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COMPENDIUM OF

ERGONOMIC ANALYSES OF

SHIPYARD WORK PROCESSES

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DISCLAIMER

Mention of company names and/or products does not constitute endorsement by the Centers for Disease Control and Prevention (CDC).

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Without the participating shipyards there would not have been any access to the worksites and obviously no project. My deepest gratitude for all the cooperation we received over the course of this project from the shipyards: Bath Iron Works, Continental Maritime, Halter Marine, Ingalls, Jeffboat, Marinette Marine, Puget Sound Naval Shipyard, and Todd Pacific Shipyards. Over the five years of the project, several companies have changed names, owners, affiliations, etc. The names listed above may not reflect the current official names of the facilities, but are what we consistently used to refer to the individual shipyards throughout the reports.

Finally, I would like to acknowledge the contribution of current and former coworkers and colleagues too numerous to mention without whom much of this project work could not have been completed.

EXECUTIVE SUMMARY

Over a three-year period NIOSH conducted a number of walkthrough surveys at both domestic and foreign shipyards to catalog and quantify the occupational risk factors associated with specific work processes or job tasks. These surveys have been documented as three-part series that are available in .pdf format on www.cdc.gov/niosh/ergship/ergship.html. This report is the compilation of those survey reports.

Pre-intervention quantitative risk factor analyses were conducted at eight participating yards focusing on 47 job tasks identified as high-risk among the 14 shipyard trades. A variety of exposure assessment techniques were used where deemed appropriate to the specific task being analyzed. These exposure assessment techniques provided a means to quantify the risk factors associated with how the job tasks were being performed. Based on the results of the quantitative risk factor analyses, the likelihood of exposure to a particular risk factor for each trade was then determined.

In addition to the quantitative risk factor analyses, workers compensation cost data for the years 1996 to 1998 were collected from participating shipyards. The workers compensation costs were identified for work-related musculoskeletal disorder (WMSD) claims associated with OSHA 200 Log recordable injuries and illnesses. These costs were tabulated by the identified occupation of the worker and part of the body affected. The costs for each of the three available years were collapsed and averaged. This information was then normalized by dividing the costs by the estimated number of full-time employees per year by body part and trade.

This injury and cost information was used in the development of a Shipyard Trade Occupational Risk Matrix (STORM). The prioritization of injuries to body parts within each trade was based on the rank ordering of injury incidence rates for WMSDs by body part and a rank ordering of the associated workers compensation costs by body part by trade. These two rank orders of injury incidence and cost were combined to create an overall ranking of injury priority or "severity." The likelihood of exposure to occupational risk factors as determined by the exposure assessment techniques was color-coded. A high likelihood of risk exposure resulted in a color coding of "red" followed by "orange" and "yellow." A "green" coding meant that the particular risk factor was not a strong factor in the development of WMSDs for that trade.

Table 1 is a matrix of the effected body parts associated with occupational risk factors and shipyard trades based on the analysis of injury and cost data and quantitative risk factor analysis of targeted shipyard work processes. The numbers represent the rank order of importance for injury to that body part based on incidence and cost, given the occupational risk factors observed for work processes performed by that specific trade. The color code (R = red, O = orange, Y = yellow, and G = green) represents the importance of that occupational risk factor in the development of musculoskeletal injuries for that trade.

Table 1. Shipyard Trade Occupational Risk Matrix (STORM)

	Sustained Postures	Awkward Postures	Repetition	Vibration	Excessive Force
Abrasive Blasters	(1) Arms (2) Shoulders (3) Back Y	(1) Arms (2) Shoulders (3) Back O	(1) Arms (2) Shoulders Y	(1) Arms (2) Shoulders Y	(1) Arms (2) Shoulders (3) Back R
Burners/ Torch Cutters	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist O	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist R	G	G	G
Electricians	(1) Back Y	(1) Back (2) Knees (3) Hand/Wrist O	(3) Hand/Wrist (5) Arms O	G	(1) Back (3) Hand/Wrist (4) Shoulders (5) Arms R
Grinders/ Chippers	(1) Back (2) Knees (3) Arms (4) Shoulders (6) Neck O	(1) Back (2) Knees (3) Arms (4) Shoulders (5) Hand/Wrist (6) Neck R	(3) Arms (4) Shoulders (5) Hand/Wrist Y	(3) Arms (4) Shoulders (5) Hand/Wrist R	(3) Arms (4) Shoulders (5) Hand/Wrist R
Insulators	(2) Shoulders (3) Neck (4) Back Y	(1) Hand/Wrist (2) Shoulders (3) Neck (4) Back R	(1) Hand/Wrist (2) Shoulders Y	G	(1) Hand/Wrist (2) Shoulders R
Machine Operator	(1) Back (2) Neck Y	(1) Back (2) Neck O	(1) Back (3) Shoulders (4) Hand/Wrist Y	G	(1) Back (3) Shoulders R
Material Handlers	G	(1) Back (2) Shoulders (3) Arms R	(1) Back (2) Shoulders (3) Arms O	G	(1) Back (2) Shoulders (3) Arms R
Outside Machinists	(1) Back (2) Neck Y	(1) Back (2) Neck O	(3) Shoulders (4) Hand/Wrist Y	(3) Shoulders (4) Hand/Wrist Y	(1) Back (3) Shoulders R
Pipefitters	G	(1) Back (2) Knees (3) Arms (4) Neck O	(3) Arms (5) Hand/Wrist Y	(3) Arms (5) Hand/Wrist Y	(1) Back (3) Arms (5) Hand/Wrist R

Table 1 (continued). Shipyard Trade Occupational Risk Matrix (STORM)

	Sustained Postures	Awkward Postures	Repetition	Vibration	Excessive Force
Riggers	G	(1) Shoulders (2) Back (3) Knees O	(1) Shoulders (4) Hand/Wrist Y	G	(1) Shoulders (2) Back R
Saw Operators	G	(1) Hand/Wrist (2) Arms (3) Shoulders (4) Back O	G	(1) Hand/Wrist (2) Arms (3) Shoulders R	(1) Hand/Wrist (2) Arms (3) Shoulders (4) Back R
Sheetmetal Workers	G	(1) Back (2) Neck (3) Knees O	(4) Arms (5) Hand/Wrist Y	(4) Arms (5) Hand/Wrist Y	(1) Back (4) Arms (5) Hand/Wrist R
Shipfitters	G	(1) Back (2) Knees (3) Neck (4) Hand/Wrist (5) Arms (6) Shoulders R	(1) Back (4) Hand/Wrist (5) Arms (6) Shoulders Y	(4) Hand/Wrist (5) Arms Y	(1) Back (4) Hand/Wrist (5) Arms (6) Shoulders R
Welders	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist R	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist R	(6) Hand/Wrist Y	(5) Arms (6) Hand/Wrist Y	(2) Back (6) Hand/Wrist Y

The Shipyard Trade Occupational Risk Matrix provides a mechanism by which shipyards can prioritize the distribution of resources to address WMSDs in the workplace. Since injury incidence, associated costs, and level of identified risk to a body part by trade were utilized to develop this risk matrix given a limited set of data over a specific period of time, the STORM must be considered a "living" document that needs to change as access to further information enables a refinement of the current prioritization scheme. Only in that way can STORM continue to give as accurate a summary of shipyard musculoskeletal risks as possible.

This report documents the quantitative risk factor analyses conducted to obtain some measure of the exposure to occupational risk factors for each of the shipyard trades for representative job tasks within those trades. Appendices A through L provide the data tables, checklists, etc. for the quantification of occupational risk factors for all of the work processes analyzed.

I. INTRODUCTION

IA. BACKGROUND FOR CONTROL TECHNOLOGY STUDIES

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency involved in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposures to potential chemical and physical hazards, including the study of engineering aspects of health hazard prevention and control.

Since 1976, NIOSH conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. The objective of each of these studies were to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involved a number of steps or phases. Initially, a series of walk-through surveys were conducted to select plants or processes with effective and potentially transferable control concepts or techniques. Next, in-depth surveys were conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys were then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the database of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

IB. BACKGROUND FOR SHIPYARD STUDIES

The domestic ship building, ship repair, and ship recycling industries have historically had much higher injury/illness incidence rates than those of general industry, manufacturing, or construction. For 2001, the latest year available, the Bureau of Labor Statistics reported that shipbuilding and repair (SIC 3731) had a total recordable injury/illness case incidence rate of 17.2 per 100 full-time employees (FTE), down from 22.0 in 2000. By contrast, in 2001, the manufacturing sector reported a rate of 8.1 per 100 FTE, construction reported a rate of 7.9 per 100 FTE, and all industries reported a rate of 5.7 injuries/illnesses per 100 FTE. When only lost workday cases for 2001 were considered, shipbuilding and repair had an incidence rate of 8.6 per 100 FTE, compared to manufacturing at 4.1, construction at 4.0, and all industries at 2.8 lost workday injuries/illnesses cases per 100 FTE. Historical trends for total recordable cases and lost workday cases have shown downward trends for each of these sectors and industries, as shown in Figures 1 and 2.

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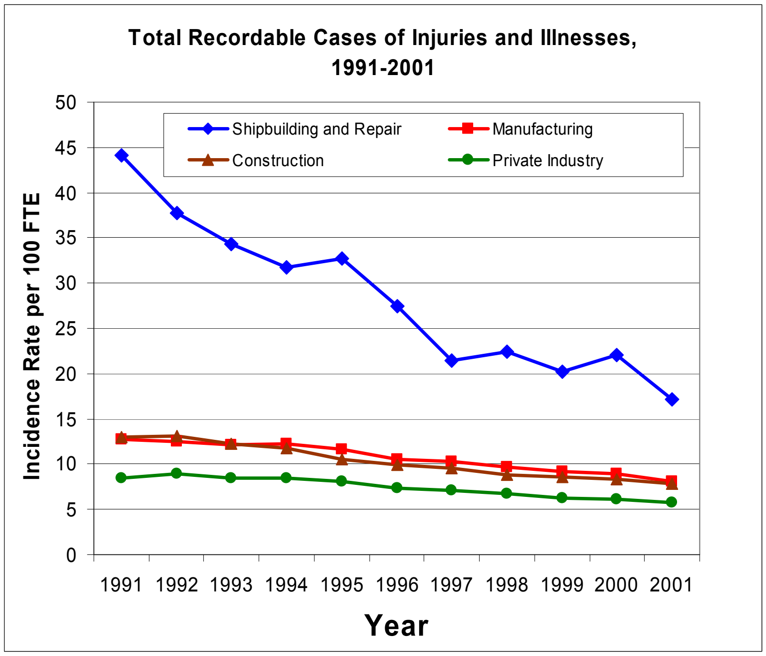

Figure 1. Total Recordable Cases Incidence Rate by Industry

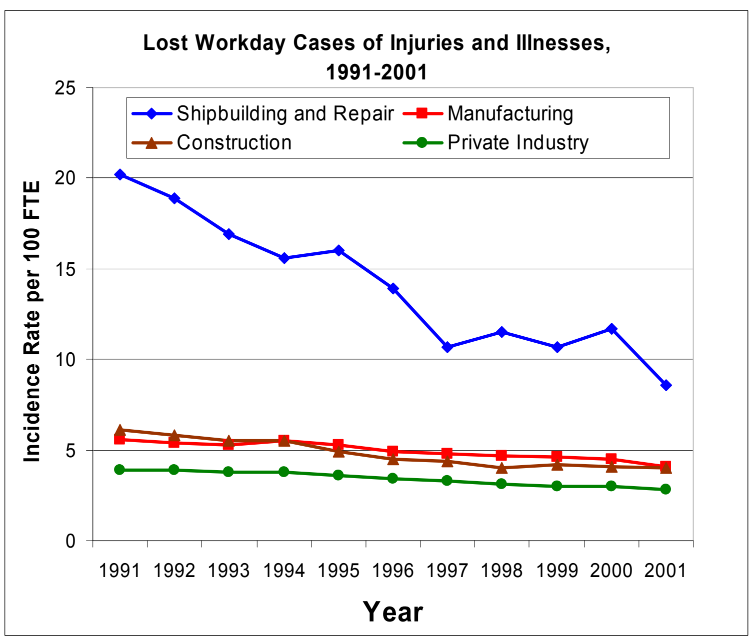

Figure 2. Lost Workday Cases Incidence Rate by Industry

When shipbuilding and repairing are compared to the manufacturing sector for injuries and illnesses to specific parts of the body that result in days away from work for the year 2001, shipbuilding is significantly higher in a number of instances. For injuries and illnesses to the trunk, including the back and shoulder, shipbuilding reported an incidence rate of 141.4 cases per 10,000 FTE, compared to manufacturing at 62.7 cases. For injuries and illnesses solely to the back, shipbuilding reported 75.9 cases per 10,000 FTE, compared to manufacturing's incidence rate of 38.4 cases. For the lower extremity, shipbuilding reported 95.4 cases per 10,000 FTE compared to manufacturing at 32.9 cases. For upper extremity injuries and illnesses, shipbuilding reported an incidence rate of 76.5 cases per 10,000 FTE while manufacturing reported 57.8 cases.

