Ergonomic Evaluation of a Gas Assembly Line Process at a Water Heater Manufacturer

HHE Report No. 2024-0006-3419

July 2025

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Keywords: North American Industry Classification System (NAICS) 335220 (Major Household Appliance Manufacturing), Ergonomics, Musculoskeletal Disorders, MSDs, Manaufacturing, Water Heaters, Gas Assembly, Tennessee

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].

Availability of Report

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

Recommended Citation

NIOSH [2025]. Ergonomic evaluation of a gas assembly line process at a water heater manufacturer. By Hayden MA, Ramsey JG, Barim MS. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Health Hazard Evaluation Report 2024-0006-3419, https://www.cdc.gov/niosh/hhe/reports/pdfs/2024-0006-3419.pdf.

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Introduction

Request

Employer and union representatives from a water heater manufacturer requested a health hazard evaluation. They were concerned about potential ergonomic risk factors and potential for musculoskeletal disorders in assembly line employees for gas water heaters.

Workplace

The facility had two shifts and three assembly lines dedicated to gas, flex, and electric water heaters. We evaluated employees with various job tasks at the assembly line for gas water heaters. The job tasks and workstations varied depending on the water heaters' height and diameter. Employee job tasks included inspecting, welding, packaging, or transporting pieces from inventory to assemble the water heater tank.

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

Our Approach

We visited the workplace on January 31–February 1, 2024, to learn more about the ergonomic risk factors in the gas assembly line. We completed the following activities during our evaluation:

- Observed work processes, practices, and workplace conditions.
- Measured workstation parameters including vertical and horizontal heights and reach distances.
- Reviewed the written ergonomic program, injury and illness records, and two prior ergonomic assessments.

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

Our Key Findings

Workstation design had ergonomic risk factors which increased employee risk of musculoskeletal disorders

- Employees repetitively reached or worked at or above shoulder height.
- Employees repetitively bent at the waist to grab materials close to the ground.
- Employees repetitively worked in awkward postures to reach for a part to attach to the tank or look under the tanks for quality check.

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

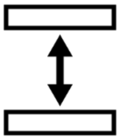
The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls 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 risks for musculoskeletal disorders

Why? Musculoskeletal disorders are conditions that involve the nerves, tendons, muscles, and supporting structures of the body. They can be characterized by chronic pain and limited mobility. A substantial body of data shows strong evidence of an association between musculoskeletal disorders and certain work-related factors (physical, work organizational, and psychosocial). The preferred method for preventing and controlling work-related musculoskeletal disorders is to design tasks, workstations, and tools and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the employee.

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

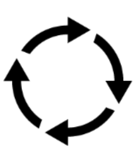


Adjust workstations or stacked material height to accommodate the employee.

- When designing workstations, consider where the employee handles assembly pieces and tools.
    - Standing hand working heights should be adjustable to 38–47 inches or fixed at 42 inches.
    - Seated hand working heights should be adjustable to 27–36 inches or fixed at 36 inches.
- Raise the material or the work when tasks require reaching down to grab materials or bending to assemble parts.
    - The reach distance to materials should be less than 16 inches.
    - For standing workstations, vertical height to grab materials should be between 24–70 inches.
    - For seated workstations, vertical height to grab materials should be less than 46 inches.
- Talk with employees about the recommended height level to use for stacking materials and discuss options to improve their vertical space.
    - Materials placed on workstations should be stacked less than 70 inches and higher than 24 inches.
    - Adjust the setup to keep materials stacked vertically within this range.

Replace worn out anti-fatigue mats or add anti-fatigue mats for employees who routinely stand as part of their job.

- Mats should be at least 0.5 inches thick. They should have an optimal compressibility (firmness) of 3%–4% and have beveled edges so they are not tripping hazards. They should be at least 8 inches under a workstation to keep standing surfaces even.
- Mats should cover the entire area where employees move while performing their work task. They should be replaced when they appear worn out or are damaged.



Continue to rotate job tasks for employees performing highly repetitive work.

- Develop a job rotation plan to move employees working in high-frequency hand and finger motion tasks to other jobs that require using different muscle-tendon groups. An effective job rotation plan will reduce the risk of musculoskeletal disorders.
- Provide frequent breaks for employees working in high-frequency hand and finger motion tasks such as hand trimming.

