HealthHazard® Evaluation Program

Evaluation of Exposure to Metals and Noise During Shipbuilding and Ship Repair Operations

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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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Availability of Report

Copies of this report have been sent to the employer and employees at the facility. The state and local health departments and the Occupational Safety and Health Administration Regional Office have also received a copy.

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Introduction

Request

In April 2023, the National Institute for Occupational Safety and Health received a request for a health hazard evaluation (HHE) from an employer representative at a shipbuilding and ship repair company. The request concerned potential exposure to airborne metals and noise during various shipbuilding and ship repair activities.

Workplace

The company manufactured new ships and repaired existing vessels at two separate worksites. The production process included the following tasks:

- Plasma cutting
- Structural welding
- Pipe welding
- Grinding
- Fitting (structural plates)
- Pipe fitting
- Abrasive blasting
- Operating skid loaders, forklifts, and cranes

Employees used multiple materials such as welding wire, plasma torches, grinding wheels, and abrasive blasting media during these tasks. Employees completed numerous production activities in multiple buildings and aboard vessels.

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

Our Approach

In September 2023, we visited each facility (new build and repair) to learn more from management and employees about the production process, work tasks, potential exposures, and health concerns. During our visit, we reviewed facility health and safety documents, observed work tasks associated with each job title, and developed our plan to return and conduct exposure monitoring for airborne metals and noise. In April 2024, we returned to the two worksites and measured employees' exposures to airborne metals and noise during 4 days. We also observed work activities, personal protective equipment use, and exposure controls.

We collected 41 full-shift personal air samples on employees (23 in the new build facility and 18 in the repair facility) across 10 job titles. We collected 52 full-shift personal noise exposure measurements on employees (30 in the new build facility and 22 in the repair facility) across 9 job titles in the new build facility and 8 job titles in the repair facility.

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

Our Key Findings

Employees were overexposed to manganese

- We analyzed the air samples for 31 different metals. For most of the metals, employees' exposures were well below occupational exposure limits and no employees were exposed above Occupational Safety and Health Administration (OSHA) limits. However, employees in the following job titles were exposed to manganese above the NIOSH recommended exposure limit (REL) of 1.0 milligrams per cubic meter (mg/m^3) and the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®) of 0.07 mg/m^3, adjusted for a 10-hour work shift.
    - Welder-Structural (new build and repair)
    - Welder-Pipe (new build)
    - Fitter (new build)
    - Helper-Tacker (new build)

Employees were overexposed to noise

- Noise exposures in the following job titles were above the NIOSH REL of 85 decibels, A-weighted (dBA) for an 8-hour shift or 84 dBA for a 10-hour shift, the OSHA action level (AL) of 85 dBA for an eight hour shift or 83.4 dBA for a 10-hour shift, and the OSHA permissible exposure limit (PEL) of 90 dBA, which is the same for both 8- and 10-hour shifts:
    - Welder-Structural (new build)
    - Fitter (new build)
    - Abrasive Blaster (repair)
- Noise exposures in the following job titles were above the NIOSH REL and OSHA AL, but below the OSHA PEL:
    - Welder-Structural (repair)
    - Welder-Pipe (new build)
    - Fitter (repair)
    - Helper-Tacker (new build)

- Pipefitter (new build)
- Helper-Grinding (repair)
- Forklift Operator (new build)
- Skid Loader Operator (repair)

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.

Potential Benefits of Improving Workplace Health and Safety:

↑ Improved worker health and well-being	↑ Enhanced image and reputation
↑ Better workplace morale	↑ Superior products, processes, and services
↑ Easier 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 is a way of determining which actions will best control exposures. In most cases, the preferred approach is to eliminate hazards or to replace the hazard with something less hazardous (i.e., substitution). Installing engineering controls to isolate people from the hazard is the next step in the hierarchy. Until such controls are in place, or if they are not effective or practical, administrative controls 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 exposure to manganese

Why? Overexposure to manganese can have harmful effects. Inhalation of manganese-containing dust and fumes may cause respiratory and neurological problems. Exposure to manganese has been associated with health effects similar to people with Parkinson disease, such as poor hand-eye coordination, slower motor response, increased tremor, mood disturbance, and possible memory and intellectual loss.

We found structural welders, pipe welders, helper-tacker, and a fitter were exposed to manganese above NIOSH and/or ACGIH occupational exposure limits.

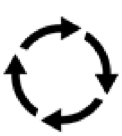
How? At your workplace, we recommend these specific actions:

Improve ventilation in work areas where employees were overexposed to manganese

- Investigate the feasibility of providing portable welding fume extractors capable of capturing welding fumes at their source.
    - The extractors should have a capture velocity in the range of 100–150 feet per minute.
    - Position extractor hoods within 18 inches of the weld. However, positioning the hood too close or capture velocities greater than 150 feet per minute may disturb the shield gas.
    - Train welders how to properly use the welding fume extractors
- Ensure that wall-mounted exhaust fans in buildings where welding is done work properly and are used when employees are welding.
- Place additional fans in work areas to move welding fumes away from employees.