When shipbuilding and repairing are compared to the manufacturing sector, by nature of injury, for injuries and illnesses resulting in days away from work for the year 2001, shipbuilding is significantly higher in a number of categories. For sprains and strains, shipbuilding reported an incidence rate of 186.3 cases per 10,000 FTE, compared to manufacturing's incidence rate of 71.2 cases. For fractures, shipbuilding reported 24.6 cases per 10,000 FTE, compared to manufacturing at 13.0 cases. For bruises, shipbuilding reported 54.7 cases per 10,000 FTE, compared to manufacturing at 14.8 cases.

In 1995, the National Shipbuilding Research Program funded a project looking at the implementation of ergonomic interventions at a domestic shipyard as a way to reduce workers' compensation costs and to improve productivity for targeted processes. That project came to the attention of the Maritime Advisory Committee for Occupational Safety and Health (MACOSH), an advisory committee to OSHA. NIOSH began an internally funded project in 1997 looking at ergonomic interventions in new ship construction facilities. In 1998, the U.S. Navy funded a number of research projects looking to improve the commercial viability of domestic shipyards, including projects developing ergonomic interventions for various shipyard tasks or processes. Project personnel within NIOSH successfully competed in that project selection process.

Over a three-year period NIOSH conducted a number of walkthrough surveys at both domestic and foreign shipyards to catalog and quantify the occupational risk factors associated with specific work processes or job tasks. These surveys have been documented as three-part series that are available in .pdf format on www.cdc.gov/niosh/ergship/ergship.html. This report is the compilation of these surveys. Note: the shipyards surveyed for this report worked primarily with steel as its primary component. Shipyard construction and repair processes involving aluminum, fiberglass, composites, and wood were not directly addressed.

IC. BACKGROUND ON EXPOSURE ASSESSMENT TECHNIQUES

A variety of exposure assessment techniques were implemented where deemed appropriate to the job task being analyzed. The techniques used for analysis include 1) the Rapid Upper Limb Assessment (RULA); 2) the Strain Index; 3) a University of Michigan Checklist for Upper Extremity Cumulative Trauma Disorders; 4) the OVAKO Work Analysis System (OWAS); 5) a Hazard Evaluation Checklist for Lifting, Carrying, Pushing, or Pulling; 6) the NIOSH Lifting Equation; 7) the University of Michigan 3D Static Strength Prediction Model; and 8) the PLIBEL method.

The RULA (McAtamney and Corlett, 1993) is a survey method developed to assess the exposure of workers to risk factors associated with work-related upper limb disorders. On using RULA, the investigator identifies the posture of the upper and lower arm, neck, trunk, and legs. Considering muscle use and the force or load involved, the investigator identifies intermediate scores, which are cross-tabulated to determine the final RULA score. This final score identifies the level of action recommended to address the job task under consideration.

The Strain Index (Moore and Garg, 1995) provides a semiquantitative job analysis methodology, that appears to accurately identify jobs associated with distal upper extremity disorders versus other jobs. The Strain Index is based on ratings of intensity of exertion, duration of exertion, efforts per minute, hand and wrist posture, speed of work, and duration per day. Each of these ratings is translated into a multiplier. These multipliers are combined to create a single Strain Index score.

The University of Michigan Checklist for Upper Extremity Cumulative Trauma Disorders (Lifshitz and Armstrong, 1986) allows the investigator to survey a job task with regard to the physical stress and the forces involved, the upper limb posture, the suitability of the workstation and tools used, and the repetitiveness of a job task. Negative answers are indicative of conditions that are associated with the development of cumulative trauma disorders.

The OWAS (Louhevaara and Suurnäkki, 1992) was developed to assess the quality of postures taken in relation to manual materials handling tasks. Workers are observed repeatedly over the course of the day and postures and forces involved are documented. Work postures and forces involved are cross-tabulated to determine an action category that recommends if, or when, corrective measures should be taken.

The NIOSH Hazard Evaluation Checklist for Lifting, Carrying, Pushing, or Pulling (Waters and Putz-Anderson, 1996) is an example of a simple checklist that can be used as a screening tool to provide a quick determination as to whether or not a particular job task is comprised of conditions that place the worker at risk of developing low back pain.

The NIOSH Lifting Equation (Waters et al., 1993) provides an empirical method to compute the recommended weight limit for manual lifting tasks. The revised equation provides methods for evaluating asymmetrical lifting tasks and less than optimal hand to object coupling. The equation allows the evaluation of a greater range of work durations and lifting frequencies. The equation also accommodates the analysis of multiple lifting tasks. The Lifting Index, the ratio of load lifted to the recommended weight limit, provides a simple means to compare different lifting tasks.

The University of Michigan 3D Static Strength Prediction Program is a useful job design and evaluation tool for the analysis of slow movements used in heavy materials handling tasks. Such tasks can best be analyzed by describing the activity as a sequence of static postures. The program provides graphical representation of the worker postures and the materials handling task. Program output includes the estimated compression on the L5/S1 vertebral disc and the percentage of population capable of the task with respect to limits at the elbow, shoulder, torso, hip, knee, and ankle.

The PLIBEL method (Kemmlert, 1995) is a checklist method that links questions concerning awkward work postures, work movements, and design of tools and the workplace to specific body regions. In addition, any stressful environmental or organizational conditions should be noted. In general, the PLIBEL method was designed as a standardized and practical assessment tool for the evaluation of ergonomic conditions in the workplace.

The data from each application of the exposure assessment techniques is available in Appendices A-L of this text. In general, a “high” amount of an occupational risk factor correlates to between 75-100% of the range for that factor; a “moderate” amount corresponds to 50-75% of the range for that factor; and, a “low” or “slight” amount corresponds to less than 50% of the range of that factor.

II. JOB TASK IDENTIFICATION

Over forty job tasks were videotaped and analyzed through the use of several exposure assessment techniques. The tables from the individual analyses are located in the appendices of this report. These tasks were categorized into twelve areas that described the primary function of the tasks involved. This report will be further divided into these twelve areas.

- Steelyard
- Shop Areas
- Sheetmetal Work
- Blasting
- Insulation
- Pipefitting
- Subassembly
- Welding
- Grinding

- Deck Work
- Electrical, and
- Manual Material Handling

IIA. STEELYARD PROCESSES

IIA1. Angle Iron Unloading and Positioning

Risk Factors

Raw material, primarily steel plate and angle iron, is brought to shipyards by truck, train, or barge. Material is stored, usually at an outdoor steelyard, until needed by the various production departments. Prior to use in any subassembly, the steel stock must undergo some surface preparation to remove rust or other residual material from the surface of the steel.

Angle iron operations were observed at two shipyards. One shipyard unloaded angle iron directly onto an outdoor blasting platform. The second yard unloaded angle iron onto a mobile roller conveyor that transported the angle iron into the surface preparation machinery. In both cases a mobile crane picked up a bundle of angle iron and unloaded them onto a platform. At each yard, one or more workers positioned the angle iron across the platform with the use of toothed turning or "gator" bars.

Two gator bar workers and one helper were videotaped performing their tasks and these tasks were then analyzed using a series of exposure assessment techniques. While positioning and flipping the angle iron, the gator bar workers were exposed to a number of occupational risk factors, including moderate wrist deviation, low to moderate wrist extension, low to moderate shoulder flexion, and low to moderate trunk flexion. The helper experienced moderate elbow extension and trunk flexion. The data from the individual analyses are presented in Appendix A – Steelyard.

Figure 3. Angle Iron Unloading

Interventions

Possible interventions include using a mobile crane to spread the stack of angle iron across the platform when dropped and automating some of the processes to eliminate the pulling of angle iron into position across the platform. At one point, one of the shipyards had several engineers working on the design of a mechanized angle iron placement system. Unfortunately, the anticipated costs exceeded the capacity of this project to support the concept. However, inexpensive and simple alterations to the gator bar tool may also reduce the amount of back flexion and effort required to separate and flip individual pieces of long angle iron. For reasons of cost-effectiveness, these tool changes were the principal suggested interventions for the angle iron positioning process.

IIB. PLATE SHOP PROCESSES

Risk Factors

The primary processes within the plate shop are to cut, size, and shape steel plate required for hulls and subassemblies using shear machines, automated plasma cutters, and manual cutting torches. The primary process for the shear operator is to cut steel plate to various dimensions as required. A standard process flow for the shear is as follows:

1) steel plates are moved from pallets to the shear by overhead or jib crane,
2) long plates are either laid across an array of roller bearing supports to hold weight of the plate or held in place by the crane rigging and guided by a second worker while being sheared,
3) the shear is activated by the operator,
4) cut plates are dropped at the back of the shear onto a sloped tray that reaches to ground level. Smaller pieces may not slide to the bottom of the tray and must be hooked and slid to the bottom by the shear operator or helper,
5) cut plates are either manually lifted or lifted by crane and placed into containers.

Shear operators often lift awkward loads from the ground-level shear chutes and material supply pallets. Contact stresses experienced by the shear operator include kneeling on the floor to get material and contact with the sharp edges of the raw or cut material. However, the primary concern for the plate shop shear operator or helper is the constant bending at the waist or kneeling to pick up material from the back of the shear at floor level.

Shear operators at two shipyard operations were videotaped performing their tasks. These tasks were than analyzed using a series of exposure assessment techniques. The shear operators experienced a moderate amount of upper extremity risk factors in the performance of their tasks. Calculated disc compressions for the lower back ranged from 555 lb to 673 lb. (The NIOSH recommended compression limit is 770 lb). The data from the individual analyses are presented in Appendix B – Shear Operations.

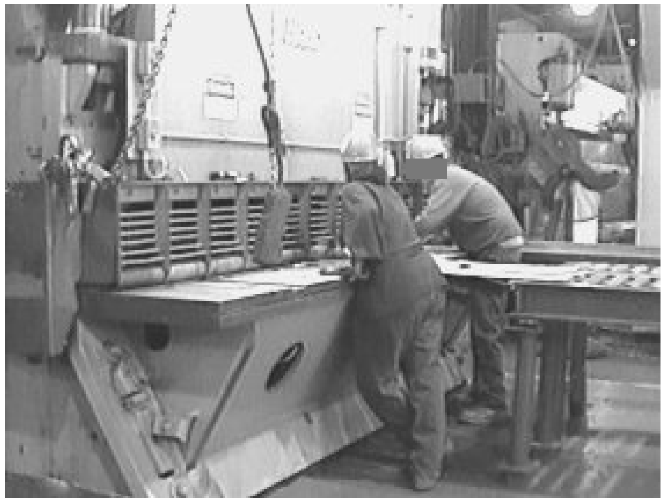
Figure 4. Shear Operation

Interventions

One possible solution was to provide an adjustable lift table for the shear chute at the back of the machine. In this way the cut material would still fall onto the rear chute of the shear, and in turn onto the lift table. The lift table can be elevated, allowing the worker to transfer cut material at approximately waist height. This would eliminate the need for the worker to lift objects off the rear chute at near floor level.

