HealthHazard Evaluation Program

Evaluation of Occupational Exposures and Indoor Environmental Quality in an Underground Cavern Workplace

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Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Authors: **Scott E. Brueck, MS, CIH, COHC**

Duane R. Hammond, MS, PE

Leonard M. Zwack, ScD, CIH

Sarah Hatcher, PhD

Analytical Support: Jennifer Roberts, Bureau Veritas North America

Desktop Publisher: Shawna Watts

Editor: Cheryl Hamilton

Logistics: Donnie Booher, Kevin Moore

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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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Revision Summary: In June 2024 the report was revised to correct minor editorial changes, change the NIOSH method listed on Page B-1 from 0600 to 0501, add ANSI information for eyewash stations on Page B-14, and clarify the ACGIH dust TLV and inhalable fraction on Pages B-1, B-3, and D-3.

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Introduction

Request

An employer representative of a warehouse facility, located in a former underground limestone quarry, requested a health hazard evaluation concerning employees' exposures to carbon monoxide, wood dust and other airborne particles, noise, and radon. The employer also wanted to know what the fibrous material and oil-like residue were on some of the cavern walls of the warehouse workspace.

Workplace

Five employees were working at the facility during the site visits. The warehouse was housed in a leased 33-thousand-square-foot space located within a large 4-million-square-foot underground cavern. The large cavern was a former limestone quarry 75 to 100 feet below ground. Vehicles used a paved concrete road to drive to the multiple other businesses in the cavern.

The company had a 1,200-square-foot woodshop within the warehouse space, partially separated from the warehouse area by a half-wall partition. Among other items, the woodshop held a table saw, miter saw, router, and handheld power tools. A small painting area outside the woodshop was used for limited painting.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

We visited the workplace on two occasions to learn more about exposures and health concerns. During our first visit on October 11, 2018, we did the following:

- Observed work processes, practices, and workplace conditions, and spoke with employees.
- Measured carbon monoxide, carbon dioxide, temperature, and relative humidity throughout the workplace, in the cavern directly outside the workplace, and outdoors.
- Took sound level measurements while workers used powered woodworking equipment and tools in the woodshop.

On our second visit, December 11, 2018, we completed these tasks:

- Collected full-shift personal air samples for wood dust and noise on employees doing woodworking and painting tasks.
- Collected area air samples for wood dust, noise, and other airborne particles.
- Set up two instruments to continuously measure carbon monoxide, carbon dioxide, relative humidity, temperature, and radon for 10 days.
- Used tracer gas to measure the air exchange rate in the cavern workspace.

- Collected bulk samples of fibrous material (referred to as "cave cotton") and an oil-like residue found on some of the rock walls of the cavern.
- Measured illumination levels at various locations throughout the space.
- Interviewed five employees on topics such as job tenure, job tasks, perceived noise exposure, personal protective equipment use, relevant medical history, and health symptoms and concerns.

To learn more about our methods, go to Section B in the Supporting Technical Information

Our Key Findings

Carbon monoxide and radon levels were well below occupational exposure limits

- Employees were not overexposed to carbon monoxide. Although carbon monoxide levels could be higher sometimes, depending on the amount of vehicle traffic and vehicle exhaust in the main cavern passageway.
- Radon levels in the cavern workspace were well below the Occupational Safety and Health Administration (OSHA) permissible exposure limit for workplaces.
- Radon levels were above recommended levels set by the Environmental Protection Agency (EPA). But the EPA limits were established for a lifetime of exposure in homes instead of workplaces.

Employee wood dust exposure in the woodshop could potentially be above recommended occupational exposure limits, depending on how much time wood working equipment is used

- Employees were mostly exposed to dust from pine wood. Exposures to wood dust for the 8-hour shift was less than the National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit. However, wood dust levels were at the NIOSH limit during the 6 hours that wood working equipment was in use.
- Wood dust exposures in the painting area and at the employee work area outside the woodshop were well below occupational exposure limits.

Employee noise exposure in the woodshop was above the NIOSH recommended exposure limit, but lower than the OSHA action level and permissible exposure limit

- Employee noise exposure was above the NIOSH recommended exposure limit due to high sound levels from powered woodworking equipment. These sound levels were sometimes above 95 decibels, A-weighted, occasionally reaching 100 decibels, A-weighted.
- Noise exposure levels in the painting area and in the employee work area outside the woodshop were below NIOSH and OSHA noise exposure limits.

- Employees sometimes used electronic noise canceling earmuffs or headphones when using woodworking equipment; however, these devices were not adequate for use as hearing protection.

Air exchange rates in the cavern warehouse were very low

- The warehouse did not have a mechanical ventilation system to bring outdoor air into the workspace. Air exchange between the warehouse and the main cavern passageway occurred when the large overhead door or loading dock door were open or through gaps around these doors when they were closed. However, air from the main cavern passageway has the potential to be contaminated with exhaust from vehicles driven throughout the cavern.
- Air exchange was very low. The air only changed about once every 13 hours between the cavern warehouse space and the main cavern passageway.

To learn more about our results, go to Section B in the Supporting Technical Information

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Benefits of Improving Workplace Health and Safety:	
↑ Improved worker health and well-being	↑ Improved image and reputation
↑ Better workplace morale	↑ Better products, processes, and services
↑ Better employee recruiting and retention	↑ Increased overall cost savings

The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment might be needed. Read more about the hierarchy of controls at https://www.cdc.gov/niosh/hierarchy-of-controls/about/index.html.

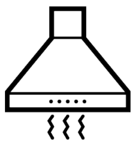
We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in *Recommended Practices for Safety and Health Programs* at https://www.osha.gov/safety-management.

Recommendation 1: Reduce wood dust exposures in the woodshop

Why? Exposure to airborne wood dust can cause health symptoms such as skin irritation, eye irritation, nasal irritation, throat irritation, coughing, and shortness of breath. Some hardwoods such as oak, maple, walnut, and western red cedar have been linked to nasal cancer.

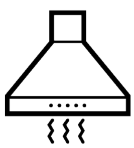
Air monitoring results showed that wood dust exposures could exceed recommended occupational exposure limits depending on how much time woodworking equipment is used.

How? At your workplace, we recommend these specific actions:



Improve wood dust capture at the table saw.

- Install an exhaust hood over the top of the saw blade to better contain and exhaust the wood dust as it is thrown from the blade. The manufacturer of the table saw in the woodshop has an overarm dust collector available for use with that table saw.
- Rotate the table saw 90 degrees to allow the saw to be connected to the dust collector with a straight length of exhaust duct. This will reduce the total length of duct needed and eliminate a greater than 90-degree bend at its point of attachment to the table.
- Replace the corrugated plastic duct with rigid smooth interior duct.



Improve wood dust capture at the compound miter saw.

- Ensure that the dust extractor suction power settings are adjusted to fully capture dust at the saw.
- Replace the lengthy plastic exhaust hose connecting the miter saw and extractor with a shorter length of exhaust hose.

Recommendation 2: Reduce hearing loss risk from occupational noise exposure

Why? Noise-induced hearing loss is an irreversible condition that gets worse with noise exposure. Unlike some other types of hearing disorders, noise-induced hearing loss cannot be treated medically. Noise-exposed workers can develop substantial noise-induced hearing loss before it is clearly recognized.

Noise monitoring results showed that noise exposures in woodshop were above the NIOSH recommended noise exposure limits.