Recommendation 2: Get regular input from employees about workplace safety and health issues and use this input to improve work conditions

Why? Monitoring employee concerns, satisfaction, and well-being is useful for finding areas of focus for intervention and improvement. Engaging employees and asking for their input about work builds trust and morale. Employees will feel their input is valued and useful for improving working conditions.

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

Use employee input to guide efforts in improving worker safety, health, and well-being.

- Form an active ergonomics committee that includes management, employee, and union representatives. Effective committees use employee input and experience to help determine work practice and engineering controls.
- Continue to provide ergonomics training. Training could include instructor-led or online classes, as well as training offered at national ergonomics conferences. The purpose of training is to learn about practical, cost-effective workplace solutions.
- Engage directly with employees to identify their specific needs, such as adjusting platform heights to suit individual preferences. Facilitate discussions to uncover potential barriers to implementing these adjustments, ensuring solutions are both effective and employee-focused.

Recommendation 3: Address other health and safety issues we identified during our evaluation

Why? A workplace can have multiple health and safety hazards that cause worker illness or injury. Similar to the ones identified above, these hazards can potentially cause serious health symptoms, lower morale and quality of life for your employees, and possibly increased costs to your business. We saw the following potential issues at your workplace:

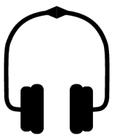
- Worn out steel-toed boots
- Poorly inserted hearing protection devices
- Trip hazard in the gas hook-up area
- Concern about exposure to eyes from infrared radiation

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

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

Remind employees the value of replacing their worn steel-toed boots.

- The company provides funding for employees to replace footwear yearly, if needed.



Improve the use of personal hearing protection.

- In required areas, make sure that employees always wear hearing protection; if ear plugs are used, be sure they are inserted properly.
- Provide hands-on training for all employees and supervisors on how to insert hearing protectors properly and the importance of proper hearing protector fit.
- Consider giving employees hearing protector fit testing to find out the noise attenuation (reduction) of protectors worn by employees.

Provide covers or secure cords to prevent tripping hazards.

Reduce employees' exposure to direct sight of infrared radiation (IR) by increased shielding or IR glasses.

- Although there are no enforceable limits on infrared radiation, there is guidance through the International Commission on Nonionizing Radiation Protection (ICNIRP) located at https://www.icnirp.org/en/frequencies/infrared/infrared.html.
- Increase shielding at the area where tanks are exiting the oven.

Supporting Technical Information

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Section A: Workplace Information

Employee Information

Number of employees at time of evaluation: 50 employees worked first shift at the gas assembly line. A total of 250 employees worked at the facility.

Length of shift: eight hours and a 30-minute lunch break.

Union: United Steelworkers

History of Issue at Workplace

Request basis: Management reported frequent musculoskeletal injuries. On the initial call between NIOSH project officers and management, management stated that the Occupational Safety and Health Administration (OSHA) Form 300 Logs of Work-Related Injuries and Illnesses for 2023 had eight sprains (38%) from 21 reported work-related injuries.

Previous issues: In 2022, a workers compensation consultant completed an ergonomic assessment. The consultant reviewed the company's workers compensation claims for musculoskeletal injuries. They found that sprains and strains accounted for 38% of reported claims (40/104).

Process Description

This manufacturing plant operated on two shifts and three assembly lines dedicated to gas, flex, and electric water heaters. Our observations focused solely on the first shift of the gas assembly line, which ran from 5:00 am to 2:30 pm. Employees performed the same job tasks across both shifts, working eight hours per day, five days per week. Production time varied depending on demand and tank size. The gas assembly line consisted of 43 tasks starting with a bare tank and ending with packaging for shipment (see Table C1). Only two areas rotated job tasks on a regular basis. Employees working in jacket throwing and lid install rotated job tasks every hour. Additionally, employees working in the door switch install, lock ring, pilot assembly, pilot assembly install, grommet install, and burner scoop job tasks rotated in sequence every hour. Tasks like leg clip installation and base table work were voluntarily included in the rotation schedules.

Section B: Methods, Results, and Discussion

Our objectives were as follows:

- Observe work practices and procedures that may cause musculoskeletal disorders (MSDs) among employees.
- Provide recommendations to reduce work-related ergonomic risk factors and MSDs.

