous) form. In crystalline silica, the silicon dioxide molecules are oriented in a fixed pattern versus the random arrangement of the amorphous form. The more common crystalline forms in workplace environments are quartz and cristobalite, and to a lesser extent, tridymite. Occupational exposures to respirable crystalline silica (quartz and cristobalite) have been associated with silicosis, lung cancer, pulmonary tuberculosis disease, and other airway diseases [NIOSH 2017]. Silicosis is an irreversible but preventable fibrotic disease of the lung caused by the deposition of fine crystalline silica particles in the lungs. Silicosis is caused by the inhalation and deposition of crystalline silica particles that are 10 micrometers or less in diameter. Particles 10 micrometers and below are considered respirable particles and have the potential to reach the lower portions of the human lung (alveolar region). Although particle sizes 10 micrometers and below are considered respirable, some of these particles can be deposited before they reach the alveolar region [Hinds 1999].

Symptoms of silicosis usually develop insidiously, with cough, shortness of breath, chest pain, weakness, wheezing, and nonspecific chest illnesses. Silicosis usually occurs after years of exposure (chronic), but may appear in a shorter period of time (acute) if exposure concentrations are very high. Acute silicosis is typically associated with a history of high exposures from tasks that produce small particles of airborne dust with a high silica content [NIOSH 1986]. Even though the carcinogenicity of crystalline silica in humans has been strongly debated in the scientific community, the International Agency for Research on Cancer in 1996 concluded that there was "sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica in the form of quartz or cristobalite from occupational sources" [IARC 1997]. Several other serious diseases from occupational exposure to crystalline silica include lung cancer and noncarcinogenic disorders such as immunologic disorders and autoimmune diseases, rheumatoid arthritis, renal diseases, and an increased risk of developing tuberculosis disease after exposure to the infectious agent [NIOSH 2002a].

When proper practices are not followed or controls are not maintained, respirable crystalline silica exposures can exceed the OSHA PEL, NIOSH REL, or the ACGIH TLV. For general industry, the OSHA PEL for respirable dust containing 1% or more of quartz is calculated by dividing 10 milligrams per cubic meter by the percent quartz in the sample, plus two [OSHA 2015]. OSHA is updating its comprehensive standard regarding exposure to crystalline silica [OSHA 2017]. OSHA's new silica standard with a PEL of 50 $\mu g/m^3$ will be in effect June 2018. NIOSH recommends an exposure limit of 50 $\mu g/m^3$ as a TWA for up to a 10-hour work day to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2010]. The ACGIH TLV for quartz is 25 $\mu g/m^3$ as an 8-hour TWA [ACGIH 2018].

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