How? At your workplace, we recommend these specific actions:

Include woodshop employees in a hearing loss prevention program.

- Provide baseline and annual audiometric testing and keep the hearing test results.
- Evaluate audiograms using the NIOSH criteria for identifying standard threshold shifts, which are significant changes from baseline hearing audiograms. The NIOSH criteria are more protective than OSHA criteria and will provide earlier identification of employees with hearing loss.
- Educate employees on noise exposures and hearing loss risks. Give them information related to hearing hazards and hearing protection requirements. Explain to them which locations and job tasks require using hearing protection.
- Instruct employees to promptly report any symptoms possibly related to workplace noise exposure, such as trouble hearing clearly, or ringing or buzzing in the ears. Keep track of such reports. Encourage employees with possible work-related hearing concerns to seek medical care from qualified healthcare professionals. Include these reports in safety committee meetings.
- Require employees use appropriate hearing protection when they run powered woodworking equipment.

Recommendation 3: Supply outdoor air to the cavern warehouse

Why? This will help meet minimum ventilation standards for occupied buildings and reduce contaminants in the warehouse and woodshop areas.

Although employees were not overexposed to carbon monoxide, the air exchange rate was very low. This could lead to a buildup of pollutants in the warehouse from the vehicles driven in the area.

How? At your workplace, we recommend these specific actions:

Supply outdoor air to the cavern warehouse space.

- Supply outdoor air to the warehouse by following ANSI/ASHRAE Standard 62.1-2022 Ventilation and Acceptable Indoor Air Quality specifications for ventilation rates.
- Ensure that outdoor air intakes are located at least 25 feet away from the closest place that vehicle exhaust is likely to be located (according to Table 5.5.1 of ANSI/ASHRAE Standard 62.1). This will prevent vehicle exhaust from being pulled into the cavern warehouse space.

Recommendation 4: Address other health and safety issues we identified during our evaluation

Why? A workplace can have multiple health hazards that cause worker illness or injury. These hazards can potentially cause health problems, lower morale and quality of life for your employees, and costs to your business. We saw the following potential issues at your workplace and recommend they be addressed:

- Lighting in the painting area and in the area with employee workstations and conference table were below OSHA limits.
- Employees reported concerns about lack of running water and bathrooms within the warehouse workspace.
- Employees reported work-related health concerns and symptoms.

How? At your workplace, we recommend these specific actions:

Improve visibility by increasing lighting in the painting area and in the work area with employee workstations and conference table.

- Improve lighting in the painting area to 110 lux (lux is a unit of illumination or lighting).
- Improve lighting in areas used for office related functions, such as the employee computer workstations and conference table, to 320 lux.

Add a portable toilet, handwashing station, self-contained emergency eyewash, and drinking water within the work area.

Encourage employees with health concerns to seek an evaluation from a healthcare provider who is familiar with occupational medicine and these types of exposures.

- Resources for locating occupational medicine physicians include the Association of Occupational and Environmental Clinics (http://www.aoec.org) and the American College of Occupational and Environmental Medicine (http://www.acoem.org).

Supporting Technical Information

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Section A: Workplace Information

The company leased a 33 thousand ft^2 (square feet) warehouse space with 18–22 feet (ft) ceilings. The leased space was located within a large 4 million ft^2 underground cavern that was a former limestone quarry 75–100 ft below ground. The underground cavern also housed multiple separate businesses. Vehicles traveled to and from the individual businesses on a paved concrete road. There was also limited parking near the businesses inside the cavern. Most of the company's leased space was used to store painted and sculptural artwork on large metal storage shelves. A small portion of the space was used as an open administrative office and included a conference table, worktables, and computer workstations. A 1,200 ft^2 woodshop was separated from the warehouse area by a half-wall partition. The woodshop was used for building shipping and storage containers for art pieces. It contained storage shelves, cabinets, worktables, and handheld power tools (table saw, miter saw, and router). A small painting area outside the woodshop was used for limited painting.

Five employees were working in the warehouse at the time of our visits. The median job tenure for these employees was 9 months (range: 6 months–4 years, 8 months). Their median age was 32 years (range: 28–43 years). Employees worked 8 hours per day, Monday through Friday. Most work was done in the warehouse space, but employees sometimes worked offsite when installing art at outside exhibits.

Section B: Methods, Results, and Discussion

The objectives of this evaluation included the following:

- Assessing indoor environmental quality (IEQ) parameters; specifically, carbon monoxide (CO), carbon dioxide (CO_2), relative humidity (RH), and temperature.
- Measuring wood dust, airborne particles, noise, and radon.
- Evaluating ventilation and air exchange rates using tracer gas.
- Analyzing samples of "cave cotton" and an oil-like residue from the cavern walls to determine their composition.
- Measuring illumination levels.
- Interviewing employees privately to discuss work-related health concerns and work-related health symptoms.

Methods: Exposure Assessment

Carbon Monoxide, Carbon Dioxide, Relative Humidity, Temperature

During the initial site visit, we took spot measurements for CO, CO_2, RH, and temperature in the workplace and outside the workplace (for comparison) using a TSI VelociCalc® Plus direct reading instrument.

We also measured and data logged CO, CO_2, RH, and temperature in the workplace using the TSI VelociCalc Plus for 10 days, during December 11–21. For these measurements, the sampling probe of the instrument was attached to the tripod at a height of about 5 ft to approximate worker breathing zone height. The control panel of the instrument was locked during the measurement period to prevent tampering. The instrument and tripod were placed near a wall in the main work area so that it did not interfere with employees' work activities. The VelociCalc data logged an averaged measurement every 15 minutes. Instrument data were downloaded, exported, and analyzed using Microsoft Excel for Office 365 (Excel).

Wood Dust

We measured time-weighted average (TWA) personal wood dust exposures in the breathing zone of two employees. One employee worked primarily in the woodshop, and the other employee worked primarily in the nearby painting area. We also collected an area sample for wood dust at the employees' workstation outside the woodshop. Wood dust samples were collected on pre-weighed 37-millimeter diameter polyvinyl chloride filters with Accucap inserts for inhalable particulate matter. The sample media was connected to air sampling pumps (SKC AirCheck Touch Model 220-5000TC) that were calibrated to a flow rate of 2.0 liters per minute. Samples were analyzed using NIOSH Method 0501 [NIOSH 2023].

Airborne Particles

We measured airborne particles using a TSI DustTrak™ DRX 8533 aerosol monitor. The instrument was placed on a table in the main work area and continuously monitored and data logged an average measurement every 5 minutes during a monitoring period of 380 minutes. The DustTrak measured particles in 5 size ranges: PM1: ≤ 1.0 micron (µm); PM2.5: ≤ 2.5 µm; Respirable: ≤ 4 µm; PM10: ≤ 10 µm; and Total: > 10 µm. Instrument data were downloaded, exported, and analyzed using Excel.

Noise

We measured TWA personal noise exposures of two employees. One employee worked primarily in the woodshop, and the other worked primarily in the nearby painting area. We also collected an area sample for noise at the employees' workstation outside the woodshop. We used Larson Davis Spark™ model 706RC integrating noise dosimeters equipped with 0.335-inch random incidence microphones. The dosimeters recorded and data logged five-second averaged noise levels for the duration of the measurement period. The dosimeters were calibrated before and after the measurement periods according to the manufacturer's instructions.

We attached the dosimeter microphone to the outside the employee's 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. 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). At the end of the work shift, we downloaded the noise measurement data from the dosimeters using PCB Piezotronics Blaze™ software.