Methods: Ergonomic Evaluation

We observed workplace conditions and work practices to identify ergonomic risk factors. We measured workstation heights, reach, and viewing distances. We also noted the availability of powered equipment, antifatigue mats, administrative controls, and personal protective equipment (PPE). A description of risk factors for work-related MSDs is provided in Section E.

Results: Ergonomic Evaluation

We observed a range of postures at the workstations depending on the job task. All but one of these tasks required employees to stand at their workstations. For certain jobs, employees walked to other areas to restock materials needed for their assembly work. Only one task (heat shield assembly) involved a seat to accommodate a stationary workstation height. The chair lacked armrests, allowing the employee to reach materials from bins located on their left and right.

Some tasks required employees to perform multiple movements including reaching above shoulder height and below waist height to grab or retrieve materials. Table C1 provides general observations of tasks associated with awkward, repetitive postures in specific job locations. These postures, particularly affecting the upper extremities (e.g., neck, shoulders, wrist) and lower back, could lead to musculoskeletal injuries over time. According to American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®) (2024), tasks involving repetitive lifting from floor to middle shin height (30 to 360 lifts per hour for more than two hours per day) have no established safe limits. Certain tasks, such as lifting the top lid in the lid install task, posed a risk of low back injury due to the lifting range between floor and middle shin height.

We also observed task variations based on differences in water heater models or workstation locations. For example, installing the T&P valve required manual rotation of the tank, which varied depending on the water heater model. Variations in workstation setup were also noted. For instance, two test tube stations were located across from each other – one near a main wall with more available space and another near the canner assembly with less room. Similarly, the canner assembly job task had three distinct locations, each designated for specific tank diameters: 14 inches, 16 inches, and 18 inches.

Engineering Controls

We observed different job tasks where employees used powered equipment designed to eliminate the need for manual tightening of screws, bolts, and control valves. Some powered tools were suspended to reduce the strain from their weight. Tasks utilizing a two-handle suspended torque gun included dip-tube installation, anode installation, baffle installation, gas valve installation, drain valve installation, and T&P valve installation. Other tasks, such as baffle installation, pilot assembly, burner scoop, tamping, and gas hook-up, involved suspended powered equipment. However, the air line for the suspended equipment ran across the floor resulting in a trip hazard.

One job task that did not include a suspended drill, but could benefit from it, was the installation of top screws. We also observed certain job tasks with platforms (e.g., drop baffle, jacket throwing) or step stools (e.g., gas hook-up area) to accommodate employees' workstation height. In some cases, the equipment was not used, and it was unclear whether barriers prevented employees from adjusting the equipment to their height.

Additionally, we observed tasks like anode installation where a mechanical device was used to lift and tilt material for easier handling. Some tasks incorporated foot pedals to activate the equipment; however, a few pedals appeared too small for employees to use comfortably. Anti-fatigue mats were missing in some areas, such as near the canner workstation #3, and the anode installation station. In other areas, the mats appeared worn down, potentially reducing their effectiveness in preventing fatigue.

Administrative Controls

Employees were given a five-to-ten-minute break each hour, with breaks staggered throughout the line. Additionally, floaters were assigned to assist with breaks. Management implemented job rotations for specific tasks to reduce strain and improve efficiency. Employees working on tasks such as lock ring installation, pilot assembly, grommet installation, pilot assembly install, burner scoop installation and door installation rotated every hour. These job tasks used similar muscle groups. Tasks like leg clip installation and base table work were voluntarily included in the rotation schedules. Similarly, employees performing jacket throwing and lid installation also rotated. The job tasks used some different muscle groups, however they could both result in shoulder injury.

We reviewed the ergonomic program developed by the facility's safety management team. The written procedure provided purpose and scope, definitions, responsibilities, requirements and training. Management provided an electronic version update yearly.

Personal Protective Equipment

We observed that employees wore safety glasses, gloves, steel toed boots, and hearing protection devices as part of their PPE. Employees had access to new gloves through a vending machine conveniently located near the break room. Management indicated that employees could request new boots annually, however we observed boots that appeared to be more than a year old. Hearing protection was required in all areas. We observed employees wearing disposable earplugs; some of them were worn improperly by not being inserted correctly. Refer to Section D for information regarding occupational exposure limits for noise.

