HealthHazard Evaluation Program

Evaluation of Noise Exposures at a Metal Walkway Manufacturer

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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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Table of Contents

Main Report

Supporting Technical Information

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Introduction

Request

Employees of a metal walkway manufacturer confidentially requested a health hazard evaluation due to concerns about the potential for hearing loss from noise exposures in production areas of the facility.

Workplace

The workplace was a large single-story building which included production areas, administrative offices, a conference room, and a break room. The company manufactured metal walkways and mezzanines from sheet metal using equipment such as reticulators (equipment which perforate metal), press brakes, riveters, mesh welders, and waterjets. The workplace had 250 employees and operated one 8-hour shift five days per week. All production employees were included in a hearing conservation program and all personnel were required to wear hearing protection while in production areas.

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

Our Approach

We visited the workplace in September 2022, to measure employees' noise exposures in the production areas of the facility. We completed the following activities during our evaluation:

- Measured production employees' full-shift personal noise exposures.
- Took sound level and noise frequency measurements across production areas.
- Observed work processes, production practices, workplace conditions, and spoke with employees and management.
- Reviewed workplace hearing conservation program documents.

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

Our Key Findings

Employees were overexposed to noise

- Employees noise exposures in all the jobs we monitored were above National Institute for Occupational Safety and Health (NIOSH) noise exposure limits. Noise exposures in most jobs were also above Occupational Safety and Health Administration (OSHA) noise exposure limits.

Some insert hearing protectors did not fit well

- Some employees did not roll the foam insert hearing protectors into a narrow cylinder before putting them into their ear.
- Some employees did not insert their hearing protectors fully into their ear.
- Some of the hearing protectors were dirty, which can affect how well they work.

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
- Better workplace morale
- Easier employee recruiting and retention
- Enhanced image and reputation
- Superior products, processes, and services
- 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 practical, 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/shpguidelines/index.html.

Recommendation 1: Reduce hearing loss risk from on-the-job noise exposure

Why? Noise-induced hearing loss is an irreversible condition that can get worse with noise exposure. Unlike some other types of hearing disorders, noise-induced hearing loss cannot be medically treated. Noise-exposed workers can develop substantial noise-induced hearing loss before it is clearly recognized. Noise monitoring results showed that employees' noise exposures were above occupational noise exposure limits.

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

Use engineering controls to reduce noise

- Enclose, partially enclose, or use sound barriers at noisy equipment, particularly reticulators, to reduce noise.
- Reduce compressed air noise using air nozzles that are specially designed to produce less turbulence and noise.
- Place heavy equipment, such as reticulators, on appropriately designed vibration isolation pads to reduce the vibration transmitted from equipment to the surrounding floor and other surfaces.
- Where feasible, construct a 3- or 4-sided booth for equipment operators to stand in while observing production. Use thick, clear acrylic windows in the booth so that operators can easily see equipment.
- Consult with noise control engineers who are certified by the Institute of Noise Control Engineers and have expertise in occupational noise reduction for additional guidance on noise controls.

Properly adjust and maintain equipment to reduce noise

- Promptly perform maintenance repairs when equipment develops rattles, squeaks, compressed air hiss, or other noise.
- 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 | CDC Archive.

Improve hearing protection use to reduce hearing loss risk

- Ensure that employees always use hearing protection properly when working in production areas.
  - For foam insert hearing protectors, train employees to roll the hearing protectors into a narrow cylinder before fully inserting into their ear canal.
  - Make sure employees replace disposable hearing protectors when dirty.
  - Conduct hearing protector fit testing to help ensure proper fit and attenuation. For additional information on NIOSH hearing protector fit testing recommendations refer to the recent NIOSH Science Policy Update: Individual Fit-Testing Recommendation for Hearing Protection Devices.