At one of the participating shipyards, a hydraulically operated lift table was installed to reduce the safety and ergonomic problems with the plate shear operation. The lift table is situated in a pit that was placed behind the plate shear. The pit is approximately 36” x 132” x 57”, depth, length, and width respectively. The lift table fits inside of this pit, the top surface measures 46” x 130”, and has a range of motion of approximately 5’ (2’ below floor surface to 3’ above floor surface). The controls for the lift table are placed to the side of the shear so that the table operator can have a clear view of the table, but cannot reach the table while it is in motion. This allows the operator to avoid being subjected to any pinch point hazards at the pit/table interface.

Initially the table was intended to allow manual stacking of the cut material at a higher more ergonomically correct height than floor level. After installation and some preliminary use, several methods were developed to mostly eliminate the stacking component of this task. Either a pallet, or a tote bin, was placed on the lift table, and the material slid directly off of the shear onto the pallet or into the bin. The material was then able to be moved directly, via crane or forklift, to the front of the shear for further cutting operations, or out to the yard as parts to be used in other operations.

The benefit of eliminating the manual material handling portion of this operation has been two-fold. First, it has greatly reduced the ergonomic and safety issues long associated with this task, and second, according to the shipyard, it has increased productivity by reducing the amount of time required to cut and deliver a piece of plate. It is no longer necessary to manually clear the rear drop-plate of the shear. This is done automatically by virtue of the pallet or tote box being placed below floor level. The shipping process is faster due to the fact that it is no longer necessary to move the pallet of finished plate to another location to be picked up by a forklift. Now the forklift can lift the container of finished plate directly off of the lift table. Also, the lift table has made the plate shear operation a single person job, instead of the previously required two to three people, all while maintaining a consistently higher production.

The cost of the hydraulic lift table for the plate shear included approximately $4300 for the table and about $300 for training in the use of the table. The cost of the pit and the installation costs also need to be considered, but were not specifically recorded by the shipyard.

IIC. SHEETMETAL PROCESSES

IIC1. Sheetmetal Shop Processes

Risk Factors

Ventilation ductwork and other sheet metal subassemblies are built within the shoreside fabrication shops as much as possible. The sheet metal is formed to shape and then fit together into various subassemblies. The worker must occasionally move the unit around on the work surface to get to necessary work locations resulting in some manual material handling and awkward postures.

The work tasks of the sheetmetal shop worker were videotaped and analyzed for presence of occupational risk factors. The worker assumed a variety of postures that resulted in slight to moderate flexion of the shoulder, slight elbow and wrist extension, neck postures from extension through flexion, and trunk postures from slight extension through hyperflexion. The data from the individual analyses are presented in Appendix C – Sheetmetal.

Figure 5. Sheetmetal Shop

Interventions

When feasible, sheetmetal workers should use bench-mounted hand brakes, and metal forming presses/machines rather than hammers, hand seamers, and hand crimpers. For the most part, shipyard sheetmetal workers did have access to these types of machines, but did not make full use of their capabilities. Thus, worker awareness training about the ergonomic benefits of these machines may be offered to entice the workers to make use of the available equipment. While administrative controls, such as worker training, are not a primary focus of this study, there are times when targeted worker awareness training may appear to be beneficial to inform or remind workers of proper and appropriate job procedures. Other types of administrative controls such as worker rotation and the hiring of additional personnel are not addressed in this document.

IIC2. Onboard Sheetmetal Processes

Risk Factors

When a vessel is in a shipyard for scheduled maintenance, often work is done to the ventilation or exhaust systems onboard. Ductwork can be removed, replaced, or initially installed depending on the proposed work. Working with ductwork is most easily performed on the deck rather than overhead. Duct installation or removal usually requires overhead work to place or remove the duct from its position. Static postures and overhead work may cause strain to the workers' shoulders and neck. Once a piece of duct is on the deck, the worker usually bends over top of it to perform some part of the work process. The back flexion may also result in some strain to the worker. The use of powered hand tools, such as grinders or reciprocating saws, exposes the worker to some amount of hand-arm, or segmental, vibration.

The work tasks of the onboard sheetmetal worker were videotaped and analyzed for presence of occupational risk factors. The worker assumed a variety of postures that resulted in slight shoulder flexion, elbow extension and flexion, wrist extension and flexion, radial and ulnar wrist deviation, neck postures from extension through flexion, and trunk postures from slight extension through hyperflexion. An estimate of spinal compression load for a typical manual material handling task was 787 pounds, slightly above the NIOSH recommended compression limit of 770 pounds. The data from the individual analyses are presented in Appendix C – Sheetmetal.

Figure 6. Shipboard Sheetmetal Work

Interventions

Commercially available portable workbenches may be used to raise a piece of duct to a height sufficient to reduce back flexion and the need to kneel while the worker performs a variety of operations on the duct. Many of these benches come equipped with vises or strap-downs that can be used to secure the duct during work and eliminate the need for a second worker to hold or secure the piece while work is being done on it. These workbenches cost approximately $100 each.

IID. BLASTING PROCESSES

IID1. Abrasive Blasting in Steelyard Process

Risk Factors

Steel structures are blasted by employees utilizing specialized blast guns which propel steel shot or silica sand at an item at up to 100 psi, thus removing all foreign debris and pitting the steel which provides for better adherence of the paint coating to the steel. Blasters are completely covered with protective clothing including positive pressure respirators. Moderate force must be exerted to hold blast nozzle as the energy created by the steel shot or sand being propelled at a high velocity raises the nozzle.

The abrasive blasters used a variety of postures in the performance of their duties. In general, abrasive blasters experienced slight to moderate levels of shoulder flexion, moderate shoulder abduction, both elbow extension and flexion, wrist extension and both radial and ulnar deviation, slight to moderate neck flexion and slight to moderate trunk flexion in the performance of their duties. The combination of occupational risk factors that the abrasive blasters were exposed to resulted in a moderate response for the distal upper extremity Strain Index, indicating the possibility of an incidence rate of approximately 106 upper extremity injuries per 100 full-time workers. Another exposure assessment technique found moderate levels of risk for the neck, shoulder and upper back of abrasive blasters. The data from the individual analyses are presented in Appendix D – Blasting.

Figure 7. Abrasive Blaster

Interventions

Possible interventions for the abrasive blasters in the beach blast area include adjustable racks to hold the materials to be blasted at approximately knee to waist height. This would reduce the amount of back flexion required for the job. Racks that allow certain work pieces to be hung would also reduce the amount of material handling that the abrasive blaster is required to perform in order to blast all sides of the material.

IID2. Waterjet Blasting of Vessel in Drydock Process

Risk Factors

When a vessel comes in for hull repair work, it may be placed in a drydock to lift the vessel out of the water. Instead of using an abrasive blasting agent within the drydock to remove paint, a high-pressure water cannon is used. This process eliminates the need to recover the abrasive agent. A worker enters the platform of a powered lift truck, which has been moved beside the vessel in the drydock. The worker raises and positions the platform to be near the work area. The worker activates the waterjet and proceeds to remove paint from the work surface.

The waterjet blasters used a variety of postures in the performance of their duties. In general, waterjet blasters experienced slight to moderate levels of shoulder flexion, moderate shoulder medial deviation, elbow and wrist extension, and slight to moderate trunk flexion in the performance of their duties. They are also exposed to a moderate level of static load from hold the waterjet gun. The combination of occupational risk factors that the waterjet blasters were exposed to resulted in an extreme response for the distal upper extremity Strain Index, indicating the possibility of an incidence rate of approximately 130 upper extremity injuries per 100 full-time workers. Another exposure assessment technique found moderate levels of risk for the neck, shoulder, upper back, elbow, forearm and hands of waterjet blasters. The data from the individual analyses are presented in Appendix D – Blasting.

Figure 8. Waterjet Blaster

Interventions

The primary concern with the waterjet blasting process is that workers are required to hold the water cannon in their hands to control and direct the high-pressure water spray. It was suggested that an orbital nozzle mount, similar to those found on fire engines, be fixed to the railing of the platform of the lift. The water spray can still be directed to the hull or other work surface with a high degree of flexibility while the nozzle mount removes the worker from the strain of holding the water cannon directly. Upon NIOSH's suggestion the shipyard set up an apparatus on a manlift to hold and position the waterjet. However, this arrangement brought about other engineering concerns, including the load capacity of the manlift.

After the initial NIOSH visit, the shipyard entered into a cooperative agreement with another shipyard to further pursue the ultra-high pressure water blasting idea (NSRP, 2001). Among the findings were a number of suggestions to address the worker fatigue found in using the ultra-high pressure water blasting as initially configured. The first suggestion was to provide ergonomic awareness training to the waterjet operators. The second suggestion was to develop an ergonomic intervention to support the vertical (and horizontal) forces of the blasting gun (kickback). One way to do that is to mount the waterjet in a nozzle mount similar to those on aerial platform firetrucks. The third suggestion with an ergonomics focus was to investigate constructing the waterjet blasting gun out of lighter-weight components to reduce the weight of the blasting gun from its current weight of 22 pounds. A double trigger mechanism placed additional strain on the arms of the blast workers, and warranted further investigation. The next two suggestions addressed the awkward postures of blast workers when spraying overhead in areas with low clearance or other constrained work postures. It was suggested that some sort of "ergonomic support device" be incorporated to the work platform to minimize the strain on the worker's back and lower extremities. It was also suggested that wedge-shaped knee support wedges be incorporated as personal protective equipment for blast operators to eliminate hyperflexion of the knee when in a squatting posture. The final ergonomic suggestion was to better manage scheduled work rotations due to an observable decrease in productivity as the work shift progressed due in part to the physical fatigue of the workers.

IIE. INSULATION PROCESSES

IIE1. Shipboard Insulation Installation Process

Risk Factors

Insulators usually work in teams consisting of one installer and one cutter. The installer measures the area to be covered and relays this information to the cutter, who measures, marks and cuts the piece of insulation to size. The piece is then handed up or over to the installer who may re-measure the piece, pushes the insulation into place, piercing the insulation material onto the insulation stud. The installer then installs a cap over the end of the stud securing it with a hammer strike. Installers and cutters will trade places from day to day. It is common for installers to work off of stepladders when performing overhead and some bulkhead installation. Cutters usually set up makeshift workbenches using several boxes of the insulation and/or sawhorses. Most of the insulation is a foam type of material, however, some fiberglass is still used. Fiberglass or foam insulation sheets are commonly 2 feet by 4 feet.

The work tasks of the onboard insulation workers, both cutters and installers, were videotaped and analyzed for presence of occupational risk factors. The cutter assumed postures that resulted in slight shoulder flexion, moderate shoulder abduction and lateral deviation. Cutters also experienced elbow extension and neck postures from slight to full flexion. Insulation installers assumed a greater variety of postures including slight to extreme flexion of the shoulder, elbow extension, wrist extension and ulnar deviation, and neck postures from slight flexion to extension. Both arms were raised over the shoulder level while working overhead. The installers also were exposed to a moderate level of risk factors for the neck, shoulder, upper back, lower back, and lower extremities. The data from the individual analyses are presented in Appendix E – Insulation.

Figure 9. Insulation Installation

Interventions

Possible interventions for the shipboard insulators (cutters) include angled knives to maintain neutral wrist postures. Possible interventions for the shipboard insulators (installers) include an alternate insulation securing process involving semi-automatic stud guns or re-designed knives and hammers. At one location, ergonomically designed hand tools are made available to shipyard employees whenever possible (Barbor, 2000a). NIOSH has no catalog of "recommended" hand tools.

