PRELIMINARY SURVEY REPORT:

PRE-INTERVENTION QUANTITATIVE RISK FACTOR ANALYSIS

FOR SHIP REPAIR PROCESSES

at

TODD PACIFIC SHIPYARDS CORPORATION
Seattle, Washington

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ABSTRACT

A pre-intervention quantitative risk factor analysis was performed at various shops and locations within Todd Pacific Shipyards Corporation facility in Seattle, Washington. This analysis was performed to identify and quantify risk factors that workers may be exposed to in the course of their normal work duties. This survey was conducted as part of a larger project, funded through Maritech Advanced Shipbuilding Enterprise and the U.S. Navy, to develop projects to enhance the commercial viability of domestic shipyards. Specific processes and locations were identified within the shipyard for further analysis. Work processes were videotaped and simple direct measures of workstation dimensions and tool weights were taken. The application of exposure assessment techniques provided a quantitative analysis of the risk factors associated with the individual tasks. Possible engineering and administrative interventions to address these risk factors for each task are briefly discussed.

I. INTRODUCTION

IA. BACKGROUND FOR CONTROL TECHNOLOGY STUDIES

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency 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, as well as the engineering aspects of health hazard prevention and control.

Since 1976, NIOSH has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of the completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been 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 involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are 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 data base 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 THIS STUDY

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 1998, the last year available, the Bureau of Labor Statistics reported that shipbuilding and repair (SIC 3731) had a recordable injury/illness incidence rate of 22.4 per 100 full-time employees (FTE), up from 21.4 in 1997. By contrast, in 1998, the manufacturing sector reported a rate of 9.7 per 100 FTE, construction reported a rate of 8.8 per 100 FTE, and all industries reported a rate of 6.7 injuries/illnesses per 100 FTE. When considering only lost workday cases, for 1998, shipbuilding and repair had an incidence rate of 11.5 per 100 FTE, compared to manufacturing at 4.7, construction at 4.0, and all industries at 3.1 lost workday injuries/illnesses per 100 FTE. Historical trends for total recordable cases and lost workday cases have shown downward trends for each of these sectors and industries.

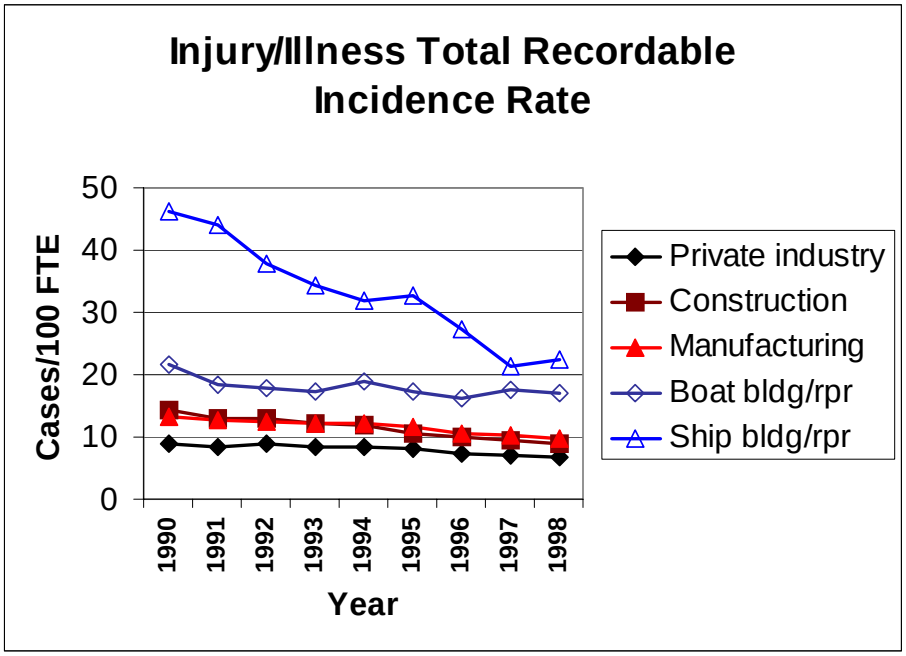

Figure 1. Injury/Illness Total Recordable Incidence Rate

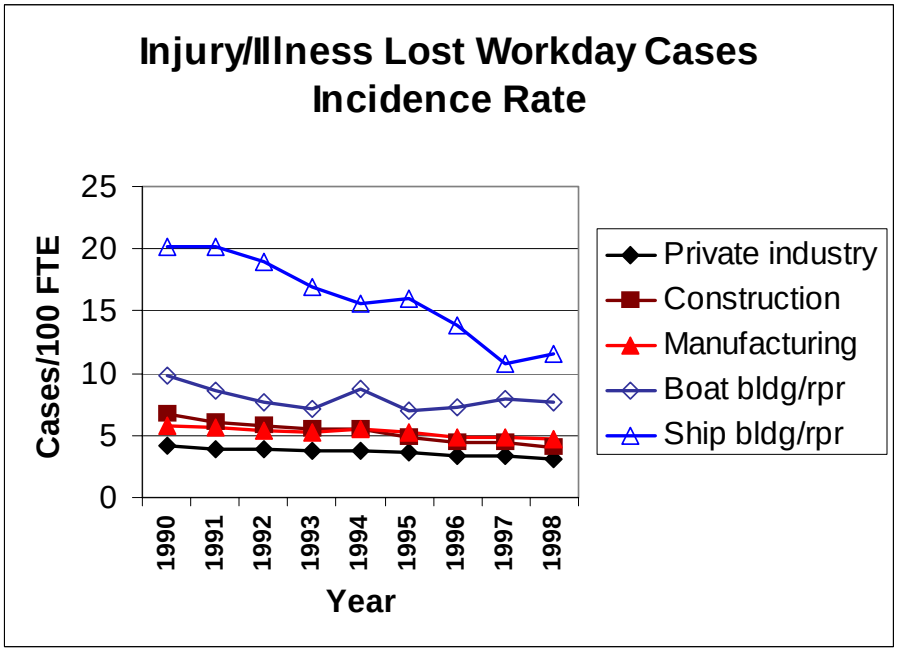

Figure 2. Injury/Illness Lost Workday Cases Incidence Rate

When comparing shipbuilding and repairing to the manufacturing sector for injuries and illnesses to specific parts of the body resulting in days away from work, for the year 1997, 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 207.7 cases per 10,000 FTE, compared to manufacturing at 82.1 cases. For injuries and illnesses solely to the back, shipbuilding reported 111.1 cases per 10,000 FTE, compared to manufacturing's incidence rate of 52.2 cases. For the lower extremity, shipbuilding reported 145.0 cases per 10,000 FTE compared to manufacturing at 40.8 cases. For upper extremity injuries and illnesses, shipbuilding reported an incidence rate of 92.2 cases per 10,000 FTE while manufacturing reported 73.4 cases.

When comparing shipbuilding and repairing to the manufacturing sector for injuries and illnesses resulting in days away from work, for the year 1997, by nature of injury, shipbuilding is significantly higher in a number of categories. For sprains and strains, shipbuilding reported an incidence rate of 237.9 cases per 10,000 FTE, compared to manufacturing's incidence rate of 91.0 cases. For fractures, shipbuilding reported 41.7 cases per 10,000 FTE, compared to manufacturing at 15.8 cases. For bruises, shipbuilding reported 61.3 cases per 10,000 FTE, compared to manufacturing at 21.5 cases. The median number of days away from work for shipbuilding and repairing is 12 days, compared to manufacturing and private industry's median of 5 days.

Beginning in 1995 the National Shipbuilding Research Program began funding 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), a standing advisory committee to the Occupational Safety and Health Administration (OSHA). The National Institute for Occupational Safety and Health (NIOSH) began an internally funded project in 1997 looking at ergonomic interventions in new ship construction facilities. In 1998, the U.S. Navy decided to fund 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 the project selection process. The Institute currently receives external project funding from the U.S. Navy through an organization called Maritech Advanced Shipbuilding Enterprise, a consortium of major domestic shipyards.

Shipyards participating in this project will receive an analysis of their injury/illness data, will have at least one ergonomic intervention implemented at their facility, and will have access to a website documenting ergonomic solutions found throughout the domestic maritime industries. The implementation of ergonomic interventions in other industries has resulted in decreases in Workers' Compensation costs, and increases in productivity.

Researchers have identified seven participating shipyards and analyzed individual shipyard recordable injury/illness databases. Ergonomic interventions will be implemented in each of the

shipyards by the end of Summer 2000. Intervention follow-up analysis will be completed by the end of 2000. A series of meetings and a workshop to document the ergonomic intervention program will be held by the end of March 2001.

IC. BACKGROUND FOR THIS SURVEY

Todd Pacific Shipyards Corporation was selected for a number of reasons. It was decided that the project should look at a variety of yards based on product, processes and location. Todd Pacific Shipyards Corporation is a private shipyard located in the Northwest corner of Harbor Island, in Elliott Bay, near downtown Seattle, Washington. Todd Pacific Shipyards Corporation current performs vessel repair and overhaul but has recently finished new vessel construction projects. This yard is considered to be a medium- to small-size yard. Currently, the primary work at the shipyard is the repair and overhaul of both commercial vessels, such as automobile and passenger ferries for the State of Washington and fishing vessels, and military vessels, such as U.S. Navy fast combat support ships (AOE's). Todd Pacific Shipyards Corporation is a member of the Shipbuilders Council of America.

Looking at all production workers within Todd Pacific Shipyards Corporation, for the years 1996 to1999, there were a total of 1651 recordable injuries and illnesses resulting in an average annual incidence rate of 44.5 per 100 FTE. However, from 1996 to 1999, the production worker recordable injury and illness incidence rate dropped quite significantly from 65.1 to 23.2 injuries per 100 FTE (a 64.4 percent decline). The average annual injury and illness incidence rate for production workers at Todd Pacific for incidents resulting in days away from work, for 1996 to 1999, was 25.4 per 100 FTE. The days away from work case incidence rate for production dropped from 31.5 in 1996 to 14.0 in 1999 (a decline of 55.4 percent). Upon review of the total of 1651 injuries and illnesses to Todd Pacific production workers from 1996 to 1999, 48 percent were characterized by NIOSH researchers as being "chronic musculoskeletal" incidents. The average annual chronic musculoskeletal disorder incidence rate for Todd Pacific production workers was 21.2 per 100 FTE, falling from 30.7 in 1996 to 12.4 in 1999 (a decline of 59.7 percent). The average annual chronic musculoskeletal disorder incidence rate for incidents resulting in days away from work for Todd Pacific production workers was 15.4 per 100 FTE, falling from 19.7 in 1996 to 9.7 in 1999 (a decline of 50.8 percent). Of all days away from work cases by Todd Pacific production workers, 61 percent were chronic musculoskeletal incidences. Occupation titles within Todd Pacific with the highest incidence rates of musculoskeletal disorders resulting in days away from work include: 1) the shipwrights at an incidence rate of 28.3, 2) the shipfitters at 23.6, 3) the riggers at 22.6, 4) the painters at 19.4, and 5) the laborers at 16.8 cases per 100 FTE. Musculoskeletal disorders, including those resulting in days away from work, most commonly involved the lower back.