Provide respiratory protection for employees overexposed to manganese

- Structural welders, pipe welders, and fitters should wear respiratory protection until manganese exposures are reduced to below occupational exposure limits.
    - At a minimum NIOSH Approved® N95® filtering facepiece respirators should be used based on our exposure measurement results.



Use the NIOSH Hierarchy of Controls to reduce exposures to below OELs

- More information about the NIOSH Hierarchy of Controls can be found on our website: About Hierarchy of Controls | Hierarchy of Controls | CDC.

Recommendation 2: Reduce risk of hearing loss from noise exposure

Why? Occupational hearing loss is one of the most common work-related illnesses in the United States. Each year, about 22 million U.S. workers are exposed to hazardous noise levels at work. Noise-induced hearing loss is irreversible and progresses 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. Even mild hearing loss can impair a person's ability to understand speech and hear many important sounds. In addition, some people with noise-induced hearing loss also develop tinnitus, a condition in which a person perceives a ringing, roaring, hissing, buzzing, chirping, or whistling sound even though no external sound is present. Currently, there is no cure for tinnitus. Noise-induced hearing loss symptoms can worsen over time and could be associated with more sick leave, job loss, and lower quality of life.

We found employees' noise exposures above the OSHA PEL, OSHA AL, and/or the NIOSH REL. Depending on work tasks and activities, noise exposures could be higher on some days.

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

Use engineering controls to reduce noise

- When appropriate and feasible, use sound barriers at noisy equipment to separate workers from noise sources.
- Reduce compressed air noise by using air nozzles that are specially designed to produce less turbulence and noise.

Properly adjust and maintain equipment to reduce noise

- Optimize voltage and wire feed speed for welding systems to meet but not exceed the proper intensity of welding power needed.
- Promptly repair equipment or tools that develop rattles, squeaks, noise from compressed air leakage, or other noises.
- Establish a preventive maintenance schedule to adjust, lubricate, and maintain equipment and production machinery.

Implement a "Buy Quiet" program to reduce noise by purchasing new equipment that produces less noise

- When replacing or purchasing equipment, seek equipment that makes the least noise.
- Information on Buy Quiet programs is available at [Buy Quiet - Background | NIOSH | CDC]

Ensure workers overexposed to noise wear appropriate hearing protection

- All employees in job titles in which noise exposures are above the NIOSH REL should continue to wear hearing protection.
- When noise exposures are above 100 dBA, employees should wear dual hearing protection (i.e., both insert ear plugs and earmuffs).

Supporting Technical Information

Evaluation of Metals and Noise Exposure During Shipbuilding and Ship Repair Operations

HHE Report No. 2023-0084-3425

August 2025

Section A: Workplace Information

The company builds new vessels (referred to as "new construction") at one location and does ship repair at another nearby location. All work is performed in either buildings located on the property adjacent to a river, or on vessels secured at a dock. Buildings at the new construction location have wall-mounted exhaust fans, but these did not operate during our visit. Each building was equipped with a large rolling door that was opened to facilitate moving of materials in and out of the building in addition to providing natural ventilation.

The company has a respiratory protection program which includes the elements specified in the OSHA respiratory protection standard [29 CFR 1910.134]. Workers wearing respirators are fit tested and medically evaluated annually. Most workers using respirators were provided with half-mask respirators with P100® particulate filters. Abrasive blasters wore loose-fitting powered air purifying respirators (PAPR) equipped with high-efficiency particulate air (HEPA) filters. The company also has a hearing conservation program as specified by the OSHA noise standard [29 CFR 1910.95]; provides and requires the use of foam-insert earplugs or earmuffs for all workers who enter the construction or repair yards, vessels and production buildings; includes all production workers in baseline and annual audiometric testing; and provides hearing conservation training.

New construction and repair activities consist of structural steel plate installation, pipe fitting and welding, structural welding, grinding, abrasive blasting, surface painting/refinishing, and oxygen-acetylene (oxy-acetylene) cutting or plasma cutting of steel. Flat pieces of zinc silicate-coated steel are cut using a handheld oxy-acetylene cutting torch and tack welded using metal inert gas (MIG) or solid electrode (stick) equipment to form the hull of a vessel or other structures within the hull. Pieces of steel are assembled and tacked in place by Fitters. Pipefitters cut and assemble lengths of steel or zinc galvanized pipe depending on the specifications of each vessel. Structural and pipe welders follow behind the work produced by the Fitters/Pipefitters and perform final welding using either MIG or stick welding machines. The composition of the welding wire/stick is mainly iron and manganese with lower amounts of zinc. Welders and helpers used pneumatic and electric grinders to clean metal, remove scale and dress welds. Abrasive blasters used pneumatically-driven blast nozzles that dispense iron silicate abrasive granules to remove rust, scale, old paint finishes from vessels prior to surface painting and refinishing. One employee operated the plasma cutting table to cut out specially shaped parts. Other jobs associated with new construction or vessel repair include mechanics, maintenance workers, forklift, skid loader, and crane operators. Each work shift usually lasts 10 hours, with exceptions made based on workload or worker personal circumstances (e.g., worker needed to leave prior to 10 hours due to an appointment).