Methods: Injury Record, Ergonomic Program, and Past Ergonomic Assessments Review

We reviewed the OSHA Log entries for the period from January 1, 2019, through December 31, 2023. We summarized injuries and illnesses by year, body part, nature of injury and area of the facility. We excluded three injuries documented by the employer as non-recordable. We labeled nature of injury or illnesses for all cases but our main focus was on MSDs due to ergonomic concerns. We used the United States Bureau of Labor Statistics for MSD 2011 and forward definition under Occupational Safety and Health injuries, illness and fatalities. This definition includes pinched nerve; herniated disc; meniscus tear; sprains, strains, tears; hernia (traumatic and nontraumatic); pain, swelling, and numbness; carpal or tarsal tunnel syndrome; Raynaud's syndrome or phenomenon; musculoskeletal system and connective tissue diseases and disorders, when the event or exposure leading to the injury or illness is overexertion and bodily reaction, unspecified; overexertion involving outside sources; repetitive motion involving microtasks; other and multiple exertions or bodily reactions; and rubbed, abraded, or jarred by vibration [BLS 2023]. We excluded one injury labeled as a tear due to lack of detail description. We also reviewed a copy of the facility's ergonomic program. Additionally, we examined the past workers' compensation report, and two ergonomic assessment scores provided by a workers' compensation claim consultant and the facility's safety management team.

Results: Injury Record, Ergonomic Program, and Past Ergonomic Assessments Review

Injury Record

Between 2019 and 2023, a total of 105 OSHA Log entries were recorded for this facility. The highest number of entries was reported in 2021 (Table C2). All recordable OSHA Log entries were within facility areas for shipping, receiving, assembling, painting/coating, maintenance shop, and outside in facility's parking lots. Strains, sprains, and tears alone were the second highest injury and illness from all recorded injuries and illnesses (Table C2). Musculoskeletal injuries accounted for 32 cases. The highest affected body part region was upper extremities for musculoskeletal injuries (Table C3).

Ergonomic Program

The facility's ergonomic program consisted of ways to prevent and control ergonomic hazards. It also included suggestions for engineering controls, administrative controls, and PPE. Per the program, workplace evaluations must be completed to prevent injuries and updated whenever equipment is added or modified. We noted this occurred between the two ergonomic assessments mentioned below. The facility was required to provide ergonomic training as part of new hire orientation and then annually afterwards. Topics that should be included in the training were safe lifting, workstation evaluation, office ergonomics, and how to identify MSDs. However, we did not see a copy of the training because it was part of the ergonomic software package and could not be printed out.

Past Ergonomic Assessments Review

The workers' compensation claim consultant used the postural analysis tool, Rapid Entire Body Assessment (REBA), to score job tasks [Hignett and McAtamney 2000]. The facility's safety management team used VelocityEHS® Ergonomics software, formerly known as Humantech, which is based on The Handbook of Ergonomic Design Guidelines [Humantech 2009]. Both assessments evaluated each task to determine the level of risk for musculoskeletal injuries. Some changes in the job tasks occurred between the two years of the assessments.

In the 2022 consultant assessment, they identified six high-risk job tasks, 25 medium-risk tasks, and four low-risk tasks. The six high-risk jobs included jacket throwing, tamping, gas hookup, pilot assembly, drop baffles, and drain valve install.

The 2023 safety management assessment identified five high-risk tasks, 15 medium-risk tasks, and 20 low-risk tasks. The five high-risk tasks included jacket throwing, dip tub install, drop baffles, gas hookup, and bubble test.

Discussion

Implementing effective interventions based on sound ergonomic principles is important in reducing the risk of work-related MSDs [NIOSH 2015]. Interventions should focus on reducing repetition, forceful exertions, and awkward and static postures [Cal/OSHA 2007]. Interventions should also prioritize hazard elimination and engineering controls whenever possible, consistent with the hierarchy of controls [NIOSH 2024a]. It is important to remember that changes to one task can have unintended consequences on other tasks. Therefore, when interventions are introduced, a re-assessment of potential risk factors for related tasks may be necessary [NIOSH 2024b].

Past Ergonomic Assessments

Between the two assessments, there was agreement that drop baffles, jacket throwing, and gas hook-up tasks were high-risk for musculoskeletal injuries. However, there were differences in scoring other high-risk tasks, including dip-tube installation, pilot assembly installation, tamping, bubble testing, and drain valve installation. Factors that could cause differences in scoring included the subjective rating, the location and set-up of that assembly line, change in process, or frequency of task. The facility management had reviewed ergonomic processes and equipment from other facilities (e.g., automated jacket throwing) and were considering implementing at this facility. Our evaluation was the next step of the process. From our observations, we agreed on the high-risk tasks and have provided some recommendations on how to address them.