Use NIOSH recommendations for evaluating hearing loss

- In addition to following OSHA requirements for identifying hearing threshold shifts, evaluate employees' hearing test results using the NIOSH recommendations for identifying hearing threshold shifts. The NIOSH recommendations are more protective and will lead to identifying employees with hearing loss earlier and allow for earlier intervention to prevent further hearing loss.
- 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.

Recommendation 2: Address other health and safety issues we identified during our evaluation

Why? A workplace can have multiple health hazards that cause employee illness or injury. Like those identified above, these hazards can potentially cause health problems, lower morale and quality of life for your employees, and possibly increase business costs. We saw the following potential issues during our evaluation:

- Mineral oils or metalworking fluids on the floor near some of the reticulators led to slippery floors and risks for slips and falls.
- Electrical cords across the floor near some reticulators could pose trip hazards. In addition, the insulation jacket of one cord showed signs of excessive wear.

Although they were not the focus of our evaluation, these hazards could cause harm to your employees' health and safety and should be addressed.

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

Implement strategies to restrict and prevent mineral oils and metalworking fluids from reaching the floors around the reticulators

- Limit the amount of mineral oil and metal working fluid used at the reticulators to the minimum needed.
- Ensure that fluid spray nozzles are properly positioned to direct fluid sprays only where needed and minimize overspray.
- Install containment shields or catch basins, if needed, to keep overspray contained.
- Promptly and thoroughly clean floor areas where mineral oils or metal working fluids or residues have accumulated.

Provide permanent wiring to equipment through electrical conduit

- Do not place extension cords across walking and working surfaces. Install permanent wiring to equipment through electrical conduit which extends to the equipment from above the equipment.
- For any extension cords in use, periodically inspect the cords to ensure that no damage is evident. If damage is noted, promptly replace the electric cords.

Supporting Technical Information

Evaluation of Noise Exposures at a Metal Walkway Manufacturer

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Section A: Workplace Information

Background

The company manufactured metal walkways and mezzanines from sheet metal. The production floor included several different work areas and equipment including reticulators which perforated metal, press brakes, riveting machines, mesh welding, and high-pressure waterjets. The worksite also had several maintenance and material handling workers. The workplace had 250 employees and operated one 8-hour shift five days per week, Monday through Friday. All production employees were included in a hearing conservation program based on previous noise measurements. All personnel were required to wear hearing protection while in the production areas.

Section B: Methods, Results, and Discussion

Our objectives for the evaluation included the following:

- Observe work processes, practices, and workplace conditions.
- Measure full-shift personal noise exposures of production employees.
- Measure sound levels and characterizing one-third octave band noise frequency levels of production equipment.
- Identify potential noise control strategies in production areas.

Methods: Noise Exposure, Sound Level and One-third Octave Band Measurements, and Document Review

Noise Exposure Measurements

We took 36 personal time-weighted average (TWA) noise dosimetry measurements of employees in 15 different work areas over two days. We also took one full-shift area noise dosimetry measurement in the woodworking area. No employee worked in the woodworking area for a full work shift, but employees used woodworking equipment and tools in the area as needed. We used Larson Davis Spartan™ model 730 integrating noise dosimeters equipped with 0.25-inch free-field pre-polarized 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.

For personal noise exposure measurements, 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 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 Larson Davis G4® software.

Sound Level and One-third Octave Band Measurements

We took sound level and noise frequency measurements in work areas where we also conducted personal noise exposure monitoring. These measurements provide information on equipment and work tasks that have high sound levels. In addition, analysis of the frequency distribution characteristics of workplace noise through one-third octave band measurements can help identify predominant noise frequencies of noise sources and provide guidance on potential engineering or other noise control strategies. 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. We measured one-third octave band noise frequency levels at each one-third octave band center frequency from 6.3 to 20,000 hertz (Hz) (corresponding to frequencies of 5.62–22,400 Hz). 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 standing or seated employees. Most measurements were taken within 3–6 feet 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 Microsoft Excel.