The specific job titles we assessed for exposure to airborne metals during shipbuilding and/or repair work were:

1. Welders (Structural)
2. Welders (Pipe)

3. Pipefitter
4. Fitter
5. Plasma cutting table operator
6. Helper-Grinding
7. Helper-Tacker
8. Abrasive Blaster
9. Mechanic
10. Skid loader operator

The specific job titles we assessed for noise exposure during shipbuilding and/or repair work were:

1. Welders (Structural)
2. Welders (Pipe)
3. Pipefitter
4. Fitter
5. Plasma cutting table operator
6. Helper-Grinding
7. Helper-Tacker
8. Abrasive Blasters
9. Mechanic
10. Maintenance
11. Forklift operator
12. Skid loader operator
13. Crane operator

Section B: Methods, Results, and Discussion

Our objectives for the evaluation included the following:

- Observing work processes, practices, and workplace conditions.
- Measuring employees' full-shift exposures to metals in welding fumes.
- Measuring employees' full-shift personal noise exposures.

Methods: Air Sampling for Metals

We collected 41 full-shift personal air samples on employees (23 in the new build facility and 18 in the repair facility) across 10 job titles. We used 37-millimeter diameter, 0.8-micrometer pore-size, mixed cellulose ester filters and air sampling pumps calibrated at a flow rate of 2 liters per minute for sample collection. The air sampling collection media was attached to the employee's outer clothing in their breathing zone, approximately 10 inches from their nose and mouth. For the abrasive blasters, the sample media was placed inside the PAPR hood covering their shoulders and upper chest. We analyzed each sample for 31 metals (shown in Table C1) using NIOSH Method 7303, fourth edition, modified [NIOSH 2025]. The analytical laboratory modified method included lanthanum, lithium, silver, and zirconium for analysis and did not include bismuth, boron, gallium, gold, indium, neodymium, palladium, platinum, or sodium; however, we did not expect to find any significant exposure to the metals that were not included. Shift lengths could vary from 8 to 10 hours depending on work demands. Most employees during our visit were working 10-hour shifts. When employees worked longer than an 8-hour work shift, we adjusted the ACGIH TLV according to procedures recommended by Brief and Scala [1975].

Results: Air Sampling for Metals

All of the air samples were analyzed for 31 metals (Table C1). However, we found that for most of the metals, the air sample concentrations were below the analytical limit of detection and/or the limit of quantification (Table C1). For the 41 air samples analyzed, the metals in the highest concentrations were iron, manganese, and zinc. The results for these metals are reported in Table C2.

Analysis of airborne concentrations for iron, manganese, and zinc revealed that none of the personal exposures for iron or zinc exceeded any OEL. However, 13 personal exposure measurements for manganese exceeded the NIOSH REL of 1 mg/m^3 and/or the ACGIH TLV 0.07 mg/m^3 (inhalable limit adjusted for a 10-hour work shift) (Table C2). Manganese exposures across all job titles ranged from none detected to 1.26 milligrams per cubic meter (mg/m^3). Job titles that exceeded the NIOSH REL and/or ACGIH TLV for manganese included: Welder-Structural, Welder-Pipe, Helper-Tacker, and a Fitter. The values of manganese exposures exceeding the NIOSH REL and/or ACGIH TLV ranged from 0.07 mg/m^3 to 1.26 mg/m^3. Most of the exceedances above these OELs for these jobs occurred at the new build facility (10/13 samples); however, the two highest concentrations for manganese exceeding an OEL were measured on structural welders at the repair facility.

Methods: Noise Measurements

We took 52 personal time-weighted average (TWA) noise dosimetry measurements on employees (30 in the new build facility and 22 in the repair facility) across 9 job titles in the new build facility and 8 job titles in the repair facility. We used Larson Davis Spartan™ model 730 integrating noise dosimeters equipped with 0.25-inch free-field prepolarized condenser microphones (Model 375A03). The dosimeters recorded and data logged one-second averaged noise levels for the duration of the measurement period. The dosimeters were calibrated each day according to the manufacturer's instructions.

We attached the dosimeter microphone to the outside of 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 contact. 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 REL, the OSHA PEL, and the OSHA AL.

We took 66 integrated area sound level and octave band noise frequency measurements during representative work activities (40 measurements in the new build facility and 26 in the repair facility). These measurements provide information on equipment and work tasks that have high sound levels. The sound levels were measured using a using 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 to match the ear level of employees doing work tasks. Most measurements were taken within 3–6 feet of employees for about 10–60 seconds.

Following measurements, the noise measurement data stored on the noise dosimeters and sound level meter were downloaded, exported, and analyzed using Larson Davis G4® software and Microsoft Excel.