Engineering Controls

Automation of tasks can reduce burden on employees. For example, management mentioned that another facility uses a robotic arm controlled by employees to place jackets over tanks. A review of robots and advanced automated equipment implemented as safety interventions in manufacturing has demonstrated a reduction in musculoskeletal injuries [Lowe et al. 2023].

Adjustment of workstations or reach for materials closer to the body can reduce risk of low back or shoulder injuries [ACGIH 2024]. Effective management strategies include:

- ***Height Adjustments:*** Customizing workstation height based on percentile ranges to accommodate a diverse workforce [Keyserling 1989].
- ***Powered Equipment:*** Utilizing tools and machines, as highlighted in the OSHA Solutions for the Prevention of Musculoskeletal Injuries in Foundries [2012].
- ***Pick-and-Place Solutions:*** Designing handles and equipment to reduce reach distances, as discussed in Lavender et al. [2023].
- ***Anti-fatigue Mats:*** Providing proper mats to reduce discomfort and fatigue for employees standing for extended periods.
- ***Foot Pedal Size:*** Ensuring foot pedals are appropriately sized for employee comfort and usability.

Administrative Controls

Job rotation is often recommended as an administrative control to reduce fatigue and stress of muscles and tendons by rotating employees to job tasks of lesser exposure or that use different muscle-tendon groups to reduce ergonomic risk factors [NIOSH 2014; OSHA 1993]. Job rotation was mentioned by management and employees. Rotating from higher exposure tasks to lower exposure tasks has been found to result in less fatigue and improved performance [NIOSH 2014; Raina and Dickerson 2009]. However, rotation among job tasks of similar exposure has not been found to reduce the risk of developing MSDs [Jonsson 1988].

Another control used to reduce ergonomic risks is ensuring adequate breaks are provided. At the time of our evaluation, employees had regularly scheduled rest breaks. Tucker et al. [2003] found that limiting continuous work to less than two hours reduced risk of injury [NIOSH 2014]. Dababneh et al. [2001] found that hourly nine-minute breaks improved employee discomfort ratings without a negative effect on productivity.

Personal Protective Equipment

A previous study assessed the impact of lifting frequency on discomfort ratings while wearing three different types of safety shoes [Alferdaws and Ramadan 2020]. The study found that shoe design significantly influenced employee comfort during repetitive lifting tasks. Properly fitted safety shoes with features like shock absorption and arch support can help mitigate lower limb fatigue and musculoskeletal strain, particularly for employees standing for prolonged periods or performing tasks requiring frequent lifting.

Employers should regularly assess and update PPE offerings to match job requirements and ensure employees have access to options that enhance safety and comfort.

Limitations

This evaluation was subject to limitations. The observations of job tasks were limited to the days when the evaluation occurred. These results may not represent conditions during other times. The results for OSHA logs included all facility locations instead of only gas assembly line injuries.

Conclusions

Workstation design increased employee risk of musculoskeletal disorders. Job tasks were repetitive with some employees working at shoulder height, below waist height or in awkward postures. Engineering and administrative controls were in place to reduce risk of musculoskeletal disorders but could be improved.

Section C: Tables

Table C1. Job tasks and activities as potential ergonomic concern(s)