II. PLANT AND PROCESS DESCRIPTION

IIA. INTRODUCTION

Plant Description: Todd Pacific Shipyards Corporation was founded in its present location near downtown Seattle, Washington in 1916. Todd Pacific has repaired or converted thousands of vessels since its start and has constructed over 300 new vessels. The 46-acre facility has three dry docks, including the largest floating dry dock in Puget Sound at 873 feet long by 134 feet wide. Two wharves and five piers provide a total of over 6000 feet of berthing space for outfitting and repair work. A dual shipway allows for the simultaneous construction of two ships with a maximum length of 550 feet and a maximum beam of 59 feet. By combining both shipways, a vessel 550 feet in length by 95 feet in beam can be constructed. The yard is serviced by fifteen whirled traveling cranes with lifting capacities up to 136 metric tons. While several original buildings remain on site, Todd Pacific undertook a major site reorganization and capital improvement plan in the mid-1990's. During this time, the shipyard incorporated modern shipbuilding techniques as acquired from Ishikawajima-Harimi Heavy Industries of Japan. Shops received new equipment, consolidated or relocated to facilitate new technology and work methods at that time.

Corporate Ties: Todd Pacific Shipyards Corporation is a wholly owned subsidiary of Todd Shipyards Corporation.

Products: Todd Pacific just recently completed the construction of three 490 feet long car ferries for the Washington State Ferry System. The shipyard is currently occupied with the repair ond overhaul of factory (fishing) trawlers, containerships, barges, tugs, and ferries. Todd Pacific was recently awarded the contract by the U.S. Navy for all long-term life-cycle maintenance on all Puget Sound homeported fast combat support ships (AOE's). The shipyard is also contracted by the Navy for non-nuclear maintenance for the aircraft carriers USS Vinson, USS Lincoln, and USS Stennis.

Age of Plant: The site of Todd Pacific Shipyards has been functioning as a shipyard since 1916. Most of the facility has been updated or rebuilt since that time as discussed above.

Number of Employees, etc: Approximately 1,000 production and administrative employees. Typically about 800 production workers. Eleven different unions represent workers at Todd Pacific.

IIB. PROCESS DESCRIPTION

Steelyard – Steel plate, beams, and angle iron are delivered to the facility by truck or train and stored in an outside storage yard.

Surface Preparation – Steel plate and shaped steel are moved from the supply yard into a surface preparation process.

Plate Shop – Steel plate is cut to size using numerical control plasma cutting tables. Sections of plate that need to be shaped are put through massive rollers to force the steel into the proper shape. Smaller shapes are cut with gas burners, cut to size at the shears or punched at the punch presses.

Subassembly – Steel shapes are pieced together and welded to form a variety of sub-assemblies for the units, or blocks, and hulls.

Final Assembly – The units or blocks are pieced together as part of final assembly.

Painting – Vessels are painted to customer specifications prior to launch.

IIC. POTENTIAL HAZARDS

Major Hazards: Awkward postures, manual material handling, confined space entry, welding fumes, UV radiation from welding, paint fumes

III. METHODOLOGY

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 Rapid Upper Limb Assessment (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 OVAKO Work Analysis System (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 which 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 vetebral 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, 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.

Five specific processes were identified for further analysis. These processes were: pipe welding, torch cutting, waterjet blasting, grinding, and welding operations. All tasks were observed onboard a vessel undergoing repair. Each of these processes are examined in greater detail below.

IIIA. PIPE WELDING ONBOARD VESSEL

Figure 3. Pipefitter Welding Task

IIIA1. Pipe Welding Process

Numerous pipe connections may be required in any repair task. Pipefitters piece together the piping subassemblies and weld them into place. The overall pipe welding process is as follows:

1) Pipefitter gets into position to weld pipe together. This may involve working in a confined space, working from an elevated surface, and/or working overhead.

Figure 4. Pipefitter Getting Into Position to Weld

2) Using stick electrodes and equipment, weld pipes into proper position.

Figure 5. Pipefitter Welding Pipe Onboard Vessel

3) If stick electrode is consumed before weld is finished, pipefitter must change out the stick electrode.

Figure 6. Pipefitter Changing Out Stick Electrode

4) After weld is completed, the pipefitter removes the slag from the weld by knocking the slag off with a hammer.

Figure 7. Pipefitter Removing Weld Slag with Hammer

5) Finally, the pipefitter grinds the weld smooth using a small angle grinder.

Figure 8. Pipefitter Using Angle Grinder to Smooth Weld

IIIA2. Pipe Welding Ergonomic Risk Factors

During pipe welding task, pipefitters undergo awkward postures including lumbar flexion and extension, overhead work, and static postures. Pipefitters undertake a variety of awkward postures such as extreme lumbar flexion, shoulder abduction, wrist flexion, both ulnar and radial deviation, and working in confined spaces.

IIIA3. Ergonomic Analysis of Pipefitters in Pipe Welding Process

Using several of the exposure assessment tools outlined above, an ergonomic analysis was performed for the pipefitter in the pipe welding task. A RULA analysis was performed on six distinct subtasks within the pipe welding activity (Table 1). Three of the six subtasks scored a 6 on a scale of 1 to 7 (investigate further and change soon). The subtasks included welding overhead, deslagging the weld with a hammer and grinding the weld smooth with an electric angle grinder. Two other subtasks, changing the stick electrode and changing the tool, resulted in score of 3 (investigate further). The final subtask of getting into position to weld was deemed "acceptable" with a score of two out of seven.

A Strain Index analysis was performed for the overhead pipe welding activity (Table 2) with the following results:

1) the Intensity of Exertion was rated as "Somewhat Hard" and given a multiplier score of 3.0 on a scale of 1 to 13
2) the Duration of the task was rated as 50 - 79 per cent of the task cycle, resulting in a multiplier of 2.0 on a scale of 0.5 to 3.0
3) the Efforts per Minute were noted to be approximately 2.2 per minute, resulting in a multiplier of 0.5 on a scale of 0.5 to 3.0
4) the Hand/Wrist posture was rated as "Fair," resulting in a multiplier of 1.5 on a scale of 1.0 to 3.0
5) the Speed of Work was rated as "Fair," resulting in a multiplier of 1.0 on a scale of 1.0 to 2.0
6) the Duration of Task per Day was rated to be between 2 and 4 hours, resulting in a multiplier of 0.75 on a scale of 0.25 to 1.50.

The multiplier values for each segment are multiplied together resulting in a final Strain Index (SI) score. For this task the SI score was 3.4. An SI score less than 5 is correlated to an incidence rate of about 2 distal upper extremity injuries per 100 FTE.

In applying the University of Michigan Upper Extremity Cumulative Trauma Disorder Checklist to the pipe welding task (Table 3), of the 21 possible responses, 13 were negative, five were positive, and three were answered both negatively and positively depending upon the situation observed. Negative responses (69 percent) are indicative of conditions associated with the risk of developing cumulative trauma disorders.

When the OWAS technique was applied to the pipe welding task (Table 4), “corrective measures in the near future” were suggested for only two of eight specific sub-tasks, those scoring a 2 on a 4-point scale. These sub-tasks were deslagging and changing tools. Analysis of the other six subtasks resulted in a score of 1 out of 4, suggesting no corrective measures were necessary.

The PLIBEL checklist for the pipe welding task (Table 5) reports low to moderate percentages (34.6 - 50 percent) of risk factors present for the any given part of body. Several environmental and organizational modifying factors are present as well that can be considered in future analysis.

IIIB. TORCH CUTTING ONBOARD VESSEL

Figure 9. Torch Cutting of Steel Deck

IIIB1. Torch Cutting Process

There are many circumstances in ship repair processes when torch cutting is used to remove steel decking or bulkheads (Figure 9). At times individual components scheduled for replacement are located in such confined spaces that it is easier to torch cut an opening either besides, 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 torch cutting process involves the following steps:

Figure 10. Adjusting Torch Flame

1) Lighting the cutting torch and adjust the flame (Figure 10)
2) Cutting the deck or bulkhead (See Figure 9 above)

Figure 11. Brushing Debris from Cut Line

3) Brushing debris away from cut line to improve line of sight (Figure 11)

Figure 12. Worker Resting Between Making Torch Cuts

4) Leaning back to rest and stretch between torch cuts (Figure 12)

Figure 13. Worker Moving Torch Leads to New Area

5) Moving torch lines to new location for next cut (Figure 13).

IIIB2. Torch Cutting Ergonomic Risk Factors

During typical torch cutting on the deck, the worker assumes relatively constrained and static postures with flexed knees, hips and torso.

IIIB3. Ergonomic Analysis of Workers in Torch Cutting Process

Using several of the exposure assessment tools outlined above, an ergonomic analysis was performed for the worker performing the torch cutting task. A RULA analysis was performed on five distinct subtasks within the torch cutting activity (Table 6). According to this specific exposure assessment tool, the actual torch cutting subtask scored a 7 on a scale of 1 to 7 (investigate and change immediately). Three subtasks including adjusting body position and clearing debris, cleaning the cut with a wrench, and leaning back to rest resulted in scores of 3 and 4 (investigate further). The final subtask of moving torch leads to get into a new location was deemed "acceptable" with a score of two out of seven.

A Strain Index analysis was performed for the torch cutting activity (Table 7) with the following results:

1) the Intensity of Exertion was rated as "Somewhat Hard" and given a multiplier score of 3.0 on a scale of 1 to 13
2) the Duration of the task was rated as greater than 80 percent of the task cycle, resulting in a multiplier of 3.0 on a scale of 0.5 to 3.0
3) the Efforts per Minute were considered to be nearly static exertions, and consequently is rated as a multiplier of 3.0 on a scale of 0.5 to 3.0
4) the Hand/Wrist posture was rated as "Fair," resulting in a multiplier of 1.5 on a scale of 1.0 to 3.0
5) the Speed of Work was rated as "Fair," resulting in a multiplier of 1.0 on a scale of 1.0 to 2.0
6) the Duration of Task per Day was rated to be between 2 and 4 hours, resulting in a multiplier of 0.75 on a scale of 0.25 to 1.50.

The multiplier values for each segment are multiplied together resulting in a final Strain Index (SI) score. For this task the SI score was 30.4. An SI score between 5 and 30 is correlated to an incidence rate of about 77 distal upper extremity injuries per 100 FTE. Regardless of actual incidence rates, the Strain Index identifies this task as one which exposes the worker to an increased likelihood of upper extremity musculoskeletal disorders.

In applying the University of Michigan Upper Extremity Cumulative Trauma Disorder Checklist to the torch cutting task (Table 8), of the 21 possible responses, 13 were negative, five were positive, and one was answered both negatively and positively depending upon the situation observed and two were not directly measured. With this exposure assessment tool, negative responses (70 percent) are indicative of conditions associated with the risk of developing cumulative trauma disorders.

When the OWAS technique was applied to the torch cutting task (Table 9), “corrective measures in the near future” were suggested for only two of five specific sub-tasks, those scoring a 2 on a 4-point scale. These sub-tasks were actual torch cutting and cleaning out the cut with a wrench. Analysis of the other three subtasks resulted in a score of 1 out of 4, suggesting no corrective measures were necessary.

The PLIBEL checklist exposure assessment tool was applied to the torch cutting task (Table 10) and resulted in reports of low percentages (25.0 - 33.3 percent) of risk factors present for the feet, knees and hips, and low back. Moderate percentages (42.3 - 50 percent) of risk factors were present for the upper extremities. Several environmental and organizational modifying factors are present as well that can be considered in future analysis.

IIIC. WATERJET BLASTING OF VESSEL IN DRYDOCK

Figure 14. Worker Using Waterjet to Remove Paint from Vessel

IIIC1. Waterjet Blasting Process

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.