Results: Noise Measurements

Personal Noise Measurement Results

A summary of employees' full-shift noise exposure measurement results is provided in Table C3. We compared measurement results to NIOSH and OSHA noise exposure limits. Employees worked 8 to 10-hour shifts, but most were working 10-hour shifts during our site visit. For noise exposures, NIOSH adjusts the REL and OSHA adjusts the AL for shift lengths longer than 8 hours. OSHA does not adjust the PEL. These limits represent the amount of noise that most employees can be exposed to without substantial risk of hearing loss. OSHA and NIOSH measure and calculate noise exposures in different ways, as noted in Section D. Employers are required to keep noise exposures below OSHA limits. However, NIOSH considers its REL to be more protective.

These results reveal that for the new build facility, one or more employees in the following jobs had full-shift noise exposures above the NIOSH REL and OSHA AL:

- Welder-Structural
- Welder-Pipe

- Fitter
- Helper-Tacker
- Pipefitter
- Forklift Operator

The Plasma Table Operator was above the NIOSH REL for a 10-hour work shift but not above the OSHA AL.

For the repair facility, one or more employees' full-shift noise exposures were above the NIOSH REL and OSHA AL in the following jobs:

- Abrasive Blaster
- Welder-Structural
- Fitter
- Helper-Grinding
- Skid Loader Operator

The Crane Operator and Mechanic were also above the NIOSH REL but not above the OSHA AL.

Noise exposures were above the OSHA PEL for Welder-Structural and Fitter job titles in the new build facility and Abrasive Blaster in the repair facility. Of note, full-shift noise exposures for all the abrasive blasters we monitored and one of the structural welders were above 100 dBA.

Figures 1 and 2 show the time-history noise exposure profiles for two different structural welders. These profiles illustrate typical fluctuations in noise exposures throughout the work shift and show how exposures can vary across welders. Figure 1 shows a welder's noise exposure that generally ranged from 60–100 for about half the work shift and ranged from 70–115 dBA (at times reaching 120 dBA) for half the shift. Figure 2 shows a welder's noise exposure that generally ranged from 70–105 dBA (at times reaching 110 dBA) for most of the shift.

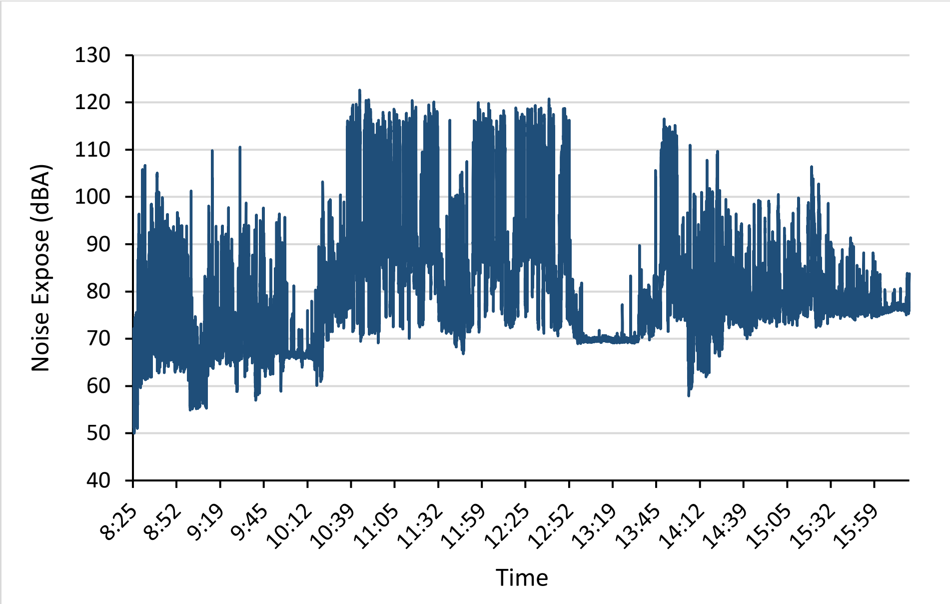


Figure 1. Time-history noise exposure profile for a structural welder with a TWA noise exposure of 102.4 dBA (based on NIOSH noise measurement criteria).