Noise and Hearing Conservation Programs Document Review

For our review, the company provided a copy of their comprehensive written hearing conservation program which included appendices on noise exposure measurements, hearing protection selection, noise exposure limits for extended work shifts, and managing audiometric testing. The company also provided a report of previous noise dosimetry monitoring at the facility in 2022, completed by an external consultant.

Results: Noise Exposure, Sound Level, and One-third Octave Band Measurements

Noise Exposure Measurements

Full-shift TWA personal noise exposure measurement results are provided in Table C1 of Section C. We compared the employees' noise exposures with the occupational noise exposure limits set by NIOSH and OSHA. 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 E. For an 8-hour work shift, the NIOSH REL is 85 decibels, A-weighted (dBA); the OSHA action level (AL) is 85 dBA; and the OSHA PEL is 90 dBA. Employers are required to keep noise exposures below OSHA limits. However, NIOSH considers its REL to be more protective.

These results reveal that full-shift noise exposures in the 15 different work areas we monitored were above the NIOSH REL. Noise exposures in all work areas except the metal support components area and water jet were also above the OSHA AL, but only one personal sample was collected in each of these areas. Results between NIOSH and OSHA measurements differ due to differences in their respective noise measurement criteria, as noted in Section E. Noise exposures at all the reticulators, except the 90-ton, were above the OSHA PEL. At times, reticulator operators' noise exposures reached or exceeded 100 dBA. Figure D1 shows the time-history noise exposure profiles for a 600 Ton Bliss and a 400 Ton Niagra reticulator operator. These profiles illustrate fluctuations in noise exposures throughout the work shift, generally ranging from 85–100 dBA, but at times exceeding 100 dBA and reaching 110 dBA.

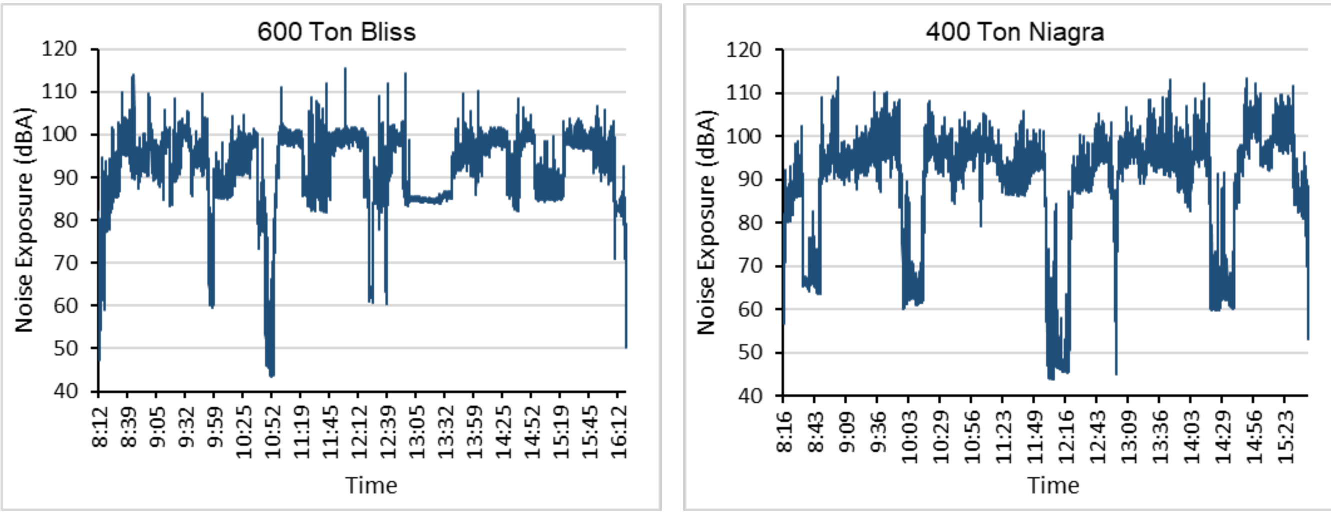

Figure 1. Time-history noise exposure profiles for a 600 Ton Bliss (left) and a 400 Ton Niagra reticulator operator.