Insulators at one shipyard are rotated through a variety of insulation tasks unless they are medically restricted. Insulation teams often alternate between cutting and installing (Barbor, 2000a). Work rotation between the cutters and installers will reduce individual exposure to occupational risk factors by reducing the time spent in overhead postures by the worker performing the installation task.

IIE2. Insulation Removal on Surface Ship in Drydock

Risk Factors

Insulation from the bulkheads and ceilings of vessels being dismantled is removed by insulators. The workers first cordon off the immediate work area to discourage entry by unauthorized personnel. This action is done by hanging warning tape and placards (e.g., "WARNING Man-

Made Vitreous Fibers") around the work area. The insulators don totally encapsulating chemical protective suits and supplied-air hoods under positive pressure. The initial task of the worker is to remove the insulation tie caps. These small, round disks secure the insulation onto the metal insulation studs. These disks are removed using pry bars or wrecking bars of various sizes while standing on ladders to reach the overhead insulation. Once all insulation tie caps have been removed, the worker uses a hawksbill knife (i.e., a knife with a short, downward-curved blade) to cut the insulation into manageable widths of approximately 18 inches. While cutting into the insulation, a co-worker sprays the surrounding air with a water mist to entrap any loose fibers that may otherwise be respirable. The worker then pulls the insulation to free it from the bulkhead or overhead area. The insulation is bagged and disposed of properly.

Figure 10. Insulation Removal

The work tasks of the onboard insulation removal worker were videotaped and analyzed for the presence of occupational risk factors. The insulation removal worker assumed a variety of postures that resulted in slight to extreme shoulder flexion, raised arms, upper arm abduction, elbow extension, wrist extension and flexion, radial and ulnar wrist deviation, neck extension and twisting, and trunk postures from slight flexion through extension. High arm and hand forces are experienced in the pulling of insulation off of surfaces and may manifest as an increased probability of distal upper extremity injuries. An extremely high percentage of risk factors for the elbow, forearm, and hand were present, as were a moderate percentage of risk factors for the neck, shoulder and upper back. The data from the individual analyses are presented in Appendix E – Insulation.

The vast majority of work for the insulation removal workers is performed with arms overhead or out in front and away from the body, either using pry bars or knives, straining the arms, shoulders, and neck. Often the worker is on a ladder and is leaning backward (back extension) to get to the work as opposed to repositioning the ladder. Back extension such as this can be stressful to the worker. All of the observed tasks were performed while the worker was wearing an encapsulating chemical-protective suit with a supplied air respirator causing an increased physiological strain on the worker.

Interventions

Shipyard personnel reported that elevated work platforms are often erected to raise the insulation removal worker. However, at times, the space constraints inherent to submarines and surface vessels preclude the use of the platforms. The worker accomplishing the insulation removal task is the one to decide if, or when, to use an elevated platform. Since platform use is not a standard work practice at this shipyard, ergonomics awareness training for all shipyard workers may allow them to make better-informed decisions on elevated platform use for insulation removal.

IIF. PIPEFITTING PROCESSES

IIF1. Shop Pipe Welding

Risk Factors

A certain amount of assembly of piping systems is conducted in the shop area of shipyards prior to pre-outfitting the unit on land. Pipe positioning units are provided to allow the welder to position the pipe in whichever attitude is necessary to make the weld easiest to complete.

The work tasks of the shop pipe welders were videotaped and analyzed for the presence of occupational risk factors. The shop pipe welder assumed a variety of postures that resulted in slight to moderate shoulder flexion, elbow extension, neck flexion from slight to extreme, and slight to moderate trunk flexion. The data from the individual analyses are presented in Appendix F – Pipefitting.

Figure 11. Pipe Welding in Shop

Interventions

A possible intervention for pipe welders using positioners is training the workers to optimally set the weld positioner to provide a work height that both reduces back flexion and still enables simple, flat welding to be performed. As administrative controls were not an intended category of intervention for this project, this particular intervention was not pursued further.

IIF2. Onboard Pipe Welding

Risk Factors

Numerous pipe connections are required in many new construction or repair tasks. Pipefitters piece together the piping subassemblies and weld them into place. In the shipboard pipe welding process, the pipefitter must first get into position to weld the pipe together. This may involve working in a confined space, working from an elevated surface, and/or working overhead.

Often the piping is located against a bulkhead or the hull of the ship limiting access to the piping. Welders will often use stick welding equipment to complete the weld. Stick welding requires static and often awkward postures of the arms of the worker resulting in strain. The neck or back of the worker may be flexed to accommodate viewing the work task. The worker may have to kneel, squat or lay down in order to complete the task. Therefore, the lower extremities may be strained as well as the upper extremities. The possibility of working in confined spaces resulting in awkward postures is relatively high.

Figure 12. Shipboard Pipe Welding

The work tasks of the shipboard pipefitters were videotaped and analyzed for the presence of occupational risk factors. The pipefitters assumed a variety of postures that resulted in slight to moderate shoulder flexion, arms occasionally raised above shoulder height, elbow extension and flexion, wrist extension and both ulnar and radial deviation, neck extension to extreme flexion, and trunk extension to moderate flexion. The data from the individual analyses are presented in Appendix F – Pipefitting.

Interventions

Although pipefitting in confined spaces and overhead are difficult processes to address with engineering controls, workers may benefit from ergonomic training. Management was also encouraged to provide administrative controls in terms of worker rotation and scheduling to reduce the time individual workers are assigned to such tasks. The use of teams (which alternate between set-up work and welding) is one such method observed in a number of shipyards.

IIG. SUBASSEMBLY PROCESSES

IIG1. Lifeboat Rack Assembly Process

Risk Factors

As each of a particular type of vessel nears completion, the upper deck is fitted with lifeboat racks from which the boats can be launched in time of need. The worker is required to perform a number of tasks at or near deck level. The frames are composed of a number of angle irons that are torch cut to exact size and ground smooth on the edges. The angle irons are then moved into their places on the deck by hand where they are welded into place on the deck. Adjustment of rack position is occasionally made by sledgehammer, especially if part of the rack has already been welded to the deck.

Figure 13. Lifeboat Rack Assembly

The work tasks of the lifeboat rack assemblers were videotaped and analyzed for the presence of occupational risk factors. The workers assumed a variety of postures that resulted in slight to moderate shoulder flexion, shoulder adduction, elbow extension, wrist extension and flexion, wrist ulnar deviation, neck extension to slight flexion, and slight to extreme trunk flexion. An estimated compressive load on the lower back was calculated to be 769 pounds, just one pound short of the NIOSH Recommended Compressive Limit of 770 pounds. The lifeboat rack worker also presented moderate risk factors for the neck, shoulder, upper and lower back, and upper extremities. The data from the individual analyses are presented in Appendix G – Subassembly.

Interventions

Whenever a worker has to kneel or squat for long periods of time to conduct their work, it is suggested that adequate stools or benches be provided which allow the worker to sit to lessen the stress on the knees and on the lower back. These seats may be useful for mostly level, non-confined areas up on deck. Four-wheeled seat carts and high quality kneepads were provided for use as interventions for this process. Upon follow-up with the shipyard, neither of the items was in use in the same operations as originally intended. This lack of initial use was primarily due to lack of worker acceptance and difficulties in making the interventions work in the chosen processes. Therefore, no appraisal of the effectiveness of these interventions is possible.

IIG2. Assembly Fitter Using Come-along in Shop Process

Risk Factors

The shipfitter must torch cut, grind and weld angle iron, steel plate and other materials into place so that subassemblies can be matched and secured exactly in place. The shipfitter uses a variety of tools in the performance of the job and must be very exact in the task, inspecting it frequently. Often the pieces can be forced into place by using come-alongs to maintain force to hold the steel in its proper position and then the subassemblies are welded together. The come-along (lever-operated chain or wire rope devices designed for pulling) is a common shipfitting tool that can require the operator to produce pulls up to 100 lbs. The required pull depends on the brand and load capacity of the come-along and most manufacturers will provide maximum required pull information.

Figure 14. Bow Subassembly Shipfitter

The work tasks of the bow assembly shipfitter were videotaped and analyzed for the presence of occupational risk factors. The worker assumed a variety of postures that resulted in slight to extreme shoulder flexion, elbow extension, wrist extension and flexion, wrist ulnar and radial deviation, neck extension to flexion, and slight to moderate trunk flexion. The worker also presented moderate risk factors for the neck, shoulder, upper back, and upper extremities. The data from the individual analyses are presented in Appendix G – Subassembly.

Interventions

Workers who use come-alongs should use the lowest possible capacity puller to do the job. Tool personnel should take the tool's required pull into consideration when purchasing new come-alongs. Brands with lower maximum required pulls are generally slightly more expensive for a given capacity and length. A participating shipyard was to purchase new come-alongs; however, no information regarding the equipment's capabilities was ever forwarded to NIOSH researchers.

IIG3. Rake Frame Subassembly

Risk Factors

Subassemblies such as rake frames, or the skeletal framework for the curved bows of tanker, chemical, and cargo barges are created within a shop area. Jigs are set-up at ground level being welded in place on the steel deck floor. Angle irons are delivered by overhead crane to each subassembly area. Angle irons are manually placed in the jig, usually by a single worker. Wedges are then hammered into place to secure the angle irons into the jig. Flat iron plates are placed at the corners of the rake frame and are secured by the use of C-clamps. Workers stick weld the joints of the rake frame that face up. The shipfitter then knocks out the wedges securing the rake frame in the jig. The subassembly is picked up by the overhead crane, flipped over and stacked in a manner so that the other side of the joints can be welded.

Figure 15. Rake Frame Subassembly

The work tasks of the rake frame shipfitter and welder were videotaped and analyzed for the presence of occupational risk factors. During rake frame subassembly, shipfitters undergo awkward postures including extreme lumbar flexion, twisting, and excessive loads to low back, as well as squatting with both legs. A sampling of simulated lifts resulted in an average estimated compressive force of 923 pounds (median of 892 pounds) on the lower back compared to the NIOSH Recommended Compression Limit of 770 pounds. Analysis of the shipfitter's work tasks revealed the presence of a high percentage of risk factors for the neck, shoulder, upper back, and upper extremities and a moderate percentage of risk factors for the lower back. The data from the individual analyses are presented in Appendix G – Subassembly.

Rake frame welders undertake awkward postures such as slight to moderate shoulder flexion, shoulder adduction, elbow extension, wrist extension, both radial and ulnar deviation, slight to extreme lumbar flexion, and kneeling on hard surfaces. Analysis revealed a moderate level of occupational risk factors for the neck, shoulder, upper back, and upper extremities. The data from the individual analyses are presented in Appendix G – Subassembly.

Figure 16. Rake Frame Welding

Interventions

The primary concern with the rake frame subassembly process is the fact that both the shipfitter and welders must bend forward, or flex, at the waist to perform their work at toe height. This is due in part to the jig for the rake frame being welded directly to the steel floor. A height-adjustable jig (more accurately, a jig top placed on a lift table) was suggested as a possible solution, but was dismissed by the company due to perceived space constraints.

IIG4. Hatch Assembly Process

Risk Factors

There are approximately three thousand hatch covers made for every large vessel produced by the participating shipyards. Every hatch cover must be attached to its base by bolts or studs. These studs are attached to each plate in a process called stud welding. An attachment on the stud welding gun holds the stud in the nose of the gun and an electric current is passed to the stud. The fluxed end of the stud is placed in contact with the steel plate. The stud is automatically retracted from the plate surface producing an arc. At the end of an automatically timed period, the molten end of the stud is forced against the molten metal pool on the plate resulting in the stud being securely welded to the plate. A typical hatch cover has approximately 26 studs attached to it. A worker can complete about 15 to 20 covers in a day, each worker welding about 400 to 500 studs to hatch covers each day. The stud gun weighs approximately 12 pounds.