Figure 15. Worker Braced in Manlift Cage from Waterjet Recoil

Occasionally the worker will stop to inspect the work area since the worker's vision is hindered by the spray from the waterjet.

Figure 16. Worker Inspecting Area Blasted by Waterjet

IIIC2. Waterjet Blasting Ergonomic Risk Factors

The waterjet blasting unit operates at very high pressure. This results in a high amount of force leaving the unit, forcing the worker to use a great deal of effort to maintain control of the unit. Since postures are fairly static with high force, it is possible that workers operating the waterjet blasting unit may experience chronic upper extremity musculoskeletal injuries.

IIIC3. Ergonomic Analysis of Workers in Waterjet Blasting Process

Using several of the exposure assessment tools outlined above, an ergonomic analysis was performed for the worker performing the waterjet blasting task. A RULA analysis was performed on four distinct subtasks within the waterjet blasting activity (Table 11). According to this specific exposure assessment tool, performing the actual blasting task while standing unbraced on the personnel platform on the manlift scored a 7 on a scale of 1 to 7 (investigate and change immediately). Performing the same task while braced against the railings of the platform resulted in a score of 6 on a scale of 1 to 7 (investigate further and change soon). Two other subtasks including adjusting body position and inspecting the work surface resulted in scores of 3 out of 7 (investigate further).

A Strain Index analysis was performed for the waterjet blasting activity (Table 12) with the following results:

1) the Intensity of Exertion was rated as "Hard" and given a multiplier score of 6.0 on a scale of 1 to 13
2) the Duration of the task was rated as greater than 80 percent of the task cycle, resulting in a multiplier of 3.0 on a scale of 0.5 to 3.0
3) the Efforts per Minute were considered to be nearly static exertions, and consequently is rated as a multiplier of 3.0 on a scale of 0.5 to 3.0
4) the Hand/Wrist posture was rated as "Fair," resulting in a multiplier of 1.5 on a scale of 1.0 to 3.0
5) the Speed of Work was rated as "Fair," resulting in a multiplier of 1.0 on a scale of 1.0 to 2.0
6) the Duration of Task per Day was rated to be between 2 and 4 hours, resulting in a multiplier of 0.75 on a scale of 0.25 to 1.50.

The multiplier values for each segment are multiplied together resulting in a final Strain Index (SI) score. For this task the SI score was 60.75. An SI score between 31 and 60 is correlated to an incidence rate of about 106 distal upper extremity injuries per 100 FTE. An SI score greater than 60 is correlated to an incidence rate of about 130 distal upper extremity injuries per 100 FTE. Regardless of actual incidence rates, the Strain Index identifies this task as one which exposes the worker to an increased likelihood of upper extremity musculoskeletal disorders.

In applying the University of Michigan Upper Extremity Cumulative Trauma Disorder Checklist to the waterjet blasting task (Table 13), of the 21 possible responses, ten were negative, eight

were positive, and one was answered both negatively and positively depending upon the situation observed and two were not directly measured. With this exposure assessment tool, negative responses (52.5 percent) are indicative of conditions associated with the risk of developing cumulative trauma disorders.

When the OWAS technique was applied to the waterjet blasting task (Table 14), "corrective measures in the near future" were suggested for only one of the four specific sub-tasks, scoring a 2 on a 4-point scale. This sub-task was the worker repositioning themselves on the platform. Analysis of the other three subtasks resulted in a score of 1 out of 4, suggesting no corrective measures were necessary.

The PLIBEL checklist exposure assessment tool was applied to the waterjet blasting task (Table 15) and resulted in reports of a high percentage (72.7 percent) of risk factors present for the elbows, forearms, and hands. Moderate percentages (37.5 - 50 percent) of risk factors were present for all other body parts. Several environmental and organizational modifying factors are present as well that can be considered in future analysis.

IIID. GRINDING ONBOARD VESSEL

Figure 17. Shipfitter Grinding Deck Stiffeners

IIID1. Grinding Process

In any ship repair process, grinding is a primary task. 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, at floor level, overhead or somewhere in between. The worker may be standing, kneeling, squatting or even laying down to perform the task.

Figure 18. Shipfitter Grinding Deck Stiffeners in Awkward Posture

Figure 19. Grinding Deck Stiffeners for Deck Replacement

Figure 20. Shipfitter Inspecting Grinding Results

IIID2. Grinding Ergonomic Risk Factors

The worker, whether a shipfitter, welder, or painter, often must assume awkward or constrained postures to get into position to grind. The grinder transmit vibration to the hand and arm of the worker. The work is primarily static which is generally very fatiguing for involved muscles.

IIID3. Ergonomic Analysis of Workers in Grinding Process

Using several of the exposure assessment tools outlined above, an ergonomic analysis was performed for the worker performing the grinding task while laying over an opening in the deck. A RULA analysis was performed on six distinct subtasks within the grinding activity (Table 16). According to this specific exposure assessment tool, two subtasks, grinding and torch cutting, scored a 6 on a scale of 1 to 7 (investigate further and change soon). Three subtasks including adjusting the tool position, deslagging and resting or inspecting the work resulted in scores of 3 and 4 (investigate further). The final subtask of repositioning the worker's body to get into a new posture was deemed "acceptable" with a score of two out of seven.

A Strain Index analysis was performed for the grinding activity (Table 17) with the following results:

1) the Intensity of Exertion was rated as "Hard" and given a multiplier score of 6.0 on a scale of 1 to 13
2) the Duration of the task was rated as being between 50 and 79 percent of the task cycle, resulting in a multiplier of 2.0 on a scale of 0.5 to 3.0
3) the Efforts per Minute were considered to be nearly static exertions, and consequently is rated as a multiplier of 3.0 on a scale of 0.5 to 3.0
4) the Hand/Wrist posture was rated as "Fair," resulting in a multiplier of 1.5 on a scale of 1.0 to 3.0
5) the Speed of Work was rated as "Fair," resulting in a multiplier of 1.0 on a scale of 1.0 to 2.0
6) the Duration of Task per Day was rated to be between 2 and 4 hours, resulting in a multiplier of 0.75 on a scale of 0.25 to 1.50.

The multiplier values for each segment are multiplied together resulting in a final Strain Index (SI) score. For this task the SI score was 40.5. An SI score between 31 and 60 is correlated to an incidence rate of about 106 distal upper extremity injuries per 100 FTE. Regardless of actual incidence rates, the Strain Index identifies this task as one which exposes the worker to an increased likelihood of upper extremity musculoskeletal disorders.

In applying the University of Michigan Upper Extremity Cumulative Trauma Disorder Checklist to the grinding task (Table 18), of the 21 possible responses, 14 were negative, six were positive, and one was answered both negatively and positively depending upon the situation observed. With this exposure assessment tool, negative responses (68 percent) are indicative of conditions associated with the risk of developing cumulative trauma disorders.

When the OWAS technique was applied to the grinding task (Table 19), "corrective measures as soon as possible" were suggested for only two of six specific sub-tasks, those scoring a 3 on a 4-point scale. These sub-tasks were grinding and torch cutting. Three subtasks resulted in a score of 2 out of 4 or "corrective measures in near future." These tasks were adjusting the tool position, deslagging and resting or inspecting the work. Analysis of the final subtasks, repositioning the worker's body, resulted in a score of 1 out of 4, suggesting no corrective measures were necessary.

The PLIBEL checklist exposure assessment tool was applied to the grinding task (Table 20) and resulted in a relatively high percentage (72.7 percent) of risk factors present for the elbows, forearms and hands. Moderate percentages (37.5 - 50 percent) of risk factors were present for all other body parts. Several environmental and organizational modifying factors are present as well that can be considered in future analysis.

IIIE. WELDING ONBOARD VESSEL

IIIE1. Welding Process

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.

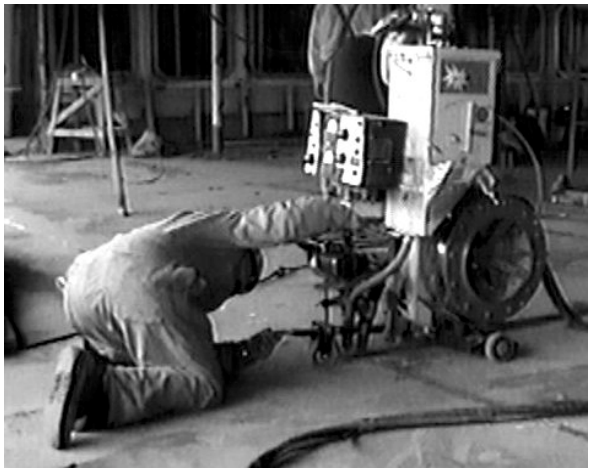

Figure 21. Worker Setting Up Semi-Automatic Wire-Feed Welder

Figure 22. Worker Operating Semi-Automatic Wire-Feed Welder

Wire welding is performed for the majority of welding tasks. The wire electrode is again continuously fed to the arc and may or may not be shielded by a flux core.

Figure 23. Wire Welding While Standing

Figure 24. Wire Welding While Kneeling

Figure 25. Worker Deslagging Wire Weld

IIIE2. Welding Ergonomic Risk Factors

During semi-automatic welding on deck plates, the worker must kneel or squat low to align and operate the automatic welding unit. These postures may result in strain to the legs and lower back. For wire welding, the worker may assume a variety of postures, often constrained, to perform the welding task. Often, the work is static, resulting in muscle fatigue of the arms.

IIIE3. Ergonomic Analysis of Workers in Welding Process

A RULA analysis was performed on two distinct subtasks within the automatic welding activity (Table 21). According to this specific exposure assessment tool, the preparation and alignment

subtask scored a 7 on a scale of 1 to 7 (investigate and change immediately) due primarily to kneeling low to the ground to align the arc. The other subtask of guiding the automatic welding unit rated a score of five out of seven or "investigate further and change soon" again due primarily to the posture the worker assumes while performing the task.

Using several of the exposure assessment tools outlined above, an ergonomic analysis was performed for the worker performing the wire welding task. A RULA analysis was performed on six distinct subtasks within the wire welding activity (Table 22). According to this specific exposure assessment tool, the actual wire welding subtask while standing scored a 7 on a scale of 1 to 7 (investigate and change immediately). Wire welding while kneeling scored a 6 out of 7, "investigate further and change soon." The four other subtasks, such as deslagging and inspecting the work, resulted in scores of 3 and 4 (investigate further).

A Strain Index analysis was performed for the wire welding activity (Table 23) with the following results:

1) the Intensity of Exertion was rated as "Somewhat Hard" and given a multiplier score of 3.0 on a scale of 1 to 13
2) the Duration of the task was rated as being between 30 and 49 percent of the task cycle, resulting in a multiplier of 1.5 on a scale of 0.5 to 3.0
3) the Efforts per Minute were measured to be low but also considered to be nearly static exertions, and consequently a compromise rating of a multiplier of 1.5 on a scale of 0.5 to 3.0 was given
4) the Hand/Wrist posture was rated as "Fair," resulting in a multiplier of 1.5 on a scale of 1.0 to 3.0
5) the Speed of Work was rated as "Fair," resulting in a multiplier of 1.0 on a scale of 1.0 to 2.0
6) the Duration of Task per Day was rated to be between 2 and 4 hours, resulting in a multiplier of 0.75 on a scale of 0.25 to 1.50.

The multiplier values for each segment are multiplied together resulting in a final Strain Index (SI) score. For this task the SI score was 7.6 An SI score between 5 and 30 is correlated to an incidence rate of about 77 distal upper extremity injuries per 100 FTE. Regardless of actual incidence rates, the Strain Index identifies this task as one which exposes the worker to an increased likelihood of upper extremity musculoskeletal disorders.