Sound Level and One-third Octave Band Measurements

Table C2 provides direct-reading sound level measurement results taken while production equipment was operating. Overall, the reticulators had the highest sound levels across all production areas and ranged from 90.2–102.7 dBA. Among the reticulators, the 400 Ton Niagra had the highest sound levels (100.2–102.9 dBA) and the 90 Ton had the lowest levels (91.7–92.1 dBA). We also found sound levels above 90 dBA at the Pacific press brake, LVD 14-foot press brake, BC-1, and woodworking (during use of the pneumatic bander). Some of the sound level measurements at the flex tray mesh welding and riveter areas were above 90 dBA. The sound level at the water jet was 82.8 dBA at the operator position but increased to 97.6 dBA when the operator used compressed air for cleaning.

One–third octave band sound level measurement results at the reticulators are provided in Figure D1. The highest frequency-specific sound levels at both the 600 Ton Bliss and 400 Ton Bliss were across the frequencies 63–1250 Hz and were above 90 dB and up to 95 dB for some of the octave band measurements across these frequencies. Sound levels at the Niagra reticulator exceeded 90 dB across most of the frequencies from 80–6300 Hz and were also slightly above 90 dB at 6.3 Hz. The highest frequency specific sound levels were at 100 Hz (94 dB) and 4000 Hz (95 dB). The #1 Verson had a similar frequency pattern as the Niagra but sound levels were only above 90 dB at frequencies of 100 Hz (91 dB) and 200 Hz (93 dB). Octave band measurements at the 250 Ton Minster showed that the highest frequency specific sound levels were at 80–1000 Hz, but only exceeded 90 dB at 100 Hz (ranging 94–98 dB) and 200 Hz (91 dB). Octave band sound levels at the 90 Ton reticulator were highest across the frequencies 125–500 Hz, ranging 81–87 dB.

Results: Document Review

Noise and Hearing Conservation Written Program

The written noise and hearing conservation program, which was last updated in 2019, outlines the minimum requirements for hearing conservation, including noise exposure assessment at the facility, hearing protection, noise controls, audiometric testing, training, and recordkeeping. Area noise surveys and personal noise dosimetry are used to determine sound levels and personal noise exposures across the facility. Hearing protection is required in areas where noise exposures are above 80 dBA. When noise exposures are above 94 dBA, the company requires the use of dual hearing protection, i.e., the use of both insert ear plugs and earmuffs. Annual audiometric testing is completed and engineering controls for noise reduction are evaluated when noise exposures are at or above 85 dBA. The company's audiometric testing program includes a baseline exam, annual audiograms, confirmation retesting if a standard threshold shift (STS) is identified, and an exit audiogram within 3 months after employment ends. Employees whose noise exposures are above 80 dBA are provided with annual training which includes the potential effects of hazardous noise on hearing, PPE selection and guidance, proper fitting and use of hearing protection, and the purpose of audiometric testing and how to interpret results.

Discussion

Noise Exposures

Employees' personal noise exposures in the 15 work areas we monitored were above the NIOSH REL. In addition, employees' noise exposures in all but the metal support component and woodworking areas were above the OSHA AL. With the exception of the 90 Ton, all the reticulator operators' noise exposures were also above the OSHA PEL. However, sound level measurements at the 90 Ton reticulator showed that levels were above 90 dBA during production. Depending on the amount of production time at the 90 Ton, employees' noise exposures could be above the OSHA PEL on some days. Personal noise exposure measurements completed for the company by an external industrial hygiene consultant in 2022 showed similar exposures when compared to our measurements for employees at the 400 Ton Niagra, riveters, and flex tray but lower exposures than our measurements at the 90 Ton, 600 Ton Bliss, and for material handlers. Variability in noise exposure measurement collected at different times can be expected due to differences in production volume that can occur over time or day-to-day. In addition, time-history noise exposure profiles also reveal varying noise levels throughout the work shift with the highest levels occurring during active production.