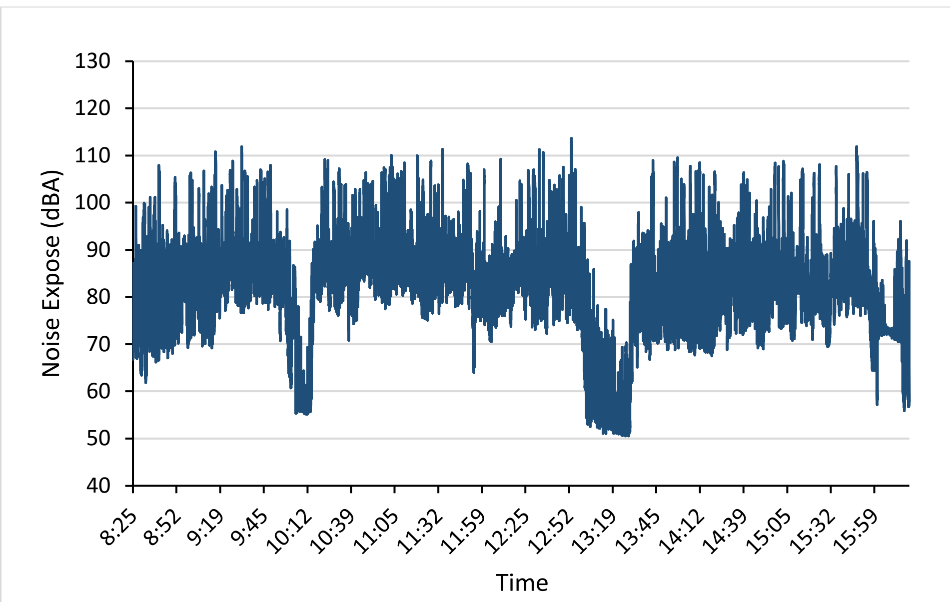


Figure 2. Time-history noise exposure profile for a structural welder with a TWA noise exposure of 92.7 dBA (based on NIOSH noise measurement criteria).

Sound Level Measurements Results

Sound level measurement results for the new build facility are provided in Table C4 and for the repair facility are provided in Table C5. Several different work tasks or tools generated high sound levels. The sound levels we measured during welding, grinding, arc gouging, using cutting torches, hammering, and abrasive blasting exceeded or nearly exceeded 100 dBA. We also found the range of sound levels for a task or during tool use could vary substantially. For example, the measured sound levels during welding ranged from 80.4–111.3 dBA, during angle grinder use ranged from 90.1–103.7 dBA, during arc gouging ranged 93.0–107.0 dBA, and at the plasma cutter ranged 77.5–102.4 dBA.

Discussion

We found that employees in jobs that involved structural welding, pipe welding, fitting (Fitters), and helper-tackers were overexposed to manganese at the new build and/or repair facilities. We observed some instances of uncontrolled welding fumes created during structural, pipe, fitter, and tacker welding operations. At times groups of welders worked very close to one another which could have increased the amount of welding fume exposure in the immediate work area. We noticed that some of the building exhaust fans located on the external walls were inoperable.

Engineering controls would be the most impactful approach to reduce employees' exposures to air contaminants. For example, using portable welding fume extractors to capture welding fumes near the point of generation may reduce exposures. Also, the general ventilation in buildings where welding occurs can be improved by ensuring that wall-mounted exhaust fans in the buildings are properly working and used consistently. In addition, using standing pedestal-style fans to move welding fumes away from employees can help reduce exposures. While engineering controls are being implemented or when engineering controls are not feasible, the use of properly selected and maintained respiratory protection is necessary to reduce exposures. We observed some employees wearing respiratory protection. Abrasive blasters wore loose-fitting PAPRs equipped with HEPA filters. Some welders used half-mask elastomeric respirators equipped with P100 disc filters.

Employee noise exposures in most of the job titles we monitored were above noise exposure limits. Employees did not typically conduct the same work task for the entire workday; therefore, an employee's noise exposure typically fluctuated across the work shift, as shown in Figures 1 and 2, as work tasks, task-related noise levels, and time-at-task varied. For example, welders spent their time alternating between welding and grinding but also used hammers. In addition, they spent time doing activities such as preparation work, which did not have high noise levels.

Sound levels in several job titles were above 100 dBA at times. At 100 dBA, an employees' full-shift TWA noise exposure would exceed the NIOSH REL in 15 minutes even if no other noise exposure occurred during the remainder of their work shift. At 111 dBA, which is the sound level measured during abrasive blasting, full-shift TWA exposure would exceed the NIOSH REL in 1 minute 11 seconds.

Sound levels for a task or during tool use could vary substantially. For example, the measured sound levels during welding ranged from 80.4–111.3 dBA, during angle grinder use ranged from 90.1–103.7 dBA, during arc gouging ranged 93.0–107.0 dBA, and at the plasma cutter ranged 77.5–102.4 dBA. These variances in sound levels can be related to the intensity of the activity. For example, more forceful hammer strikes, or grinder pressure may be necessary when working on some of the metal parts. Likewise, for some welds, greater intensity through higher voltage and wire feed speed may be needed, which leads to higher noise levels during the welding.

Noise reduction is best achieved using engineering controls when possible. For example, using a portable barrier wall to separate workers from high noise sources. Properly adjusting or setting up equipment can also lead to noise reduction. As an example, the welder may optimize the voltage and wire feed speed for welding systems to meet but not exceed the proper intensity of welding power needed. In addition, repairing equipment or tools that develop rattles, squeaks, or other noises, and establishing a preventive maintenance schedule to adjust, lubricate, and maintain equipment can help reduce unnecessary noise.

