Evaluation of Chemical and Noise Exposures in an Artificial Casing Manufacturing Facility

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Disclaimer

The Health Hazard Evaluation Program investigates possible health hazards in the workplace under the authority of the Occupational Safety and Health Act of 1970 [29 USC 669a(6)]. The Health Hazard Evaluation Program also provides, upon request, technical assistance to federal, state, and local agencies to investigate occupational health hazards and to prevent occupational disease or injury. Regulations guiding the Program can be found in Title 42, Code of Federal Regulations, Part 85; Requests for Health Hazard Evaluations [42 CFR Part 85].

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Table of Contents

Introduction

The Health Hazard Evaluation Program received a request from the union at an artificial casing manufacturing facility. Employees were concerned about the health effects from exposures in the viscose process, including carbon disulfide (CS_2), hydrogen sulfide (H_2S), and noise in the workplace. We visited the manufacturing facility in October 2016 to learn more about their health concerns and to assess potential exposures to CS_2, H_2S, ammonia, and caustic agents. Following our initial visit, we returned in August 2017 to better characterize personal exposures to chemicals and to perform a survey and biomonitoring for employees. We sent a letter to union and management representatives in November 2016 and August 2017 with preliminary findings and recommendations. In September 2017 and December 2017, we notified employees by mail about their measured exposures. In April 2018, we provided an interim letter to management and the union detailing exposures to CS_2 and associated health effects. We also shared air sampling results with the state OSHA office.

Background

At the time of our visits, this facility produced cellulose and fibrous casings. Cellulose casings were used as a cooking mold in which sausages or other meat products are formed and peeled off prior to sale to the end-consumer. Fibrous casings are cellulose casings that have been reinforced with manila hemp. They are primarily used for large sausages and other slicing meats.

Process Descriptions

Chemical Processing

The process of manufacturing artificial casings started with receiving and storing wood pulp, which is material similar to cardboard stock. The wood pulp was transported to the chemical department where it was placed in steeping trays. The wood pulp was treated with caustic alkali, and then a hydraulic press pressed the treated wood pulp out of the end of the steeping tray and into a chute. One to two operators were responsible for steeping the material and ensuring the treated pulp made its way into the chute.

The chute was a conduit to the floor below where it was dumped into a large shredder. The pulp was shredded, resulting in a product called "white cake." The white cake was dumped into a second chute that led to a large horizontal drum (called a "baratte") on the floor below.

An operator closed the baratte hatch, and then the baratte rotated mechanically. CS_2 gas was injected into the baratte at a high pressure. The operator ran the baratte from a control room, ensuring all the white cake contacted the CS_2 gas and was thus treated. CS_2 was an essential chemical in this process due to its unique ability to react with alkaline-treated cellulose. This process, called xanthation, resulted in a cellulose xanthate.

After the appropriate treatment time and pressure had been applied to the "white cake," excess CS_2 was removed from the baratte via vacuum. The baratte was turned so the hatch faced towards the ground. The operator then opened the hatch, and the contents were dropped to the floor below. The operator ensured all the cellulose xanthate was removed from the baratte by scraping the contents of the baratte with a long handheld tool. The resulting material from the CS_2 treatment was called "yellow cake." The yellow cake was aged and further treated with a series of chemical baths (i.e., sulfuric acid, ammonia, H_2S) through an enclosed process. The length of time aged and the type of chemical treatment indicated whether the material will be sent to the (1) cellulose casing (skinless) line or (2) the hemp reinforced (fibrous) product line for further processing. Both treatments result in viscose material.

Workers were routinely rotated through job tasks in the chemical department. The work ran continuously and was performed over two 12-hour shifts. Workers typically worked four shifts per week but could work overtime if requested or required by management.

Production Lines

The treated viscose was extruded through a series of pipes that connected to a series of spindles through a process referred to as "pitch and catch." A small cut was made in the artificial casing material, so the cellulose casing or hemp treated cellulose maintained a flat surface when running over a series of spindles. The casings were then sent through a series of chemical baths for further treatment. Operators (wet end) were responsible for checking on the casings as they moved through the chemical baths. They also ensured the chemicals were washed off prior to going to the high heat area. As the cellulose casings traveled out of the chemical baths, operators received the bathed materials and washed them in a series of water baths. The casings were then treated at high heat in an area that did not routinely have operators stationed there. After the casings were heat-treated, an operator (dry end) received them at the end of the line. There, the operators ensured the casings were mechanically wrapped around a wheel. The wheel of casings was removed from the machinery where it could be placed on a palette and transported to another facility location where it could be prepared for sale.

Methods

We had the following objectives for this evaluation:

1) Evaluate employees' exposures to chemicals used in the workplace and created as reactionary byproducts, including CS_2, H_2S, sulfuric acid mist, and ammonia.
2) Evaluate employees' exposure to occupational noise.
3) Assess work-related health problems and concerns of employees.

Our evaluation included (1) a workplace walkthrough and a record review of company policies and procedures, (2) confidential medical interviews, (3) air sampling for CS_2 and sulfuric acid mist, (4) real-time air monitoring for H_2S and ammonia, (5) personal noise monitoring, and (6) a health survey with associated urine testing to assess for CS_2 exposure and associated same day, acute, and chronic health symptoms.

Initial Site Visit

We observed work practices, procedures, and personal protective equipment (PPE) use of employees in the chemical, skinless, and fibrous departments.

Record Review

We reviewed the following records pertinent to health and safety at the company:

- Procedures for assessing, testing, and notifying employees of 2-thiothiazolidine-4-carboxylic acid (TTCA), a metabolite of CS_2 in the urine, along with results of the urinary TTCA testing conducted in 2015
- Occupational Safety and Health Administration (OSHA) Log 300 Forms during 2013–2017
- Monthly logs of real-time gas readings (CS_2, H_2S, and ammonia) during May–August 2017
- Respiratory Protection Program dated July 2009

Confidential Medical Interviews

We invited employees from two day shifts in the chemical, fibrous, skinless, and maintenance departments to participate in confidential medical interviews. We conducted interviews to discuss potential health and safety concerns during the manufacturing of artificial meat casings and during the maintenance of equipment on the site. The interview included yes/no and open-ended questions to assess job tasks, employment history, health and safety concerns, PPE use, injuries at work, and medical symptoms and diagnoses. The medical questions focused on symptoms consistent with exposure to CS_2, H_2S, ammonia, sulfuric acid mists, and noise.

Environmental Sampling

On our initial visit in October 2016, we collected samples in Tedlar® sample bags at multiple locations within the plant to analyze for volatile organic compounds. Analysis was conducted with a portable thermal desorption-gas chromatograph-mass spectrometry (TD-GC-MS) instrument onsite. Also, side-by-side sample pairs were collected on thermal desorption (TD) tubes with analysis of one of the tubes completed on a portable TD-GC-MS instrument and the other tube analyzed on a laboratory benchtop TD-GC-MS instrument at a National Institute for Occupational Safety and Health (NIOSH) laboratory. Of particular interest was determining whether workers were being exposed to 1,3,5-trithiane (CAS number 291-21-4), a chemical that had been reported as a possible reactionary product and irritant in a chemical process performed at the plant.

Draft NIOSH Method 3705 was followed to analyze the samples onsite at the plant using the portable TD-GC-MS instrumentation [NIOSH 2017]. NIOSH Method 2549 was followed to analyze the corresponding paired TD tube sample on the benchtop TD-GC-MS instrument [NIOSH 1996]. Field blanks were also analyzed after returning to the NIOSH lab to assess whether contamination had occurred. Two different types of stainless-steel TD tubes were used. One type contained a single Tenax TA bed of sorbent from Markes International (Ohio). The other type of tube had a special inert coating (Sulfinert) on the interior surface of the stainless steel to prevent adsorption to the metal surface and had a double bed of sorbent materials containing Tenax TA and Spherocarb. Prior to the samples being collected, the tubes had been conditioned using standard techniques.

A HAPSITE ER (Serial # 70050906) portable GC-MS was used to analyze the sample bags and the TD tubes onsite. The handheld probe was used to analyze the sample bags. The TD system attachment (Serial # 70077930) was used for desorption of the TD tube samples. The TD tube samples were not purged for drying. For desorbing the sample, the temperature of the TD system was set at 300 degrees Celsius (°C) for 5 minutes. A dimethyl polysiloxane fused silica capillary chromatography column was used (15 meter, 1 micrometer film thickness, 0.25 millimeter inside diameter). The initial temperature of the column was set at 60°C for 1 minute with a ramp set at 6°C per minute to 80°C; then 12°C per minute to 120°C; and finally 26°C per minute to 180°C.

For the analysis completed on the benchtop instrument, a Markes Unity/Ultra automatic TD system with an internal focusing trap packed with graphitized carbon adsorbent was used. The thermal unit is interfaced directly to an Agilent 7890 gas chromatograph with an HP5977 mass selective detector (ATD-GC-MS) that operated under electron ionization conditions. Samples were analyzed using NIOSH Method 2549 with a modified desorption time of 5 minutes [NIOSH 1996]. Samples were purged prior to analysis. A 30-meter HP-1ms fused silica capillary column (1 micrometer film thickness, 0.25 millimeter insider diameter) was used for the analysis.

Follow-up Site Visit

During our follow-up visit in August 2017, we conducted personal air sampling for CS_2, sulfuric acid, H_2S, ammonia, and personal noise sampling. We also collected urine for TTCA analysis and completed a comprehensive medical survey of participating employees.

Carbon Disulfide

We measured CS_2 in the breathing zone of employees using solid sorbent tubes and drying tubes. Air sampling pumps were calibrated to a flow rate of 100 cubic centimeters per minute (cc/min) for full-shift samples. Due to the 12-hour work shift, we changed sample media every 4 hours and calculated 12-hour full-shift samples. The American Conference of Governmental Industrial Hygienists (ACGIH®) recommends adjusting the threshold limit value (TLV®) using the Brief and Scala model for longer work schedules due to greater risk from increased exposure and reduced recovery times [ACGIH 2024]. We also collected short term exposure limit (STEL) samples for 15 minutes for certain tasks. Air sampling pumps used for STEL samples were calibrated to a flow rate of 200 cc/min. Samples were analyzed using NIOSH Method 1600 [NIOSH 2024]. A brief description of Occupational Exposure Limits (OELs) and health effects for CS_2 is provided in Appendix B.

Sulfuric Acid Mist

We measured sulfuric acid in the breathing zone of employees using 37-millimeter diameter quartz fiber filters. Air sampling pumps were calibrated to a flow rate of 2 liters per minute. Samples were analyzed using NIOSH Method 7908 [NIOSH 2024]. A brief description of OELs and health effects for sulfuric acid is provided in Appendix B.

Hydrogen Sulfide and Ammonia

We measured H_2S and ammonia using separate real-time BW Honeywell GasAlert Extreme single gas monitors. Monitors were calibrated per the manufacturer requirements prior to the site visit. Ammonia monitors were set to a datalogging sampling rate of 5 seconds. H_2S monitors were set to a datalogging sampling rate of 1 minute. Both sets of monitors had a maximum reading of 100 parts per million (ppm). Time-weighted averages (TWAs) and 15-minute STELs were calculated and datalogged by the monitor. Employees wore the monitors in their breathing zone for their entire work shift. A brief description of OELs and health effects of H_2S and ammonia are provided in Appendix B.