Figure 17. Hatch Subassembly

The work tasks of the hatch cover assembler were videotaped and analyzed for the presence of occupational risk factors. During this process, workers undergo awkward postures including slight to moderate shoulder flexion, moderate upper arm abduction, elbow extension, wrist extension, both ulnar and radial deviation, slight to extreme neck flexion, and slight to extreme lumbar flexion. An analysis of a simulated lift resulted in an estimated compressive force of 821 pounds on the lower back compared to the NIOSH Recommended Compression Limit of 770 pounds. Analysis of the hatch worker's work tasks revealed the presence of a moderate percentage of risk factors for the neck, shoulder, upper back, and upper extremities. The data from the individual analyses are presented in Appendix G – Subassembly.

Interventions

Possible interventions for the hatch assemble include an adjustable lift table to set the work height of the hatch cover above the waist to reduce trunk flexion during assembly operations. A similar arrangement may also be used to store the hatch covers prior to stud welding so that the hatch is lifted from a height that minimizes trunk flexion. Training in proper lifting techniques and in the setting of currently available adjustable equipment to optimal working heights may also be useful.

IIG5. Reciprocating Saw Operations in Ship Dismantling

Risk Factors

Ship dismantling requires the separation of components, bulkheads, and hull sections from adjoining locations. This separation is accomplished either by torch cutting or by using a reciprocating saw to cut through the steel, aluminum or other material. Torch cutting requires a fire-watch crew to stand by and a certain level of expertise by the user. Cutting with a reciprocating saw does not require the fire-watch crew and can be accomplished by nearly every worker making it the preferred method among supervisors. Also, areas containing suspected hazardous materials must be mechanically cut to minimize worker exposure to the substance. Chemical protective clothing is worn when there is the possibility of exposure to known hazards. Mechanical cutting can take place overhead to remove wire hangers, between shoulder and floor height to remove bulkheads, or below floor level to remove decking and supports. Some components are lowered to the deck to be cut to reduce the amount of overhead work.

Workers assume a variety of postures to cut the pieces of metal including kneeling, sitting, lying down, bending over, standing on ladders, etc. Workers typically cut for 2-3 hours and then carry cut material to a disposal area for another 2 hours. Workers often work in pairs, switching between cutting the material with the eight pound reciprocating saw and supporting the item being cut. Heavier items are removed using tandem lifts.

Figure 18. Reciprocating Saw Use

The ergonomic risk factors for reciprocating saw operators include: awkward postures of the spine and wrist, static kneeling postures, forceful exertion of the upper extremity to hold the reciprocating saw, and high noise exposure. Particularly significant is the exposure to hand-arm or segmental vibration from using the powered reciprocating saw. (Vibration damping gloves are required personal protective equipment at one shipyard while using the saw). Normal operation of the saw results in vibration that has been reduced by an anti-vibration mechanism incorporated into the design of the saw. However, when initiating a cut (plunge cutting) or when the blade binds in the material, an extreme amount of vibration is transferred to the arm of the user. The manual material handling of the cut pieces may result in back, neck or shoulder strain of the workers.

The work tasks of the reciprocating saw operators were videotaped and analyzed for the presence of occupational risk factors. During this process, workers undergo awkward postures including slight to moderate shoulder flexion, upper arm adduction, elbow extension, wrist extension, ulnar deviation, neck flexion, and slight to moderate trunk flexion. Analysis revealed that reciprocating saw operators may be high risk to develop distal upper extremity injuries and showed a high percentage of risk factors for the upper extremities. A moderate percentage of risk factors were present for the neck, shoulder, upper back and lower back. The data from the individual analyses are presented in Appendix G – Subassembly.

Interventions

One participating shipyard has developed and offered a safety and ergonomics course for reciprocating saw operators. The shipyard has started to purchase pneumatic reciprocating saws that have a vibration rating of 8.75 m/s^2, which is about 25% lower than that of the current electric reciprocating saws in use at the yard.

If saws are utilized, the use of wheeled tripods or standing jigs as already developed at the shipyard, will remove the worker from the vibration exposure. The addition of a stabilizing handle near the front of the tool that isolates some of the vibration from the worker is also a promising idea. Modification of the saw trigger mechanism to work from palm pressure as opposed to finger pressure was also done at the shipyard to minimize trigger finger complaints. Shipyard personnel noted that while tripods and stands are available to support the reciprocating saws, the present supports have not been widely accepted by the workforce due to their being cumbersome and of limited application.

IIH. WELDING PROCESSES

IIH1. Engine Room Wire Welding Process

Risk Factors

Onboard vessels under construction, steel structures, whether they are units or subassemblies, must be welded together to form a more complete product. Depending on the location of the work, and the size and training of the individual, the worker may be exposed to constrained and awkward postures. The work may be at or below deck level, on the bulkhead, or over the worker's head. Often one or more other workers are in the vicinity performing their job duties that may or may not be similar to those of the welders.

The work tasks of the engine room welder were videotaped and analyzed for the presence of occupational risk factors. During this work, welders undertake awkward postures including slight shoulder flexion, moderate shoulder abduction, elbow extension, wrist extension, slight to moderate neck flexion, and slight to moderate trunk flexion. The data from the individual analyses are presented in Appendix H – Welding.

Figure 19. Engine Room Welding

Interventions

Whenever a worker has to kneel or squat for long periods of time to conduct their work, it is suggested that adequate stools or benches be provided which allow the worker to sit to lessen the stress on the knees and on the lower back. These seats may be useful for mostly level, non-confined areas of the engine room. Four-wheeled seat carts and high quality knee pads were provided for use as interventions for this process. Upon follow-up with the shipyard, neither of the items was in use in the same operations as originally intended. Therefore, no appraisal of the effectiveness of these interventions is possible.

IIH2. Tripod Subassembly Wire Welding in Shop Process

Risk Factors

Small subassemblies are brought to this location to be welded together or to add additional pieces of steel to the subassembly. A dedicated workstation is provided for the worker to perform these tasks. A number of jigs are available to hold the work piece and saw horses and small tables are available to place the work piece on. The worker must perform the job from a variety of postures, including seated, standing bent over the work, or kneeling. Occasionally, the worker must turn the work piece over or adjust its position so that the worker can weld or grind a particular seam easier. If the worker needs to move the subassembly on or off the workstation, the worker may rig it to be lifted by one of the hoists available in the shop area.

The work tasks of the worker in the tripod subassembly area were videotaped and analyzed for the presence of occupational risk factors. During this process, welders undertake awkward postures including slight shoulder flexion, elbow extension and flexion, wrist extension and ulnar deviation, slight to moderate neck flexion, neck side bend, slight to moderate trunk flexion, and trunk side bend. Analysis of the welder's work tasks revealed the presence of a moderate percentage of risk factors for the neck, shoulder, upper back, and upper extremities. The data from the individual analyses are presented in Appendix H – Welding.

Figure 20. Tripod Subassembly Welding

Interventions

Currently, the worker in the tripod subassembly area must perform the job from a variety of postures, including seated, standing bent over the work, or kneeling. The welder must also occasionally manually reposition the work piece and weld in positions other than flat. Thus, an intervention such as a tilting, rotating weld positioner may offer a solution both to eliminate the risk factor of awkward postures required for the job and to increase the efficiency and quality of the weld job.

IIH3. Wire Welding in Panel Line Process

Risk Factors

Welders working in the panel line area are responsible for welding sheets and other structural members to form bulkheads, decks and overhead units. Items to be welded have been tacked into place by the shipfitters. If necessary, welders grind the area to remove any foreign debris and using wire welding equipment perform the welding operation. Once a weld bead has been run, it is cleaned using a slag hammer, offset wire brush or other pneumatic tool. Most work in the panel line is performed in the downward position. It is common for welders to sit, kneel, crouch, bend and even lay down on the steel when welding.

The work tasks of the welders were videotaped and analyzed for the presence of occupational risk factors. Welders undertake awkward postures including slight to moderate shoulder flexion, shoulder adduction, elbow extension and ulnar deviation, neck extension through extreme flexion, and moderate to extreme trunk flexion. Analysis of the work tasks revealed the presence of a moderate percentage of risk factors for the neck, shoulder, upper back, and upper extremities. The data from the individual analyses are presented in Appendix H – Welding.

Figure 21. Panel Line Wire Welding

Interventions

Possible interventions for the panel line welders include the use of low profile, wheeled carts or stools as movable seats for the welders to reduce back flexion and the need to assume kneeling postures. Such carts may be able to be custom designed to include upper body supports and knee supports that allow a variety of postures, such as semi-sitting or kneeling and leaning forward. Carts are already in place in one shipyard and are used successfully by the operator of the automatic plate-welding machine and by those performing tack welding (Barbor, 2000a). However, there is some concern whether similar carts for the rest of the welders would result in prolonged and static lumbar and cervical postures and keep the welders out of close proximity to the welds.

Kneepads and thigh-supports to prevent hyperflexion of the knees during squatting are also commercially available. One shipyard has tried several different types of these products with limited success (Barbor, 2000a), finding that a 12" x 18" welding pad offers the most useful protection.

IIH4. Welding Onboard Vessel Process

Risk Factors

There are three primary types of welding that occur during ship repair processes: manual stick welding, manual wire welding, and semi-automatic wire welding. Stick welding has already been addressed previously for pipe welding. Semi-automatic welding is performed primarily for long straight welds on horizontal surfaces, such as decks. This type of welding is often flux core arc welding where the wire is continuously fed to the arc and the electrode wire has a flux core center that helps to shield the weld. The machine is positioned on the seam to be welded, activated, and then guided by the operator. Wire welding is performed for the majority of welding tasks. The wire electrode is continuously fed to the arc and may or may not be shielded by a flux core.

The work tasks of shipboard welders were videotaped and analyzed for the presence of occupational risk factors. Welders undertake awkward postures including slight to extreme shoulder flexion, shoulder abduction, elbow extension and flexion, wrist extension and flexion, slight to extreme neck flexion, and trunk extension to moderate flexion. The data from the individual analyses are presented in Appendix H – Welding.

Figure 22. Shipboard Wire Welding

Interventions

Whenever a worker has to kneel or squat for long periods of time to conduct their work, it was suggested that adequate stools or benches be provided which allow the worker to sit to lessen the stress on the knees while still enabling the worker to perform the assigned task at or near floor level without additional strain on the lower back. Wedge-shaped knee supports are also commercially available that attach to the back of the calf to prevent hyperflexion of the knees while assuming squatting postures. Several shipyards supply and encourage employees to wear industrial kneepads when necessary.

IIH5. Honeycomb Welding

Risk Factors

This process involved stick welding in spaces known as honeycombs that are two feet by two feet by sixteen feet long. The bottom plate was welded to the vertical supports on both sides of the honeycomb. At the time of the site visit, a stick welding process was used. Typically 8 - 10 honeycombs are completed in a shift by each welder. Ventilation was primarily by blower fan forcing outside air into the honeycomb. A detailed report on ventilation interventions for this process can be found in Wurzelbacher et al, 2002.


Figure 23. Simulation of Honeycomb Welding Task

The welders assumed constrained postures in order to crawl to the far end of the honeycomb to begin welding. This task also included extreme lumbar flexion in confined spaces, contact stress on the knees and elbows, pulling and lifting weld leads into and out of the honeycomb, positioning the blower fan and moving it from one honeycomb to the next, and extreme environmental temperatures in summer and winter. The postures undertaken include slight to extreme shoulder flexion, shoulder adduction, elbow flexion, wrist extension and ulnar deviation, and trunk flexion. Analysis of the work tasks revealed the presence of a high percentage of risk factors for the upper extremities and a moderate percentage of risk factors for the neck, shoulder, upper and lower back, and lower extremities. The data from the individual analyses are presented in Appendix H – Welding. A detailed analysis of musculoskeletal findings for this job can be found in Lowe et al, 2001.