In applying the University of Michigan Upper Extremity Cumulative Trauma Disorder Checklist to the wire welding task (Table 24), of the 21 possible responses, 12 were negative, eight were positive, and one was answered both negatively and positively depending upon the situation observed. With this exposure assessment tool, negative responses (60 percent) are indicative of conditions associated with the risk of developing cumulative trauma disorders.

When the OWAS technique was applied to the wire welding task (Table 25), "corrective measures in the near future" were suggested for five of the six specific sub-tasks, those scoring a 2 on a 4-point scale. These sub-tasks included welding while standing, deslagging and inspecting the work. Analysis of the other subtask resulted in a score of 1 out of 4, suggesting no corrective measures were necessary.

The PLIBEL checklist exposure assessment tool was applied to the wire welding task (Table 26) and resulted in reports of moderate percentages (37.5 - 45.5 percent) of risk factors being present for the all body parts. Several environmental and organizational modifying factors are present as well that can be considered in future analysis.

IV. CONTROL TECHNOLOGY

Possible interventions and control technologies are mentioned briefly here. A more detailed report of possible interventions is under development. Five work processes within a ship repair facility were surveyed to determine the presence of risk factors associated with musculoskeletal disorders. The pipe welding task requires workers to combine pipe assemblies, usually in place onboard the vessel. These conditions can result in constrained and awkward postures and unstable footing. Similar conditions also occur for torch cutting, grinding and other welding tasks. 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 work station 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 is 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 minimized due to the constraints of ship repair, it is possible to educate the workforce on proper procedures, better work methods and postures to assume while performing the work onboard vessels.

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 is 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.

Figure 26. Worker Running Automatic Welder While on Stool

Figure 27. Closeup of Worker Stool

The primary concern with the waterjet blasting is the worker having to hold the water cannon in their hands to control and direct the high-pressure water spray. It is 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, but yet the nozzle mount removes the worker from the strain of holding the water cannon directly.

V. CONCLUSIONS AND RECOMMENDATIONS

Five distinct repair processes were examined at Todd Pacific Shipyard facilities to quantify the musculoskeletal risk factors associated with these processes. The processes included: pipe welding, torch cutting, waterjet blasting, grinding, and welding. Since ship repair work greatly differs from ship construction processes, particularly with respect to the ability to change the work environment, it is suggested that administrative controls such as ergonomics awareness training may be suitable interventions for the ship repair workforce, rather than direct changes to the work station or processes themselves..

It is recommended that further action be taken to mitigate the exposure to musculoskeletal risk factors within each of the identified tasks. The implementation of ergonomic interventions has been found to reduce the amount and severity of musculoskeletal disorders within the working population in various industries. It is recommended that ergonomic interventions, both engineering and administrative, be implemented at Todd Pacific Shipyards to minimize hazards in the identified job tasks.

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APPENDIX A

ERGONOMIC ANALYSIS TABLES

A1. Pipe Welders

Table 1. Pipe Welders RULA

Rapid Upper Limb Assessment (RULA), Matamney and Corlett (1993)

Date/ Time 4/13/00 Facility: Todd Pacific Area/ Shop: Onboard vessel

Task : Pipe welding task Performed by: Steve Wurzelbacher

RULA: Posture Sampling Results												
RULA Component	**Frame # 92040 Arctime**		**Frame # 101880 Deslag**		**Frame # 98940 Change, bend stick**		**Frame # 120539 Position body**		**Frame # 107760 Change tools**		**Frame # 108180 Grind w/ angle grinder**	
	Spec	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***
Shoulder Extension/ Flexion	sl flex	2	mod flex	3	neut	1	neut	1	neut	1	sl flex	2
Shoulder is Raised (+1)		1		1		0		0		0		0
Upper Arm Abducted (+1)		0		0		0		0		0		0
Arm supported, leaning (-1)		0		0		0		0		0		0
Elbow Extension/ Flexion	flx	2	neut	2	neut	2	neut	2	neut	2	neut	2
Shoulder Abduction/ Adduction	neut	0	neut	0	neut	0	neut	0	neut	0	add	1
Shoulder Lateral/ Medial	neut	0	neut	0	neut	0	neut	0	neut	0	mod med	1
Wrist Extension/ Flexion	neut	1	ext	2	neut	1	neut	1	neut	1	ext	2
Wrist Deviation	ulnar	1	ulnar	1	neut	0	neut	0	neut	0	ulnar	1
Wrist Bent from Midline (+1)		0		0		0		0		0		0
Wrist Twist (1) In mid range or (2) End of range		1		1		1		1		1		1
Arm and Wrist Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		0		0		0		0		1
Arm and Wrist Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		2		1		0		0		1		2

Table 1. Pipe Welders RULA (continued)

RULA Component	**Frame # 92040 Arctime**		**Frame # 101880 Deslag**		**Frame # 98940 Change, bend stick**		**Frame # 120539 Position body**		**Frame # 107760 Change tools**		**Frame # 108180 Grind w/ angle grinder**	
	Spec	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***	***Spec***	***RULA Score***
Neck Extension/ Flexion	sl flx	2	ext	4	extr flx	3	ext	***4***	extr flx	3	sl flx	2
Neck Twist (+1)		0		1		0		0		0		0
Neck Side-Bent (+1)		0		0		0		0		0		0
Trunk Extension/ Flexion	neut	1	ext	1	neut	1	neut	1	sl flx	2	neut	1
Trunk Twist (+1)		0		0		0		0		0		0
Trunk Side Bend (+1)		0		0		0		0		0		0
Legs If legs and feet are supported and balanced: (+1); If not: (+2)		1		1		1		1		1		1
Neck, Trunk, and Leg Muscle Use Score If posture mainly static (i.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		1		0		0		0		1
Neck, Trunk, and Leg Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		2		2		1		0		1		2
Total RULA Score	**6**		**6**		**3**		**2**		**3**		**6**	

1 or 2 = Acceptable
3 or 4 = Investigate Further
5 or 6 = Investigate Further and Change Soon
7 = Investigate and Change Immediately

Table 2. Pipe Welders Strain Index

Strain Index: Distal Upper Extremity Disorders Risk Assessment
Moore and Garg, 1995

Date/ Time 4/13/00 Facility: Todd Pacific Area/ Shop: Onboard vessel
Task : Pipe welding task Performed by: Steve Wurzelbacher

1. Intensity of Exertion: An estimate of the strength required to perform the task one time. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.					
Rating Criterion	**% MS** *(percentage of maximal strength)*	**Borg Scale** *(Compare to Borg Cr-10 Scale)*	**Perceived Effort**	**Rating**	**Multiplier**
Light	< 10%	< or = 2	barely noticeable or relaxed effort	1	1.0
Somewhat hard	10 - 29%	3	noticeable or definite effort	2	3.0
Hard	30 - 49%	4 - 5	obvious effort; unchanged facial expression	3	6.0
Very Hard	50 - 79%	6 - 7	substantial effort; changes to facial expression	4	9.0
Near Maximal	> or = 80%	> 7	uses shoulder or trunk to generate force	5	13.0
Intensity of Exertion Multiplier					**3.0**

Table 2. Pipe Welders Strain Index (continued)

2. Duration of Exertion (% of cycle): Calculated by measuring the duration of all exertions during an observation period, then dividing the measured duration of exertion by the total observation time and multiplying by 100. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box.*NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet:	**Rating Criterion**	**Rating**	**Multiplier**
% Duration of Exertion = 100 x duration of all exertions (sec) / Total observation time (sec) = 100 x 1310 (sec)/ 1677 (sec) = 78	< 10	1	0.5
	10 - 29	2	1.0
	30 - 49	3	1.5
	50 -79	4	2.0
	> or = 80	5	3.0
Duration of Exertion Multiplier			**2.0**

3. Efforts per Minute: Measured by counting the number of exertions that occur during an observation period, then dividing the number of exertions by the duration of the observation period, measured in minutes. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box. *NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet:	**Rating Criterion**	**Rating**	**Multiplier**
Efforts per Minute = number of exertions / total observation time (min) = 61/ 28 = 2.2	< 4	1	0.5
	4 - 8	2	1.0
	9 -14	3	1.5
	15 -19	4	2.0
	> or = 20	5	3.0
Efforts per Minute Multiplier			**0.5**

Table 2. Pipe Welders Strain Index (continued)

4. Hand/ Wrist Posture: An estimate of the position of the hand or wrist relative to neutral position. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.						
Rating Criterion	**Wrist Extension** *(Stetson et al, 1991)*	**Wrist Flexion** *(Stetson et al, 1991)*	**Ulnar Deviation** *(Stetson et al, 1991)*	**Perceived Posture**	**Rating**	**Multiplier**
Very Good	0 -10 degrees	0 - 5 degrees	0 - 10 degrees	perfectly neutral	1	1.0
Good	11 - 25 degrees	6 - 15 degrees	11 -15 degrees	near neutral	2	1.0
Fair	26 -40 degrees	16 - 30 degrees	16 - 20 degrees	non-neutral (*estimated, based on RULAs performed)	3	1.5
Bad	41 - 55 degrees	31 - 50 degrees	21 -25 degrees	marked deviation	4	2.0
Very Bad	> 60 degrees	> 50 degrees	> 25 degrees	near extreme	5	3.0
Hand/ Wrist Posture Multiplier						**1.5**

5. Speed of Work: An estimate of how fast the worker is working. Mark the rating on the far right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.				
Rating Criterion	**Compared to MTM** *(observed pace is divided by MTM's predicted pace and expressed as %)*	**Perceived Speed**	**Rating**	**Multiplier**
Very Slow	< or = 80%	extremely relaxed pace	1	1.0
Slow	81 - 90%	"taking one's own time"	2	1.0
Fair	91 -100%	"normal" speed of motion	3	1.0
Fast	101-115%	rushed, but able to keep up	4	1.5
Very Fast	> 115%	rushed, barely or unable to keep up	5	2.0
Speed of Work Multiplier				**1.0**

Table 2. Pipe Welders Strain Index (continued)

6. Duration of Task per Day: Either measured or obtained from plant personnel. Mark the rating on the right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.			
Worksheet:	***Rating Criterion***	***Rating***	***Multiplier***
Duration of Task per Day (hrs) = duration of task (hrs) + duration of task (hrs) + ... = (estimate @ 2-4 hrs)	< or = 1 hrs	1	0.25
	1 - 2 hrs	2	0.50
	2 - 4 hrs	3	0.75
	4 - 8 hrs	4	1.00
	> or = 8 hrs	5	1.50
Duration of Task per Day Multiplier			**0.75**

7. Calculate the Strain Index (SI) Score: Insert the multiplier values for each of the six task variables into the spaces below, then multiply them all together.							
Intensity of Exertion	**Duration of Exertion**	**Efforts per Minute**	**Hand/ Wrist Posture**	**Speed of Work**	**Duration of Task**		**SI SCORE**
3.0 X	**2.0 X**	**0.5 X**	**1.5 X**	**1.0 X**	**0.75**	**=**	**3.4**

SI Scores are used to predict Incidence Rates of Distal Upper Extremity injuries per 100 FTE:
- SI Score < 5 is correlated to an Incidence Rate of about 2 DUE injuries per 100 FTE;
- SI Score of between 5-30 is correlated to an Incidence Rate of about 77 DUE injuries per 100 FTE;
- SI Score of between 31-60 is correlated to an Incidence Rate of about 106 DUE injuries per 100 FTE;
- SI Score > 60 is correlated to an Incidence Rate of about 130 DUE injuries per 100 FTE.