Fourteen of the employees we monitored worked at the same job or equipment on the two consecutive days of personal noise monitoring. For these employees we evaluated the day-to-day variability in their noise exposures. Overall, the day-to-day variability ranged from 0.4 dBA to 5.1 dBA. However, for 13 of the 14 employees the variability was much less, ranging from 0.4 dBA to 2.2 dBA (Median = 0.7).

The hearing protectors used by these employees, if well-fitting, can provide adequate noise attenuation. Poor fit can occur due to improper insertion of hearing protectors or inability of a specific brand/model of hearing protector to properly fit an individual employee. We observed consistent use of hearing protection by employees but some of the foam insert earplugs were dirty which can affect fit or increase risk for ear irritation or infection. We also observed that some employees did not fully insert foam hearing protectors into their ear canal or did not roll their foam earplugs into a narrow cylinder before inserting into the ear canal. Research has shown that ear plugs can appear to be properly inserted into the ear canal but still provide minimal noise attenuation because of poor fit due to factors such as improper insertion technique or incorrectly sized ear plugs for the wearer [NIOSH 1998; Smalt et al. 2021]. Conducting hearing protector fit testing can help ensure that the hearing protectors used by employees fit properly and will provide adequate noise attenuation [NIOSH 2025].

Octave Band Sound Level Measurements and Engineering Controls

Most workplace noise is broadband noise distributed over a wide range of frequencies. For analysis of the frequency distribution characteristics of workplace noise, the frequency spectrum is broken into smaller frequency bands. The most common being the octave band, which is defined as a frequency band where the upper band frequency is twice the lower band frequency. The one-third octave band further divides each octave band into three smaller frequency bands to provide more detailed information about noise frequency characteristics. Analysis of the frequency distribution characteristics of workplace noise can help identify the predominate frequencies of noise sources and provide guidance on selection of possible engineering or other noise control measures.

Engineering controls for noise should focus on reducing noise at the reticulator area where workers had the highest noise exposures. One-third octave band noise frequency measurements at the reticulators showed that the highest sound levels varied across noise frequencies. Most of the reticulators had higher one-third octave band noise levels within the frequencies ranging from 63 Hz to 1000 Hz. However, the Niagra and Verson reticulator also had high one-third octave band noise levels at frequencies above or below this range. In general, lower frequency noise of 500 Hz or less is likely generated by vibration. Installing noise controls that reduce or isolate the vibration from equipment such as mounting equipment on vibration isolation pads can help decrease noise levels. Strategies to reduce higher frequency noise include noise enclosures, barriers, or sound absorption [Driscoll 2022]. In addition, where feasible, installing booths for operators to stand in when observing production could also help reduce personal noise exposures. Regular and preventive equipment maintenance can also reduce noise. For example, we noted noise from some squeaky roller wheels on conveyors in the rivet area, which could potentially be alleviated through lubrication or other maintenance of the roller mechanisms. Noise from compressed air was also evident in the facility. Compressed air which exits open-ended 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.

Noise reduction should also be part of an overall long-term strategy. For example, when equipment is replaced, the amount of noise generated by the new equipment should be considered as part of the purchasing decision. “Buy Quiet” 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.

Limitations

This evaluation is subject to some limitations. The employee noise exposure assessment and sound level measurements only documented exposures, conditions, and results on the days of the evaluation. These results are subject to day-to-day variation and may not be representative of other days. The production processes used at this facility were unique; findings from this evaluation may not be generalizable to other facilities.

Conclusions

Employees' noise exposures in all the jobs we monitored were above National Institute for Occupational Safety and Health (NIOSH) noise exposure limits. Noise exposures in most jobs were also above Occupational Safety and Health Administration (OSHA) noise exposure limits. We observed some deficiencies in hearing protection use such as not rolling foam insert hearing protectors into a narrow cylinder before insertion into the ear or not fully inserting hearing protection into the ear. To reduce noise exposures, we recommend using engineering controls, properly adjusting and maintaining equipment to reduce noise from rattles, squeaks, and compressed air hiss, implementing a "Buy Quiet" program by purchasing new equipment that produces less noise, and improving hearing protection use.