Interventions

This stick welding process was replaced by an automatic welding process that minimizes exposure of the worker to the previously detailed occupational risk factors.

III. GRINDING PROCESSES

III1. Panel Line Grinding Process

Risk Factors

In the panel line, horizontal and vertical stiffeners are welded to steel plate to create subassemblies. This requires the worker to use a variety of tools including welding units, pneumatic grinders and needle guns. A complete seam weld is placed to secure the stiffener to the plate. Then grinders or needle guns are used to smooth out the weld and remove any weld splatter. Once the subassemblies are completed, they are combined into blocks or units.

The work tasks of the panel line grinder were videotaped and analyzed for the presence of occupational risk factors. Workers undertake awkward postures including slight to moderate shoulder flexion, shoulder adduction, elbow extension, wrist extension and ulnar deviation, slight to moderate neck flexion, and slight to extreme trunk flexion. Analysis of the work tasks revealed the presence of a moderate percentage of risk factors for the neck, shoulder, upper and lower back, and upper extremities. The data from the individual analyses are presented in Appendix I – Grinding.

Figure 24. Panel Line Grinding

Interventions

Possible interventions for grinders in the panel line assembly area include adjustable lift tables with jig tops to elevate the various subassemblies prior to grinding and needle gun operations to minimize back flexion. Process changes (e.g. weldable primer, more efficient and clean welding processes) to reduce the amount of required grinding may also be explored, but would probably require permission from the vessel's intended owner.

III2. Grinding Onboard Vessel Process

Risk Factors

In any ship construction or repair process, grinding is a primary task. Old paint must be removed from bulkheads or decks prior to painting; weld beads must be ground flush with the plates or attachments. Grinding surfaces can be vertical or horizontal and at floor level, overhead, or somewhere in between. The worker may be standing, kneeling, squatting, or even laying down to perform the task.

The work tasks of the shipfitter were videotaped and analyzed for the presence of occupational risk factors. Shipfitters undertake awkward postures including slight to moderate shoulder flexion, raised arms, elbow extension, wrist extension and ulnar deviation, and neck extension to flexion. Analysis of the shipfitter's work tasks revealed the presence of a moderate percentage of risk factors for the neck, shoulder, upper back, and upper extremities. The data from the individual analyses are presented in Appendix I – Grinding.

Figure 25. Shipboard Grinding

Interventions

Whenever a worker has to kneel or squat for long periods of time to conduct their work, it was suggested that adequate stools or benches be provided which allow the worker to sit to lessen the stress on the knees while still enabling the worker to perform the assigned task at or near floor level without additional strain on the lower back. Wedge-shaped knee supports are also commercially available that attach to the back of the calf to prevent hyperflexion of the knees while assuming squatting postures. Several shipyards supply and encourage employees to wear industrial kneepads when necessary.

III3. Shipboard Tank Grinding Process

Risk Factors

Primary responsibilities of tank grinders include removing paint, rust and other foreign objects from tanks, the bilge, bulkheads, etc. The main purpose is to prepare surface for painting. Tank grinders use multiple pneumatic tools, depending on specific task to be completed and available workspace. The most common pneumatic tools used include the 5- and 3-inch disc sanders, offset wire brush and needle gun. After the area has been ground, it is cleaned using various cleaning solutions.

The work tasks of the tank grinders were videotaped and analyzed for the presence of occupational risk factors. Workers undertake awkward postures including slight to moderate shoulder flexion, shoulder adduction, elbow flexion and ulnar deviation, and neck extension to slight flexion, and slight trunk flexion. Analysis of the tank grinder work tasks revealed the presence of a high percentage of risk factors for the upper extremities and a moderate percentage of risk factors for the neck, shoulder, upper and lower back, and lower extremities. The data from the individual analyses are presented in Appendix I – Grinding.

Figure 26. Shipboard Tank Grinding

Interventions

Possible interventions for the shipboard tank grinders include lighter tools that induce less vibration. More and more tools claiming to be "ergonomic" in nature are available commercially. The specifics of why a particular model of tool is deemed to be "ergonomic" must be carefully determined. An "ergonomic" tool does not necessarily mean it passes a lower level of vibration to the tool user. NIOSH has no current project to catalog or suggest specific "ergonomic" tools for certain work processes. The buyer is urged to exercise caution and to make an informed decision in the selection of particular tools.

Another possible intervention is the use of support devices such as spring returns for areas where extended vertical grinding is required. Appropriate tool balancers cost in the range of about $50-150. There are numerous types of tool balancers available, some of which can be implemented in confined spaces. Portable, self-contained abrasive blasting units may also be used instead of manual grinding in some cases.

IIJ. DECK WORK PROCESSES

IIJ1. Deck Scraping Process

Risk Factors

When a vessel is in a yard for scheduled maintenance, often the exterior deck's surface must be replaced with a new coating of high-friction anti-slip material. First the old coating must be removed. This is accomplished by using large machines, similar in size and function to commercial floor sanders. However, there are usually numerous fixtures and encumbrances on the deck surface, such as ladders and machinery mounting brackets. Around these fixtures and in the area between the deck and the bulkheads, the old coating must be removed be using a variety of pneumatic tools including deck scalers, needle guns and scrapers

Since all this work is done at deck level, workers must squat, sit, kneel, crawl or lie down in order to reach all the areas that must be stripped of the old coating. Stresses to the lower extremities, neck and back can be quite high depending on the worker posture, whether the posture is constrained, and the length of time the worker must assume that posture. Exposure to the vibration created from using pneumatic vibrating hand tools may contribute to the development of hand-arm vibration syndrome or carpal tunnel syndrome.

Figure 27. Deck Scraping

The work tasks of the deck workers were videotaped and analyzed for the presence of occupational risk factors. Common awkward postures include slight to extreme shoulder flexion, both shoulder abduction and adduction, elbow extension and flexion, slight to moderate neck flexion, neck twist, slight to extreme trunk flexion, and trunk twisting and side bending. Analysis of the work tasks revealed the presence of a moderate percentage of risk factors for the upper extremities. The data from the individual analyses are presented in Appendix J – Deck Work.

Interventions

Although large scaling machines are difficult to use around various encumbrances on the deck surface, there are commercially available long-handled pneumatic tools including deck scalers, needle guns and scrapers. These may reduce the need for the worker to squat, sit, kneel, crawl or lie down in order to reach all the areas that must be stripped of the old coating and may reduce the exposure to vibration. Suggested approximate long-handled tool characteristics were provided in a previous report (No. 229-16b).

Another option for the deck scrapers is the use of commercially available seats designed specifically for kneeling and squatting. These seats may at least improve the postures associated with the use of hand-held scraping tools by enabling the worker to sit to lessen the stress on the knees while still enabling the worker to perform the assigned task at or near floor level without additional strain on the lower back. Supports are also commercially available that attach to the back of the calf to prevent hyperflexion of the knees during squatting postures.

Although welding grinding in confined spaces, overhead and at deck level are difficult processes to address with engineering controls, workers may benefit from ergonomic training. Management is also encouraged to provide administrative controls in terms of worker rotation and scheduling to reduce the time individual workers are assigned to such tasks. The use of teams (which alternate between set-up work and welding) is one such method observed in a number of shipyards.

IIJ2. Torch Cutting Process

Risk Factors

There are many ship repair processes in which torch cutting is used to remove steel decking or bulkheads. At times, individual components scheduled for replacement are located in such confined spaces that it is easier to torch cut an opening either beside, above or below an item in order to remove it from its original location. At other times, the physical dimensions of compartments are slated to change for one reason or another, again calling for the removal of decking or bulkheads.

The work tasks of the torch cutter were videotaped and analyzed for the presence of occupational risk factors. Common postures undertaken include slight to moderate shoulder flexion, elbow extension, moderate neck flexion, and trunk flexion. Analysis of the work tasks revealed the presence of a moderate percentage of risk factors for the upper extremities. The data from the individual analyses are presented in Appendix J – Deck Work.

Figure 28. Torch Cutting Deck

Interventions

Whenever a worker has to kneel or squat for long periods of time to conduct their work, whether it be torch cutting, grinding, or welding, it was suggested that adequate stools or benches be provided which allow the worker to sit to lessen the stress on the knees while still enabling the worker to perform the assigned task at or near floor level without additional strain on the lower back. Wedge-shaped knee supports are also commercially available that attach to the back of the calf to prevent hyperflexion of the knees while assuming squatting postures. Several shipyards supply and encourage employees to wear industrial kneepads when necessary.

IIJ3. Tile Removal Process

Risk Factors

During the outfitting of vessels, some of the deck surfaces are covered in tile. This is particularly true of mess hall and lavatory facilities. During repair or replacement work, before the deck plate can be cut by either torch or reciprocating saw, a path must be cleared of tile. The tile is removed by using a chipping hammer to flake the tile off the deck surface. This task requires the worker to kneel, sit or bend over the deck surface to operate the chipping hammer.

Chipping tile from deck surfaces puts the worker in awkward postures, having to kneel or sit on the deck. The back and neck are often flexed. Exposure to hand-arm or segmental vibration is due to having to hold the chipping blade in place with one hand while holding the tool weight and operating the trigger with the other hand. Few improvements to these tools have been made since the 1900's. Noise exposure is also very high with the use of chipping hammers.

The work tasks of the tile chipper were videotaped and analyzed for the presence of occupational risk factors. Common postures undertaken include slight shoulder flexion, elbow extension, wrist extension and ulnar deviation, extreme neck flexion, neck twist, and moderate to extreme trunk flexion. Analysis of the work tasks revealed the presence of a high percentage of risk factors for the upper extremities and a moderate percentage of risk factors for the neck shoulder, and upper and lower back. The data from the individual analyses are presented in Appendix J – Deck Work.

Figure 29. Tile Chipping

Interventions

Removing tile from deck surfaces requires the worker to kneel or sit on the deck. Providing kneepads or cushions minimizes some of the contact stresses. Low industrial seating wheeled stools are available for approximately $150 each. Depending on the application, worker postures may benefit from using the stools.

If chipping hammers can not be replaced as the tool of choice for this task, it is recommended that the widest blade possible (at least 2 inches) be used to minimize exposure time and the most vibration-damped tool available be used. New chipping hammers range in price from $400 to $750. No known action was taken for the tile chipping intervention.

IIK. ELECTRICAL PROCESSES

IIK1. Shipboard Cable Pulling Process

Risk Factors

Multiple lines of cable varying in length, size and weight are pulled by hand throughout areas of the ship. The size of the crew is largely dependent on the size, length, routing and final location of cable. The larger cable pulls are performed by workers in groups numbering as high as 20. Cable runs are located overhead, along bulkheads, and below deck plate level. This often requires forceful pulling while in a variety of awkward postures.

The work tasks of the cable pullers were videotaped and analyzed for the presence of occupational risk factors. Depending on the location and size of the cable, a variety of postures were used including slight to extreme shoulder flexion, elbow extension, wrist extension and ulnar deviation, neck extension through slight flexion, neck twisting, slight to extreme trunk flexion, and trunk twisting. A sampling of simulated cable pulls resulted in an average estimated compressive force of 449 pounds (median of 425 pounds) on the lower back compared to the NIOSH Recommended Compression Limit of 770 pounds. Several individual pulls resulted in compressive forces in excess of the Recommended Compression Limit. Analysis of the work tasks revealed the presence of a high percentage of risk factors for the upper extremities and a moderate percentage of risk factors for the neck, shoulder, and upper and lower back. The data from the individual analyses are presented in Appendix K – Electrical.