Table 3. Pipe Welders UE CTD Checklist
Michigan Checklist for Upper Extremity Cumulative Trauma Disorders
Lifshitz and Armstrong (1986)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Pipe Welding Area/ Shop: Onboard Vessel
* "No" responses are indicative of conditions associated with the risk of CTD's

Risk Factors	No	Yes
1. Physical Stress		
1.1 Can the job be done without hand/ wrist contact with sharp edges		Y
1.2 Is the tool operating without vibration?	N	Y
1.3 Are the worker's hands exposed to temperature >21degrees C (70 degrees F)?	N	Y
1.4 Can the job be done without using gloves?	N	
2. Force		
2.1 Does the job require exerting less than 4.5 kg (10lbs) of force?	N	
2.2 Can the job be done without using finger pinch grip?		Y
3. Posture		
3.1 Can the job be done without flexion or extension of the wrist?	N	
3.2 Can the tool be used without flexion or extension of the wrist?	N	
3.3 Can the job be done without deviating the wrist from side to side?	N	
3.4 Can the tool be used without deviating the wrist from side to side?	N	
3.5 Can the worker be seated while performing the job?	N	
3.6 Can the job be done without "clothes wringing" motion?		Y
4. Workstation Hardware		
4.1 Can the orientation of the work surface be adjusted?	N	
4.2 Can the height of the work surface be adjusted?	N	
4.3 Can the location of the tool be adjusted?	N	
5. Repetitiveness		
5.1 Is the cycle time longer than 30 seconds?	N	
6. Tool Design		
6.1 Are the thumb and finger slightly overlapped in a closed grip?	N	
6.2 Is the span of the tool's handle between 5 and 7 cm (2-2 3/4 inches)?	N	Y (grinder)
6.3 Is the handle of the tool made from material other than metal?		Y
6.4 Is the weight of the tool below 4 kg (9lbs)?		Y
6.5 Is the tool suspended?	N	
TOTAL	**16 (67%)**	**8 (33%)**

Table 4. Pipe Welders OWAS

OWAS: OVAKO Work Analysis System
Louhevaara and Suurnäkki (1992)

Procedure: Observe workers at intervals of 30-60 seconds. Record postures and forces over a representative period (~ 45 minutes)

Date/ Time 4/13/00 Facility Todd Pacific
Task Pipe Welder (stick) Area/ Shop Onboard Vessel

Risk Factor	**Work Phase1** **Position stick holder**	**Work Phase 2** **Arctime**	**Work Phase 3** **Deslag**	**Work Phase 4** **Change, bend stick**	**Work Phase 5** **Position body**	**Work Phase 6** **Change tools**	**Work Phase 7** **Grind O/H w/ electric offset**	**Work Phase 8** **Resting, change over to wire**
TOTAL Combination Posture Score	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**1**
Common Posture Combinations (collapsed across work phases)								
Back	1	1	2	1	1			
Arms	2	1	2	1	3			
Legs	3	7	2	2	2			
Posture Repetition (% of working time)	14	27	18	13	15			
Back % of Working Time Score	1	1	1	1	1			
Arms % of Working Time Score	1	1	1	1	1			
Legs % of Working Time Score	1	1	1	1	1			

ACTION CATEGORIES:
1 = No corrective measures
2 = Corrective measures in near future
3 = Corrective measures as soon as possible
4 = Corrective measures immediately

Table 4. Pipe Welders OWAS (continued)

Risk Factor	**Work Phase1** **Position stick holder**	**Work Phase 2** **Arctime**	**Work Phase 3** **Deslag**	**Work Phase 4** **Change, bend stick**	**Work Phase 5** **Position body**	**Work Phase 6** **Change tools**	**Work Phase 7** **Grind O/H w/ electric offset**	**Work Phase 8** **Resting, change over to wire**
Posture								
Back 1 = straight 2 = bent forward, backward 3 = twisted or bent sideways 4 = bent and twisted or bent forward and sideways	1	1	2	1	1	2	1	1
Arms 1 = both arms are below shoulder level 2 = one arm is at or above shoulder level 3 = both arms are at or above shoulder level	2	2	2	1	1	1	3	1
Legs 1 = sitting 2 = standing with both legs straight 3 = standing with the weight on one straight leg 4 = standing or squatting with both knees bent 5 = standing or squatting with one knee bent 6 = kneeling on one or both knees 7 = walking or moving	3	2, 3	2	2	7	7	2	7
Load/ Use of Force								
1 = weight or force needed is = or <10 kg (<22lbs)	1	1	1	1	1	1	2	1
2 = weight or force > 10 but < 20kg (>22lbs < 44 lbs)								
3 = weight or force > 20 kg (>44 lbs)								
Phase Repetition								
% of working time (0,10,20,30,40,50,60,70,80,90,100)	2	12	18	13	12	5	15	15

Table 5. Pipe Welders PLIBEL

PLIBEL Checklist, Kemmlert (1995)

Date/ Time 4/13/00 Facility Todd Pacific
Task Pipe Welder (stick) Area/ Shop Onboard Vessel

Section I: Musculoskeletal Risk Factors
Methods of Application:
1) Find the injured body region, answer yes or no to corresponding questions
2) Answer questions, score potential body regions for injury risk

Musculoskeletal Risk Factor Questions	Body Regions				
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
1: Is the walking surface uneven, sloping, slippery or nonresilient?			N	N	N
2: Is the space too limited for work movements or work materials?	N	N	N	N	N
3: Are tools and equipment unsuitably designed for the worker or the task?	Y	Y	Y	Y	Y
4: Is the working height incorrectly adjusted?	Y				Y
5: Is the working chair poorly designed or incorrectly adjusted?	N				N
6: If work performed standing, is there no possibility to sit and rest?			Y	Y	Y
7: Is fatiguing foot pedal work performed?			N	N	
8: Is fatiguing leg work performed? e.g. ...					
a) repeated stepping up on stool, step etc..			Y	Y	Y
b) repeated jumps, prolonged squatting or kneeling?			N	N	N
c) one leg being used more often in supporting the body?			Y	Y	Y
9: Is repeated or sustained work performed when the back is:					
a) mildly flexed forward?	N				N
b) severely flexed forward?	N				N
c) bent sideways or mildly twisted?	N				N
d) severely twisted?	N				N

Table 5. Pipe Welders PLIBEL (continued)

10: Is repeated/sustained work performed with neck:					
a) flexed forward?	N				
b) bent sideways or mildly twisted?	N				
c) severely twisted?	N				
d) extended backwards?	Y				
11: Are loads lifted manually? Note important factors:					
a) periods of repetitive lifting	N				N
b) weight of load	N				N
c) awkward grasping of load	N				N
d) awkward location of load at onset or end of lifting	N				N
e) handling beyond forearm length	Y				Y
f) handling below knee length	N				N
g) handling above shoulder height	Y				Y
12: Is repeated, sustained or uncomfortable carrying, pushing or pulling of loads performed?	Y	Y			Y
13: Is sustained work performed when one arm reaches forward or to the side without support?	Y				
14: Is there a repetition of:					
a) similar work movements?	Y	Y			
b) similar work movements beyond comfortable reaching distance?	N	N			
15: Is repeated or sustained manual work performed? Notice factors of importance as:					
a) weight of working materials or tools	N	N			
b) awkward grasping of working materials or tools	Y	Y			
16: Are there high demands on visual capacity?	N				
17: Is repeated work, with forearm and hand, performed with:					
a) twisting movements?		N			
b) forceful movements?		N			
c) uncomfortable hand positions?		Y			
d) switches or keyboards?		N			

Table 5. Pipe Welders PLIBEL (continued)

Musculoskeletal Risk Factors Scores					
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
SUM	9	5	4	4	8
PERCENTAGE	34.6	45.5	50.0	50.0	38.1
Section II: Environmental / Organizational Risk Factors (Modifying) Answer below questions, use to modify interpretation of musculoskeletal scores					
18: Is there no possibility to take breaks and pauses?	N				
19: Is there no possibility to choose order and type of work tasks or pace of work?	N				
20: Is the job performed under time demands or psychological stress?	N				
21:Can the work have unusual or expected situations?	N				
22: Are the following present?					
a) cold	Y				
b) heat	Y				
c) draft	Y				
d) noise	Y				
e) troublesome visual conditions	Y				
f) jerks, shakes, or vibration	N				
Environmental / Organizational Risk Factors Score					
SUM	5				
PERCENTAGE	50.0				

A2. Torch Cutters

Table 6. Torch Cutters RULA

Rapid Upper Limb Assessment (RULA), Matamney and Corlett (1993)

Day/Time: 4/13/00 Facility: Todd Pacific

Task: Torch Cutting Area/Shop: Onboard Vessel

RULA: Posture Sampling Results										
RULA Component	**Frame # 77580 Apply torch to surface (torch- time)**		**Frame # 51450 Adjust body position, clear debris**		**Frame # 60450 Begin new cut (move location)**		**Frame # 65460 Rest**		**Frame # 65850 Cleaning cut with wrench**	
	Specific	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***
Shoulder Extension/ Flexion	sl flex	2	neut	1	neut	1	neut	1	mod flex	3
Shoulder is Raised (+1)		0		0		0		0		0
Upper Arm Abducted (+1)		0		0		0		0		0
Arm supported, leaning (-1)		0		0		0		0		0
Elbow Extension/ Flexion	neut	2	neut	2	ext	1	ext	1	ext	1
Shoulder Abduction/ Adduction	neut	0	neut	0	neut	0	neut	0	neut	0
Shoulder Lateral/ Medial	mod med	1	neut	0	neut	0	neut	0	lat	1
Wrist Extension/ Flexion	flx	2	neut	1	neut	1	neut	1	neut	1
Wrist Deviation	ulnar	1	neut	0	neut	0	neut	0	neut	0
Wrist Bent from Midline (+1)		0		0		0		0		0
Wrist Twist (1) In mid range Or (2) End of range		1		1		1		1		1
Arm and Wrist Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		0		0		0		0
Arm and Wrist Force/ load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		2		1		1		1		0

Table 6. Torch Cutters RULA (continued)

RULA Component	**Frame # 77580 Apply torch to surface (torch-time)**		**Frame # 51450 Adjust body position, clear debris**		**Frame # 60450 Begin new cut (move location)**		**Frame # 65460 Rest**		**Frame # 65850 Cleaning cut with wrench**	
	Specific	*RULA Score*	*Specific*	*RULA Score*	*Specific*	*RULA Score*	*Specific*	*RULA Score*	*Specific*	*RULA Score*
Neck Extension/ Flexion		2		3		1		1		2
Neck Twist (+1)		0		0		0		0		0
Neck Side-Bent (+1)		0		0		0		0		0
Trunk Extension/ Flexion	flx	3	neut	1	neut	1	neut	1	flx	3
Trunk Twist (+1)		0		0		0		0		0
Trunk Side Bend (+1)		0		0		0		0		0
Legs If legs and feet are supported and balanced: (+1); If not: (+2)		1		1		1		1		1
Neck, Trunk, and Leg Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		0		0		1		1
Neck, Trunk, and Leg Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		2		1		1		2		2
Total RULA Score	**7**		**3**		**2**		**3**		**4**	

1 or 2 = Acceptable
3 or 4 = Investigate Further
5 or 6 = Investigate Further and Change Soon
7 = Investigate and Change Immediately