Job task	Observations of activities
Tank rolling	• Poor wrist posture to tip the tank ~35–45 degrees to help roll it on the conveyor. • Working at shoulder height using the powered screwdriver to drill out membrane.
Dip-tube install	• Workstation height at top of tank on conveyor was 52 inches (above recommended fixed height). • Poor wrist posture to manually start tightening the cold and hot water outlet pipe caps. • Working at shoulder height to move the torque gun over the tank to tighten the dip tubes.
Anode install	• Workstation height at top of tank on conveyor was 52 inches (above recommended fixed height). • Working at shoulder height to manually install anode spud. • Working at shoulder height to move the torque gun over the tank to tighten the anode. • Working at shoulder height to manually start the cold and hot water outlet pipe cap.
Test tube	• Working at shoulder height to reach the air box and button to activate air box. • Potential for low back injury from bending forward to push the tank back onto the main line after the inspection is complete.
Tox press	• Workstation height for retrieving material from top of the cart with supplied lids was 32 inches (below recommended fixed height). • Workstation height for retrieving stacked material height for pans at the top was 45.2 inches (above recommended fixed height). • Working at shoulder height to reach for power button that activates press. • Hand pinch grip used to connect the clips. • Potential for low back injury from bending to reach for lids from bin. • Forearm rotation to place the flame trap into the top die.
Canner	• Workstation height for retrieving canner from conveyor was 38.5 inches (below recommended fixed height). • Hand pinch grip when adding the two clips into the side of the chamber.
Door switch install	• Workstation height of the table was 34 inches (below recommended fixed height). • Workstation height for top of screw was 38 inches (below recommended fixed height). Working at shoulder height to grab the torque gun to connect socket and extension tube. • Working at shoulder with elbow elevated when using equipment to screw socket over the extension tube. • Potential for low back injury from bending to reach door supplies when low from cart.
Lock ring	• Workstation height of the table was 34 inches (below recommended fixed height). • Potential for low back injury from bending to reach material for manifold bracket. • Poor wrist posture from manually placing lock ring onto the flex tube.

Table C1 continued. Job tasks and activities as potential ergonomic concern(s)

Job task	Observations of activities
Pilot assembly	• Workstation height of the table was 34 inches (below recommended fixed height). • Workstation height of the suspended screw drill was 38 inches (below recommended fixed height). • Workstation height of hand placement was 44 inches (above recommended fixed height). • Potential for low back injury from bending to get material pilot tube from boxes on floor. • Repetitive movement to bend pilot tube.
Grommet	• Workstation height of the table was 34 inches (below recommended fixed height). • Hand pinch grip to place grommets on manifold door. • Hand pinch grip used on plyers to secure clip into place. • Repetitive movement to bend tube.
Pilot assembly install	• Workstation height of the table was 34 inches (below recommended fixed height). • Workstation height of hand placement 44 inches (above recommended fixed height). • Hand pinch grip used to screw on the orifice piece to the manifold bracket. • Working at shoulder height to install manifold door into the bracket.
Burner scoop	• Workstation height of the table was 34 inches (below recommended fixed height). • Workstation height of hand placement 38 inches (below recommended fixed height).
Door install	• Workstation height of the conveyor 36 inches (below recommended fixed height). • Workstation height of hand placement area was 38 inches (below recommended fixed height). • Potential for trigger finger from pressing the pneumatic screwdriver.
Base ring (prep)	• Workstation height for formed base rings was 48 inches (above recommended fixed height). • Workstation height to feed and bend the base ring sheet into machine ~55 inches or more (above recommended fixed height). • Working at shoulder height to place the base ring over the designated rack. • Potential for low back injury from bending to place the base ring at the bottom of designated rack. • Repetitive motion of manually pushing the filter into the ring with fingertips.
Heat shield	• Potential for low back injury from bending to the side to reach for heat shields located on left side of workstation. Depth of the container ~34.5 inches. • Potential for low back injury from bending to side to reach for mounting brackets located on right side of workstation. Depth of container ~34.5 inches. • Repetitively pressing on a foot pedal to activate the presses. • Hand pinch grip used to pick up heat shield.

Table C1 continued. Job tasks and activities as potential ergonomic concern(s)