Section C: Tables

Table C1. Range of full-shift personal noise exposure measurement results (in dBA) compared to the NIOSH REL, OSHA AL, and OSHA PEL

Work area	Number of measurements	NIOSH REL measurement*	OSHA AL measurement*	OSHA PEL measurement†
600 Ton Bliss Reticulator	2	94.5–96.3	93.1–95.0	91.8–94.3
400 Ton Bliss Reticulator	2	94.8–95.8	93.0–94.2	92.2–93.9
400 Ton Niagra Reticulator	2	95.3–95.7	93.2–94.3	92.6–93.9
250 Ton Minster Reticulator	2	93.3–93.9	92.0–92.8	90.5–91.9
250 Ton #1 Reticulator	2	93.3–93.7	91.2–91.9	90.6–91.5
90 Ton Reticulator	2	91.0–91.6	89.1–90.1	87.8–88.9
Grating Press Brake	2	92.1–94.3	89.2–91.0	86.4–89.3
Cincinnati 14 Foot Press Brake	2	87.1–92.2	85.0–89.0	77.2–85.9
Pacific 26 Foot Press Brake	2	91.3–91.7	89.4–89.7	87.4–87.5
Material handler	2	90.8–91.1	88.1–88.7	84.3–85.6
Flex tray	6	85.3–90.2	83.1–89.0	72.4–85.2
Riveter	6	86.1–88.6	84.1–86.9	69.8–83.5
Maintenance	2	90.8–91.8	86.5–88.0	84.5–85.8
Metal support components	1	87.2	84.1	79.3
Water jet	1	85.7	81.9	75.7
Woodworking (area sample)	1	82.5	81.0	60.8
Noise exposure limits (8-hour work shift)		85.0	85.0	90.0

* The criteria for the NIOSH REL and OSHA AL includes all noise exposures greater than or equal to 80 dBA. NIOSH uses a 3-dB exchange rate and OSHA uses a 5-dB exchange rate.

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

Table C2. Direct reading sound level measurements

Work area	Number of measurements	Sound level (dBA)
600 Ton Bliss Reticulator	7	95.3–99.7
400 Ton Bliss Reticulator	3	94.6–99.7
400 Ton Niagra Reticulator	6	98.4–102.9
250 Ton Minster Reticulator	3	95.2–97.3
#1 Verson Reticulator	7	90.2–98.1
90 Ton Reticulator	2	91.7–92.1
Pacific Press Brake	8	90.5–94.5
LVD Press Brake 26-foot	2	85.9–86.2
LVD Press Brake 14-foot	1	90.2
Cincinnati Press Brake 14-foot	2	84.7–85.3
BC-1	9	90.2–94.4
Flex tray mesh welding	4	86.6–93.3
Metal support components	2	85.8–86.9
Riveter (#8, #9, #10 stations)	6	84.4–91.9
Water jet	2	82.9–97.6
Woodwork (pneumatic bander)	1	94.2
Maintenance	1	81.6