Figure 30. Overhead Cable Pulling

Interventions

A possible intervention for the shipboard cable pullers was the introduction of a semi-automated cable pulling system. These systems typically use a cable-pulling winch (capstan), double braided low stretch ropes, pulleys, and Teflon sheets to reduce cable friction. The ropes are attached to the end of the cable and capstan pulls at a range of speeds and in a wide range of positions. Most capstans are self-contained and allow for easy transport and set-up shipboard. The capstan pulling system may be able to be coupled with portable inline pullers that are also commercially available. Preliminary testing with similar systems aboard Navy vessels "indicate a potential for reducing cable pulling time and costs by as much as 50% with no personnel injuries" (NAVOSH website, 2000). Some interest was expressed in this intervention by members of one of the union locals, but no firm plans are known to exist to implement this intervention at any participating shipyard. However, initial testing of a similar system at one shipyard lead to the conclusion that, due to the multiple turns in the cable run in the current ship design which would necessitate numerous set-ups of the system, the cable pulling system was not feasible (Barbor, 2000a). A participating shipyard has instituted the use of double braided stretch rope to assist in pulling degaussing cable.

Other possible interventions for the shipboard cable pullers include work rotation among pullers so that time spent in postures involving overhead work, kneeling, and back flexion are minimized and work practices to begin pulls in the middle of the cable rather than at the end (which requires pulling the entire length of cable in one pull). At one participating shipyard the cable crew is rotated.

IIK2. Cable Connection Process

Risk Factors

Often referred to as switchboard installers, electricians identify routes and hook up wire cable ends to large switchboard units located throughout the ship. The process involves identifying specific cables and attachment locations. Cable is routed in, around and through the bottom of switchboard to the specific hook-up/connection lug. Once at the desired location, wire ties are used to secure cable. Cable covering is removed and ends are stripped back to permit good attachment of cable ends. The lugs are then secured to the switchboard units. Hook-up is then inspected to assure proper arrangement has been achieved in the switchboard.

Figure 31. Cable Connection Task

The work tasks of the electricians connecting cable were videotaped and analyzed for the presence of occupational risk factors. Common postures undertaken include slight shoulder flexion, wrist extension, slight neck flexion, neck twisting and side bending, and trunk twisting. Analysis of the work tasks revealed the presence of a moderate percentage of risk factors for the upper extremities. The data from the individual analyses are presented in Appendix K – Electrical.

Interventions

Possible interventions for the shipboard cable connectors include work practices that reduce the amount of cable preparation (stripping, tying, etc.) at the switchboard, where the confined space limits work movements and postures. This practice is already used at one participating shipyard but only when preparing short pieces of wire between 10 and 12 inches in length. When this practice was applied to larger pieces of cable, the stripped cable ends were vulnerable and sustained considerable damage in manual material handling operations.

The use and maintenance of specialized cable tools may also reduce grip and other upper extremity forces. Many hand tool companies are beginning to develop and market tools such as "ergonomic" wire strippers. The applicability of these tools to specific tasks should be considered by each shipyard. In fact, ergonomic wire strippers have been considered and implemented in the shop environment at a participating shipyard.

IIL. MANUAL MATERIAL HANDLING PROCESSES

IIL1. "Cut and Carry" Process

Risk Factors

As part of the dismantling process, material is cut apart and stored at temporary locations within the vessel. This material is then manually moved from the internal storage areas to scrap bins for removal from the ship by crane. Depending on how the material was cut, it may require more than one individual to safely lift the object and carry it to the scrap bin. Somewhat confined spaces and the clutter of the stored material create tripping hazards in the narrow passageways.


Figure 32. “Cut and Carry” Task

The work tasks of the “cut and carry” workers were videotaped and analyzed for the presence of occupational risk factors. The manual material handling of scrap metal may result in strains of the lower back, neck, shoulder and upper extremities. Tripping hazards may be present. Sharp edges on the cut metal may cause lacerations to ungloved hands. Analysis of the work tasks revealed the presence of a moderate percentage of risk factors for the neck, shoulder, upper and lower back, and upper extremities. The data from the individual analyses are presented in Appendix L – Manual Material Handling.

Interventions

Ship dismantling requires that most internal components be removed from the vessel before the vessel is cut to pieces. The removal of components through ship passageways to staging areas is currently performed by manual material handling. The possibility was considered that flexible conveyor systems or cable pulley systems can be used to either move material to the staging area or to move material into the scrap bins in the staging areas. Portable hoists may also be useful in the staging areas as well to move heavy or bulky material. However, the shipyard responded that a major constraint was the limited deck space. Several conveyor types had been tried with limited success. During the trials, there were difficulties in starting and stopping the conveyors as desired, parts would hang up in the narrow passageways and maintaining good control of the off loading end was also a problem.

IIL2. Drydock Sorting Pad Process

Risk Factors

As vessels are dismantled, hundreds of bins of scrap metal are generated. Each bin measures approximately 5 feet by 3 feet by 3 feet. The bins hold a variety of material: stainless steel, painted steel, unpainted steel, aluminum, and other metal components. Each bin is filled during the "cut and carry" dismantling process for each vessel within the drydock. The scrap bins are moved from the vessels to the sorting pad area by forklifts. The sorting pad is surrounded by large shipping containers (approximately 5 feet x 20 feet), each for a specific type of metal.

The sorting pad worker removes the individual pieces of metal from the scrap bin by hand. The worker makes a determination of the type of metal in hand and then carries the item to the appropriate shipping container. The worker then places or throws the item into the shipping container and returns to the scrap bin for the next item. Each bin takes approximately 20 minutes to empty and sort. During on-site evaluation, several heavy objects were weighed. A common type of scrap, such as valves and flanges from high-pressure steam lines, weigh approximately sixty pounds, and one object was weighed at 120 pounds. According to the workers, such objects weighing in excess of 100 pounds are not uncommon, and may be encountered many times in a single day.

The sorting pad worker often reached far across or deep into the bin while grasping objects of unknown weight. Awkward postures of the back and neck, such as extreme lumbar flexion and neck extension, were fairly common. Strain of the shoulder, neck, and back are possible due to the manual lifting tasks. Some items are relatively heavy resulting in increased physiological strain on the worker. The data from the individual analyses are presented in Appendix L – Manual Material Handling.

Figure 33. Drydock Sorting Task

Interventions

Changes in how the scrap bins are presented to the worker may help in eliminating the extreme back flexion required to reach to the bottom of the bins to remove items. Tilting pallet jacks can be used to tilt the scrap bin once some of the material has been distributed to the shipping containers. Ultimately, the accurate sorting of material into separate scrap bins at the vessel would eliminate the need for the sorting pad.

After much consideration and research into the commercial materials handling products available for this type of operation, a tilting table was chosen. A forklift is used to load the self-dumping hoppers onto the tilting table, at which point they are slowly and incrementally tilted to a maximum of 30 degrees. This allows the discharge chute to function as a horizontal work surface, at a height of approximately 30.5 inches. By limiting vertical rotation to 30 degrees, the material in the hopper will not inadvertently fall out onto the operator's feet.

No commercially available, off-the-shelf products with the required specifications existed on the open market. Only one vendor was found that was willing to modify an existing platform, with a capacity greater than the estimated 5700 pounds, according to the shipyards specifications. Vestil Manufacturing Company (Angola, Indiana) supplied a modified table as a test model for the project. This table included a 30-degree tilt mechanism, was pneumatically powered, with a guarded remote foot pedal control, and was welded to the raised segregation platform at the bottom of the drydock.

The test table was installed in the drydock sorting area and was in use for several months. The tilting table received favorable reviews from the sorting pad workers. The sorting pad workers generally liked the tilting table, since it made the sorting task less strenuous by reducing the amount of bending, and the overall effort required to segregate a hopper of scrap material. The shipyard felt that the pace of the task was not significantly changed by the use of the tilting table.

The workers also mentioned a few problems with the table, and suggested modifications to increase the device's usefulness and durability.

1. Tilt table platform was not large enough to easily accommodate the bins. The loading platform needs to be larger to allow more space within which to place a full bin. This makes the task of the forklift driver easier.

2. Construction of tilt table was not heavy enough to be durable over long-term use. It should be made of heavier gauge material to reduce flexure and increase durability, in the interest of reduced repairs.

3. The tilt table needed to be more mobile, or there needed to be more units to allow for more than one bin at a time on the sort-slab. Instead of being rigidly welded to the sort slab, it should be mounted on a heavy platform that could be easily moved by a forklift.

Based on worker reaction to the experimental tilting table, more such tables have been purchased. The new tables are improved over the original test table in several ways. They are made of heavier material so as to be more durable. The loading platform is larger to allow easier loading of the bins onto the table. The exterior of the tilt table around the edges of the loading platform are enclosed in an expandable skirt to minimize pinch point hazards. The new tables will also be made mobile by mounting them on a large ballast plate that can be moved by forklift. These mounting plates will be made of 1.5-2" steel. The shipyard has purchased two more tilting tables for $4025 each plus the cost of installation, and construction of mounting plates that will be carried out by the shipyard.

IIL3. Shipboard Rigger Equipment Load-In Process

Risk Factors

At one shipyard, equipment is lifted off of the transportation vehicle via a large gantry crane and lowered into the ship. Depending on the final location of equipment and location of access hole, the degree of manual manipulation of the object will vary. A tag line is used to safely guide the load down to the shipboard riggers located below deck. Once the equipment is unhooked from the crane, shipboard riggers are responsible for getting the equipment/item to its final position. Shipboard riggers maneuver the equipment into the general vicinity of its final destination using low cart rollers, which can be very effective for moving equipment over flat decks with no lips or protrusions. Unfortunately, only a few areas within the ship are suitable for this mode of transport. Once the equipment or item is close to its final destination, or needs to move off of the low profile cart, it is slid across the deck. When feasible, shipboard riggers place a one-inch pipe under the equipment permitting it to be rolled with less effort. To place or remove the pipe roller from underneath the equipment, the item being moved must be tilted on one end, which permits the pipe to be set in place. Once the equipment or item is in place, the process repeats until truck is unloaded.

The work tasks of the shipboard riggers were videotaped and analyzed for the presence of occupational risk factors. Shipboard riggers undergo awkward postures including slight to moderate shoulder flexion, raised arms, moderate shoulder abduction, elbow extension, wrist extension, slight neck flexion, and slight trunk flexion. An analysis of a simulated equipment move resulted in an estimated compressive force of 789 pounds on the lower back, slightly higher than the NIOSH Recommended Compression Limit of 770 pounds. Analysis of the shipboard rigger work tasks revealed the presence of a moderate percentage of risk factors for the upper extremities, neck, shoulder, upper back and lower back. The data from the individual analyses are presented in Appendix L – Manual Material Handling.

Figure 34. Equipment Load-In

Interventions

Possible interventions for the shipboard riggers during equipment load-in include the work practice of preparing the temporary deck surface to reduce the number of uneven plate and plywood surfaces that inhibit cart travel. This technique is already used at one of the participating shipyards wherever feasible (Barbor, 2000a).

Modified, low-profile carts with ball-bearing plates for top and bottom surfaces that utilize lowered axles and adjustable wheels located outside the perimeter of the transported equipment may also be used to maneuver taller pieces of equipment into place. Such carts should reduce or eliminate the need for tilting the equipment on and off the pipe rollers allow for a smoother placement of the equipment into the retaining bracket. Multiple air bearing movers may also be used to lift equipment using normal compressed air, thus eliminating floor friction and allowing omnidirectional movement. Again this technique is utilized at one of the participating shipyards where feasible (Barbor, 2000a), however the movement of material through hatches and down ship's ladders complicates the manual material handling process.

IIL4. Bin Unloading in the Panel Line Area Process

Risk Factors

At one shipyard, pre-cut shapes are shipped into the panel line area from off-site facilities in large metal shipping containers. Shipping containers are delivered by forklift and are placed into the material handling area by utilizing a hand operated pallet jack. Workers remove individual pieces from the shipping containers and identify hull, unit and job and other pertinent numbers. Once an item has been identified, it is carried and placed onto the appropriate shelf and location. Shapes or pieces are then arranged on the shelves to allow easy retrieval by shipfitters working within the area.