Noise and Hearing Conservation

We measured personal noise exposures using Larson Davis Spark™ Model 706RC integrating noise dosimeters equipped with 0.375-inch random incidence microphones connected by a cord to the dosimeter. The dosimeters integrated noise at a 50-hertz (Hz) sampling rate (50 measurements per second) and data-logged 5-second averaged noise levels for the duration of the measurement period. Employees wore dosimeters on their waistband, and we attached the dosimeter microphone on their clothing in an upright position midway between the neck and the edge of their shoulder. The microphone was covered with a windscreen to reduce artifact noise caused by air movement or by accidental bumping or rubbing. At the end of the work shift, we downloaded the noise measurement data from the dosimeters using the PCB Piezotronics Blaze™ software. The dosimeters simultaneously collected noise data using three different settings to allow comparison of noise measurement results with three different noise exposure limits: the NIOSH recommended exposure limit (REL), the OSHA permissible exposure limit (PEL), and the OSHA action level (AL). Noise exposure limits are meant to be the amount of noise that most employees can be exposed to without substantial risk of hearing loss. Additional information on noise exposure limits and health effects are provided in Appendix B.

TTCA Testing and Postshift (Same Day) Questionnaire

We received informed consent from all participating employees. Immediately prior to urine collection, we asked employees to complete a one-page questionnaire with information specific to the shift that was just completed. Questions included yes/no, check all that apply, scaled, and open-ended questions about work area, hours worked, PPE usage, same-day symptoms, and behavioral and medical factors that could influence urinary TTCA levels. These factors could include open skin wounds, cigarette smoking, and dietary intake of vegetables metabolized to TTCA. We asked questions about symptoms consistent with acute, high-concentration exposures to CS_2. Postshift questionnaires took less than 5 minutes to complete. Following completion of the postshift questionnaire, we provided employees with a sterile cup for urine collection. Samples were collected, packaged, and shipped to the National Center for Environmental Health, Division of Laboratory Sciences, Tobacco and Volatiles Branch. These samples were tested for urinary TTCA and creatinine. The limit of detection for TTCA was 11.2 nanograms per milliliter. TTCA results were creatinine-corrected for comparison with the ACGIH Biological Exposure Index® (BEI®) for CS_2. The BEI for CS_2 is 0.5 mg TTCA per gram of creatinine taken at the end of a shift [ACGIH 2024].

On the basis of the air CS_2 results, we assigned employees to high- and low-exposure groups within the chemical, skinless, and fibrous departments. We analyzed results for the skinless and fibrous departments together due to the similar work processes and routes of CS_2 exposure. We will refer to the combination of skinless and fibrous departments as the production group for the remainder of this report.

We evaluated whether there was a correlation between air CS_2 exposures and urinary TTCA results. We completed correlation analyses for the chemical department and the production group. This assisted us in determining if there was a completed inhalational exposure pathway for employees (i.e., could employees be exposed to site-related contaminants). We used Spearman's correlation coefficient (r) to determine if a very weak, weak, moderate, or strong relationship existed between air concentrations and urine results. A strong correlation is consistent with a completed inhalational exposure. We interpreted the findings using the following criteria [Hinkle et al. 2003].

- No correlation or very weak: $r \leq 0.3$
- Weak correlation: $0.3 < r \leq 0.5$
- Moderate correlation: $0.5 < r < 0.7$
- Strong correlation: $r \geq 0.7$

We visually evaluated the distribution of urinary TTCA levels in the high- and low-exposure groups. Since the values did not appear to be normally distributed, they were log-transformed. We then compared urinary TTCA levels in the high- versus low-exposure groups using the t-test.

Medical Survey

Employees took approximately 15 minutes to complete the comprehensive medical survey that included yes/no, scaled, and open-ended questions. Questionnaires were offered to employees in the chemical, fibrous, and skinless departments.

In addition to questions about demographics and work characteristics, we asked employees scaled questions about acute symptoms experienced at work over the last 14-day period. We asked about headaches, nose or throat irritation, dizziness or lightheadedness, loss of coordination or balance, fainting or passing out, blurry or double vision, stinging or burning eyes, nausea or upset stomach, feeling confused or disoriented, changes in personality or mood swings, difficulty remembering things, fluttering in the chest or irregular heartbeat, skin irritation, and skin burns. Employees were presented with a five-point scale and asked to indicate their frequency of symptoms over the last two weeks (1 = not at all, 2 = less than half the days, 3 = about half the days, 4 = more than half the days, and 5 = every day). For analysis, we grouped responses of 2–5 together as indicating the presence of symptoms. We compared the prevalence of symptoms in the high-exposure group with symptoms in the low-exposure groups among chemical department employees and production group employees, respectively.

We asked yes/no questions about symptoms consistent with peripheral neuropathies of the hands and feet. We compared the frequency of "yes" responses in the high-exposure group with those in the low-exposure groups.

The survey included standardized screening scales for symptoms consistent with anxiety and depression. Employees were presented with a four-point scale and asked to indicate their frequency of symptoms over the last two-week period (0 = not at all, 1 = several days (1–7), 2 = over half the days, and 3 = nearly every day). For each of the following scales, we summed the scores and interpreted as follows [Kroenke and Spitzer 2002; Kroenke et al. 2009; Spitzer et al. 2006]:

- Generalized Anxiety Disorder-7 Scale (Possible scores: 0–21)
    - 0–4: No or minimal anxiety symptoms

- 5–9: Mild anxiety symptoms
- 10–14: Moderate anxiety symptoms
- 15 or more: Severe anxiety symptoms

- Patient Health Questionnaire-8 (Possible scores: 0–24)
    - 0–4: No or minimal depression symptoms
    - 5–9: Mild depression symptoms
    - 10–14: Moderate depression symptoms
    - 15–19: Moderate-to-severe depression symptoms
    - 20 or more: Severe depression symptoms

Employees were also presented with a five-point scale regarding sleep disturbances and asked to indicate their level of agreement (1 = never, 2 = rarely, 3 = occasionally, 4 = most nights/days, 5 = always). These items are scored, and individuals with scores of 11 or above screen positive for sleep disturbance [Douglass et al. 1994].

We evaluated dental health effects that employees could be experiencing from sulfuric acid mist exposures. We asked employees if they had lost any teeth or had teeth pulled since working at the facility, if staining or discoloration had been noted since working at the facility, and if they had experienced dental disease in the last 6 months. These questions were primarily derived based on findings from our initial visit, where employees noted concerns of tooth loss.

We asked yes/no and scaled questions about how well employees hear and hearing protection use at work.

For all health effects, we performed descriptive statistics. For acute symptoms, symptoms consistent with peripheral neuropathy, anxiety, depression, or sleep disturbance, and dental symptoms (production group), we also analyzed the prevalence of the health effect by comparing the frequency of positive responses in the high-exposure group to the frequency in the low-exposure group. We used SAS statistical software to calculate prevalence ratios with 95% Wald confidence intervals for our analysis. We used the t-test to determine if the high-exposure group had statistically different scores for anxiety, depression, or sleep disturbance than the low exposure groups within the chemical, skinless, and fibrous departments, respectively. A two-tailed *P* value < 0.05 was considered to indicate statistical significance.

For the general survey, we used job titles to assign employees who routinely worked on the baratte floor and in the extrusion area to the high-exposure group. For the chemical department, these job titles included Chemical Operator, Chemical Recovery Operator, Control Operator, and Pressman/Press Operator. Low-exposure job titles for the chemical department included all other titles working in that department. For the production group, job titles assigned to the high-exposure group included Extrusion Operators and Process Machine Operators (PMOs). Low-exposure titles for the production group included all other titles assigned to the skinless or fibrous departments.

Results

Initial Site Visit

During our initial walkthrough, we noted that respiratory protection was stored in the production areas and not maintained or cleaned properly for safe and effective use. Additionally, signage for potentially high exposure areas were not clearly communicated.

Record Review

TTCA Testing Procedures

The company had established procedures for testing and notifying employees of urinary TTCA results. Urinary TTCA testing had historically been performed at the company but had ceased until 2015. In 2015, the company underwent collective bargaining, and again urinary TTCA testing was offered to employees. Urine samples were collected in August and September 2015 throughout the shift, as employees became available.

We reviewed the company's procedures for assessing, testing, and notifying employees of urinary TTCA results, along with the results of urinary TTCA testing done in 2015. The company provided an information sheet about TTCA testing prior to collecting the urine specimen. This document informed the employee of the purpose of the test, what the test was looking for (TTCA, a metabolite of CS_2), and what the employee could do if TTCA levels were elevated. Employees were then issued a short questionnaire to determine where they were working, what work practices and processes were performed, and if there were possible confounding factors for elevated TTCA levels.

In August–September 2015, 127 employees underwent testing for TTCA. After excluding 3 employees without test results, urinary TTCA values ranged from not detected to 4.3 milligrams per gram (mg/g) creatinine. Of 124 employees, 46 (37%) had urinary TTCA levels above 0.5 mg/g creatinine. By department, these 46 employees consisted of 7 of 27 (26%) employees in the chemical department, 15 of 35 employees (43%) in the fibrous department, 22 of 38 employees (58%) in the skinless department, and 2 of 16 (13%) maintenance workers. Employees were notified of their results via letter, recommending compliance with using PPE to protect employees from exposure until other measures to reduce exposures were instituted.

Occupational Injury and Illness Logs

During 2013–2017, the OSHA 300 logs revealed 170 recordable injuries or illnesses. Recordable cases included several instances of sprains and strains, cuts and lacerations, and eye injuries. There was one case of occupational hearing loss reported in the OSHA 300 logs. However, audiogram reports for the hearing conservation program identified additional cases.

Hearing Conservation Program and Audiometric Test Reports

The company supplied us with a written copy of the prior owner's hearing conservation program. During our initial visit, health and safety professionals indicated that the company's processes had not substantially changed since the change in ownership in 1993, so a new noise exposure assessment had not been performed.

We also reviewed annual audiometric reports from 2014–2017 that were performed by an outside contractor. During 2014–2017, 431 employees underwent audiometric testing. OSHA standard threshold shifts (STSs), defined as a change in hearing threshold, relative to the baseline audiogram of an average of 10 decibels (dB) or more at 2000, 3000, and 4000 Hz in one or both ears, were identified in seven employees over this period. Audiometric reports did not state where employees worked at the time of their STS. Eighteen additional employees were identified as having an imminent STS. The audiometric test provider defined "imminent STS" as an age-corrected difference between the current test and the OSHA baseline ranging from 8 to just under 10 dB. The provider recommended that the importance of correctly wearing hearing protection be emphasized with those individuals to prevent a future STS from occurring.

Respiratory Protection Program

The company supplied a written respiratory protection program dated July 2009. For routine and maintenance tasks, the company provided supplied air positive pressure respirators. For emergency work, the company had self-contained breathing apparatus and airline respirators provided for employees. The program included requirements for medical clearance, fit testing, respirator selection, respirator usage/cleaning/storage, and training. The storage sections included instructions to protect against dust, sunlight, heat, extreme cold, moisture or damaging chemicals. However, we observed respirator face pieces with visible dust stored in the extrusion areas of the fibrous and skinless departments. We also observed employees with beards in areas where tight-fitting respirators were used. This would affect the proper seal of the respirator. There was also a section of the plan regarding the breathing air system. It included supply air pressures and frequency of maintenance. Air pressure checks were mentioned as "routine" but a specific time requirement was not provided in the document. Airline calibration was not listed in the maintenance procedures.

Confidential Medical Interviews

Forty-four employees participated in confidential medical interviews during our initial site visit. The average age was 37 years (23–60 years), and the median tenure working at the facility was 3 years (0.2–24 years). Participants reported working on average 44 hours per week (40–74 hours).