We used a Larson Davis Model 831 type 1 integrating sound level meter and frequency analyzer equipped with a 0.5-inch random incidence microphone for sound level measurements. The sound level meter was calibrated before and after each day of measurements. The instrument integrated sound levels using linear averaging at 1-second time history intervals. During measurements, the sound level meter was handheld at a height of about 5 ft above floor or ground level. Most measurements were taken within 3–6 ft of employees for about 30–60 seconds. Following measurements, the noise measurement data stored on the instrument were downloaded, exported, and analyzed using Larson Davis G4® software and Excel.

Radon

We measured radon levels using a Durridge RAD7 real-time continuous radon monitor for 10 days, during December 11–21. The intake probe of the instrument was attached to the tripod at a height of about 5 ft to approximate worker breathing zone height. The RAD7 and tripod were placed near a wall in the main work area so that it did not interfere with employees' daily activities. The RAD7 recorded and data logged a measurement every 2 hours during this period. Instrument data were downloaded, exported, and analyzed using Excel.

Results and Discussion: Exposure Assessment

Carbon Monoxide, Carbon Dioxide, Relative Humidity, and Temperature

Results of short duration spot measurements across the warehouse during the initial walkthrough are shown in Table C1. In summary, CO levels ranged 1.8–2.1 parts per million (ppm), CO_2 ranged 1,218–1,237 ppm, RH ranged 53.2%–57.2%, and temperature ranged 68.8°F–70.7°F. These levels in the cavern outside the warehouse were CO (0 ppm), CO_2 (560 ppm), RH (78.2%), and temperature (65.3°F). Outdoor levels outside the cavern were CO (0 ppm), CO_2 (414 ppm), RH (38.9%), and temperature (68.0°F).

Table C2 provides the average and range for long-term continuous measurements. CO levels in the warehouse during this time averaged 0.1 ppm (range: 0–0.8 ppm). CO_2 levels averaged 770 ppm (range: 657–933). Both CO and CO_2 levels were less than those measured during the October 11 initial visit. The reasons for this difference are unclear but could be potentially related to differences in air exchange or air movement between the two sampling periods. The amount of vehicle traffic through the cavern is another factor that could potentially influence CO levels.

Long-term continuous measurements over 10 days showed that temperature and RH levels were similar to those measured during the initial visit. Temperature measurements taken inside the warehouse were within ANSI/ASHRAE recommendations. ANSI/ASHRAE Standard 55-2020, Thermal Environmental Conditions for Human Occupancy, specifies conditions in which 80% or more of the occupants would be expected to find the environment thermally acceptable [ANSI/ASHRAE 2020]. Assuming slow air movement and 50% RH, the operative temperatures recommended by ANSI/ASHRAE range from 68.5°F to 76°F in the winter and from 75°F to 80.5°F in the summer. The difference between the two is largely due to differences in seasonal clothing selection.

Similarly, humidity measurements taken in the warehouse were within ANSI/ASHRAE recommendations. ASHRAE Standard 62.1-2022, Ventilation for Acceptable Indoor Air Quality, recommends RH levels be limited to 65% or less for mechanical systems with dehumidification capability [ANSI/ASHRAE 2022]. The EPA recommends that RH be maintained below 60% (ideally 30%–50%) to prevent mold growth. Excessive humidity can also promote the growth of microorganisms and dust mites. The ASHRAE standard does not specify a lower humidity limit, but very low RH levels may contribute to dry and irritated mucous membranes of the eyes and airways [Wolkoff and Kjaergaard 2007].

Wood Dust

TWA airborne wood dust measurement results are shown in Table C3. Before beginning work in the woodshop and painting areas, employees did administrative tasks in which they did not have wood dust exposures; therefore, we collected air samples for wood dust for under 6 hours of the 8-hour workday. Personal exposure measurement results during the monitoring period showed that the TWA wood dust exposure in the woodshop were at the NIOSH REL of 1 milligram per cubic meter of air (mg/m^3) [NIOSH 2010] and the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®), which is also 1 mg/m^3 (as an inhalable fraction) [ACGIH 2023]. This suggests the potential for wood dust exposures to exceed these recommended occupational exposure limits (OELs) depending on the amount of time woodworking equipment is in use. Additional wood dust monitoring would help clarify day-to-day exposure variability. If we assumed no exposure for the unsampled portion of the work shift, full-shift personal wood dust exposure in the woodshop was 0.73 mg/m^3. Employees reported sometimes using N95 respirators on a voluntary basis, depending on the amount of woodworking they were doing. Personal wood dust exposures in the painting area outside the woodshop and for the area sample collected at the workstation outside the woodshop were well below the NIOSH and ACGIH OELs. None of the wood dust exposures were at or above the OSHA PEL of 15 (mg/m^3). When exposures exceed NIOSH or ACGIH recommended OELs, proper respiratory protection, along with a comprehensive respiratory protection program, is recommended.

On the day of air monitoring, the employee in the painting area did a limited amount of sanding using a handheld sander. The employee in the woodshop used the table saw, compound miter saw, and handheld router to cut and prepare various sized boards for building crates and other wood items. The wood was primarily pine. The table saw was connected to a Powermatic company dust collection system (Figure B1). The miter saw was connected to a mobile dust extractor built by the miter saw manufacturer, Festool (Figure B2). Because the router was also manufactured by Festool, this mobile dust extractor was disconnected from the miter saw and also used for the router. The company planned to purchase a separate mobile dust extractor for the handheld router.

Figure B1. Woodshop table saw with exhaust duct connected to the dust collector. Photo by NIOSH.

Figure B2. Compound miter saw connected to a mobile dust extractor. Photo by NIOSH.

Although the handheld router, miter, and table saw were connected to dust collection systems, improving dust capture efficiency of these dust collectors could increase their effectiveness and reduce wood dust exposures. The dust extractor suction power settings should be adjusted to adequately capture dust at the saw. Because the miter saw was permanently affixed to the worktable, replacing the lengthy plastic exhaust hose connecting the miter saw and extractor with a shorter length of exhaust hose could reduce air resistance within the hose and increase exhaust efficiency.

Wood dust at the table saw was exhausted through the bottom of the table and connected to the dust collector with large diameter corrugated plastic exhaust duct. Rotating the table saw 90° would allow the saw to be connected to the dust collector with a straight length of exhaust duct. This could improve capture efficiency by reducing the total length of duct needed and eliminate a greater than 90° bend at its point of attachment to the table. Replacing the corrugated duct with rigid smooth interior duct could also improve efficiency. In addition, installing an exhaust hood over the top of the saw blade can help contain and exhaust dust as it is thrown from the blade. Previous NIOSH laboratory testing has indicated that an exhaust hood can reduce wood dust emissions by 90% when it is installed on a typical table saw [NIOSH 1996]. The manufacturer of the table saw used in the woodshop has an overarm dust collector available for use with the saw.

Airborne Particles

Table C4 provides a summary of minimum, maximum, and average particle concentrations measured in the main work area during the workday on the second visit. For all size ranges, the particle concentrations were far below the OSHA PEL for particulates not otherwise regulated of 5 mg/m^3 (respirable fraction) and 15 mg/m^3 (total dust) and the ACGIH TLV of 3 mg/m^3 (respirable particles) and 10 mg/m^3 (inhalable particles). Particle concentrations increased with particle size. However, the differences between PM1, PM2.5, and respirable-sized particles were minimal. Figure B3 shows how particle concentrations varied during the workday. Higher levels at times during the afternoon corresponded with woodworking activities and painting activities in adjacent work areas.