Job task	Observations of activities
Leg clip install	• Workstation height to place top of stacked rings was 66 inches (above recommended fixed height). • Potential for low back injury from bending to get base rings off the stacked materials when low. • Working at shoulder height to reach to get base ring off the stacked materials when full. • Hand pinch grip used to insert the leg brackets into the base ring.
Base table (fold bottom pads)	• Potential for low back injury from reaching forward to place base table pad near next station. • Working at shoulder height to reach when stacking top folded bottom pad (current stack limit is 5 per stack).
Bottom trim to chamber	• Workstation height to reach for top of stacked rings to place in pad was 66 inches (above recommended fixed height). • Potential for low back injury from bending to get bottom trim off the stacked when materials are low. • Working at shoulder height to reach bottom trim off the stacked materials when full. • Hand pinch grip when holding the chamber to align the leg brackets.
Leg bracket screws	• Hand pinch grip when grabbing screws from a standard height holder. • Poor wrist posture when holding the powered screwdriver to secure the leg brackets to the chamber. This is repeated 3 times per bracket.
Tip-up	• Hand pinch grip when lifting chamber from conveyor located behind employee. • Manual force to pull the tank on the conveyor towards the tip-up base. • Foot flexion from lifting to activate the welding presses by foot pedal.
Baffle welding	• Poor wrist and forearm posture from rotation to weld baffle tabs onto the hanger. • Working at shoulder height to place finished baffle into bin.
Drop baffles	• Working at shoulder height to use the torque gun to remove the cold and hot water outlet pipe caps. • Working at shoulder height to lower the baffle into the tank. • Potential for low back injury from bending down to reach for welded baffle pieces. • Possible infrared exposure when looking into oven.
Foam rings	• Working at shoulder height to place the foam over the flue pipe and foam ring over the top tanks. • Possible infrared exposure when looking into oven.
Insulation install	• Potential for low back injury from bending to wrap insulation foam around tank.
Jacket throwing	• Workstation height for reach of top jacket was 71 inches (above recommended fixed height). • Workstation height middle area for hand placement on jacket was 48 inches (above recommended fixed height). • Workstation height of the platform at lowest setting 8 inches. • Workstation height of the conveyor was 26 inches. • Hand pinch grip used to stabilize the jacket during lift. • Shoulder contact stress when lifting jacket to place over tank. • Over shoulder height when lowering jacket over the tank.

Table C1 continued. Job tasks and activities as potential ergonomic concern(s)

Job task	Observations of activities
Base screws	• Potential for low back injury from bending to install the base screws and manually apply paperwork.
Top table	• Working at shoulder height to retrieve top trim from stacked materials. • Potential for low back injury from bending down to retrieve top trim from stacked materials when low.
Control valve install	• Poor wrist posture when manually apply pipe dope to the gas valve and hand start the gas valve into the tank.
Tamping	• Working at shoulder height to move the tamper over the tank and push down to help move the ring installation into the correct position.
Lid install	• Potential for low back injury from bending down to grab jacket top lid from the conveyor.
Top screws	• Hand pinch grip to hold the screws to place into the top trim. • Hand and wrist contact stress to keep the lid in place while putting in the screws with a powered screwdriver.
Gas hook-up area (tasks includes hook-up of manifold, pilot, and gas)	• Workstation height of conveyor was 42.5 inches (above recommended fixed height). • Workstation height of hand placement was 51 inches (above recommended fixed height). • Potential for low back injury from bending down to grab draft hood when supplies get low in the cart. • Potential trip hazard from cord of pneumatic tool on the ground.
Bubble test	• Potential for low back injury from bending down to inspect connection and see if any bubble formed. • Poor neck posture (bending and flexion) when looking up at the control valve connections to see if any bubbles form. • Potential for low back injury from bending and shoulder height from reaching to grab outer door from cart when supplies get low.
Drain valve install	• Working at shoulder height when reaching to use a mallet hammer to tap flange into place near top.
Foaming	• Working at shoulder height to make sure the foam head clears the tank to insert into the nozzle to fill. • Poor wrist posture when pushing the plug into place on jacket top.
Labels	• Hand pinch grip to grab the label stickers. • Working at shoulder height for tanks that need a T&P warning label.
T&P valve install	• Poor wrist posture from rotation to add pipe dope for sealing. • Poor wrist posture from rotation to hand start the T&P valve. • Repetitive motion to rotate tank on conveyor for correct alignment. • Working at shoulder height to reach area for adding the burn sticker.
Quality scanning	• Workstation height of monitor height low for eye level.
Carton throwing	• Working at shoulder height to reach and grab material box. • Hand pinch grip to open the box. • Contact stress to place box over heater.
Top pad	• Workstation height when stacking pads based on height preference. • Working at shoulder height to add foam on top. • Working at shoulder height to place the top pads into the box.

Table C1 continued. Job tasks and activities as potential ergonomic concern(s)

Job task	Observations of activities
Glue & staple	• Working at shoulder height and poor wrist posture (deviation) when using staple gun to staple flaps. • Potential for low back injury from lean to apply glue with roller on the far major flap.

All tasks listed are repetitive and vary in frequency based on product demand.