We asked about symptoms and conditions associated with acute and chronic chemical exposures. The most common symptoms reported by employees included difficulty with sleep (33; 75%), skin burns (26; 59%), rashes or skin irritation (26; 59%), headaches (24; 55%), changes in mood or personality (19; 43%), eye irritation (17; 39%). Further details of reported symptoms are shown in Table A1: Appendix A.

Employees reported several concerns of health and safety in the workplace. Twenty-three interviewed employees (52%) reported that they had symptoms they believed were work-related at the time of their interview. Thirty (68%) employees noted that they had suffered from a workplace injury or illness caused by their job. The results of the confidential interviews were used to inform a health survey for follow-up assessment of work-related symptoms and conditions.

Environmental Sampling

Thirteen samples were collected in Tedlar sample bags at various locations throughout the plant. The compounds in the samples were identified using the Automated Mass Spectral Deconvolution and

Identification System (AMDIS) program. The AMDIS program first deconvolutes the GC-MS data file to find all of the separate components. Each of these components is then compared against a library of target compounds. The target library used for the samples contained 781 compounds including 1,3,5-trithiane. The match between the target spectrum and the deconvoluted component spectrum is reported as the Net Fit score (range 0–100). Values at or above 80 are good matches and 70–79 are fair matches [U.S. Department of Commerce 1997]. Net Fit scores above 70 were considered as possible identifications and are included in Table A2: Appendix A. Scores close to 100 are marked as high (H), those above 80 are marked with an X, and scores between 70–79 are indicated with FM (fair match).

Table A2: Appendix A provides a summary listing of the compounds identified in the Tedlar bag samples. CS_2 was identified in all but two of the samples. Samples taken at Line 7, Tank 5 and Line 2, Tank 5 (between 2–3) showed elevated peaks of CS_2. Phenol and N,N-dimethylacetamide were identified in most of the bag samples and are known artifacts of Tedlar sample bags. The other compounds identified were at trace levels. We did not identify 1,3,5-trithiane in any of the Tedlar bag samples.

Table A3: Appendix A lists the chemicals identified on the TD sample tubes analyzed on the portable TD-GC-MS instrument. CS_2 was identified on 5 of the 12 samples, with samples #334031 (skinless line 2 tank 5) and #21565 (fibrous between lines 9 and 10) showing significant peaks. We did not identify 1,3,5-trithiane in any of the TD tubes analyzed on the portable GC-MS.

Follow-up Site Visit

Carbon Disulfide

Employees' full-shift air sampling results for CS_2 are shown in Table A4: Appendix A. All field blanks and media blanks were below the limit of detection. Some of the exposures were at or above the lowest OEL, set by ACGIH. We used the Brief and Scala model to adjust the TLV for a 12-hour work shift. All the samples collected on chemical baratte operators and fibrous extrusion operators were above the exposure limit. A majority (87%) of the samples collected on skinless extrusion operators were also above the adjusted recommended exposure limit. None of the exposures were above the OSHA PEL of 20 ppm.

Employees' short duration (15 minute) air sampling results for CS_2 are shown in Table A5: Appendix A. Some of the exposures were at or above the lowest OEL, set by NIOSH. Additionally, one sample during a baratte dump in the Chemical department was over the OSHA ceiling value of 30 ppm.

Sulfuric Acid Mist

Employees' full-shift air samples for sulfuric acid mist in the fibrous and skinless departments ranged from 0.0032 to 0.071 milligrams per cubic meter (mg/m^3) in air. Of the 15 samples, none were at or above the lowest OEL of 0.1 mg/m^3 in air, set by ACGIH. We used the Brief and Scala model to adjust the TLV for a 12-hour work shift.

Hydrogen Sulfide

Employees' air sampling results for H_2S are shown in Table A6: Appendix A. Some of the exposures were at or above the lowest OEL set by OSHA, NIOSH, and ACGIH. Each sample may have measurements that exceeded more than one limit. Of the 13 air samples in the fibrous department, 7 (54%) measurements were over the OSHA ceiling limit including 5 (38%) reaching the NIOSH Immediately Dangerous to Life and Health (IDLH) limit; 7 (54%) measurements were over the ACGIH STEL of 5 ppm; and 4 (31%) samples were over the ACGIH TLV of 0.5 ppm. Of the 22 air samples in the skinless department, 3 (14%) measurements were over the OSHA ceiling limit including 1 (5%) reaching the NIOSH IDLH limit; 4 (18%) measurements were over the ACGIH STEL of 5 ppm; and 6 (27%) samples were over the ACGIH TLV of 0.5 ppm. We used the Brief and Scala model to adjust the TLV for a 12-hour work shift. NIOSH has an established IDLH level of 100 ppm for H_2S exposure [NIOSH 2014]. IDLH levels indicate that an airborne contaminant is likely to cause death or immediate or delayed adverse health effects or prevent escape from such an environment [NIOSH 2019a]. OSHA has set a ceiling limit of 20 ppm as a 15-minute time-weighted average that cannot be exceeded at any time during the workday [OSHA 2024c].

Ammonia

Employees' full-shift air samples for ammonia in the fibrous and chemical departments ranged from not detected to 4.4 ppm. Of the 11 samples, none were at or above the lowest full-shift OEL of 12.5 ppm set by ACGIH. We used the Brief and Scala model to adjust for a 12-hour work shift. While full-shift samples indicated exposures below the OEL, a monitor worn by a fibrous extrusion operator did indicate a 15-minute average of 39.3 ppm that exceeded the ACGIH and NIOSH STEL of 35 ppm.

Noise Sampling

Employee full-shift noise exposures are shown in Table A7: Appendix A. Most employees' noise exposures were at or above the NIOSH REL of 83.2 decibels, A-weighted (dBA), for a 12-hour work shift. Some employees in each department had full-shift noise exposures at or above the OSHA AL of 82.1 dBA for a 12-hour work shift. Some employees in the chemical department, working in the baratte and anhydrous areas, had noise exposures above the OSHA PEL of 90 dBA.

Health Survey and Biomonitoring

We asked employees about their demographics and work history. Ninety employees were available to participate: 85 (94%) agreed to participate in the general survey and 5 (6%) declined. Of the 85 employees, 2 who noted multiple departments on their surveys were excluded from the analysis. Among the 83 employees included in the analysis, 19 worked in the chemical department, and 64 employees worked in the production group, 32 from fibrous and 32 from skinless.

For the 83 participants working in only one department, 64 (77%) of participants were male. Participants had an average age of 36 years (range: 20–60 years). Participants reported an average job tenure of 56 months (range: 3 days–23 years). They reported an average number of hours worked over the past two-week period as 94 hours (range: 14–240 hours). Participants stated that they worked overtime an average of 13 hours in the last two-week period (range: 0–46 hours). Of the 83 participants, 52 (63%) currently used alcohol and 37 (45%) currently smoked cigarettes.

Employees were asked about acute symptoms at work over the last two-week period. Headaches were the most commonly reported symptom (56 employees), followed by nose or throat irritation (48), changes in personality or mood swings (41), nausea or upset stomach (39), dizziness or lightheadedness (39), skin irritation (37), difficulty remembering things (31), stinging or burning eyes (29), skin burns

(26), loss of coordination or balance (22), fluttering in the chest or irregular heartbeat (20), blurry or double vision (16), feeling confused or disoriented (10), and fainting or passing out (2).

We asked about signs and symptoms consistent with peripheral neuropathies of the hand and feet over the last 12 months. Of the 83 participants, 39 (47%) answered "yes" to one or more of these symptoms for the hands, and 29 (35%) answered "yes" to one or more symptoms for the feet.

We also asked employees about symptoms consistent with anxiety, depression, and sleep disturbances. Forty-six (55%) scored 5 or greater on the General Anxiety Disorder-7 scale, consistent with symptoms of anxiety of at least mild severity. Forty-four (53%) employees scored 5 or greater on the Patient Health Questionnaire-8 scale, consistent with symptoms of depression of at least mild severity. Sixty-five (78%) employees scored an 11 or greater on the sleep scale, consistent with sleep disturbance. Within the chemical, skinless, and fibrous departments, the high-exposure groups did not show increased reporting of symptoms consistent with anxiety, depression, or sleep disturbance compared with the low-exposure groups. Similarly, the production group did not show increased reporting of symptoms consistent with anxiety, depression, or sleep disturbances compared with the chemical department. For each symptom grouping (anxiety, depression, and sleep disturbances), the high-exposure group did not have statistically different scores from the low-exposure group (all P values > 0.05; t-test).

In addition to symptoms consistent with chemical exposure to CS_2, H_2S, and ammonia, we asked about dental conditions that could have been caused by acid mist exposure, such as sulfuric acid mist. There was concern that acid mists were being generated during extrusion of viscose. Of 83 employees analyzed, 26 (31%) reported having lost teeth or having to have teeth pulled by a dental professional since starting to work at the plant, while 33 (40%) reported that they had noticed staining or discoloration to their teeth since starting work at this plant.

Over a 5-day period, 92 urine samples were collected from 82 employees. There were 16 samples collected from individuals who had not completed a full shift of 8 hours or more. Thus, we included 76 urinary TTCA samples from 76 employees in the analysis (Table A8: Appendix A). All samples were above the limit of detection for TTCA. Urinary TTCA levels ranged from 0.0068–3.7 mg TTCA per gram of creatinine. The geometric mean was 0.25 mg TTCA per gram of creatinine. Of 76 employees, 21 (28%) had urinary TTCA levels above 0.5 mg/g creatinine.

Hearing Health

Finally, we asked employees about exposure to occupational noise and issues with hearing over the prior 6-month period, including tinnitus. Tinnitus is a constant ringing sound in the ear. Out of 83 employees analyzed, 12 (14%) reported having ringing, roaring, or buzzing in their ears or head lasting for 5 minutes or more. Of these 12 employees, 7 (58%) noted that ringing began after they began working at this plant.

We also asked if employees could usually hear and understand what a person says without seeing that person's face when they (1) whisper, (2) talk in a normal voice, or (3) shout from across a quiet room. Overall, 28 (34%) employees reported difficulty hearing during a whisper, 12 (14%) reported difficulty hearing if someone spoke in a normal voice, and 3 (4%) reported difficulty when someone shouted from across a quiet room. In addition, 33 (40%) employees reported that they found it difficult to follow a conversation if there was background noise at least occasionally (about half the time). All employees reported difficulty with hearing in one or more of these four situations, regardless of whether they reported using hearing protection at work.

Twenty-four (29%) of the 83 included employees reported wearing hearing protection while at work. All chemical department employees reported wearing hearing protection, while only five production employees used hearing protection while at work. These employees worked on the fibrous line in positions classified in the high-exposure group.

Results for Chemical Department Employees

Urinary TTCA levels from the chemical department ranged from 0.01–1.2 mg TTCA per gram of creatinine (Table A8: Appendix A). Four (25%) of 16 full-shift chemical department employees had urinary TTCA levels greater than the BEI of 0.5 mg/g creatinine; they all worked on the baratte floor on the day of testing.

On the basis of our air and urine findings, we classified employees working on the baratte floor in the high-exposure group. We assigned all other employees working in the chemical department on the day of testing into the low-exposure group. We then assessed if there was a correlation between air CS_2 exposures and urinary TTCA results. Nine chemical department employees had full-shift air CS_2 and urinary TTCA results performed on the same day. The Spearman Correlation Coefficient (r = 0.53) showed a moderate relationship between air CS_2 and urine TTCA, but this was not a statistically significant result ($P = 0.14$).

For the high-exposure group in the chemical department, the urinary TTCA geometric mean was 0.30 mg TTCA per gram of creatinine. For the low-exposure group, the geometric mean was 0.11 mg TTCA per gram of creatinine. This difference in body burden between the high-exposure and low-exposure groups was not statistically significant ($P = 0.08$).