Noise from compressed air was evident in the facility. Compressed air which exits nozzles or other open-ended ports generates air turbulence and high noise levels, particularly high frequency noise. These tend to use much more compressed air than may be necessary and can therefore be more costly. Some manufacturers of engineered compressed air nozzles have shown that open tube nozzles generate up to 10 dB more noise than properly engineered nozzles. In contrast, efficient air nozzles complete the required task, produce less noise, and reduce compressed air consumption by 30% to 60%, resulting in substantial cost savings [Saidur et al. 2010]. Nozzles specifically designed to effectively complete the required tasks could be installed to use less compressed air and produce less noise. In addition, promptly repairing damaged compressed air hoses and fittings can eliminate unnecessary noise due to hose leaks. We measured sound levels of 98 dBA from a leaking compressed air hose.

Noise reduction is a critical part of an overall long-term exposure mitigation strategy. For example, when equipment is replaced, the amount of noise generated by the new equipment could be considered as part of the purchasing decision. "Buy Quiet" (Buy Quiet - Background | NIOSH | CDC) is a concept by which companies can reduce hazardous noise levels through the procurement process. Through this process, purchasers are encouraged to consult with equipment and tool manufacturers, compare noise emission levels for differing models of equipment and, whenever possible, choose equipment that produces less noise and vibration but are equally effective in accomplishing the required task. In addition, we recommend that the company continue to investigate the feasibility of using robotics for the cutoff process to reduce employees' noise exposures.

Continue to provide and ensure that workers overexposed to noise properly wear hearing protection. When noise exposures are above 100 dBA, employees should wear dual hearing protection (i.e., both insert ear plugs and earmuffs). In addition, we recommend using dual hearing protection when noise from tools or tasks are above 100 dBA.

Limitations

Our evaluation is subject to limitations. First, industrial hygiene sampling can only document exposures on the days of sampling at the locations sampled. These results may not be representative of conditions during other days. Also, we were unable to account for potential seasonal effects on general building/vessel ventilation at the two facilities (e.g., summer versus winter, open doors versus closed, fans on versus off).

Conclusions

The results of our air and noise sampling showed that Welders (Structural and Pipe), Fitters and Helper-tackers were overexposed to manganese. We found that employees' noise exposures in most of the jobs we monitored were above the NIOSH REL. Engineering controls such as portable welding exhaust, general building ventilation, use of noise barriers along with respiratory and hearing protection can prevent or reduce manganese and noise exposures at these facilities.

Attribution Statement

N95 and NIOSH Approved are certification marks of the U.S. Department of Health and Human Services (HHS) registered in the United States and several international jurisdictions.

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Section C: Tables

Table C1. List of possible elements on air sampling filters (NIOSH Method 7303)

Analyte	LOD (µg)	LOQ (µg)	Analytical range (µg/sample)
Aluminum	1.0	3.8	1.0–2500
Antimony	0.3	0.92	0.3–500
Arsenic	0.2	0.61	0.2–1250
Barium	0.02	0.056	0.02–500
Beryllium	0.001	0.0046	0.001–250
Cadmium	0.009	0.029	0.009–500
Calcium	0.4	1.5	0.4–2500
Chromium	0.09	0.29	0.09–1250
Cobalt	0.02	0.070	0.02–1250
Copper	0.3	0.95	0.3–2500
Iron	8.0	26	8.0–2500
Lanthanum	0.02	0.056	0.02–250
Lead	0.2	0.66	0.2–1250
Lithium	0.3	0.93	0.3–500
Magnesium	0.06	0.19	0.06–2500
Manganese	0.2	0.57	0.2–250
Molybdenum	0.04	0.13	0.04–1250
Nickel	0.2	0.75	0.2–500
Phosphorus	0.3	1.0	0.3–1250
Potassium	0.2	0.83	0.2–1250
Selenium	0.2	0.55	0.2–500
Silver	0.02	0.080	0.02–250
Strontium	0.005	0.016	0.005–250
Tellurium	0.1	0.43	0.1–250
Thallium	0.3	1.1	0.3–250
Tin	0.2	0.63	0.2–1250
Titanium	0.006	0.020	0.006–1250
Vanadium	0.05	0.17	0.05–250
Yttrium	0.008	0.027	0.008–250
Zinc	0.8	2.8	0.8–250
Zirconium	0.03	0.098	0.03–500

µg = micrograms
LOD = Analytical limit of detection
LOQ = Analytical limit of quantitation

Table C2. Full-shift personal air sample results for metals in milligrams per cubic meter of air (mg/m³)