Table 7. Torch Cutters Strain Index

Strain Index: Distal Upper Extremity Disorders Risk Assessment
Moore and Garg, 1995

Date/ Time 4/13/00 Facility: Todd Pacific
Task : Torch Cutting Task Area/ Shop: Onboard vessel

1. Intensity of Exertion: An estimate of the strength required to perform the task one time. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.					
Rating Criterion	**% MS** *(percentage of maximal strength)*	**Borg Scale** *(Compare to Borg Cr-10 Scale)*	**Perceived Effort**	**Rating**	**Multiplier**
Light	< 10%	< or = 2	barely noticeable or relaxed effort	1	1.0
Somewhat hard	10 - 29%	3	noticeable or definite effort	2	3.0
Hard	30 - 49%	4 - 5	obvious effort; unchanged facial expression	3	6.0
Very Hard	50 - 79%	6 - 7	substantial effort; changes to facial expression	4	9.0
Near Maximal	> or = 80%	> 7	uses shoulder or trunk to generate force	5	13.0
Intensity of Exertion Multiplier					**3.0**

Table 7. Torch Cutters Strain Index (continued)

2. Duration of Exertion (% of cycle): Calculated by measuring the duration of all exertions during an observation period, then dividing the measured duration of exertion by the total observation time and multiplying by 100. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box.*NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0

Worksheet:	**Rating Criterion**	**Rating**	**Multiplier**
% Duration of Exertion = 100 x duration of all exertions (sec) / Total observation time (sec) = 100 x 1430 (sec)/ 1549 (sec) = 92	< 10	1	0.5
	10 - 29	2	1.0
	30 - 49	3	1.5
	50 -79	4	2.0
	> or = 80	5	3.0
Duration of Exertion Multiplier			**3.0**

3. Efforts per Minute: Measured by counting the number of exertions that occur during an observation period, then dividing the number of exertions by the duration of the observation period, measured in minutes. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box. *NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0

Worksheet:	**Rating Criterion**	**Rating**	**Multiplier**
Efforts per Minute = number of exertions / total observation time (min) = nearly static exertion, therefore = 3.0	< 4	1	0.5
	4 - 8	2	1.0
	9 -14	3	1.5
	15 -19	4	2.0
	> or = 20	5	3.0
Efforts per Minute Multiplier			**3.0**

Table 7. Torch Cutters Strain Index (continued)

4. Hand/ Wrist Posture: An estimate of the position of the hand or wrist relative to neutral position. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.						
Rating Criterion	**Wrist Extension** *(Stetson et al, 1991)*	**Wrist Flexion** *(Stetson et al, 1991)*	**Ulnar Deviation** *(Stetson et al, 1991)*	**Perceived Posture**	**Rating**	**Multiplier**
Very Good	0 -10 degrees	0 - 5 degrees	0 - 10 degrees	perfectly neutral	1	1.0
Good	11 - 25 degrees	6 - 15 degrees	11 -15 degrees	near neutral	2	1.0
Fair	26 -40 degrees	16 - 30 degrees	16 - 20 degrees	non-neutral (*estimated, based on RULAs performed)	3	1.5
Bad	41 - 55 degrees	31 - 50 degrees	21 -25 degrees	marked deviation	4	2.0
Very Bad	> 60 degrees	> 50 degrees	> 25 degrees	near extreme	5	3.0
Hand/ Wrist Posture Multiplier						**1.5**

5. Speed of Work: An estimate of how fast the worker is working. Mark the rating on the far right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.				
Rating Criterion	**Compared to MTM** *(observed pace is divided by MTM's predicted pace and expressed as %)*	**Perceived Speed**	**Rating**	**Multiplier**
Very Slow	< or = 80%	extremely relaxed pace	1	1.0
Slow	81 - 90%	"taking one's own time"	2	1.0
Fair	91 -100%	"normal" speed of motion	3	1.0
Fast	101-115%	rushed, but able to keep up	4	1.5
Very Fast	> 115%	rushed, barely or unable to keep up	5	2.0
Speed of Work Multiplier				**1.0**

Table 7. Torch Cutters Strain Index (continued)

6. Duration of Task per Day: Either measured or obtained from plant personnel. Mark the rating on the right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.			
Worksheet:	***Rating Criterion***	***Rating***	***Multiplier***
Duration of Task per Day (hrs) = duration of task (hrs) + duration of task (hrs) + ... = (estimate @ 2-4 hrs)	< or = 1 hrs	1	0.25
	1 - 2 hrs	2	0.50
	2 - 4 hrs	3	0.75
	4 - 8 hrs	4	1.00
	> or = 8 hrs	5	1.50
Duration of Task per Day Multiplier			**0.75**

7. Calculate the Strain Index (SI) Score: Insert the multiplier values for each of the six task variables into the spaces below, then multiply them all together.							
Intensity of Exertion	**Duration of Exertion**	**Efforts per Minute**	**Hand/ Wrist Posture**	**Speed of Work**	**Duration of Task**	=	**SI SCORE**
3.0 X	**3.0 X**	**3.0 X**	**1.5 X**	**1.0 X**	**0.75**		**30.4**

SI Scores are used to predict Incidence Rates of Distal Upper Extremity injuries per 100 FTE:
- SI Score < 5 is correlated to an Incidence Rate of about 2 DUE injuries per 100 FTE;
- SI Score of between 5-30 is correlated to an Incidence Rate of about 77 DUE injuries per 100 FTE;
- SI Score of between 31-60 is correlated to an Incidence Rate of about 106 DUE injuries per 100 FTE;
- SI Score > 60 is correlated to an Incidence Rate of about 130 DUE injuries per 100 FTE.

Table 8. Torch Cutters UE CTD Checklist

Michigan Checklist for Upper Extremity Cumulative Trauma Disorders
Lifshitz and Armstrong (1986)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Torch Cutting Area/ Shop: Onboard Vessel
* "No" responses are indicative of conditions associated with the risk of CTD's

Risk Factors	No	Yes
1. Physical Stress		
1.1 Can the job be done without hand/ wrist contact with sharp edges		Y
1.2 Is the tool operating without vibration?		Y
1.3 Are the worker's hands exposed to temperature >21degrees C (70 degrees F)?	N	Y
1.4 Can the job be done without using gloves?	N	
2. Force		
2.1 Does the job require exerting less than 4.5 kg (10lbs) of force?	N	
2.2 Can the job be done without using finger pinch grip?		Y
3. Posture		
3.1 Can the job be done without flexion or extension of the wrist?	N	
3.2 Can the tool be used without flexion or extension of the wrist?	N	
3.3 Can the job be done without deviating the wrist from side to side?	N	
3.4 Can the tool be used without deviating the wrist from side to side?	N	
3.5 Can the worker be seated while performing the job?		Y
3.6 Can the job be done without "clothes wringing" motion?		Y
4. Workstation Hardware		
4.1 Can the orientation of the work surface be adjusted?	N	
4.2 Can the height of the work surface be adjusted?	N	
4.3 Can the location of the tool be adjusted?	N	
5. Repetitiveness		
5.1 Is the cycle time longer than 30 seconds?	N	
6. Tool Design		
6.1 Are the thumb and finger slightly overlapped in a closed grip?	N	
6.2 Is the span of the tool's handle between 5 and 7 cm (2-2 3/4 inches)?	Not measured	
6.3 Is the handle of the tool made from material other than metal?	N	
6.4 Is the weight of the tool below 4 kg (9lbs)?	Not measured	
6.5 Is the tool suspended?	N	
TOTAL	**14 (70%)**	**6 (30%)**

Table 9. Torch Cutters OWAS

OWAS: OVAKO Work Analysis System
Louhevaara and Suurnäkki (1992)

Procedure: Observe workers at intervals of 30-60 seconds. Record postures and forces over a representative period (~ 45 minutes)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task Pipe Welder (stick) Area/ Shop Onboard Vessel

Risk Factor	**Work Phase1** **Apply torch to surface (torch time)**	**Work Phase 2** **Adjust body position, clear debris**	**Work Phase 3** **Begin new cut (move location)**	**Work Phase 4** **Rest**	**Work Phase 5** **Cleaning cut with wrench**
TOTAL Combination Posture Score	**2**	**1**	**1**	**1**	**2**
Common Posture Combinations (collapsed across work phases)					
Back	2	1	1		
Arms	1	1	1		
Legs	6	6	7		
Posture Repetition (% of working time)	81	15	3		
Back % of Working Time Score	3	1	1		
Arms % of Working Time Score	1	1	1		
Legs % of Working Time Score	3	1	1		
ACTION CATEGORIES: 1 = no corrective measures 2 = corrective measures in the near future 3 = corrective measures as soon as possible 4 = corrective measures immediately					

Table 9. Torch Cutters OWAS (continued)

Risk Factor	**Work Phase1** **Apply torch to surface (torch time)**	**Work Phase 2** **Adjust body position, clear debris**	**Work Phase 3** **Begin new cut (move location)**	**Work Phase 4** **Rest**	**Work Phase 5** **Cleaning cut with wrench**
Posture					
Back 1 = straight 2 = bent forward, backward 3 = twisted or bent sideways 4 = bent and twisted or bent forward and sideways	2	1	1	1	2
Arms 1 = both arms are below shoulder level 2 = one arm is at or above shoulder level 3 = both arms are at or above shoulder level	1	1	1	1	1
Legs 1 = sitting 2 = standing with both legs straight 3 = standing with the weight on one straight leg 4 = standing or squatting with both knees bent 5 = standing or squatting with one knee bent 6 = kneeling on one or both knees 7 = walking or moving	6	6	7	6	6
Load/ Use of Force					
1 = weight or force needed is = or <10 kg (<22lbs)	1	1	1	1	1
2 = weight or force > 10 but < 20kg (>22lbs < 44 lbs)					
3 = weight or force > 20 kg (>44 lbs)					
Phase Repetition					
% of working time (0,10,20,30,40,50,60,70,80,90,100)	79	9	3	6	2

Table 10. Torch Cutters PLIBEL

PLIBEL Checklist, Kemmlert (1995)

Date/ Time: 4/13/00 Facility: Todd Pacific

Task: Torch Cutter Area/ Shop: Onboard Vessel

Section I: Musculoskeletal Risk Factors **Methods of Application:** **1) Find the injured body region, answer yes or no to corresponding questions** **2) Answer questions, score potential body regions for injury risk**					
Musculoskeletal Risk Factor Questions	Body Regions				
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
1: Is the walking surface uneven, sloping, slippery or nonresilient?			N	N	N
2: Is the space too limited for work movements or work materials?	N	N	N	N	N
3: Are tools and equipment unsuitably designed for the worker or the task?	Y	Y	Y	Y	Y
4: Is the working height incorrectly adjusted?	Y				Y
5: Is the working chair poorly designed or incorrectly adjusted?	N				N
6: If work performed standing, is there no possibility to sit and rest?			N	N	N
7: Is fatiguing foot pedal work performed?			N	N	
8: Is fatiguing leg work performed? e.g. ...					
a) repeated stepping up on stool, step etc..			N	N	N
b) repeated jumps, prolonged squatting or kneeling?			Y	Y	Y
c) one leg being used more often in supporting the body?			N	N	N
9: Is repeated or sustained work performed when the back is:					
a) mildly flexed forward?	Y				Y
b) severely flexed forward?	Y				Y
c) bent sideways or mildly twisted?	N				N
d) severely twisted?	N				N

Table 10. Torch Cutters PLIBEL (continued)