Few chemical department employees reported symptoms on the day of urine testing. Two employees reported anxiety, headaches, and skin irritation or burns on the day of testing. One employee reported nausea. Employees did not report issues with balance, confusion, eye pain or irritation, lightheadedness, stomach pain, unusual tiredness, or vomiting. Due to low numbers reporting same-day symptoms in this department, we did not assess the differences by exposure group.

Similarly, our evaluation of the medical survey showed that chemical department employees in the high-exposure group did not have a higher frequency of self-reported acute symptoms or symptoms of peripheral neuropathy, anxiety, depression, or sleep disturbance than chemical department employees in the low-exposure group.

Five of 19 (26%) chemical department employees reported having lost or pulled teeth during their work tenure, while 9 of 19 (47%) reported tooth discoloration.

Some employees in the chemical department reported tinnitus or hearing loss. Four of 19 (21%) employees reported that they had experienced ringing, roaring, or buzzing in their ears or head for 5 minutes or more. Two of these four employees stated that this started after initiating work at the facility. Only two individuals noted that this ringing, roaring, or buzzing occurred every week or more frequently.

Results for Production Group Employees

Urinary TTCA levels from the production group ranged from 0.0068–3.7 mg TTCA per gram of creatinine (Table A8: Appendix A). Thirty-two participants worked in the wet or dry end, and 28 worked in the extrusion areas. Seventeen (28%) of 60 production employees had urinary TTCA levels greater than the BEI of 0.5 mg/g creatinine. Sixteen of those workers worked in the extrusion area of either the skinless (n = 9) or fibrous (n = 7) lines on the day of testing. The sole employee with TTCA levels above the BEI outside of the extrusion area worked on the wet end of the fibrous department.

On the basis of our air and urine findings, we classified employees working in extrusion areas of either the skinless or the fibrous departments as the high-exposure group. We assigned all employees working outside of extrusion in the skinless or the fibrous department into the low-exposure group.

We then assessed if there was a correlation between air CS_2 exposures and urinary TTCA results. Nineteen production group employees had full-shift air CS_2 and urinary TTCA results performed on the same day. The Spearman correlation coefficient ($r = 0.75$) showed a strong relationship between air CS_2 and urine TTCA ($P < 0.0001$). A strong relationship shows a clear association between air exposures and the employees' uptake of the chemical. A strong air-urine relationship indicates inhalational exposures, showing that respiratory protection in the production group employees was not adequate to prevent uptake of CS_2.

For the high-exposure group in the production group, the urine TTCA geometric mean was 0.58 mg TTCA per gram of creatinine (Table A8: Appendix A). For the low-exposure group, the geometric mean was 0.13 mg TTCA per gram of creatinine. When we compared body burdens between these two groups, we found a *P* value of <0.01, indicating a statistically significant difference.

For employees in the skinless department, urine TTCA results ranged from 0.0068–2.4 mg TTCA per gram of creatinine (Table A8: Appendix A). The geometric mean for the high-exposure group was 0.52 mg TTCA per gram of creatinine. For the low-exposure group, the geometric mean was 0.09 mg TTCA per gram of creatinine. When we compared body burdens between these two groups, we similarly found a *P* value of <0.01, indicating a statistically significant difference.

For fibrous employees, urine TTCA results ranged from 0.02–3.7 mg TTCA per gram of creatinine (Table A8: Appendix A). The geometric mean for the high-exposure group was 0.63 mg TTCA per gram of creatinine. For the low-exposure group, the geometric mean was 0.18 mg TTCA per gram of creatinine. When we compared body burdens between these two groups, we found a *P* value of <0.01, indicating a statistically significant difference.

Some production group employees reported symptoms on the day of urine testing. Headache was the most commonly reported symptom (17), followed by anxiety (8), nausea (7), eye pain or irritation (5), lightheadedness (5), unusual tiredness (5), loss of balance (3), confusion (2), stomach pain (2), skin irritation or burns (2), and vomiting (1). Due to low numbers reporting same-day symptoms, we did not assess the differences by exposure group within the skinless and fibrous departments, respectively. When we evaluated the production group as a whole, we did not find any same-day symptoms that showed a significantly higher prevalence of reporting for either the high- or low-exposure group.

Our evaluation of the medical survey showed increased prevalence of self-reported symptoms for the high-exposure production group. When we evaluated prevalence ratios for the production group, we found higher proportions of high-exposure group employees reporting mood swings and personality changes, skin irritation, and skin burns than low-exposure group employees (shown in bold in Table A9: Appendix A). Other symptoms did not show a statistically significant difference. A full list of symptoms, prevalence ratios, and 95% confidence intervals is provided in Table A9: Appendix A.

During confidential interviews during the initial site visit, several employees expressed concern about potential chemical exposures contributing to tooth decay or dental issues. There was concern that exposures to corrosive materials during extrusion were causing or contributing to dental disease. Considering exposure to sulfuric acid mist is known to erode dental enamel and cause dental disease, we asked several questions related to dental health on our return visit. We assessed prevalence ratios using the same exposure groups as before, considering exposure to sulfuric acid mists would more likely occur within those in more highly exposed job series. Results of dental questions within the past 6 months are shown in Table A10: Appendix A.

We asked employees if they had lost any teeth or had teeth pulled by a dental professional since starting work at the facility. Twenty-one (33%) of 64 production employees reported losing teeth or having teeth pulled after starting work at the facility. Fourteen production employees classified into the high-exposure group (44%) reported losing teeth or having them pulled since starting to work at the facility, while seven (22%) production employees in the low-exposure group reported losing teeth or having them pulled. When comparing the high- and low-exposure groups, teeth were lost or pulled more frequently in those in the high-exposure group, though the 95% confidence interval indicates that this result is not statistically significant (prevalence ratio = 2.0, confidence interval 0.93–4.3).

Additionally, we asked if employees had noticed staining or discoloration to their teeth since starting to work at the plant. Tooth staining or discoloration was reported in 24 (38%) production group employees. When comparing the prevalence of tooth staining or discoloration between exposure groups, the high-exposure group reported this outcome more frequently. However, we are unable to draw further conclusions from this, as the 95% confidence interval indicated that this result was not statistically significant (prevalence ratio = 1.4, confidence interval 0.73–2.7).

Seven of 64 (11%) production employees reported ringing, roaring, or buzzing in their ears that lasted 5 minutes or more. Four (57%) of these seven reported ringing started after working at this facility. Some production employees noted difficulty hearing. Eleven (17%) production employees noted that they had difficulty hearing someone if they talked from across a quiet room, while 2 (3%) reported difficulty hearing someone if they shouted across a quiet room.

Discussion

Carbon Disulfide, Sulfuric Acid Mist, Hydrogen Sulfide, and Ammonia

We confirmed the presence of CS_2 at the plant by identifying CS_2 in the sample bags and on the TD tubes. However, only 5 of the 12 TD samples analyzed on the portable instrument showed CS_2 while 11 of 13 analyzed on the benchtop had positive identifications for CS_2. These findings simply indicated that CS_2 was present at the locations tested. It did not quantify the amount of CS_2 in the work environment. Confirming CS_2 was present throughout the plant, even in spaces where CS_2 was not routinely used, prompted the need to do further air sampling of the work environment.

While initial site visit testing revealed the presence of CS_2 throughout the plant, a reactionary product in the viscose process, triamterene, was not identified in the analysis. Historically, triamterene has been linked with irritation. There was concern that the presence of triamterene could contribute to ocular irritation during the viscose process [Rankine 1938]. The absence of triamterene indicates it is unlikely to be a contributing factor to eye irritation while at this plant.

However, employees did report irritant symptoms at work that were nonspecific. While nonspecific irritant symptoms are common in the general public, they are also consistent with chemicals worked with at this facility. Chemicals used at this facility, including CS_2, ammonia, and sulfuric acid mist, all can irritate the skin, eyes, nose, and upper respiratory tract. Furthermore, H_2S, a reactionary product of the viscose manufacturing process, can also cause irritation to the eye, which is a form of keratoconjunctivitis commonly called "gas eye" in the viscose industry. Prior OSHA logs and health survey data collected onsite showed that several workers experienced eye irritation.

Exposure to a mixture of irritants and volatile organic compounds can have an additive effect and result in irritant symptoms, even when testing for the individual chemical shows levels below exposure limits [Hudnell et al. 1992]. The most common route of exposure to these chemicals in the workplace would be inhalation, though some chemicals can be absorbed into the body through the skin.

Workers primarily expressed concerns over exposure to CS_2, a chemical essential to the viscose manufacturing process. CS_2 exposure can cause irritant dermatitis, nerve damage, mood and sleep disturbances, and irritability. Chronic inhalation exposure may cause atherosclerosis, coronary heart disease, and neurobehavioral effects including psychomotor slowing, positional tremors, peripheral polyneuropathy, hearing loss, and Parkinsonism [ATSDR 2012].

Numerous OELs exist for CS_2. OSHA has established a PEL of 20 ppm as an 8-hour TWA, 30 ppm as a ceiling limit, and 100 ppm as a 30-minute maximum peak [OSHA 2024b]. NIOSH has established an REL of 1 ppm as an 8-hour TWA, and a STEL of 10 ppm. It is also designated with a skin notation indicating this chemical can be absorbed through the skin [NIOSH 2007]. ACGIH has established a TLV of 1 ppm as an 8-hour TWA and has also assigned it a skin designation [ACGIH 2024]. ACGIH has a BEI for CS_2 using the urinary metabolite TTCA. The BEI is based on slowed conduction velocities in motor and sensory nerves of occupationally exposed workers at or above 1 ppm [ACGIH 2024]. End-of-shift levels at or above 0.5 mg/g of creatinine would indicate occupationally exposed workers are exposed to CS_2 at levels above the ACGIH TLV of 1 ppm. These measurements are reflective of levels of CS_2 that has been internalized by the body, rather than levels that are in the air.

Results of air sampling during our visit showed levels of CS_2 above OELs in all parts of the plant. Breathing zone sampling is a good indicator of exposure, as it samples the air directly in one's breathing zone for potential chemicals. However, PPE can serve to filter or supply air, so contaminants are not inhaled. In circumstances where breathing zone sampling shows elevated levels, workplace controls and PPE can be effective. The end-of-shift urine sample should be below the ACGIH BEI of 0.5 mg/g creatinine for TTCA. Our sampling indicated that over a quarter of workers had elevated body burdens of TTCA postshift when compared with the BEI. Furthermore, levels of air CS_2 correlated with TTCA body burdens, particularly during production line processes. This indicated that PPE was not protective for workers. Additionally, we noted workers with beards in areas where respirators were used as well as respirators that were stored improperly in the extrusion area during our initial visit.

Workers at this facility reported symptoms consistent with CS_2 exposure. Workers in the high-exposure groups on the production lines had a higher prevalence of mood swings and personality changes compared with workers in the low-exposure groups. Mood swings and personality changes have historically been associated with CS_2 exposures, with workers in the viscose industry known to experience anxiety, depression, mood swings, and personality changes [NIOSH 1977a].

Although workers' concerns mainly focused on CS_2 exposures, they were also concerned about health effects from working with and near H_2S and ammonia. Acute airborne exposures to H_2S above 10 ppm have been associated with eye disorders, including conjunctivitis and keratitis [NIOSH 1977b]. Conclusive evidence of adverse health effects from chronic exposure to H_2S at concentrations below 20 ppm is lacking [Beauchamp et al. 1984; CFR 2024; Glass 1990; NIOSH 1992; Schechter et al. 1989]. OSHA has established a ceiling limit for H_2S of 20 ppm and a 10-minute maximum peak of 50 ppm [OSHA 2024c]. NIOSH has established a 10-minute ceiling limit of 10 ppm [NIOSH 2007]. ACGIH has established a TLV of 1 ppm as an 8-hour TWA and a STEL of 5 ppm [ACGIH 2024].