Job Title	Sample ID	Facility	Iron	Manganese	Zinc
Welder - Structural	MET-1	New	0.08	0.01	0.01
	MET-2		1.85	0.92*	0.07
	MET-3		0.55	0.28*	0.29
	MET-14		0.98	0.58*	0.49
	MET-19		0.12	0.05	0.05
	MET-20		1.20	0.07*	0.04
	MET-21		0.62	0.16*	0.11
	MET-25	Repair	3.36	1.18†	0.39
	MET-26		1.18	0.39*	0.17
	MET-27		3.16	1.26†	0.35
	MET-37		0.15	0.002	0.03
	MET-38		0.10	0.001	0.01
Welder - Pipe	MET-11	New	1.59	0.70*	0.34
	MET-16		1.43	0.23*	0.51
Supervisor Pipefitter	MET-9	New	0.03	(0.001)	(0.002)
	MET-10		(0.02)	(0.001)	0.01
	MET-18		(0.01)	(0.001)	0.01
Pipefitter	MET-6	New	0.15	0.01	0.02
	MET-13		0.07	0.004	0.05
	MET-23		0.36	0.06	0.05
Fitter	MET-5	New	2.33	0.93*	0.58
	MET-8		0.63	0.03	0.10
	MET-15		0.40	0.03	0.14
	MET-22		0.05	0.004	0.01
	MET-28	Repair	0.06	0.001	(0.001)
	MET-29		0.34	0.003	0.01
	MET-30		0.11	0.01	0.01
	MET-34		0.38	0.002	0.03
	MET-36		0.26	0.002	0.03
Plasma Table Operator	MET-4	New	0.06	0.002	0.02
	MET-12		0.16	0.003	0.05
Abrasive Blaster	MET-31	Repair	0.12	(0.0005)	0.03
	MET-32		(0.02)	0.001	0.01
	MET-39		0.11	(0.0005)	0.04
	MET-40		0.06	(0.0003)	0.02
Mechanic	MET-24	Repair	(0.02)	(0.0002)	(0.001)
	MET-33		(0.02)	(0.0003)	(0.001)
Skid Loader Operator	MET-35	Repair	0.48	0.002	0.04
Helper - Tacker	MET-7	New	2.67	1.03†	0.68
	MET-17		1.54	0.07*	0.48
Helper - Grinding	MET-41	Repair	0.17	0.002	0.01
		NIOSH REL	5.0	1.0	5.0
		OSHA PEL	10.0	5.0 (ceiling limit)	5.0
		ACGIH TLV	3.5‡	0.07 (inhalable)‡	1.4‡
		MDC	0.01	0.0002	0.001
		MQC	0.03	0.001	0.003

MDC=Minimum Detectable Concentration; MQC=Minimum Quantifiable Concentration
Values in parentheses are estimates because the analytical result was below the MQC but above the MDC
* Indicates exposure was above the TLV
† Indicates exposure was above the NIOSH REL and the TLV
‡ Indicates exposure limit was adjusted to reflect a 10-hour work shift using the Brief & Scala model [1975]

Table C3. Range of full–shift personal noise exposure measurement results (in dBA) compared to the NIOSH REL, OSHA AL, AND OSHA PEL

Job Title	Facility	Number of Measurements	NIOSH REL measurement*	OSHA AL measurement*	OSHA PEL measurement†
Welder - Structural	New	7	87.9–102.4	82.6–95.9	79.8–95.7
Welder - Pipe	New	2	91.7–97.5	85.3–90.2	83.0–88.9
Fitter	New	4	85.9–97.4	80.8–91.3	76.2–90.0
Helper - Tacker	New	2	84.9–95.7	78.8–89.1	72.8–87.7
Pipefitter	New	6	75.9–93.1	66.9–88.7	58.5–85.9
Forklift Operator	New	3	85.2–88.7	79.8–85.2	73.1–80.9
Plasma Table Operator	New	2	80.4–84.4	72.3–77.4	66.5–73.8
Crane Operator	New	2	77.1–83.6	69.2–74.3	58.6–70.5
Maintenance	New	2	79.1–83.2	71.4–78.5	64.0–68–8
Abrasive Blaster	Repair	4	103.1–110.8	100.2–108.2	100.0–108.1
Welder - Structural	Repair	5	84.0–94.2	79.9–89.4	72.1–88.2
Fitter	Repair	5	87.8–91.8	83.6–87.5	78.7–85.4
Helper - Grinding	Repair	1	90.8	84.5	80.8
Skid Loader Operator	Repair	1	89.3	87.2	85.7
Crane Operator	Repair	2	84.3–85.7	76.1–78.4	70.8–74.0
Mechanic	Repair	2	83.8–85.1	77.5–79.3	72.3–75.6
Forklift Operator	Repair	2	80.2–83.0	77.0–79.9	60.7–69.5
Noise exposure limits (8–hour work shift)			85.0	85.0	90.0
Noise exposure limits (9–hour work shift)			84.5	84.2	90.0
Noise exposure limits (10–hour work shift)			84.0	83.4	90.0

* The criteria for calculating the NIOSH REL and OSHA AL includes all noise exposures greater than or equal to 80 dBA.

† The criteria for calculating the OSHA PEL includes all noise exposures greater than or equal to 90 dBA.