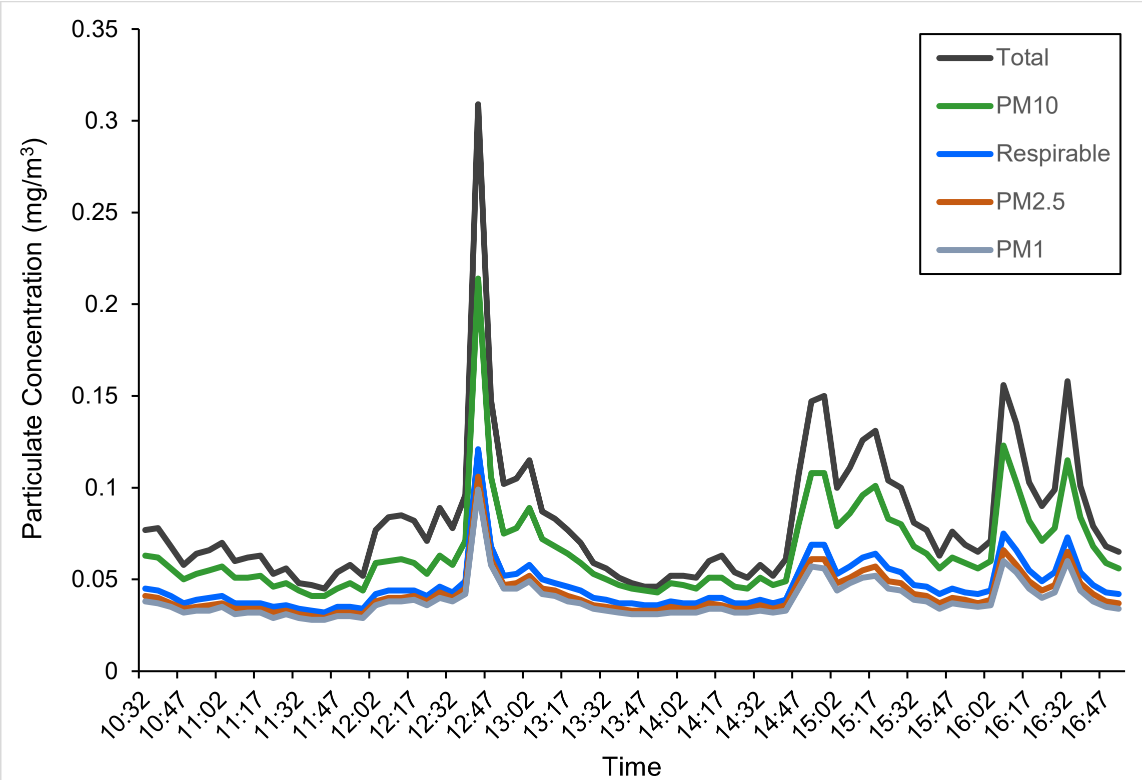

Figure B3. Time-history graph showing particle concentrations in the main work area on our second visit on December 11.

Noise

Table C5 shows direct reading sound level measurement results. Overall, sound level measurements in the woodshop during use of woodworking equipment (table saw, miter saw, and router) ranged from approximately 86–94 decibels, A-weighted (dBA). Sound levels were highest during use of the handheld router, ranging 92–94 dBA. Background sound levels in the woodshop were 65–66 dBA when no woodworking equipment was in use. Sound levels in the painting area were about 76–78 dBA when the router was in use in the woodshop. Sound levels near the conference table outside the woodshop ranged from 62 dBA when no woodworking equipment was in use to 71 dBA when the table saw was in use.

Noise measurement results, shown in Table C6, show that personal noise exposures in the woodshop were above the NIOSH REL, but below the OSHA noise exposure limits. Depending on the length of time powered woodworking equipment are used, exposures could increase and potentially increase above OSHA noise exposure limits. Figure B4 shows the time history noise exposure profile in the woodshop revealing that sound levels sometimes exceeded 95 dBA and occasionally reached 100 dBA during the use of powered woodworking equipment. These high sound levels were the primary contributor to employees' noise exposures. Employees had both ear plugs and earmuffs available for use. We learned during the site visit that some employees used noise canceling headphones or earbuds. It should be noted that noise canceling headphones and earbuds are not considered hearing protection and should not be used for protection from occupational noise exposures. Employees using powered woodworking equipment in the woodshop should wear appropriate earmuffs or earplugs for hearing protection. In addition, because noise exposures were above the NIOSH REL, woodshop employees should be included in a hearing loss prevention program. The area noise measurement results from the employee work area outside the woodshop indicate that exposure would be far below the NIOSH REL and OSHA noise exposure limits.

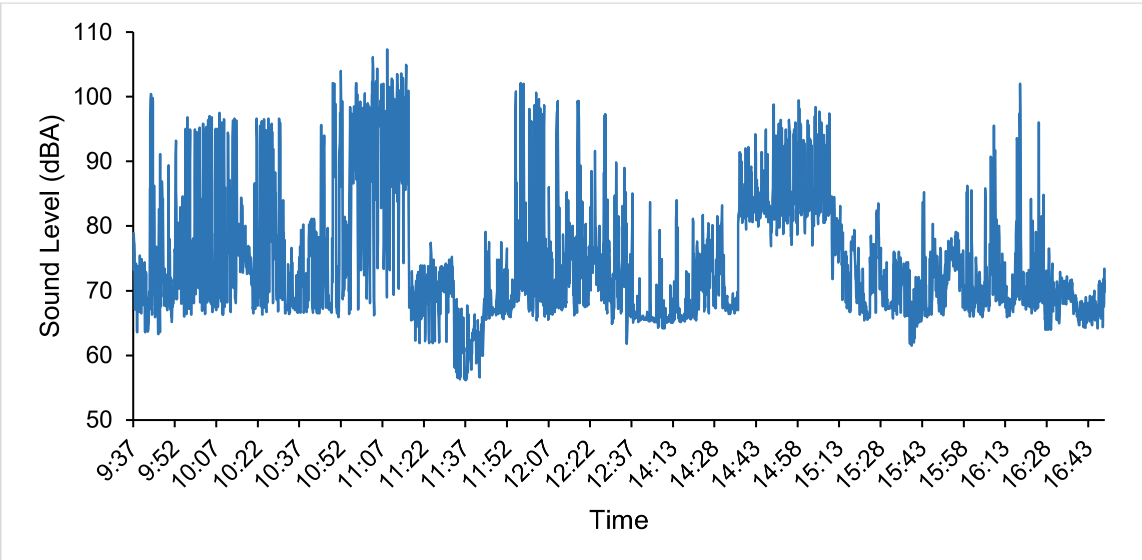

Figure B4. Time-history noise exposure profile for work in the woodshop.

Radon

Radon is a radioactive gas that is a product of the breaking down of radioactive elements, such as uranium. These radioactive elements are found naturally in different amounts in soil and rock throughout the world. Radon gas emitted from soil or rock can enter buildings through cracks or other openings in their foundation. Radon levels are typically highest in the basement as this level is closest to the rock or soil that is the source of radon. High levels of radon exposure are more typically observed in workers in industries like uranium processing. The American Cancer Society (ACS) states that long-term exposure to high levels of radon can cause lung cancer [ACS 2015].