Real-time air monitoring identified instantaneous levels of H_2S that exceeded the IDLH level of 100 ppm. H_2S exposures, which intermittently peaked throughout the shift and were noted to be most frequent on the fibrous line, could have contributed to symptoms of headache, dizziness, and eye irritation. Excursions above the IDLH value are meant to be rare and should not last longer than 30 minutes. We were unable to determine how high the concentrations of H_2S reached in the air because the sampling equipment's maximum reading was 100 ppm. However, concentrations of 700 to 1,000 ppm can be life-threatening in workers through a "knockdown effect." At concentrations of 100 to 150 ppm, olfactory fatigue sets in, and the characteristic smell of "rotten eggs" can no longer be appreciated by the affected individual [OSHA, no date]. Moderate irritation to the eyes may be experienced at concentrations of 50 to 100 ppm [OSHA, no date].

Ammonia is a colorless, strongly alkaline, extremely soluble gas with a characteristic pungent odor. It causes irritation of the eyes, respiratory tract, and skin. Repeated exposure to ammonia vapor may cause chronic irritation of the eyes and upper respiratory tract [ATSDR 2004]. The NIOSH REL for ammonia is 25 ppm for a 10-hour TWA. The NIOSH STEL for ammonia is 35 ppm [NIOSH 2007]. The OSHA PEL for ammonia is 50 ppm over an 8-hour TWA [OSHA 2024a]. The ACGIH has established a TLV of 25 ppm as an 8-hour TWA and a STEL of 35 ppm [ACGIH 2024].

Compared with the low-exposure group, a higher proportion of employees in the high-exposure group reported skin irritation and skin burns. Skin irritation is consistent with both viscose and ammonia exposure to the skin. We did not identify a statistically significant higher prevalence for eye or upper respiratory tract irritation, though several employees reported these symptoms. Sampling revealed one of the air samples for ammonia on a fibrous extrusion operator (39.3 ppm) was above the ACGIH and NIOSH STEL of 35 ppm.

In evaluating employee chemical exposures, we assessed concentrations of sulfuric acid mists. Sulfuric acid mist can cause eye, nose, and throat irritation, as well as respiratory irritation and dental changes [NIOSH 1974]. The NIOSH REL and OSHA PEL are 1 mg/m^3 for an 8-hour TWA, which are intended to prevent dental erosion and irritant effects [CFR 2024; NIOSH 1974]. ACGIH has a TLV of 0.2 mg/m^3, which aims to minimize pulmonary irritation and prevent injury to the skin and teeth [ACGIH 2024].

During our sampling, levels of sulfuric acid mist were detectable, but all below relevant OELs. Reported dental conditions were generally consistent with frequencies of dental disease in the general population. For instance, 1 in 4 adults aged 20–64 years currently has at least one cavity [CDC 2019], with similar overall frequency of cavities reported in the production group (18 of 64; 28%). We noted that prevalence of cavities tended to be higher among production employees in the high-exposure group than production employees in the low exposure group. However, this difference was not statistically significant.

Noise

Hearing loss and tinnitus are common among workers in the United States [Masterson et al. 2016]. Research has shown that workers in the manufacturing industry may have higher levels of noise-induced hearing loss (NIHL) and tinnitus than other job series [Masterson et al. 2016]. Seven cases of OSHA-defined STS were identified in company audiogram reports during 2013–2017. Two of these cases, in 2017, were noted by the audiometric test provider as OSHA recordable hearing losses, defined as an employee having an STS and also having an overall hearing level that is 25 dB or more above audiometric zero (averaged across 2000, 3000, and 4000 Hz in the same ear(s) as the STS. One of these recordable hearing losses had been entered on the OSHA 300 Log in 2017. The company used OSHA criteria for identifying STS in annual audiograms, as required by regulations. However, analyzing audiograms using the more sensitive NIOSH hearing threshold shift criteria, which is a 15 decibel change in any of the audiometric test frequencies, could lead to earlier identification and intervention to prevent further hearing loss. This could reduce the number of employees who eventually progress to an OSHA STS or further hearing loss. Employees in the chemical department were required to wear hearing protection, and we confirmed that exposures to noise exceeded OELs. However, we observed that some employees did not consistently wear the hearing protection that was provided. Although production line workers in the extrusion area were not required to wear hearing protection, the levels of hazardous noise measured on the days we visited exceeded the NIOSH REL for a 12-hour shift. An employee we informally spoke with during the site visit noted that his foam-insert hearing protection did not fit well and sometimes fell out.

Although few employees reported issues with hearing health, workers in these areas would be at risk for NIHL with continued exposures at the noise levels measured during the site visit. The potential effects of hazardous levels of noise on hearing is compounded by a concomitant exposure to industrial solvents, which are known to be ototoxicants. Ototoxicants can cause hearing loss or balance problems, regardless of noise exposure [Morata and Kardous 2018]. When workers are exposed to both ototoxicants and noise, the risk of hearing loss is increased. The combination may result in temporary or permanent hearing loss and is dependent on the duration of noise and the dose of the exposure

[Morata and Kardous 2018]. CS_2 is also a recognized ototoxicant [EU-OSHA 2009]. Ototoxicants can affect central portions of the auditory system, such as the nerves in the central nervous system, or the brain itself. When these effects occur, not only do sounds need to be louder to be detected, but they may lose clarity, resulting in speech discrimination dysfunction.

Other

Some employees had concerns about required overtime and shift scheduling. They were also concerned about what they perceived as the company's lack of interest in the well-being of their employees. Although we did not evaluate these concerns, we note that they can affect work performance and cause employee stress.

Limitations

A number of factors limited our evaluation. Due to low sample sizes for specific groups, most notably in the chemical department, we did not always have the statistical power to make clear associations between exposures and health outcomes. We were unable to correlate all urinary TTCA levels with air CS_2 results because air and urine measurements were collected on different days. CS_2 can also be absorbed by the skin, however due to the already large scope of the project we did not perform skin test sampling to determine what effect that potential route of exposure had on this set of workers. Lastly, we were not able to observe all employees during their entire shift, therefore we could not document respirator use throughout the day.

Conclusions

Employees in the chemical and production group had air exposures to CS_2 at or above the lowest OEL, set by ACGIH as well as elevated body burdens of TTCA. Air CS_2 levels for extrusion area workers correlated closely with TTCA body burdens, indicating that inhalational exposures were resulting in high body burdens. Employees routinely assigned to extrusion areas, including PMOs and extrusion operators, were more likely to report skin irritation, skin burns, and mood swings and personality changes than employees assigned to other production areas. Some employees had instantaneous readings of H_2S that were at the NIOSH IDLH level of 100 ppm. Employees were exposed to hazardous levels of noise in the production and nonproduction areas of the facility, including in locations where exposure to CS_2, an ototoxicant, were ongoing.

Recommendations

On the basis of our findings, we recommend the following actions. We encourage the artificial casing manufacturer to use a health and safety committee or working group to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the artificial casing manufacturing facility.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix B). 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 PPE may be needed.

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 making the employee responsible for implementing the control effort.

1. Hire a mechanical engineer to improve ventilation in the extrusion and baratte areas.
2. Until H_2S and CS_2 levels can be reasonably controlled, install fall arrest systems in the extrusion area to prevent injuries from loss of consciousness that may follow chemical exposures.
3. H_2S exposures should be further measured in the extrusion area to determine how long they are above the IDLH and how frequently the high values occur to determine if access to areas should be restricted until engineering or administrative controls are in place.

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. Implement worker rotation for employees working in the extrusion and baratte areas to reduce cumulative exposures to chemicals.
2. Update the Respiratory Protection Plan to include procedures for IDLH atmospheres (29 CFR 1910.134[g][3]) for employees working in the extrusion areas.
3. Reevaluate the workplace for chemical exposures to CS_2, H_2S, and ammonia gas if there is a change in process.
4. Update the hearing conservation program to include all workers who have overexposures to noise based on individual testing or on testing for employees in a similar exposure group. Include all employees above the REL in the hearing conservation program.
5. Retrain employees on hearing protection use in all areas of the plant where it is required to be worn.
6. To improve early detection of potential hearing loss, use NIOSH criteria in addition to OSHA criteria to identify hearing threshold shifts. Refer to NIOSH audiometric evaluation and monitoring recommendations at http://www.cdc.gov/niosh/docs/98-126/ for additional information on audiometric testing and hearing loss prevention.

7. Ensure that employees with NIHL meeting OSHA recordability requirements are recorded on OSHA 300 logs as required by the OSHA Recordkeeping Standard (29 CFR 1904 Subpart C).

Personal Protective Equipment

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

1. Employees should wear respiratory protection when working in the extrusion area and doing other work activities that may result in high exposures to H_2S and CS_2.
    a. Exposures below 100 ppm for H_2S require a full-face air-purifying respirator with specialized canisters/cartridges for H_2S.
    b. Exposures at or above 100 ppm require a full-face pressure-demand self-contained breathing apparatus with a minimum service life of 30 minutes or a combination full-face pressure-demand supplied-air respirator with an auxiliary self-contained air supply.
2. Ensure employees coming in contact with viscose, CS_2, or other skin irritants cover their skin with a nonpermeable covering.
3. Provide and require hearing protection for extrusion operators.
4. Ensure that the hearing protection provided fits properly.

Appendix A: Tables

Table A1. Frequency of self-reported conditions and symptoms on interview, N = 44

Symptom/Condition	Frequency of employees reporting “Yes” (%)
Difficulty with sleep	75%
Rash or skin irritation	59%
Skin burns	59%
Headaches	55%
Changes in personality or mood	43%
High blood pressure	43%
Insomnia	41%
Lightheadedness	41%
Anxiety	39%
Chronic fatigue	39%
Eye irritation	39%
Numbness in hands	36%
Loss of appetite	34%
Stomach pain	32%
Weakness	32%
Change or loss of vision	30%
Tinnitus	28%
Hearing loss or change in hearing	26%
Abnormal cholesterol	25%
Dizziness or vertigo	25%
Numbness in feet	25%
Chest pain or angina	23%
Depression	23%
Nausea	23%
Shortness of breath	23%
Difficulty concentrating	20%
Arrythmia or palpitations	16%
Erectile dysfunction (n = 37)	16%
Tremors	14%
Circulation problems	11%
Fainting or loss of consciousness	9%

Table A1 Continued. Frequency of self-reported conditions and symptoms on interview, N = 44

Symptom/Condition	Frequency of employees reporting "Yes" (%)
Mental or emotional illness	6.8%
Infertility	4.9%
Miscarriage in self or spouse (n = 41)	4.9%
Heart disease	4.6%
Lung disease	2.3%
Confusion	2.2%
Cardiovascular disease	0%
Heart attack	0%
Seizure or epilepsy	0%
Stroke	0%
Vomiting	0%