Table C4. Direct reading sound level measurements in the new build facility

Work Area, Task, or Tool	Number of measurements	Sound levels (dBA)
Compressor room	2	80.1–80.3
Exhaust area for plasma cutter dust (outside building)	1	86.7
Hammering on metal	4	98.2–102.2
Inside guard house	1	66.6
Leaking compressed air hose	1	97.8
Overhead crane alarm beeping (center of buildings 2 and 3)	3	83.0–91.3
Plasma cutter (at control panel during cutting)	5	85.4–102.4
Plasma cutter (at opposite side to control panel during cutting)	2	77.5–87.2
Plasma cutter background noise (plasma cutter off)	1	74.8
Using angle grinder	6	90.1–102.4
Using arc gouger on vessel	4	93.0–107.0
Using cutting torch	4	84.4–98.0
Using pencil grinder inside vessel	2	98.7–99.8
Using transition bevel torch	1	93.5
Welding on metal	4	80.4–111.3

Table C5. Direct reading sound level measurements in the repair facility

Work Area, Task, or Tool	Number of measurements	Sound levels (dBA)
Abrasive blasting inside hull of vessel	3	110.7–111.2
Background noise during work in vessel engine room	2	95.2–96.4
Crane cab (engine on idle to high RPM)	2	84.0–94.6
Employees in yard using grinder, hammer, chisel	1	89.6
Outside blast containment area on vessel (50 to 100 feet away)	6	88.9–96.2
Unloading abrasive blasting material from semi–tank (5 to 20 feet away)	5	94.3–108.6
Using angle grinder	3	99.9–103.7
Using sledge on metal (light strikes to heavy strikes)	2	94.4–105.4
Using torch on underside of vessel	2	94.8–95.8

Section D: Occupational Exposure Limits

NIOSH investigators refer to mandatory (legally enforceable) and recommended occupational exposure limits (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 time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limits (STEL) 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 recommended exposure limits (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, 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 the American Conference of Governmental Industrial Hygienists (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.

Welding Fumes

The effect of welding fumes on an individual's health can vary depending on the length and intensity of the exposure and the specific metals involved. Of particular concern are welding processes involving stainless steel, cadmium or lead-coated steel, and metals such as manganese, iron, nickel, chrome, zinc, and copper. Epidemiologic studies and case reports of employees exposed to welding emissions have shown an excess incidence of acute and chronic respiratory diseases [Antonini 2003; de Perio et al. 2022; NIOSH 1988]. These diseases include metal fume fever, pneumonitis, pulmonary edema, and lung cancer. Exposure to manganese has been associated with Parkinson-like health effects, such as poor hand-eye coordination, motor slowing, increased tremor, reduced response speed, mood disturbance, and possible memory and intellectual loss [Antonini et al. 2006; Bowler et al. 2006; Lundin et al. 2014; Racette et al. 2012; Welch et al. 2004].

Airborne welding fume concentrations vary greatly between workplaces [Korczynski 2000; Susi et al. 2000; Tharr et al. 1997]. The content of welding fumes depends on the base metal being welded, the welding process, and parameters such as voltage and amperage, the composition of the consumable welding electrode or wire, the shielding gas, and any surface coatings or contaminants on the base metal. The flux coating (core) of the electrode/wire may contain several organic and inorganic compounds. Welding fume constituents may include minerals, such as silica and fluorides, and metals, such as arsenic, beryllium, cadmium, chromium, cobalt, nickel, copper, iron, lead, magnesium, manganese, molybdenum, tin, vanadium, and zinc [NIOSH 1988; Welding Institute 1976].

OSHA has not established a PEL for total welding fumes; however, individual welding fume constituents (e.g., iron, manganese) have PELs [OSHA 2008a]. NIOSH has concluded that it is not possible to establish an exposure limit for total welding emissions because the composition of welding fumes and gases varies greatly, and the welding constituents may interact to produce adverse health effects. Therefore, NIOSH recommends controlling total welding fumes to the lowest feasible concentration and meeting the exposure limit for each welding fume constituent [NIOSH 2010].

In addition to welding fumes, many other potential health hazards exist for welders. Welding operations can produce gaseous emissions, such as carbon monoxide, ozone, nitrogen dioxide, and phosgene (formed from chlorinated solvent decomposition) [NIOSH 1988; Welding Institute 1976]. Welders can also be exposed to hazardous levels of ultraviolet radiation from the welding arc if welding curtains or other precautions are not used [Korczynski 2000].

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 2025, 1998]. NIOSH defines material hearing impairment as an average of the hearing threshold levels (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 logarithm of the ratio of the squares of the measured sound pressure to a reference sound pressure of 20 micropascals. The reference pressure 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 above the NIOSH REL or OSHA AL 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. Appendix D of the OSHA noise standard specifies maximum allowable octave-band background sound pressure levels in rooms used for audiometric testing [29 CFR 1910.95]. 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, 2025].

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]. 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 2025, 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). 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 [Mirza et al. 2018; Osguthorpe and Klein 1991; Schlauch and Carney 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 [NIOSH 2025, 1998]. When noise exposures exceed the REL, NIOSH recommends using hearing protection and implementing a hearing loss prevention program [NIOSH 2025, 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 2008b]. OSHA requires implementation of a hearing conservation program when noise exposures exceed the AL [OSHA 2008b].

An employee's daily noise dose, based on the duration and intensity of noise exposure, can be calculated according to the formula: Dose = $100 \times (C_1/T_1 + C_2/T_2 + ... + C_n/T_n)$, 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.

Section E: References

Methods, Results, and Discussion

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