Radon levels measured across the 10-day sample period averaged 6 picocuries per liter (pCi/L), ranging 4.6–9.0 pCi/L. Daily averages, shown in Table C7, ranged 5.2–7.6 pCi/L. Figure B5 provides a time history of radon levels across the measurement period. Although not substantially different, radon levels were slightly higher December 20–21, relative to previous days of measurements. The reason for these higher levels is unclear but could be related to slightly less air exchange in the cavern on those days.

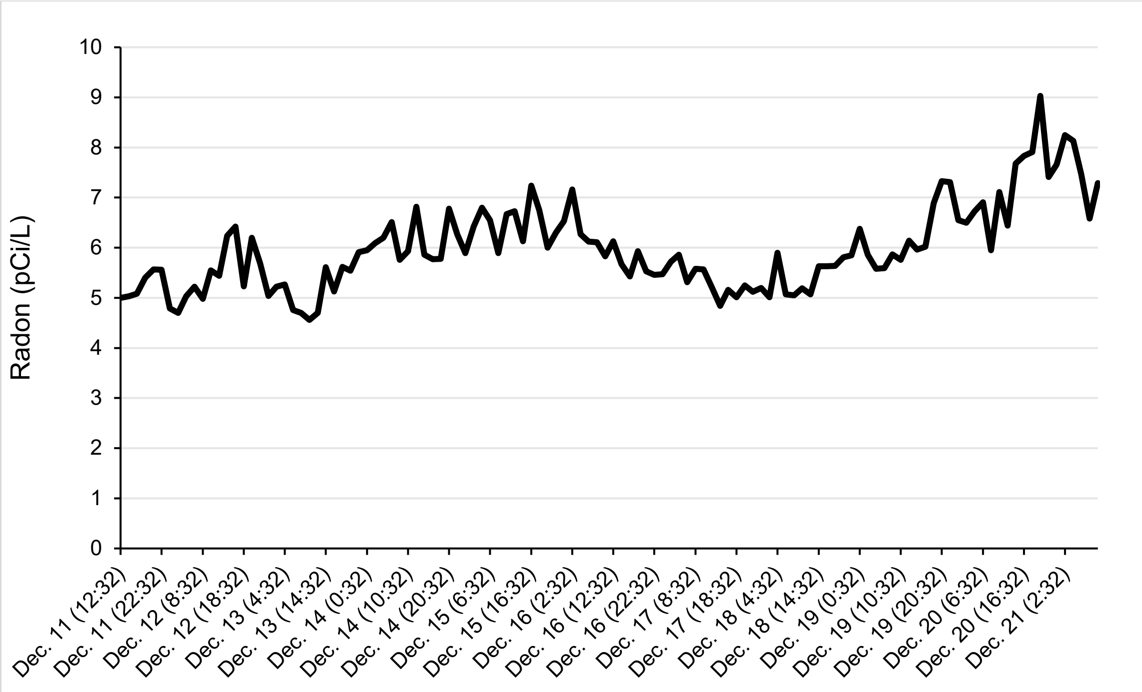

Figure B5: Time-history for radon concentrations over a 10-day period.

Across the United States, background concentrations of radon in outdoor air range from 0.003 to 2.6 pCi/L and are higher in areas with uranium and thorium deposits or granite formations [DOE 1995]. According to the EPA map of radon zones, the geographic area where the warehouse is located is in a zone where the EPA predicts that the "average indoor radon levels may be less than 2 pCi/L." However, because the cavern workplace is below ground with limited air exchange, it is not surprising that background radon levels might be higher than those predicted by EPA for the zone. In addition, radon levels can vary within any given zone.

The EPA recommends taking corrective measures when indoor home radon levels exceed 4 pCi/L. However, the recommendations and action levels for indoor radon provided by the EPA are not directly applicable to a workplace environment. For occupational settings, the OSHA permissible exposure limit (PEL) is 100 pCi/L for a 40-hour exposure in any work week of seven consecutive days.

None of the radon levels we measured were above the OSHA PEL of 100 pCi/L. Radon concentrations were above the EPA AL of 4 pCi/L. However, the EPA AL is not considered an OEL but rather a limit intended to protect the general public from exposure to radon in homes and schools. The EPA AL was established based, in part, on the risk of lung cancer for a person exposed to 4 pCi/L for 7,000 hours per year over a lifetime. In contrast, workplace exposure limits are based on the general assumption that employees are exposed for 2,000 hours per year (equivalent to 40 hours per week for 50 weeks per year).

Methods: Ventilation and Air Exchange

During our second site visit on December 11, we measured air exchange within the cavern workspace following procedures specified in ASTM standard E741-11 [2017] "Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution." We measured the workplace dimensions (including the office, warehouse, and woodshop areas). We also measured the dimensions of overhead doors between the workspace and the main cavern passageway.

We released sulfur hexafluoride (SF_6) as a tracer gas in the back of the warehouse space and used existing large floor fans and dehumidifier fans to achieve even mixing of air throughout the space. We measured SF_6 concentrations using tracer gas analyzers in the warehouse, office, and woodshop areas to determine the rate at which air is exchanged between the workspace and external main cavern passageway.

We also used a TSI VelociCalc® anemometer to measure air velocities from local exhaust ventilation (LEV) controls connected to a finish sander and table saw in the woodshop. In addition, we visually inspected portable room air cleaners and documented filter type and efficiency.

Results and Discussion: Ventilation and Air Exchange

Ventilation in the cavern workplace included the following:

- Two ceiling-mounted heat pumps provided heated air to the space.
- Two industrial dehumidifiers reduced and maintained humidity levels.
- Three stationary floor fans to circulated air within the space.
- A portable recirculating air filtration unit in the main warehouse area (was not in use during site visit).
- A large overhead door measured 18 ft wide by 16 ft high.
- A loading dock door measured 8.3 ft wide by 10 ft high.
- A stationary floor fan in the woodshop directed air from the woodshop toward the loading dock area.
- Two portable recirculated air filtration units located between the woodshop and loading dock.
- The woodshop had state-of-the-art LEV dust controls and filtration but did not have general ventilation to remove dust that escapes LEV capture.

Based on our tracer gas measurements, we calculated that the facility had 0.079 air changes per hour (ACH) or one air exchange every 13 hours between the workplace and the main cavern passageway. However, it should be noted that the air in the main cavern passageway has the potential to be contaminated with exhaust from vehicles driven throughout the cavern. Also, air exchanged between the main cavern passageway and the workspace more closely matched the ANSI/ASHRAE Standard 62.1 definition of transfer air (air moved from one indoor space to another) rather than providing ambient air or outdoor air.

To improve overall air quality within the warehouse workspace and woodshop, we recommend supplying outdoor air to the company's warehouse and workshop areas following the specifications of ANSI/ASHRAE Standard 62.1 Table 6-1. This would require minimum ventilation rates of 0.06 cubic feet per minute per square foot (cfm/ft^2) of outdoor air to the warehouse and 0.18 cfm/ft^2 of outdoor air to the woodshop [ANSI/ASHRAE 2022]. Based on the size of the warehouse and woodshop, 2,200 cfm of outdoor air would need to be supplied to meet ANSI/ASHRAE 62.1 Table 6.2.2.1

specifications (1,980 cfm to the warehouse and 216 cfm to the woodshop). ASHRAE Standard 62.1 defines requirements for ventilation and applies to spaces intended for human occupancy within buildings.