Table A2. Tedlar sample bag results

Run number	1025-004	1025-008	1025-010	1025-012	1025-014	1025-016	1025-018	1025-020	1025-022	1025-024	1026-004	1026-007	1026-009
Location	Line 7, Tank 5	Tank 8 Wash, Btw 9&10	Line 9, Wet End Op	Line 9, B tanks	Line 7, Cut Area Window ½ Open	Wet End Op	Line 7, Tank 13	Line 2 Wet End Op Btw 2&3	Line 2 Cut Area Btw 2&3	Line 2, Tank 5 Btw 2&3	Ripening Corner Without Cover	Steep	Pigment Area
2-Butanone													
Trichloromethane													
Propanol, 2-methyl													
Carbon disulfide	H	X	X	X	X	X	X	X	X	H			X
Cyclohexanone													
Acetamide, N,N-dimethyl	X	H	H	H	H	H	H	H	H	H		X	X
Phenol	X	H	H	H	H	H	H	H	H	H	X	X	X
Propanoic acid, anhydride													
Toluene								FM	FM	X			
Ethylbenzene											FM		
o-Xylene											X		X
p-Xylene			FM	X									
Cyclohexanone													
Furan				FM							FM	FM	
Benzaldehyde		FM				FM		FM		FM			
Benzene, propyl											FM		
Benzene, 1-ethyl-2-methyl											FM		FM
Benzene, 1-methylethyl											X		
Benzene, 1,2,4-trimethyl											X		
Benzene, 1,3,5-trimethyl								FM					FM

Table A2 Continued. Tedlar sample bag results

Run number	1025-004	1025-008	1025-010	1025-012	1025-014	1025-016	1025-018	1025-020	1025-022	1025-024	1026-004	1026-007	1026-009
Location	Line 7, Tank 5	Tank 8 Wash, Btw 9&10	Line 9, Wet End Op	Line 9, B tanks	Line 7, Cut Area Window ½ Open	Wet End Op	Line 7, Tank 13	Line 2 Wet End Op Btw 2&3	Line 2 Cut Area Btw 2&3	Line 2, Tank 5 Btw 2&3	Ripening Corner Without Cover	Steep	Pigment Area
Decane		FM		FM	FM	FM	X	X	FM	FM		X	
Cyclotetrasiloxane, octamethyl						FM		FM				FM	
1-Hexanol, 2-ethyl											X	FM	
Limonene									FM				
Acetophenone		X	X	X	X		X	X			X	FM	
2-Propenamide												FM	
Benzene, 1-methyl-4-(1-methyethyl)				X									
Benzene, 1-methyl-2-(1-methyethyl)							FM						
Undecane		FM					FM						
Benzene, 1,2,4,5-tetramethyl	FM	FM	X	X			X	X			FM	FM	FM
Decane, 4-methyl											FM		
Cyclopentasiloxane, decamethyl	X	X	FM	X			X	X			X	X	FM
Napthalene													
Dodecane	X	X	X	X			X	X			X	X	X

H = High level
X = Net Fit score greater than 80
FM = Net Fit fair match score of 70–79
Btw = between

Table A3. Thermal desorption tubes results

		Sample number and Run number					
		334031*	334843	334844*	334011*	21565*	21566*
Compound	CAS #	1026_02	1026_04	1102_03	1102_009	1102_006	1026_007
2-Butanone	87-93-3		X				
Trichloromethane	67-66-3		FM			FM	
Propanol, 2-methyl	78-84-2					FM	
Carbon disulfide	71-15-0	X		FM	FM	H	FM
Furan, tetrahydro	109-99-9					X	
Benzene	71-43-2			X			
Propanoic acid, anhydride	132-62-6			FM			
Toluene	108-88-3	X		X		X	X
Furfural	98-01-1			X			
Ethylbenzene	100-41-4			X			
o-Xylene	95-47-6	FM	X	X		X	X
p-Xylene	106-42-3						
Cyclohexanone	108-94-1	X	X	X			FM
Acetone	67-64-1		FM	FM			
1-Butanol, 3-methyl	123-51-3			FM			
Furan	110-00-9	FM					
Benzaldehyde	100-52-7	X	X	X			X
Alpha-pinene	80-56-8			FM			
Benzene, propyl	103-65-1		X	X			
Benzene, 1-ethyl-2-methyl	611-14-3		X	X			
Phenol	108-95-2		X	X			
Benzene, 1-ethyl-4-methyl	622-96-8	X					
Benzene, 1-methylethyl	98-82-8		X				
Benzene, 1,2,4-trimethyl	95-63-6		X				
Benzene, 1,3,5-trimethyl	108-67-8		X	X			
Decane	124-18-5		X	X			
Cyclotetrasiloxane, octamethyl	555-67-2		X				
1-Hexanol, 2-ethyl	104-76-7		X	X			
Limonene	138-86	FM	X	X			
Acetophenone	98-86-2	X	X	X			X
Benzene, 1-methyl-4-(1-methyethyl)	99-87-6			X			

Table A3 Continued. Thermal desorption tubes results

		Sample number and Run number					
		334031*	334843	334844*	334011*	21565*	21566*
Compound	CAS #	1026_02	1026_04	1102_03	1102_009	1102_006	1026_007
Acetamide	60-35-5		FM				
Undecane	1120-21-4		X	X			
Benzene, 1,2,4,5-tetramethyl	95-93-2			FM			
Benzene, 1,3-diethyl	141-93-5			FM			
Cyclopentasiloxane, decamethyl	541-02-6	X	X	FM			X
Tetradecane	629-59-4	X					
Napthalene	91-20-3	X	X	X			FM
Dodecane	112-40-3	FM	X	X			X

H = High level
X = Net Fit score greater than 80
FM = Net Fit fair match score of 70–79
* Corresponding paired sample with CS_2 identified

Table A4. Personal breathing zone air sampling results for carbon disulfide

Department (n = number of samples)	Air concentration, parts per million		
	Full-shift measurement (range)	Median	Percentage over the lowest exposure limit
Chemical (n = 26)	Not detected*–13	0.73	65%
Baratte (n = 4)	2.01–13	10	100%
Others (n = 22)	Not detected–2.1	0.60	59%
Fibrous (n = 25)	0.26–8.5	0.95	56%
Extrusion (n = 10)	2.0–8.5	3.6	100%
PMO (n = 3)	0.34–4.6	0.95	67%
Wet/Dry End/Other (n = 12)	0.26–0.98	0.40	33%
Skinless (n = 32)	Not detected–11	1.2	59%
Extrusion (n = 15)	Not detected–6.9	1.7	87%
PMO/Relief (n = 4)	0.30–11	2.9	75%
Wet/Dry End/Other (n = 13)	Not detected–5.6	0.27	23%
Lowest exposure limit	0.5		ACGIH

*The minimum detectable concentration of CS_2 was greater than 0.1 parts per million.

Table A5. Short duration (15-minute) air sampling results for carbon disulfide

Department (number of samples)	Task performed	Air concentration, parts per million
		STEL measurements
Chemical (n = 3)	Baratte dump	4.3, 25, 38
Fibrous (n = 1)	Dye change	2.2
Skinless (n = 3)	Pitch/catch	3.1, 10, 15
NIOSH STEL limit		10

STEL = short term exposure limit

Table A6. Personal breathing zone air sampling results for hydrogen sulfide

Job/Activity	Date	Sample time	TWA (ppm)	Max* (ppm)	STEL (ppm)
Fibrous – wet end, line 10	08/16/2017	08:45–20:12	0	0	0
Fibrous – wet end, line 11	08/17/2017	08:32–20:05	0	0	0
Fibrous – wet end, line 10	08/17/2017	08:28–14:21	0	0	0
Fibrous – wet end, line 11	08/16/2017	08:42–20:11	0	0	0
Fibrous – wet end, line 9	08/18/2017	09:00–20:12	0	0	0
Fibrous – extrusion, line 10	08/17/2017	09:08–20:04	2.4	100	21.9
Fibrous – extrusion, line 11	08/20/2017	08:15–19:18	1.9	100	10.6
Fibrous – extrusion, line 9	08/20/2017	10:34–19:15	1.2	50	13.3
Fibrous – extrusion, line 10	08/18/2017	08:29–19:37†	1.5	70	12.3
Fibrous – extrusion, line 10	08/20/2017	08:21–19:18	0.2	100	19.6
Fibrous – PMO/extrusion	08/18/2017	13:51–19:24	0.4	100	18.5
Fibrous – PMO	08/20/2017	08:11–19:27	0.2	100	25.3
Fibrous – PMO	08/18/2017	09:00–19:33†	0	0	0

Table A6 Continued. Personal breathing zone air sampling results for hydrogen sulfide

Job/Activity	Date	Sample time	TWA (ppm)	Max* (ppm)	STEL (ppm)
Skinless – wet end, line 4	08/16/2017	10:48–19:39	0	0	0
Skinless – wet end, line 2/3	08/17/2017	08:29–19:44	0	0	0
Skinless – wet end, line 7	08/16/2017	09:02–19:41	0	0	0
Skinless – wet end, line 4	08/17/2017	08:26–19:30	0	0	0
Skinless – wet end, line 3	08/16/2017	08:55–19:36	0	0	0
Skinless – supervisor	08/16/2017	09:15–20:19	0	0	0
Skinless – extrusion, line 7	08/18/2017	09:49–19:28	0	18	1.5
Skinless – extrusion, line 7	08/20/2017	08:26–19:28	0	0	0
Skinless – extrusion, line 7	08/16/2017	08:41–19:24	0	3	0.2
Skinless – extrusion, line 2	08/18/2017	09:54–19:23	0.9	14	3.5
Skinless – extrusion, line 4	08/18/2017	09:52–19:23	1.1	100	18
Skinless – extrusion, relief	08/20/2017	08:49–19:22	0.1	8	2.3
Skinless – extrusion, line 2	08/16/2017	08:49–19:30	0.6	16	4.9
Skinless – extrusion, line 4	08/20/2017	08:35–19:31	0.2	70	4.7
Skinless – extrusion, line 2/3	08/17/2017	08:13–19:20	0.5	19	7.2
Skinless – extrusion, line 2	08/18/2017	08:59–19:14†	0.3	9	3.3
Skinless – extrusion, line 2	08/20/2017	08:39–19:33	1.4	16	9.0
Skinless – extrusion, line 2/3	08/17/2017	08:10–19:18	1.9	88	13
Skinless – extrusion, line 3	08/20/2017	08:31–19:21	0.1	8	1.2
Skinless – extrusion, line 4	08/17/2017	08:43–19:14	0	7	0.5
Skinless – PMO	08/20/2017	08:42–19:39	0.3	12	4.3
Skinless – PMO	08/17/2017	08:51–19:36	0	7	0.7
ACGIH TLV			0.5		
NIOSH IDLH				100	
OSHA Ceiling				20	
ACGIH STEL					5

* We were unable to determine how high the concentrations of H_2S reached in the air because the sampling equipment's maximum reading was 100 ppm for a 1 minute reading

† Sampling equipment turned off and removed for break

Table A7. Range of employees' full-shift time-weighted average noise exposures (dBA)

Department	Number of measurements	Results based on OSHA AL criterion	Results based on OSHA PEL criterion	Results based on NIOSH REL criterion
Chemical	24	76.1–92.9	65.2–92.3	80.9–97.7
Fibrous	4	76.5–82.2	64.4–76.3	81.6–85.9
Skinless	5	79.9–88.6	76.2–85.9	85.8–92.4
Noise Exposure Limits (8-hour work shift)		85.0	90.0	85.0
Noise Exposure Limits (12-hour work shift)		82.1	90.0	83.2

AL = action level; PEL = permissible exposure limit; REL = recommended exposure limit

Table A8. Urinary 2-thiothiazolidine-4-carboxylic acid results for chemical department and production group employees, by exposure group (N = 76)