The work tasks of the bin unloaders were videotaped and analyzed for the presence of occupational risk factors. During rake frame subassembly, workers undergo awkward postures including slight to moderate shoulder flexion, elbow extension, wrist extension, extension to moderate flexion of the neck, and moderate to extreme trunk flexion. A simulated lift from the bottom of the bin resulted in an estimated compressive force of 898 pounds on the lower back, well above the NIOSH Recommended Compression Limit of 770 pounds. Analysis of the work tasks revealed the presence of a moderate percentage of risk factors for the neck, shoulder, upper and lower back , and upper extremities. The data from the individual analyses are presented in Appendix L – Manual Material Handling.

Figure 35. Bin Unloading

Interventions

Possible interventions for the bin unloaders area include adjustable bin lifters that raise and tilt the load towards the worker. Many inexpensive models of this type are commercially available. One shipyard had installed this type of bin lifter in various locations across their facility with positive results and their placement along the panel line was under consideration (Barbor, 2000a)

A hook-like tool for grasping individual workpieces may also help to bring the load closer to the material handler and also reduce the need for pinch-grip hand postures. However, for a hook-like tool to work, there would need to be a hole or pad-eye on the piece through which the hook can be attached. Some pieces may have such holes available, many other components such as steel plates would not have such holes. This intervention would be of limited usefulness for those items.

Work practices of pre-sorting heavier items and emptying them by forklift onto a rotatable table top before handling may also be feasible. At one shipyard, the process of material handling has been streamlined by sorting work pieces by hull and delivering these kits as they are needed (Barbor, 2000a), which effectively reduced the amount of material handling performed.

III. RELATED SHIPYARD INTERVENTIONS

Over the approximate 5-year course of this project, many opportunities to address ergonomics at the individual shipyards have arisen. Some interventions have developed as byproducts of this project. Others had been developed before this project was initiated; yet, others were undertaken after this project was primarily completed. Regardless of the timing of these ergonomic interventions and irrespective of the motivation behind the implementation of these interventions, it is still noteworthy to report them so that the industry at large can appreciate the scope of ergonomics within the shipbuilding and ship repair industries.

IIIA. ERGONOMICS TRAINING PROGRAM

Since each repair process to be carried out onboard a vessel is constrained by the physical layout and dimensions of the existing structure, very little can be done in the area of workstation redesign or even engineering interventions, in general. It is, however, possible to address concerns raised by improper tool selection and tool usage and poor body positioning. It was suggested that basic ergonomics awareness training be considered for all production workers, emphasizing the areas cited above. While direct changes to the work environment are inherently minimized due to the constraints of ship repair, it may be possible to educate the workforce on proper procedures, better work methods and postures to assume while performing the work onboard vessels.

In February 2001, NIOSH project personnel and one contractor provided three 2.5-hr sessions of ergonomics awareness training to the labor-management team and first-line supervisors of a participating shipyard. This training was deemed successful by the shipyard's Safety Manager. While ergonomic training has not yet been offered to the rest of the workforce, the shipyard is a member of the Shipbuilders Council of America (SCA) that has recently received a grant from the Occupational Safety and Health Administration to develop an ergonomics training program for all shipyard workers.

IIIB. PNEUMATIC TOOL VIBRATION RESEARCH

A shipyard loaned to NIOSH two pairs of pneumatic grinders: one set of 14,000 rpm angle grinders and one set of 18,000 rpm die grinders. Each set consisted of a brand new tool and a tool ready for issuing from the shipyard's tool supply crib. These tools served as the basis for a series of laboratory tests to determine the effect of wear and implement type on the vibration characteristics of the tools (Wasserman et al, 2002).

Results of the limited study showed that hand-arm vibration standards (ACGIH TLV and ANSI S3.34) were not exceeded, but there was a consistent tendency for the acceleration levels to increase between the new and used tool while using grinding wheels and carbide burrs, both hard implements. The increases were not statistically significant, however, due to the limited sample size. Weighted acceleration levels were mixed with both set of tools when soft implements such as flap wheels were used on the tools. These results are possibly due to the inability to maintain consistent pressure of the soft tool attachment on the steel test piece.

In general, with no knowledge of the previous hours of operation for the used tool, but with identical implement usage, the overall results suggest the need for and implementation of a regular tool vibration monitoring and maintenance program as a primary element to help maintain tool acceleration levels to a minimum level. A study with more tool pairs and with known hours of usage for the tools may have posited a correlation between hours of use and vibration levels. While many shipyards currently run comprehensive tool maintenance programs, few, if any, programs include tool vibration monitoring.

IIIC. "5S" PROGRAM

The National Shipbuilding Research Program has a project titled "5S – Applications and Education Programs for Shipyards." The "5S" system was developed in Japan as an outgrowth of the Total Quality movement, where attention is placed on the state of the workplace itself. The name "5S" comes from the initial letters of the Japanese key words associated with the components. Table 2 lists the original Japanese word, the direct translation, and an English-equivalent "S" key word (DiBarra, 2002).

Table 2. “5S” Components

Original Japanese word	Direct translation	English-equivalent “S” word
Seiri	Organization	Sorting
Seiton	Neatness	Simplifying
Seiso	Cleaning	Systematic cleaning
Seiketzu	Standardization	Standardizing
Shitsuke	Discipline	Sustaining

“Sorting” stands for separating what is essential and required to conduct a particular job task from what is not needed. This will reduce workplace clutter and reduce the possibility of hazards from contact with extraneous material (trips, struck by accidents, etc.), “Simplifying” means that all items needed for the immediate work task are stored in particular and unique locations near the work area for ease of retrieval and minimal downtime. “Systematic cleaning” means that the work place is neat and clean. Once normal operating conditions are established, any abnormal conditions are more easily recognized and acted upon, such as the need for preventive maintenance. “Standardizing” stands for the development of common work practices and consistency in how items are stored, how production processes are executed, and how changes are implemented in the workplace. “Sustaining” means the maintenance of gains and the constant improvement on those gains.

To date, one of the participating shipyards has implemented the “5S” program in approximately twenty locations across the shipyard including: yard maintenance; rigging area; electric, hose and pump repair; drydock riggers; welder maintenance; carpenters; inside and outside machine shops; central tool room; and indoor blasting and painting facilities. On average, the shipyard has identified and documented a 30% decrease in cycle time throughput, or a 30% reduction in wasted time, from the implementation of this program. Specific examples of how the workplaces were improved are illustrated in the article by DiBarra (2002). The shipyard reported that the best gains came from their 5S program when it was used as a vehicle for addressing productivity, workflow, culture change, continuous process improvement, safety, ergonomics, and total productive maintenance.

IIID. LEAN SHIP REPAIR AND LEAN MANUFACTURING

The same shipyard is also an active participant in a second project of the National Shipbuilding Research Program titled “A Lean Enterprise Model for U.S. Ship Construction, Overhaul and Repair.” This project addresses the application of lean manufacturing principles to the work processes of the various shipyard industries. Lean manufacturing focuses on the elimination of sources of waste or any non-value-added activity. The shipyard has combined a “lean ship repair” program with a mobilize, maintain, and demobilize (MMD) program which plans for the layout of temporary facilities which allows an orderly and systematic “pullback” of equipment following completion of the repair operations.

As with many other shipyards, one of the participating shipyards is investigating lean manufacturing principles and their application to the shipbuilding or ship repair workplace. The shipyard joined a National Shipbuilding Research Program pilot project (Liker and Lamb, 2002). A circuit breaker repair process was identified for intervention. Upon enactment of the lean policies, including 5S, a number of positive results were obtained. Broken test equipment, a shock hazard, and general clutter was removed from the work area. The 5S program identified 80 non-essential items in the workplace which were removed. The walking distance of the mechanics was reduced by 81%. The lead time to repair the circuit breakers was reduced by over 90%. The floor space utilization improved by 20% and the part travel distance was reduced by 20%.

IIIE. TOOLING

One of the participating shipyards was recently able to purchase new power tools under a hazard abatement program. New models purchased include the Ingersoll-Rand Cyclone Series pneumatic grinders and sanders, Ingersoll-Rand Series 7 pneumatic drills, the Cleco pneumatic reciprocating saws mentioned earlier, and Honsa tools. New motors for the Aro pneumatic 3" angle grinders vibrated less than the old motors (3-6m/s^2 v. 6-8 m/s^2).

A number of tool-related issues were addressed at another shipyard. Pneumatic tools are continuously upgraded to include damping devices, isolated handles, composite handles with increased diameter, two-handled grinders, etc. Welding guns with adjustable nozzles have been adopted in the yard. In one of the metal fabrication areas, clamping devices have replaced bent metal pins or "dogs" which were used to secure a subassembly to a work surface. These "dogs" were installed by striking them repeatedly with a hammer.

IIIF. MATERIAL HANDLING

Height-adjustable lift tables are provided throughout the shops at one shipyard to bring the load to be transferred to approximately waist height to minimize strain on the lower back. Easy-reach tilt storage boxes are used for small part storage in subassembly areas to provide easier access to these components. Overhead hoists and jib cranes are available at workbenches where manual material handling of fairly large or heavy items is common. Suction and magnet cranes are available for unique lifts that cannot be rigged in a traditional manner. A conveyor system was installed in the warehouse for delivery of items. Stock-pickers and scissor manlifts are utilized to raise the worker to the height of the item to be pulled from the storage racks. One shipyard has contracted with a number of its suppliers to provide items in smaller and lighter packages or groupings that are easier to carry by an individual.

IIIG. TASK SPECIFIC STRETCHING EXERCISES

Over the past five years or so, several shipyards have developed a number of task specific stretching exercises that the workers may voluntarily perform prior to carrying out specific operations such as confined space overhead grinding. This reflection of the "industrial athlete" concept is gaining popularity in a number of shipyards.

IV. CONCLUSION

The integration of ergonomic work practices within the shipbuilding and ship repair industries is an ongoing process. Many yards have seen the economic advantages of implementing ergonomic interventions in their more hazardous or costly operations, either through direct contact with this project or through participation in some other project. The economic and technical feasibility of individual interventions needs to be seriously considered and examined before being fully implemented in any given shipyard. The ultimate goal of the project is to develop a set of best manufacturing work practices that may be adopted by shipyards throughout the country to reduce the number and severity of musculoskeletal injuries within the industry..

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VI. ANATOMICAL POSITION GLOSSARY

Elbow Extension – Forearm moved farther away from upper arm

Elbow Flexion – Forearm brought closer to upper arm

Hip Extension – Upper leg moved behind the body

Hip Flexion – Upper leg moved forward of the body

Knee Extension – Lower leg moved away from upper leg

Knee Flexion – Lower leg brought closer to upper leg

Lateral Rotation of Arm – With arm down at side, thumb rolled away from body

Medial Rotation of Arm – With arm down at side, thumb rolled towards body

Neck Extension – Chin raised away from chest

Neck Flexion – Chin lowered toward chest

Pronation – Forearm is rolled so that palm of hand is down

Radial Deviation – Hand is bent at wrist toward thumb side

Shoulder Abduction – Upper arm moved to side away from body

Shoulder Adduction – Upper arm moved inwards toward side of body

Shoulder Extension – Upper arm moved back behind body

Shoulder Flexion – Upper arm moved forward of the body

Supination – Forearm rolled so that palm of hand is up

Trunk Extension – Torso bent backward

Trunk Flexion – Torso bent forward

Ulnar Deviation – Hand is bent at wrist toward little finger side

Wrist Extension – Hand is bent upward at wrist away from palm side

Wrist Flexion – Hand is bent downward at wrist toward palm side