Methods: Evaluation of "Cave Cotton" Mineral Fibers and Oil-like Residue Collected from Cavern Walls

"Cave Cotton" Mineral Fibers

Bulk samples of mineral fibers, referred to by employees as "cave cotton," were collected from the cavern wall using tweezers and placed in glass specimen jars. The samples were submitted to determine the composition and morphologies using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). For analysis, the bulk samples were directly placed on the standard SEM stubs by using the conductive carbon tape. Representative images of the sample were obtained by the back scattered detector (BSD) on a Phenom XL SEM in the variable pressure mode (1–60 Pascals) at acceleration voltage of 10 and 15 kilovolts. In addition, the elemental composition was determined by the integrated EDS detector and Elemental ID software installed on the Phenom XL SEM.

Oil-like Residue

Small pieces of rock that were partially coated with an oil-like residue were placed in glass specimen jars. Because of the oil-like nature of the residue, we asked the lab to conduct a screening analysis for volatile organic chemicals in the residue. For laboratory analysis, the rock samples were placed in separate jars for extraction. For one of the jars, 5 milliliters of toluene were added to cover the rock sample. For the other jar, 3 milliliters of methanol were added to cover the rock sample. Each sample jar containing the rock sample and extraction agent (as well as toluene and methanol blanks) were shaken for 30 minutes to allow sufficient extraction time. Analysis using gas chromatography-mass spectrometry (GC-MS) and thin layer chromatography (TLC) was done for each of the samples.

For GC-MS analysis, an aliquot of each sample (and blank) was analyzed using NIOSH Method NMAM 2549 [NIOSH 2023]. The samples were modified for liquid injection using multiple injection port temperatures and run (hold) times. The analysis was conducted using an Agilent 6890 gas chromatograph with an Agilent 5973 mass spectrometer that was operated under electronic ionization conditions. A HP-1MS fused silica capillary column was used for the analyses. For TLC analysis, the extracts were also spotted on TLC plates using both methanol and toluene as the elution solvent.

Results and Discussion: Evaluation of "Cave Cotton" Mineral Fibers and Oil-like Residue Collected from Cavern Walls

"Cave Cotton" Mineral Fibers

Figure B5 shows the white-colored translucent fibers on a wall of the cavern. Facility staff referred to the fibers as "cave cotton" due to the texture and appearance of the fibers. The analytical laboratory reported that the bulk minerals were white/transparent fibers that were readily soluble in water. The SEM images show typical structures of fibers with diameters in the range of 3 to 30 µm (Figure B6). Elemental analysis showed the presence of magnesium, sulfur, and oxygen in the fibers. The proportional average calculated atomic weight concentrations for the four different samples analyzed were oxygen (61.3), magnesium (19.5), and sulfur (19.2). The atomic weight concentrations suggest that the mineral fiber contained a compound consisting of magnesium sulfate with formula $MgSO_4$, referred to as epsomite.

Figure B5. Mineral fibers on cavern surface. Photo by NIOSH.

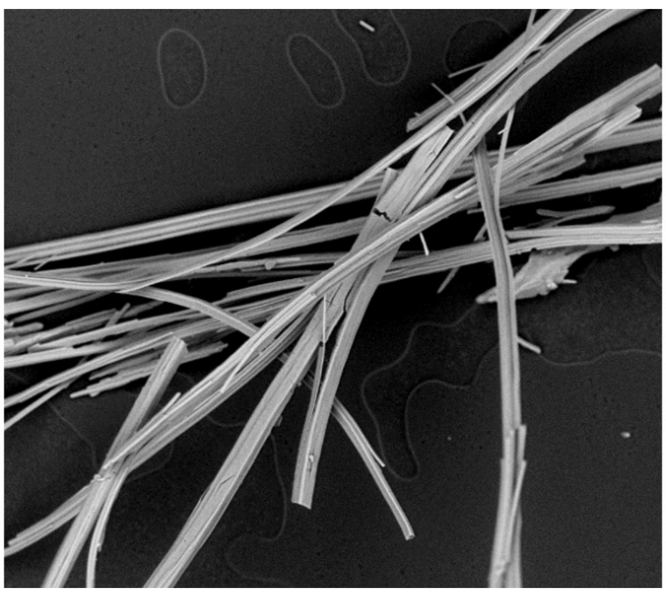

Figure B6. Photomicrograph of the mineral fibers magnified 300 times. Photo by NIOSH.

Epsomite has been known to form on the internal surface of cave walls, particularly limestone caves, on magnesium-rich rocks and under dry conditions. It has been referred to as "cave cotton" in its fibrous form. Self and Hill [2003] reported on the mechanisms for growth of fibrous aggregates in caves. A theoretical study by Giordani et al. [2022] explored whether epsomite fibers could potentially present a health risk. Their research on epsomite fibers from a cave in Italy noted that about 25% of the fibers were small enough to penetrate the lungs, if airborne. Because of the high solubility of the fibers under internal lung conditions, they would not be able to cause damage such as could occur with insoluble fibers. However, if the fibers contained other chemicals, these could be released when fibers dissolved.

The study authors cautioned that due to the lack of in-vivo, in-vitro, and epidemiological studies, additional research was needed to determine actual human toxicological risk.

Because the warehouse has relatively limited amounts of these fibers present on the cavern walls, and typical workplace conditions would not cause fibers to become airborne, the fibers should not present a risk to employees. However, if fibers needed to be removed from the wall, use a high efficiency particulate air (HEPA)-filtered vacuum for removal tasks.

Oil-like Residue

A brownish-colored oil-like residue was present on a few of the cavern walls within the warehouse. There were no known external or internal sources for the residue. The residue had a somewhat stratified appearance on the cavern wall (Figure B7) suggesting the possibility it could be leaching through the cavern rock from an underground or above ground source. However, the depth of the residue was not known so we could not determine whether it extended beneath the cavern wall surface or was present primarily on the rock surface. It is also possible that the residue was a remnant from activities related to its former use as a limestone quarry.

Figure B7. Oil-like residue on cavern wall. Photo by NIOSH.

During analytical laboratory analysis, the toluene extract turned very dark brown. The methanol extract turned light yellow. These color changes in the extract indicated that the residue extracted from the rock samples was primarily nonpolar (i.e., the electrical charge of the molecules were evenly distributed across the molecule).

Neither the GC-MS nor TLC analyses provided conclusive results. The methanol extract, when injected at 320°C during GC-MS analysis, resulted in a few small hydrocarbon peaks, likely in the range of C_{20} and greater (i.e., the molecule contains 20 or more carbon atoms). The toluene extract, when injected at 320°C during GC-MS analysis, resulted in a few small peaks, potentially indicating polycyclic hydrocarbons with molecular weights greater than 300 atomic mass units. The analysis indicated that the components of the oil-like residue were of higher molecular weight than what is typically observed using NIOSH Method NMAM 2549 for volatile organic chemical screening. However, due to the lack of hydrocarbons in the C_{10}–C_{15} range, the residue was unlikely to be diesel or crude oil. During TLC analysis, the toluene and methanol extracted some highly fluorescing components. The toluene extracted more nonpolar compounds. The analysis indicated that the (nonpolar) residue must be of higher molecular weight since it did not move on the TLC plate for either the toluene or methanol eluting solvent.

Methods: Illumination Levels

We used a Sper Scientific company light meter (Model S40020) to measure illumination levels in several areas across the facility.