Group or department	Number of employees	Urinary TTCA, mg per gram creatinine	
		Geometric mean	Range
Chemical department			
High exposure	9	0.30	0.06–1.2
Low exposure	7	0.11	0.01–0.48
Production group*†			
High exposure	28	0.58	0.78–3.7
Low exposure	32	0.13	0.0068–0.77
Skinless department*			
High exposure	14	0.52	0.13–2.4
Low exposure	13	0.09	0.0068–0.21
Fibrous department*			
High exposure	14	0.63	0.09–3.7
Low exposure	19	0.18	0.02–0.77
Overall	76	0.25	0.0068–3.7

* Statistically significant difference between high-exposure and low-exposure groups

† The production group consisted of the skinless and fibrous departments.

mg = milligram

Table A9. Prevalence ratios for self-reported symptoms by exposure group, production employees, N = 64

Symptom	Exposure group*	Symptom present n (%)	Prevalence ratio	95% confidence interval
Headaches				
	High	21 (66)	1.0	0.70–1.4
	Low	21 (66)	reference	
Nose/throat irritation				
	High	21 (66)	1.3	0.86–2.0
	Low	16 (50)	reference	
Dizziness/lightheaded				
	High	15 (47)	1.0	0.59–1.7
	Low	15 (47)	reference	
Loss of coordination				
	High	10 (31)	1.7	0.69–4.0
	Low	6 (19)	reference	
Fainting/passing out				
	High	2 (6)	0.94	0.86–1.0
	Low	0 (0)	reference	
Blurred/double vision				
	High	6 (19)	0.86	0.32–2.3
	Low	7 (22)	reference	
Stinging/burning eyes				
	High	11 (34)	1.0	0.51–2.0
	Low	11 (34)	reference	
Nausea/upset stomach				
	High	18 (56)	1.4	0.82–2.3
	Low	13 (41)	reference	
Confused/disoriented				
	High	5 (16)	2.5	0.52–12
	Low	2 (6)	reference	
Mood swings/ personality changes				
	High	22 (69)	**1.7**	**1.1–2.8**
	Low	13 (41)	reference	

Table A9 Continued. Prevalence ratios for self-reported symptoms by exposure group, production employees, N = 64

Symptom	Exposure group*	Symptom present n (%)	Prevalence ratio	95% confidence interval
Difficulty remembering				
	High	16 (50)	1.6	0.86–3.0
	Low	10 (31)	reference	
Fluttering in chest				
	High	7 (22)	0.88	0.36–2.1
	Low	8 (25)	reference	
Skin irritation				
	High	19 (59)	**2.1**	**1.1–3.9**
	Low	9 (28)	reference	
Skin burns				
	High	15 (47)	**3.8**	**1.4–10**
	Low	4 (13)	reference	
Weakness in arms/hands				
	High	13 (41)	1.4	0.72–2.9
	Low	9 (28)	reference	
Numbness in fingers				
	High	7 (22)	0.70	0.30–1.6
	Low	10 (31)	reference	
Difficulty grasping				
	High	10 (31)	1.3	0.57–2.8
	Low	8 (25)	reference	
Weakness in legs/feet				
	High	11 (34)	1.4	0.64–3.0
	Low	8 (25)	reference	
Numbness in toes				
	High	5 (16)	1.0	0.32–3.1
	Low	5 (16)	reference	

* N = 32 for each exposure group

Table A10. Self-reported dental symptoms within the prior 6 months and prevalence ratios by exposure group, production employees, N = 64

Symptom	Exposure group*	Number responding "yes" (%)	Prevalence ratio	95% confidence interval
Toothache				
	High	17 (53%)	1.6	0.87–2.8
	Low	11 (34%)	reference	
Sensitive teeth				
	High	17 (53%)	1.4	0.81–2.5
	Low	12 (38%)	reference	
Bleeding gums				
	High	9 (28%)	0.82	0.39–1.7
	Low	11 (34%)	reference	
Gum disease				
	High	2 (7%)	2.1	0.20–22
	Low	1 (3%)	reference	
Loss of enamel				
	High	11 (34%)	2.2	0.86–5.6
	Low	5 (16%)	reference	
Loose teeth (not due to an injury)				
	High	4 (13%)	4.0	0.47–34
	Low	1 (3%)	reference	
Cavities				
	High	12 (38%)	2.0	0.86–4.7
	Low	6 (19%)	reference	
Broken or missing fillings				
	High	8 (25%)	1.1	0.47–2.8
	Low	7 (22%)	reference	
Broken or missing teeth				
	High	8 (25%)	2.7	0.78–9.2
	Low	3 (9%)	reference	

* N = 32 for each exposure group

Appendix B: Occupational Exposure Limits

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 preexisting 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 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 STELs or ceiling values. Unless otherwise noted, the STEL 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.

- OSHA, an agency of the U.S. Department of Labor, publishes permissible exposure limits [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry] called PELs. These legal 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 2007]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, 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 includes the threshold limit values or TLVs, which are recommended by ACGIH. The ACGIH 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 2024].

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 https://www.dguv.de/ifa/gestis/gestis-stoffdatenbank/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA (Public Law 91-596) 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. 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.

Carbon Disulfide

Carbon disulfide (CS_2) exposure can cause dizziness, poor sleep, headache, anxiety, anorexia, weight loss, and vision changes in humans [NIOSH 2019b]. Chronic inhalation exposure may cause atherosclerosis, coronary heart disease, and neurobehavioral effects including psychomotor slowing, positional tremors, peripheral neuropathy, hearing loss, and Parkinsonism [ATSDR 2012]. OSHA has established a PEL of 20 ppm as an 8-hour TWA, 30 ppm as a ceiling limit, and 100 ppm as a 30-minute maximum peak [OSHA 2024b]. NIOSH has established a REL of 1 ppm as an 8-hour TWA and a STEL of 10 ppm. It is also designated with a skin notation indicating that the chemical can be absorbed through the skin [NIOSH 2007]. ACGIH has established a TLV of 1 ppm as an 8-hour TWA and a BEI of 0.5 mg TTCA per gram of creatinine taken at the end of shift. [ACGIH 2024].

Hydrogen Sulfide

Acute airborne exposures to H_2S above 10 ppm have been associated with eye disorders, including conjunctivitis and keratitis [NIOSH 1977b]. Conclusive evidence of adverse health effects from chronic exposure at concentration below 20 ppm is lacking [Beauchamp et al. 1984; CFR 2024; Glass 1990; NIOSH 1992; Schechter et al. 1989]. OSHA has established a ceiling limit of 20 ppm, and a 10-minute maximum peak of 50 ppm [OSHA 2024c]. NIOSH has an established IDLH level of 100 ppm for H_2S exposure [NIOSH 2014]. IDLH levels indicate that an airborne contaminant is likely to cause death or immediate or delayed adverse health effects or prevent escape from such an environment [NIOSH 2019a]. ACGIH has established a TLV of 1 ppm as an 8-hour TWA and a STEL of 5 ppm [ACGIH 2024].

Ammonia

Ammonia is a colorless, strongly alkaline, extremely soluble gas with a characteristic pungent odor. It causes irritation of the eyes, respiratory tract, and skin. Repeated exposure to ammonia vapor may cause chronic irritation of the eyes and upper respiratory tract [ATSDR 2004]. The NIOSH REL for ammonia is 25 ppm for a 10-hour TWA [NIOSH 2007]. The NIOSH STEL for ammonia is 35 ppm [NIOSH 2007]. The ACGIH has established a TLV of 25 ppm as an 8-hour TWA and a STEL of 35 ppm [ACGIH 2024]. The OSHA PEL for ammonia is 50 ppm over an 8-hour TWA [OSHA 2024a].

Sulfuric Acid

Concentrated sulfuric acid is a dense, colorless liquid that is a severe irritant to the eyes, mucous membranes, and skin. Sulfuric acid mist can cause eye, nose, and throat irritation, as well as respiratory irritation and dental changes [NIOSH 1974]. The NIOSH REL and OSHA PEL are 1 mg/m^3 for an 8-hour TWA and are intended to prevent dental erosion and irritant effects [NIOSH 1974; OSHA 2021]. ACGIH has a TLV of 0.2 mg/m^3, which aims to minimize pulmonary irritation and prevent injury to the skin and teeth [ACGIH 2024].

Noise

NIHL is an irreversible condition that progresses with noise exposure. NIHL is caused by damage to the nerve cells of the inner ear and, unlike some other types of hearing disorders, cannot be treated medically [AIHA 2022]. Approximately 25% of U.S. workers have been exposed to hazardous noise [Kerns et al. 2018] and more than 22 million U.S. workers are estimated to be exposed to workplace noise levels above 85 dBA [Tak et al. 2009]. NIOSH estimates that workers exposed to an average daily noise level of 85 dBA over a 40-year working lifetime have an 8% excess risk of material hearing impairment. This excess risk increases to 25% for an average daily noise exposure of 90 dBA [NIOSH 1998]. NIOSH defines material hearing impairment as an average of the HTLs for both ears that exceeds 25 dB at frequencies of 1 kilohertz (kHz), 2 kHz, 3 kHz, and 4 kHz.

Although hearing ability commonly declines with age, exposure to excessive noise can increase the rate of hearing loss. In most cases, NIHL develops slowly from repeated exposure to noise over time, but the progression of hearing loss is typically the greatest during the first several years of noise exposure [Rosler 1994]. NIHL can result from short duration exposures to high noise levels or even from a single exposure to an impulsive noise or a continuous noise, depending on the intensity of the noise and the individual's susceptibility to NIHL [AIHA 2022]. Noise exposed workers can develop substantial NIHL before it is clearly recognized. Even mild hearing losses can impair one's ability to understand speech and hear many important sounds. In addition, some people with NIHL also develop "tinnitus". Tinnitus is a condition in which a person perceives hearing sound in one or both ears, but no external sound is present. Persons with tinnitus often describe hearing ringing, roaring, hissing, buzzing, whistling, clicking, or chirping like crickets. Tinnitus can be intermittent or continuous and the perceived volume can range from soft to loud. Currently, no cure for tinnitus exists.

Noise measurements are usually reported as dBA, A-weighting is used because it approximates the "equal loudness perception characteristics of human hearing for pure tones relative to a reference of 40 dB at a frequency of 1 kHz" and is considered to provide a better estimation of hearing loss risk than using unweighted or other weighting measurements [Murphy et al. 2022]. The dB unit is dimensionless, and it represents the logarithmic ratio of the measured sound pressure level to an arbitrary reference sound pressure of 20 micropascals, which is defined as the threshold of normal human hearing at a frequency of 1 kHz. Because the dB is logarithmic, an increase of 3 dB is a doubling of the sound energy, an increase of 10 dB is a 10-fold increase, and an increase of 20 dB is a 100-fold increase in sound energy. Noise exposures expressed in dB or dBA cannot be averaged using the arithmetic mean.

Workers exposed to noise should have baseline and yearly hearing tests (audiograms) to evaluate their hearing thresholds and determine whether their hearing has changed over time. Hearing testing should be done in a quiet location, such as an audiometric test booth, where background noise does not interfere with accurate measurement of hearing thresholds. In workplace hearing conservation programs, hearing thresholds must be measured at frequencies of 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz. NIOSH also recommends testing be done at 8 kHz [NIOSH 1998].

The OSHA hearing conservation standard requires analysis of hearing changes from baseline hearing thresholds to determine if an STS has occurred. OSHA defines an STS as a change in hearing threshold relative to the baseline hearing test of an average of 10 dB or more at 2 kHz, 3 kHz, and 4 kHz in either ear [29 CFR 1910.95]). If an STS occurs, the company must determine if the hearing loss also meets the requirements to be recorded on the OSHA Form 300 Log of Work-Related Injuries and Illnesses [29 CFR 1904.1]. In contrast to OSHA, NIOSH defines an STS as an increase in the hearing threshold level of 15 dB or more, relative to the baseline audiogram, at any test frequency in either ear measured twice in succession [NIOSH 1998].