10: Is repeated/sustained work performed with neck:					
a) flexed forward?	Y				
b) bent sideways or mildly twisted?	N				
c) severely twisted?	N				
d) extended backwards?	N				
11: Are loads lifted manually? Note important factors:					
a) periods of repetitive lifting	N				N
b) weight of load	N				N
c) awkward grasping of load	N				N
d) awkward location of load at onset or end of lifting	N				N
e) handling beyond forearm length	Y				Y
f) handling below knee length	N				N
g) handling above shoulder height	N				N
12: Is repeated, sustained or uncomfortable carrying, pushing or pulling of loads performed?	Y	Y			Y
13: Is sustained work performed when one arm reaches forward or to the side without support?	Y				
14: Is there a repetition of:					
a) similar work movements?	Y	Y			
b) similar work movements beyond comfortable reaching distance?	Y	Y			
15: Is repeated or sustained manual work performed? Notice factors of importance as:					
a) weight of working materials or tools	N	N			
b) awkward grasping of working materials or tools	Y	Y			
16: Are there high demands on visual capacity?	N				
17: Is repeated work, with forearm and hand, performed with:					
a) twisting movements?		N			
b) forceful movements?		N			
c) uncomfortable hand positions?		Y			
d) switches or keyboards?		N			

Table 10. Torch Cutters PLIBEL (continued)

Musculoskeletal Risk Factors Scores					
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
SUM	11	6	2	2	7
PERCENTAGE	42.3	54.5	25.0	25.0	33.3
Section II: Environmental / Organizational Risk Factors (Modifying) **Answer below questions, use to modify interpretation of musculoskeletal scores**					
18: Is there no possibility to take breaks and pauses?	N				
19: Is there no possibility to choose order and type of work tasks or pace of work?	N				
20: Is the job performed under time demands or psychological stress?	N				
21:Can the work have unusual or expected situations?	N				
22: Are the following present?					
a) cold	Y				
b) heat	Y				
c) draft	Y				
d) noise	Y				
e) troublesome visual conditions	Y				
f) jerks, shakes, or vibration	N				
Environmental / Organizational Risk Factors Score					
SUM	5				
PERCENTAGE	50.0				

A3. Waterjet Blaster

Table 11. Waterjet Blaster RULA

Rapid Upper Limb Assessment (RULA), Matamney and Corlett (1993)

Day/Time: 4/13/00 Facility: Todd Pacific

Task: Waterjet Blasting Area/Shop: Vessel in Drydock

RULA: Posture Sampling Results								
RULA Component	**Frame # 101460** **Waterblasting/ standing**		**Frame # 103110** **Waterblasting/ standing braced**		**Frame # 101880** **Inspect**		**Frame # 105120** **Reposition**	
	Specific	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***
Shoulder Extension/ Flexion	mod flex	3	mod flex	3	neut	1	sl flex	2
Shoulder is Raised (+1)		0		0		0		0
Upper Arm Abducted (+1)		0		0		0		0
Arm supported, leaning (-1)		0		0		0		0
Elbow Extension/ Flexion	ext	1	ext	1	neut	2	ext	1
Shoulder Abduction/ Adduction	neut	0	neut	0	neut	0	neut	0
Shoulder Lateral/ Medial	mod med	1	mod med	1	neut	0	neut	0
Wrist Extension/ Flexion	ext	2	ext	2	neut	1	neut	1
Wrist Deviation	neut	0	neut	0	neut	0	neut	0
Wrist Bent from Midline (+1)		0		0		0		0
Wrist Twist (1) In mid range Or (2) End of range		1		1		1		1
Arm and Wrist Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		1		0		0
Arm and Wrist Force/ load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		3		3		1		1

Table 11. Waterjet Blaster RULA (continued)

RULA Component	**Frame # 101460** **Waterblasting/ standing**		**Frame # 103110** **Waterblasting/ standing braced**		**Frame # 101880** **Inspect**		**Frame # 105120** **Reposition**	
	Specific	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***
Neck Extension/ Flexion	sl flx	2	neut	1	neut	1	neut	1
Neck Twist (+1)		0		0		0		0
Neck Side-Bent (+1)		0		0		0		0
Trunk Extension/ Flexion	sl flx	2	neut	1	neut	1	mod flx	3
Trunk Twist (+1)		0		0		0		0
Trunk Side Bend (+1)		0		0		0		0
Legs If legs and feet are supported and balanced: (+1); If not: (+2)		1		1		1		1
Neck, Trunk, and Leg Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		1		0		0
Neck, Trunk, and Leg Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		2		2		2		1
Total RULA Score	**7**		**6**		**3**		**3**	

1 or 2 = Acceptable
3 or 4 = Investigate Further
5 or 6 = Investigate Further and Change Soon
7 = Investigate and Change Immediately

Table 12. Waterjet Blaster Strain Index

Strain Index: Distal Upper Extremity Disorders Risk Assessment
Moore and Garg, 1995

Date/ Time 4/13/00 Facility: Todd Pacific
Task : Waterjet Blasting Area/ Shop: Vessel in Drydock

1. Intensity of Exertion: An estimate of the strength required to perform the task one time. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.					
Rating Criterion	**% MS** *(percentage of maximal strength)*	**Borg Scale** *(Compare to Borg Cr-10 Scale)*	**Perceived Effort**	**Rating**	**Multiplier**
Light	< 10%	< or = 2	barely noticeable or relaxed effort	1	1.0
Somewhat hard	10 - 29%	3	noticeable or definite effort	2	3.0
Hard	30 - 49%	4 - 5	obvious effort; unchanged facial expression	3	6.0
Very Hard	50 - 79%	6 - 7	substantial effort; changes to facial expression	4	9.0
Near Maximal	> or = 80%	> 7	uses shoulder or trunk to generate force	5	13.0
Intensity of Exertion Multiplier					**6.0**

Table 12. Waterjet Blaster Strain Index (continued)

2. Duration of Exertion (% of cycle): Calculated by measuring the duration of all exertions during an observation period, then dividing the measured duration of exertion by the total observation time and multiplying by 100. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box.*NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet: % Duration of Exertion = 100 x duration of all exertions (sec) / Total observation time (sec) = 100 x 134 (sec)/ 145 (sec) = 92	**Rating Criterion**	**Rating**	**Multiplier**
	< 10	1	0.5
	10 - 29	2	1.0
	30 - 49	3	1.5
	50 -79	4	2.0
	> or = 80	5	3.0
Duration of Exertion Multiplier			**3.0**

3. Efforts per Minute: Measured by counting the number of exertions that occur during an observation period, then dividing the number of exertions by the duration of the observation period, measured in minutes. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box. *NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet: Efforts per Minute = number of exertions / total observation time (min) = nearly static exertion, therefore = 3.0	**Rating Criterion**	**Rating**	**Multiplier**
	< 4	1	0.5
	4 - 8	2	1.0
	9 -14	3	1.5
	15 -19	4	2.0
	> or = 20	5	3.0
Efforts per Minute Multiplier			**3.0**

Table 12. Waterjet Blaster Strain Index (continued)

4. Hand/ Wrist Posture: An estimate of the position of the hand or wrist relative to neutral position. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.						
Rating Criterion	**Wrist Extension** *(Stetson et al, 1991)*	**Wrist Flexion** *(Stetson et al, 1991)*	**Ulnar Deviation** *(Stetson et al, 1991)*	**Perceived Posture**	**Rating**	**Multiplier**
Very Good	0 -10 degrees	0 - 5 degrees	0 - 10 degrees	perfectly neutral	1	1.0
Good	11 - 25 degrees	6 - 15 degrees	11 -15 degrees	near neutral	2	1.0
Fair	26 -40 degrees	16 - 30 degrees	16 - 20 degrees	non-neutral (*estimated, based on RULAs performed)	3	1.5
Bad	41 - 55 degrees	31 - 50 degrees	21 -25 degrees	marked deviation	4	2.0
Very Bad	> 60 degrees	> 50 degrees	> 25 degrees	near extreme	5	3.0
Hand/ Wrist Posture Multiplier						**1.5**

5. Speed of Work: An estimate of how fast the worker is working. Mark the rating on the far right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.				
Rating Criterion	**Compared to MTM** *(observed pace is divided by MTM's predicted pace and expressed as %)*	**Perceived Speed**	**Rating**	**Multiplier**
Very Slow	< or = 80%	extremely relaxed pace	1	1.0
Slow	81 - 90%	"taking one's own time"	2	1.0
Fair	91 -100%	"normal" speed of motion	3	1.0
Fast	101-115%	rushed, but able to keep up	4	1.5
Very Fast	> 115%	rushed, barely or unable to keep up	5	2.0
Speed of Work Multiplier				**1.0**

Table 12. Waterjet Blaster Strain Index (continued)

6. Duration of Task per Day: Either measured or obtained from plant personnel. Mark the rating on the right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.			
Worksheet:	***Rating Criterion***	***Rating***	***Multiplier***
Duration of Task per Day (hrs) = duration of task (hrs) + duration of task (hrs) + ... = (estimate @ 2-4 hrs)	< or = 1 hrs	1	0.25
	1 - 2 hrs	2	0.50
	2 - 4 hrs	3	0.75
	4 - 8 hrs	4	1.00
	> or = 8 hrs	5	1.50
Duration of Task per Day Multiplier			**0.75**

7. Calculate the Strain Index (SI) Score: Insert the multiplier values for each of the six task variables into the spaces below, then multiply them all together.							
Intensity of Exertion	**Duration of Exertion**	**Efforts per Minute**	**Hand/ Wrist Posture**	**Speed of Work**	**Duration of Task**	=	**SI SCORE**
6.0 X	**3.0 X**	**3.0 X**	**1.5 X**	**1.0 X**	**0.75**		**60.75**

SI Scores are used to predict Incidence Rates of Distal Upper Extremity injuries per 100 FTE:
- SI Score < 5 is correlated to an Incidence Rate of about 2 DUE injuries per 100 FTE;
- SI Score of between 5-30 is correlated to an Incidence Rate of about 77 DUE injuries per 100 FTE;
- SI Score of between 31-60 is correlated to an Incidence Rate of about 106 DUE injuries per 100 FTE;
- SI Score > 60 is correlated to an Incidence Rate of about 130 DUE injuries per 100 FTE.