Results and Discussion: Illumination Levels

We measured illumination intensities ranging 62–169 lux in the front painting area. Illumination intensities ranged 202–252 lux in the area with the conference and worktables. In the warehouse space, illumination intensities ranged from 77 lux (at the border between this facility and the adjacent tenant's space) to 265 lux (in the middle of the second aisle, near the artwork on the floor). OSHA's minimum illumination intensity requirement depends upon the classification of a workspace. For indoor warehouses, OSHA's minimum illumination intensity is 54 lux. For general construction plants and shops (including carpentry shops and workrooms), OSHA's minimum requirement is 110 lux. OSHA also has a standard for office space of 320 lux. Our measurements indicated that illumination in the warehouse area exceeded OSHA's minimum limits. To improve visibility in other areas and be aligned with OSHA's specifications, we recommend improving lighting in the painting area to 110 lux and to 320 lux in areas that used for office-related functions, such as the conference table and computer worktables near the conference table.

Methods: Employee Health Assessment

- We invited all employees working on the day of our second visit to participate in private interviews.
- We collected information about employees' work history and practices, personal protective equipment use, work-related exposures and health symptoms, and relevant medical history through these voluntary confidential medical interviews.
- Work-related health symptoms were defined as health symptoms that reportedly improved away from work.

Results and Discussion: Employee Health Assessment

All five employees working in the cavern warehouse during our second visit participated in confidential medical interviews, including art handlers (n = 2), design preparators (n = 2), and a collection manager (n = 1). The median age of employees was 32 (range: 28–43 years). Some employees reported a history of smoking or being a current smoker.

Interviewed employees reported working in the facility a median of 9 months (range: 6 months–4 years 8 months). All employees reported typically spending 5 days per week and a median of 8 hours per day in the workplace (range: 8.0–8.5 hours). Employees sometimes worked outside of the cavern warehouse, at hotels or private homes, when installing art exhibits.

All five interviewed employees reported being exposed to loud noise at work at times. Three employees reported wearing hearing protection during the use of saws or other tasks that generated high noise levels. Among those reporting using hearing protection, the types of hearing protection reported included earmuffs or noise canceling headphones. Two employees reported also being exposed to loud noise outside of work from sources such as power tools, lawn mowers, or leaf blowers. None of the five interviewed reported having trouble hearing.

All five interviewed employees reported one or more health symptom during the past month that improved when they were away from work. These symptoms included eye irritation, nasal irritation, throat irritation, shortness of breath, cough, headache, lightheadedness or dizziness, fatigue, weakness, nausea, and confusion. No employees reported seeking medical attention from a doctor or other healthcare provider for these symptoms. Some employees reported a history of allergies in the form of hay fever or seasonal allergies.

Some symptoms reported by employees, such as eye irritation, nasal irritation, throat irritation, coughing, and shortness of breath, could potentially be associated with exposures to airborne wood dust for those employees who used woodworking equipment. Air sampling results for wood dust indicated that exposures in the woodshop were at the NIOSH REL and the ACGIH TLV. Levels outside the woodshop were well below these levels and not likely to lead to associated health symptoms.

Air sampling results showed that CO levels were well below OELs. Levels for other parameters (CO_2, RH, and temperature), typically used to assess IEQ, were all within recommended guidelines. However, some of the employees reported health symptoms, such as headaches and respiratory symptoms, which have been reported previously by employees in buildings with IEQ problems [Brightman et al. 2008; Malkin et al. 1996]. These symptoms are nonspecific, meaning they can be caused by many things, and they are common. For example, 86%–95% of the general population have one or more of these symptoms during any given 2- to 4-week period. The average adult reports a minimum of one symptom every 4–6 days [Barsky and Borus 1995]. Further, the average adult has two to three upper respiratory infections per year, also causing these nonspecific symptoms [Benninger et al. 2003].

The warehouse did not have running water or a bathroom facility within in the workspace. Employees who needed to use a bathroom had to leave the warehouse and walk to facilities available in the common area of the cavern. It took about a minute or more to walk to these bathroom facilities. Four of the five interviewed employees reported that lack of running water and bathrooms in the warehouse impacted their work or health. When asked about these reported health impacts, employees expressed concerns related to dehydration (choosing not to drink water because the bathroom was not nearby), sanitation, and the inability to quickly access water in the case of accidental exposure to adhesive or solvents that were occasionally used in the woodshop or painting area. Adding a portable toilet, handwashing station, bottled water dispenser, and a self-contained emergency eyewash that meets the performance specifications in ANSI/ISEA Standard Z358.1-2014 for emergency eyewash and shower equipment [ANSI/ISEA 2020] could help alleviate these employee concerns.

Limitations

This evaluation was subject to limitations. Exposure assessment could only document exposures and conditions in the locations evaluated and on the days evaluations occurred. These results may not have been representative of conditions during other times. Medical interviews were also subject to similar limitations. We were only able to document concerns and symptoms that were reported to us during our evaluations by current employees. We were not able to include information from employees who had left the workforce or were not present at the time of the evaluation. Interviews may have been impacted by selection, recall, and social desirability biases.

Conclusions

We found employees' noise exposures in the woodshop exceeded the NIOSH REL due to noise generated during the use of powered woodworking equipment. Wood dust exposures in the woodshop could exceed OELs depending on how much time woodworking equipment was used. We recommended including woodshop employees in a hearing loss prevention program, which includes audiometric testing, proper hearing protection use, and employee training. We also recommended improving wood dust capture at the saws. Our measurements indicated that carbon monoxide and radon levels were well below OELs.

Section C: Tables

Table C1. Spot measurement results for carbon monoxide, carbon dioxide, relative humidity, and temperature during initial visit

Measurement location	Carbon monoxide (*ppm)	Carbon dioxide (*ppm)	Relative humidity (%)	Temperature (°F)
Main hallway near workstation	2.1	1,224	53.2	70.7
Back of main hallway	2.2	1,237	53.6	70.6
Back of second hallway	2.1	1,230	53.8	70.4
Middle of second hallway	2.2	1,218	53.9	70.3
Near front bay door	2.1	1,219	53.8	70.4
Front left side of workspace	2.1	1,240	52.9	68.8
Woodshop	1.8	1,230	57.3	69.1
Cavern parking area outside the workspace	0	560	78.2	65.3
Outdoor parking lot outside the cavern	0	414	38.9	68.0

*parts per million

Table C2. Average, minimum, and maximum carbon monoxide, carbon dioxide, relative humidity, and temperature levels during December 11–21, 2018 (measurements taken every 15 minutes)

	Carbon monoxide (ppm*)	Carbon dioxide (ppm*)	Relative humidity (%)	Temperature (°F)
Average	0.1	770	51.3	70.0
Minimum	0	657	48.9	69.5
Maximum	0.8	933	53.1	71.2

*parts per million

Table C3. Time-weighted average air sampling results for wood dust

Work area	Sample duration (minutes)	Concentration (*mg/m^3)
Woodshop (personal sample)	349	1.00
Painting area outside woodshop (personal sample)	338	0.22
Employee workstation (area sample)	425	0.13
NIOSH recommended exposure limit (REL)		1
OSHA permissible exposure limit (PEL)		15
ACGIH threshold limit value (TLV)		1

*milligrams per cubic meter

Table C4. Minimum, maximum, and average particle concentrations (in milligrams per cubic meter)

	PM1	PM2.5	Respirable	PM10	Total
Minimum	0.028	0.029	0.032	0.041	0.045
Maximum	0.099	0.106	0.121	0.214	0.309
Average	0.039	0.042	0.046	0.066	0.082