Section D: Figures

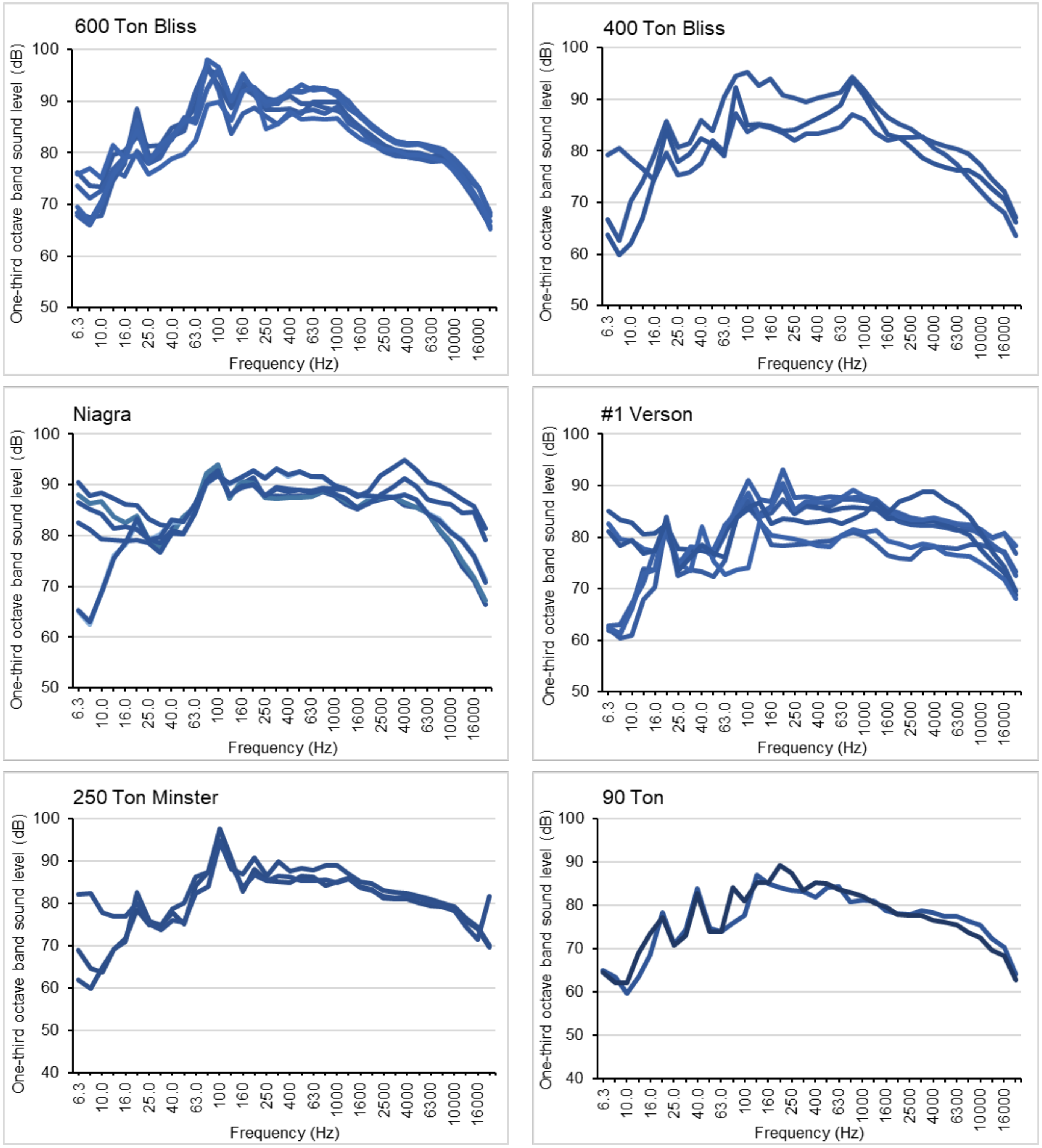

Figure D1. One-third octave band sound levels at the reticulators. Each line is a separate measurement.

Section E: 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 2007]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.

- Another set of OELs commonly used and cited in the United States includes the threshold limit values or TLVs, which are recommended by 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.

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 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, as recommended by NIOSH [NIOSH 1998] and required by OSHA [29 CFR 1910.95]. 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].

The OSHA hearing conservation standard requires analysis of hearing changes from baseline hearing thresholds to determine if a 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). 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. When noise exposures exceed the REL, NIOSH recommends 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 = $100 \times (C_1/T_1 + C_2/T_2 + ... + C_n/T_n)$, 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 F: References

Discussion

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