Table C2. Nonfatal occupational injuries and illnesses occurring by nature of injury or illness as reported on OSHA logs, 2019–2023

Cases	2019 n = 20	2020 n = 16	2021 n = 24	2022 n = 23	2023 n = 22	Total n = 105	%
All other natures	4	0	2	2	3	11	10
Bruises, contusions	0	0	1	3	0	4	4
Burns	0	0	0	1	0	1	1
Cuts, Lacerations	4	10	11	5	7	37	35
Fractures	5	1	1	1	1	9	9
Hearing loss	1	0	2	2	0	5	5
Hernia*	0	0	0	1	0	1	1
Soreness, pain*	2	2	4	2	0	10	10
Sprains, strains, tears*	3	3	1	6	8	21	20
Tendonitis*	0	0	0	0	1	1	1
Unknown†	1	0	2	0	2	5	5

* Musculoskeletal-related injuries and illnesses; one tear excluded due to lack of detail

† Description did not provide enough information on injury result

Table C3. Nonfatal occupational injuries and illnesses occurring with signs and symptoms of musculoskeletal injuries by body part affected and general work area as reported on OSHA logs, 2019–2023

	2019	2020	2021	2022	2023	Total	
Cases	n = 5	n = 4	n = 5	n = 9	n = 9	n = 32	%
Body part affected							
Lower extremity	2	3	2	3	2	12	38
Neck	0	0	0	0	1	1	3
Trunk	0	1	0	0	1	2	6
Upper extremity	3	0	3	6	5	17	53
General work area							
Assembly*	2	2	2	3	4	13	41
Distribution	0	1	0	0	0	1	3
Enamel	0	1	0	0	2	3	9
Paint	0	0	1	2	1	4	13
Press	0	0	0	1	0	1	3
Receiving	0	0	0	0	1	1	3
Tank	3	0	2	3	1	9	28

* Includes all assembly lines and assembly stockroom location

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 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 TLVs, which are recommended by ACGIH. The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards” [ACGIH 2024].

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

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

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

Occupational Exposure Limit of 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 for both ears that exceeds 25 dB at frequencies of 1,000 Hz; 2,000 Hz; 3,000 Hz; and 4,000 Hz. 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.

The NIOSH REL for noise is 85 dBA as an 8-hour TWA. For calculating exposure limits, NIOSH uses a 3-dB time/intensity trading relationship, or exchange rate. Using the NIOSH 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 140 dBA. NIOSH recommends the use of hearing protection and the implementation of a hearing loss prevention program when noise exposures exceed the REL [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 or impact noise must not exceed 140 dB peak noise level [29 CFR 1910.95].

Section E: Occupational Exposure Criteria

Risk Factors for Work-related Musculoskeletal Disorders

MSDs are conditions that involve the nerves, tendons, muscles, and supporting structures of the body. They can be characterized by chronic pain and limited mobility. Work-related musculoskeletal disorder refers to (1) MSDs to which the work environment and the performance of work contribute significantly, or (2) MSDs that are made worse or longer lasting by work conditions. A substantial body of data provides strong evidence of an association between MSDs and certain work-related factors (physical, work organizational, psychosocial, individual, and sociocultural). The multifactorial nature of MSDs requires a discussion of individual factors and how they are associated with work-related MSDs.

Strong evidence shows that employees whose job tasks involve high levels of static contraction, prolonged static loads, or extreme working postures involving the neck/shoulder muscles are at increased risk for neck/shoulder MSDs [NIOSH 1997]. Further strong evidence shows job tasks that require a combination of risk factors (highly repetitious, forceful hand/wrist exertions) increased risk for hand/wrist tendonitis [NIOSH 1997]. Finally, evidence shows that low-back disorders are associated with work-related lifting and forceful movements, awkward postures such as bending and twisting, and whole-body vibration [NIOSH 1997].

A number of personal factors can also influence the response to risk factors for MSDs: age, sex, smoking, physical activity, strength, and body measurements. Although personal factors may affect an individual's susceptibility to overexertion injuries/disorders, studies conducted in high-risk industries show that the risk associated with personal factors is small compared to that associated with occupational exposures [NIOSH 1997].

In all cases, the preferred method for preventing and controlling work-related MSDs is to design jobs, workstations, tools, and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the employee. Most of the recommendations provided in this report were adapted from principles outlined in The Handbook of Ergonomic Design Guidelines [Humantech 2009]. Under these conditions, exposures to risk factors considered potentially hazardous are reduced or eliminated.

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HHE Report No. 2024-0006-3419