Table C5. Sound level measurement results

Measurement description	Sound level (dB*)
Background noise in woodshop with only the fan operating	65.5
Using miter saw (Festool KS120EB) cutting 1" × 7" pine board	89.9
Using handheld router (Festool OF1400EQ) on 1" × 7" pine board	92.4–93.6
Using handheld router on wood corner pieces	93.4
In painting area when routing occurring in adjacent woodshop	75.6–78.4
Using table saw (SawStop Professional 1.75 horsepower) cutting plywood	85.6
Background noise at table saw with only local exhaust operating	79.8
Background noise at the conference table with woodshop table saw operating	70.7
Background noise at the conference table with woodshop table saw local exhaust on	67.3
Background noise at the conference table with only the fan in the woodshop on	62.0

*decibels

Table C6. Full-shift personal noise measurement results in decibels, A-weighted

Work area	Result using NIOSH REL criterion*	Result using OSHA AL criterion*	Result using OSHA PEL criterion†
Woodshop	88	82	80
Painting area outside woodshop	75	67	55
Employee workstation (area sample)	56	39	‡
Noise exposure limits (as 8-hour time-weighted averages)	85	85	90

*The criteria for calculating the NIOSH recommended exposure limit (REL) and OSHA action level (AL) include all sound levels greater than or equal to 80 decibels, A-weighted (dBA).

†The criteria for calculating the OSHA permissible exposure limit (PEL) include all sound levels greater than or equal to 90 dBA.

‡All sounds levels were below 90 dBA; therefore, no sound was integrated to calculate a result.

Table C7. Daily average radon concentration during December 11–21, 2018

Date	Radon (pCi/L*)
December 11	5.3
December 12	5.5
December 13	5.2
December 14	6.1
December 15	6.5
December 16	6.0
December 17	5.3
December 18	5.4
December 19	6.2
December 20	7.2
December 21	7.6

*picocuries per liter

Table C8. Illumination measurements in work areas

Measurement location	Lux
Painting station (middle)	73
Painting station (far end)	169
Painting station (close to office)	62
Far end of occupied space	77
Conference table	202
Worktable (near conference table)	208
Worktable (large table in back)	252
Back of facility	262
Center of warehouse row 2 (middle of artwork)	265

Section D: 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 the 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 short-term exposure limits ceiling values. Unless otherwise noted, the short-term exposure limit is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

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

- The U.S. Department of Labor OSHA permissible exposure limits (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the NIOSH Pocket Guide to Chemical Hazards [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Another set of OELs commonly used and cited in the United States is the ACGIH TLVs. The TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2023].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident

Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

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

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions.

Carbon Monoxide

CO is a colorless, odorless, tasteless gas produced by incomplete burning of carbon-containing materials, e.g., gasoline. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, and nausea. These initial symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. Coma or death may occur if high exposures continue. Exposure to CO limits the ability of the blood to carry oxygen to the tissues by binding with the hemoglobin to form carboxyhemoglobin (COHb) [ACGIH 2001; NIOSH 1972, 1977, 1979, 2010; Proctor et al. 1988].

The NIOSH REL for CO is 35 ppm for an 8-hour TWA exposure, with a ceiling limit of 200 ppm that should not be exceeded [NIOSH 2010]. The NIOSH REL is designed to protect workers from health effects associated with COHb levels in excess of 5% [NIOSH 1972]. The ACGIH recommends a TLV of 25 ppm as an 8-hour TWA. This is designed to protect workers from health effects associated with COHb levels in excess of 3.5% [ACGIH 2001]. The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure [29 CFR 1910.1000].

Wood Dust

Exposure to wood dust has been reported to cause both increases in respiratory symptoms, including nasal dryness, irritation, bleeding, obstruction, coughing, wheezing, and sneezing; sinusitis; and prolonged colds. These increases have been seen even at mean total dust concentrations below 4 mg/m^3. Reduced mucociliary transport rates have also been reported in workers chronically exposed to wood dust, and in one study the reduced rates were related to increasing dust concentrations. These effects were not seen following acute inhalation exposure, nor were they seen following inhalation of high concentrations of inert plastic spheres with a size distribution similar to that of beech dust. This implies that reduce respiratory mucous secretion and transport results from long-term exposure and is not caused simply by the mechanical action of the dust, although such irritation may be a contributing factor. Nasal mucosa changes have also been reported in woodworkers. Several studies have reported decreased ventilatory function, as measured by forced vital capacity and forced expiratory volume in one second, among workers exposed to wood dust. Some studies have also shown a significant decrease in woodworkers' lung function over the work shift, although no concentration-response relationship was seen [NIOSH 1987a].

Wood dust exposure may cause eye and skin irritation and respiratory effects. In industrial settings, certain hard woods, such as oak, maple, and walnut, have been linked to nasal cancer [Hathaway et al. 1991]. Loggers and persons involved in initial wood processing are exposed to irritant chemicals found in the bark or sap in the outer part of the tree. They are most affected by primary irritant dermatitis, which consists of erythema and blistering [Hathaway et al. 1991]. The adverse health effects that have been associated with exposure to wood dust upon which evaluation criteria are based include dermatitis, allergic respiratory effects, and mucosal and nonallergenic respiratory effects. NIOSH recommends that wood dust be considered a potential occupational carcinogen and that exposures be reduced to the lowest feasible level, not to exceed the REL of 1 mg/m^3 for both soft and hard woods [NIOSH 2010]. ACGIH has a TLV of 0.5 mg/m^3 for Western Red Cedar and 1 mg/m^3 for all other wood species, both of these limits are for the inhalable fraction [ACGIH 2023]. There is currently no specific OSHA PEL for wood dust. The OSHA PEL for total particulate not otherwise regulated is 15.0 mg/m^3 and 5.0 mg/m^3 for the respirable fraction, determined as 8-hour averages [29 CFR 1910.1000].

Noise

Noise-induced hearing loss (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, 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 a standard threshold shift (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 a significant threshold shift 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 −10 or 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 = $100 \times (C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n)$, where C_n 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.

Radon

OSHA has two relevant OELs for radon. The OSHA PEL for radon gas is 100 pCi/L or 3,700 becquerels per cubic meter (Bq/m^3), averaged over 40 hours in any work week of 7 consecutive days. However, because radon is a radioactive material, the OSHA whole body ionizing radiation dose limits also apply. The OSHA whole body ionizing radiation dose limit is 1.25 roentgen equivalent man (rem) or 12.5 millisieverts (mSv) per quarter. Given that there are four quarters per year, this implies that no one should receive a dose larger than 5 rem (50 mSv) in a year. This is the same as the National Council on Radiation Protection and Measurements (NCRP) recommended dose limit of 5 rem (50 mSv) [NCRP 1993]. Measuring radon gas concentrations alone are not sufficient to assess compliance with the OSHA ionizing radiation dose limits. Instead, dose modeling based on the radon gas concentrations must be done.

Other agencies also have recommendations for radon gas and radon progeny. NIOSH has an REL for radon progeny in underground mines of 1-working-level-month per year (WLM/yr). This REL is an upper limit of cumulative exposure; however, NIOSH recommends that exposures should be reduced to the lowest feasible level [NIOSH 1987b]. EPA has an action level of 4 pCi/L (148 Bq/m^3) for radon gas in homes and schools.

Section E: References

Methods

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