Hearing test results are often presented in an audiogram, which is a plot of an individual's hearing thresholds (y-axis) at each test frequency (x-axis). Hearing threshold levels (HTLs) are plotted such that fainter sounds are shown at the top of the y-axis, and more intense sounds are plotted below. Typical audiograms show HTLs from 0 dB to about 100 dB. Lower frequencies are plotted on the left side of the audiogram, and higher frequencies are plotted on the right. NIHL often manifests itself as a "notch" at 3 kHz, 4 kHz, or 6 kHz, depending on the frequency spectrum of the workplace noise and the anatomy of the individual's ear [ACOM 1989; Mirza et al. 2018; Osguthorpe and Klein 1991; Schlaucha and Carneya 2011; Suter 2002]. A notch in an individual with normal hearing may indicate early onset of NIHL. A notch is defined as the frequency where the HTL is preceded by an improvement of at least 10 dB at the previous test frequency and followed by an improvement of at least 5 dB at the next test frequency.

NIOSH has an REL for noise of 85 dBA as an 8-hour TWA. For calculating exposure limits, NIOSH uses a 3-dB time/intensity trading relationship, or exchange rate. Using this criterion, an employee can be exposed to 88 dBA for no more than 4 hours, 91 dBA for 2 hours, 94 dBA for 1 hour, 97 dBA for 0.5 hours, etc. Exposure to impulsive noise should never exceed a peak level of 140 dBA. For extended work shifts, NIOSH adjusts the REL to 84.5 dBA for a 9-hour shift, 84.0 dBA for a 10-hour shift, 83.6 dBA for an 11-hour shift, and 83.2 dBA for a 12-hour work shift. When noise exposures exceed the REL, NIOSH recommends the using hearing protection and implementing a hearing loss prevention program [NIOSH 1998].

The OSHA noise standard specifies a PEL of 90 dBA and an AL of 85 dBA, both as 8-hour TWAs. OSHA uses a less conservative 5-dB exchange rate for calculating the PEL and AL. Using the OSHA criterion, an employee may be exposed to noise levels of 95 dBA for no more than 4 hours, 100 dBA for 2 hours, 105 dBA for 1 hour, 110 dBA for 0.5 hours, etc. Exposure to impulsive noise must not exceed 140 dB peak noise level. OSHA does not adjust the PEL for extended work shifts. However, the AL is adjusted to 84.1 dBA for a 9-hour shift, 83.4 dBA for a 10-hour shift, 82.7 dBA for an 11-hour shift, and 82.1 dBA for a 12-hour work shift. OSHA requires implementation of a hearing conservation program when noise exposures exceed the AL [29 CFR 1910.95].

An employee's daily noise dose, based on the duration and intensity of noise exposure, can be calculated according to the formula: Dose = $100 \times (C1/T1 + C2/T2 + \ldots + Cn/Tn)$, where Cn indicates the total time of exposure at a specific noise level, and Tn indicates the reference exposure duration for which noise at that level becomes hazardous. A noise dose greater than 100% exceeds the noise exposure limit.

Appendix C: References

ACGIH [2024]. TLVs and BEIs: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists, https://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/.

ACOM [1989]. Occupational noise-induced hearing loss. American College of Occupational Medicine Noise and Hearing Conservation Committee. J Occup Med *31*(12):996.

AIHA [2022]. The noise manual. 6th ed. Meinke DK, Berger EH, Driscoll DP, Neitzel RL, Bright K, eds. Falls Church, VA: American Industrial Hygiene Association.

ATSDR [2004]. Toxicological profile for ammonia. Atlanta, GA: U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, http://www.atsdr.cdc.gov/toxprofiles/tp126.pdf.

ATSDR [2012]. Addendum to the 1996 toxicological profile for carbon disulfide (update). Atlanta, GA: U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry.

Beauchamp RO Jr., Bus JS, Popp JA, Boreiko CJ, Andjelkovich DA [1984]. A critical review of the literature on hydrogen sulfide toxicity. Crit Rev Toxicol *13*(1):25–97, https://doi.org/10.3109/10408448409029321.

CDC [2019]. Oral health surveillance report: trends in dental caries and sealants, tooth retention, and edentulism, United States, 1999–2004 to 2011–2016. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, https://www.cdc.gov/oralhealth/publications/OHSR-2019-index.html.

CFR [2024]. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register, https://www.ecfr.gov/.

Douglass AB, Bornstein R, Nino-Murcia G, Keenan S, Miles L, Zarcone VP Jr., Guilleminault C, Dement WC [1994]. The sleep disorders questionnaire. I: creation and multivariate structure of SDQ. Sleep *17*(2):160–167, https://doi.org/10.1093/sleep/17.2.160.

EU-OSHA [2009]. Combined exposure to noise and ototoxic substances. European Agency for Safety and Health at Work, https://osha.europa.eu/en/publications/combined-exposure-noise-and-ototoxic-substances.

Glass DC [1990]. A review of the health effects of hydrogen sulphide exposure. Ann Occup Hyg *34*(3):323–327, https://doi.org/10.1093/annhyg/34.3.323.

Hinkle DE, Wiersma W, Jurs SG [2003]. Applied statistics for the behavioral sciences. 5th ed. Boston, MA: Hughton Mifflin.

Hudnell HK, Otto DA, House DE, Molhave L [1992]. Exposure of humans to a volatile organic mixture. II. Sensory. Arch Environ Health *47*(1):31–38, https://doi.org/10.1080/00039896.1992.9935941.

Kerns E, Masterson EA, Themann CL, Calvert GM [2018]. Cardiovascular conditions, hearing difficulty, and occupational noise exposure within U.S. industries and occupations. Am J Ind Med *61*(6):477–491, https://doi.org/10.1002/ajim.22833.

Kroenke K, Spitzer RL [2002]. The PHQ-9: a new depression and diagnostic severity measure. Psychiatr Ann *32*(9):509–521, https://doi.org/10.1046/j.1525-1497.2001.016009606.x.

Kroenke K, Strine TW, Spitzer RL, Williams JBW, Berry JT, Mokdad AH [2009]. The PHQ-8 as a measure of current depression in the general population. J Affect Disorder Rep *114*(1–3):163–173, http://doi.org/10.1016/j.jad.2008.06.026.

Masterson EA, Themann CL, Luckhaupt SE, Li J, Calvert GM [2016]. Hearing difficulty and tinnitus among U.S. workers and non-workers in 2007. Am J Ind Med *59*(4):290–300, http://doi.org/10.1002/ajim.22565.

Mirza R, Kirchner DB, Dobie RA, Crawford J [2018]. Occupational noise-induced hearing loss. The American College of Occupational and Environmental Medicine (ACOEM) guidance statement. J Occup Environ Med *60*(9):e498–e501, https://doi.org/10.1097/JOM.0000000000001423.

Morata TC, Kardous C [2018]. Ototoxicant chemicals and workplace hearing loss. NIOSH Science Blog, April 6, https://blogs.cdc.gov/niosh-science-blog/2018/04/06/ototoxicant-chemicals/.

Murphy WJ, Kardous CA, Brueck SE [2022]. Sound measurement: instrumentation and noise metrics. In: AIHA. The noise manual, 6th ed. Falls Church, VA: American Industrial Hygiene Association.

NIOSH [1974]. Criteria for a recommended standard: occupational exposure to sulfuric acid. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 74-128, https://www.cdc.gov/niosh/docs/74-128/.

NIOSH [1977a]. Criteria for a recommended standard: occupational exposure to carbon disulfide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-156.

NIOSH [1977b]. Criteria for a recommended standard: occupational exposure to hydrogen sulfide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-158.

NIOSH [1992]. Recommendations for occupational safety and health: compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.

NIOSH [1996]. NIOSH manual of analytical methods (NMAM). 4th ed. Eller PM, Cassinelli ME, eds. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-113, https://www.cdc.gov/niosh/docs/2003-154/default.html.

NIOSH [1998]. Criteria for a recommended standard: occupational noise exposure (revised criteria 1998). Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-126, http://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf.

NIOSH [2007]. NIOSH pocket guide to chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2005-149, http://www.cdc.gov/niosh/npg/.

NIOSH [2014]. Immediately dangerous to life or health concentrations (IDLH): hydrogen sulfide. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, CDC - Immediately Dangerous to Life or Health Concentrations (IDLH): Hydrogen sulfide - NIOSH Publications and Products.

NIOSH [2017]. Volatile organic compounds (screening) by portable TD-GC/MS. Draft Method 3705, Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NIOSH [2019a]. Immediately dangerous to life or health concentrations (IDLH). Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Immediately Dangerous to Life or Health | NIOSH | CDC.

NIOSH [2019b]. Carbon disulfide. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, http://www.cdc.gov/niosh/topics/carbon-disulfide/.

NIOSH [2024]. NIOSH manual of analytical methods (NMAM). 5th ed. O'Connor PF, Ashley K, eds. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2014-151, http://www.cdc.gov/niosh/nmam.

Osguthorpe JD, Klein AJ [1991]. Occupational hearing conservation. Otolaryngol Clin North Am *24*(2):403–414, https://doi.org/10.1016/S0030-6665(20)31147-6.

OSHA [no date]. Safety and health topics: hydrogen sulfide. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/hydrogen-sulfide/hazards. Date accessed: September 27, 2023.

OSHA [2021]. OSHA occupational chemical database: sulfuric acid. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/chemicaldata/624.

OSHA [2024a]. OSHA occupational chemical database: ammonia. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/chemicaldata/623.

OSHA [2024b]. OSHA occupational chemical database: carbon disulfide. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/chemicaldata/574.

OSHA [2024c]. OSHA occupational chemical database: hydrogen sulfide. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/chemicaldata/652.

Rankine D [1938]. Artificial silk keratitis. Br Med J *2*(3939):6–9, https://doi.org/10.1136/bmj.2.3939.6.

Rosler G [1994]. Progression of hearing loss caused by occupational noise. Scand Audiol *23*(1):13–37, https://doi.org/10.3109/01050399409047483.

Schechter MT, Spitzer WO, Hutcheon ME, Dales RE, Eastridge LM, Steinmetz N, Tousignant P, Hobbs C [1989]. Cancer downwind from sour gas refineries: the perception and the reality of an epidemic. Environ Health Perspect *79*:283–290, https://doi.org/10.1289/ehp.8979283.

Schlaucha RS, Carneya E [2011]. Are false-positive rates leading to an overestimation of noise-induced hearing loss? J Speech Lang Hear Res *54*(2):679–692, https://doi.org/10.1044/1092-4388(2010/09-0132).

Spitzer RL, Kroenke K, Williams JBW, Löwe B [2006]. A brief measure for assessing generalized anxiety disorder: the GAD-7. Arch Intern Med *166*(10):1092–1097, http://doi.org/10.1001/archinte.166.10.1092.

Suter AH [2002]. Hearing conservation manual. 4th ed. Milwaukee, WI: Council for Accreditation in Occupational Hearing Conservation.

Tak S, Davis RR, Calver GM [2009]. Exposure to hazardous workplace noise and use of hearing protection devices among U.S. workers—NHANES, 1999–2004. Am J Ind Med *52*(5):358–371, http://doi.org/10.1002/ajim.20690.

U.S. Department of Commerce [1997]. Automated Mass Spectral Deconvolution and Identification System (AMDIS) user guide. Technology Administration, National Institute of Standards and Technology, Standard Reference Data Program, https://chemdata.nist.gov/mass-spc/amdis/docs/amdis.pdf.

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