Table 13. Waterjet Blaster UE CTD Checklist

Michigan Checklist for Upper Extremity Cumulative Trauma Disorders
Lifshitz and Armstrong (1986)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Waterjet Blasting Area/ Shop: Vessel in Drydock
* "No" responses are indicative of conditions associated with the risk of CTD's

Risk Factors	No	Yes
1. Physical Stress		
1.1 Can the job be done without hand/ wrist contact with sharp edges		Y
1.2 Is the tool operating without vibration?	N	
1.3 Are the worker's hands exposed to temperature >21degrees C (70 degrees F)?	N	Y
1.4 Can the job be done without using gloves?	N	
2. Force		
2.1 Does the job require exerting less than 4.5 kg (10lbs) of force?	N	
2.2 Can the job be done without using finger pinch grip?		Y
3. Posture		
3.1 Can the job be done without flexion or extension of the wrist?	N	
3.2 Can the tool be used without flexion or extension of the wrist?	N	
3.3 Can the job be done without deviating the wrist from side to side?		Y
3.4 Can the tool be used without deviating the wrist from side to side?		Y
3.5 Can the worker be seated while performing the job?		Y
3.6 Can the job be done without "clothes wringing" motion?		Y
4. Workstation Hardware		
4.1 Can the orientation of the work surface be adjusted?		Y
4.2 Can the height of the work surface be adjusted?		Y
4.3 Can the location of the tool be adjusted?	N	
5. Repetitiveness		
5.1 Is the cycle time longer than 30 seconds?	N	
6. Tool Design		
6.1 Are the thumb and finger slightly overlapped in a closed grip?	Not measured	
6.2 Is the span of the tool's handle between 5 and 7 cm (2-2 3/4 inches)?	Not measured	
6.3 Is the handle of the tool made from material other than metal?	N	
6.4 Is the weight of the tool below 4 kg (9lbs)?	N	
6.5 Is the tool suspended?	N	
TOTAL	**11 (55%)**	**9 (45%)**

Table 14. Waterjet Blaster OWAS

OWAS: OVAKO Work Analysis System
Louhevaara and Suurnäkki (1992)

Procedure: Observe workers at intervals of 30-60 seconds. Record postures and forces over a representative period (~ 45 minutes)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Waterjet Blasting Area/Shop: Vessel in Drydock

Risk Factor	**Work Phase1** **Waterblasting /standing**	**Work Phase 2** **Waterblasting/ standing braced**	**Work Phase 3** **Inspect**	**Work Phase 4** **Reposition**
TOTAL Combination Posture Score	**1**	**1**	**1**	**2**
Common Posture Combinations (collapsed across work phases)				
Back	1	1	2	
Arms	3	1	2	
Legs	3	2	2	
Posture Repetition (% of working time)	73	8	18	
BACK % of Working Time SCORE	1	1	1	
ARMS % of Working Time SCORE	3	1	1	
LEGS % of Working Time SCORE	2	1	1	
ACTION CATEGORIES: 1 = no corrective measures 2 = corrective measures in the near future 3 = corrective measures as soon as possible 4 = corrective measures immediately				

Table 14. Waterjet Blaster OWAS (continued)

Risk Factor	**Work Phase1** **Waterblasting standing**	**Work Phase 2** **Waterblasting/ standing braced**	**Work Phase 3** **Inspect**	**Work Phase 4** **Reposition**
Posture				
Back 1 = straight 2 = bent forward, backward 3 = twisted or bent sideways 4 = bent and twisted or bent forward and sideways	1	1	1	2
Arms 1 = both arms are below shoulder level 2 = one arm is at or above shoulder level 3 = both arms are at or above shoulder level	3	3	1	2
Legs 1 = sitting 2 = standing with both legs straight 3 = standing with the weight on one straight leg 4 = standing or squatting with both knees bent 5 = standing or squatting with one knee bent 6 = kneeling on one or both knees 7 = walking or moving	3	3	2	2
Load/ Use of Force				
1 = weight or force needed is = or <10 kg (<22lbs)	3	3	1	1
2 = weight or force > 10 but < 20kg (>22lbs < 44 lbs)				
3 = weight or force > 20 kg (>44 lbs)				
Phase Repetition				
% of working time (0,10,20,30,40,50,60,70,80,90,100)	16	57	8	20

Table 15. Waterjet Blaster PLIBEL

PLIBEL Checklist, Kemmlert (1995)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Waterjet Blasting Area/ Shop: Vessel in Drydock

Section I: Musculoskeletal Risk Factors
Methods of Application:
1) Find the injured body region, answer yes or no to corresponding questions
2) Answer questions, score potential body regions for injury risk

Musculoskeletal Risk Factor Questions	Body Regions				
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
1: Is the walking surface uneven, sloping, slippery or nonresilient?			Y	Y	Y
2: Is the space too limited for work movements or work materials?	N	N	N	N	N
3: Are tools and equipment unsuitably designed for the worker or the task?	Y	Y	Y	Y	Y
4: Is the working height incorrectly adjusted?	Y				Y
5: Is the working chair poorly designed or incorrectly adjusted?	Y				Y
6: If work performed standing, is there no possibility to sit and rest?			N	N	N
7: Is fatiguing foot pedal work performed?			N	N	
8: Is fatiguing leg work performed? e.g. ...					
a) repeated stepping up on stool, step etc..			N	N	N
b) repeated jumps, prolonged squatting or kneeling?			N	N	N
c) one leg being used more often in supporting the body?			Y	Y	Y
9: Is repeated or sustained work performed when the back is:					
a) mildly flexed forward?	N				N
b) severely flexed forward?	N				N
c) bent sideways or mildly twisted?	N				N
d) severely twisted?	N				N

Table 15. Waterjet Blaster PLIBEL (continued)

10: Is repeated/sustained work performed with neck:					
a) flexed forward?	N				
b) bent sideways or mildly twisted?	N				
c) severely twisted?	N				
d) extended backwards?	N				
11: Are loads lifted manually? Note important factors:					
a) periods of repetitive lifting	N				N
b) weight of load	N				N
c) awkward grasping of load	Y				Y
d) awkward location of load at onset or end of lifting	Y				Y
e) handling beyond forearm length	Y				Y
f) handling below knee length	N				N
g) handling above shoulder height	Y				Y
12: Is repeated, sustained or uncomfortable carrying, pushing or pulling of loads performed?	Y	Y			Y
13: Is sustained work performed when one arm reaches forward or to the side without support?	Y				
14: Is there a repetition of:					
a) similar work movements?	Y	Y			
b) similar work movements beyond comfortable reaching distance?	Y	Y			
15: Is repeated or sustained manual work performed? Notice factors of importance as:					
a) weight of working materials or tools	Y	Y			
b) awkward grasping of working materials or tools	Y	Y			
16: Are there high demands on visual capacity?	N				
17: Is repeated work, with forearm and hand, performed with:					
a) twisting movements?		N			
b) forceful movements?		Y			
c) uncomfortable hand positions?		Y			
d) switches or keyboards?		N			

Table 15. Waterjet Blaster PLIBEL (continued)

Musculoskeletal Risk Factors Scores					
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
SUM	13	8	3	3	10
PERCENTAGE	50.0	72.7	37.5	37.5	47.6
Section II: Environmental / Organizational Risk Factors (Modifying) **Answer below questions, use to modify interpretation of musculoskeletal scores**					
18: Is there no possibility to take breaks and pauses?	N				
19: Is there no possibility to choose order and type of work tasks or pace of work?	Y				
20: Is the job performed under time demands or psychological stress?	N				
21:Can the work have unusual or expected situations?	N				
22: Are the following present?					
a) cold	Y				
b) heat	Y				
c) draft	Y				
d) noise	Y				
e) troublesome visual conditions	N				
f) jerks, shakes, or vibration	Y				
Environmental / Organizational Risk Factors Score					
SUM	6				
PERCENTAGE	60.0				

A4. Shipfitter Grinding

Table 16. Shipfitter Grinding RULA

Rapid Upper Limb Assessment (RULA), Matamney and Corlett (1993)

Day/Time: 4/13/00 Facility: Todd Pacific
Task: Shipfitter Grinding Area/Shop: Onboard Vessel

RULA: Posture Sampling Results												
RULA Component	**Frame # 57300, 57930 Grind surface**		**Frame # 59250 Reposition body**		**Frame # 60990 Reposition adjust tool**		**Frame # 66090 Inspect, rest**		**Frame # 82230 Torch cut**		**Frame # 91680 De-slag**	
	Specific	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***
Shoulder Extension/ Flexion	sl flex	2	sl flex	2	mod flex	3	sl flex	2	mod flex	3	mod flex	3
Shoulder is Raised (+1)		1		0		1		1		1		0
Upper Arm Abducted (+1)		0		0		0		0		1		0
Arm supported, leaning (-1)		-1		-1		-1		-1		-1		0
Elbow Extension/ Flexion	ext	1	ext	1	ext	1	ext	1	neut	2	neut	2
Shoulder Abduction/ Adduction	add	1	neut	0	neut	0	neut	0	mod abd	1	neut	0
Shoulder Lateral/ Medial	neut	0	neut	0	neut	0	neut	0	lat	1	lat	1
Wrist Extension/ Flexion	ext	2	neut	1	neut	1	neut	1	ext	2	flx	2
Wrist Deviation	ulnar	1	neut	0	neut	0	neut	0	ulnar	1	neut	0
Wrist Bent from Midline (+1)		0		0		0		0		0		0
Wrist Twist (1) In mid range Or (2) End of range		1		1		1		1		1		1
Arm and Wrist Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		0		0		0		1		0
Arm and Wrist Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		2		1		1		1		2		1

Table 16. Shipfitter Grinding RULA (continued)

RULA Component	**Frame # 57300, 57930 Grind surface**		**Frame # 59250 Reposition body**		**Frame # 60990 Reposition adjust tool**		**Frame # 66090 Inspect, rest**		**Frame # 82230 Torch cut**		**Frame # 91680 De-slag**	
	Specific	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***
Neck Extension/ Flexion		4		1		4		4		4		2
Neck Twist (+1)		0		0		0		0		0		0
Neck Side-Bent (+1)		0		0		0		0		0		0
Trunk Extension/ Flexion	neut	1	neut	1	neut	1	neut	1	neut	1	sl flx	2
Trunk Twist (+1)		0		0		0		0		0		0
Trunk Side Bend (+1)		0		0		0		0		0		0
Legs If legs and feet are supported and balanced: (+1); If not: (+2)		1		1		1		1		1		1
Neck, Trunk, and Leg Muscle Use Score If posture mainly static (i.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		0		0		0		1		0
Neck, Trunk, and Leg Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		1		1		1		1		1		1
Total RULA Score	**6**		**2**		**3**		**3**		**6**		**4**	

1 or 2 = Acceptable
3 or 4 = Investigate Further
5 or 6 = Investigate Further and Change Soon
7 = Investigate and Change Immediately

Table 17. Shipfitter Grinding Strain Index

Strain Index: Distal Upper Extremity Disorders Risk Assessment
Moore and Garg, 1995

Date/ Time 4/13/00 Facility: Todd Pacific
Task : Shipfitter Grinding Area/ Shop: Onboard Vessel

1. Intensity of Exertion: An estimate of the strength required to perform the task one time. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.					
Rating Criterion	**% MS** *(percentage of maximal strength)*	**Borg Scale** ***(Compare to Borg Cr-10 Scale)***	**Perceived Effort**	**Rating**	**Multiplier**
Light	< 10%	< or = 2	barely noticeable or relaxed effort	1	1.0
Somewhat hard	10 - 29%	3	noticeable or definite effort	2	3.0
Hard	30 - 49%	4 - 5	obvious effort; unchanged facial expression	3	6.0
Very Hard	50 - 79%	6 - 7	substantial effort; changes to facial expression	4	9.0
Near Maximal	> or = 80%	> 7	uses shoulder or trunk to generate force	5	13.0
Intensity of Exertion Multiplier					**6.0**

Table 17. Shipfitter Grinding Strain Index (continued)

2. Duration of Exertion (% of cycle): Calculated by measuring the duration of all exertions during an observation period, then dividing the measured duration of exertion by the total observation time and multiplying by 100. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box.*NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet: % Duration of Exertion = 100 x duration of all exertions (sec) / Total observation time (sec) = 100 x 1167 (sec)/ 1499 (sec) = 78	**Rating Criterion**	**Rating**	**Multiplier**
	< 10	1	0.5
	10 - 29	2	1.0
	30 - 49	3	1.5
	50 -79	4	2.0
	> or = 80	5	3.0
Duration of Exertion Multiplier			**2.0**

3. Efforts per Minute: Measured by counting the number of exertions that occur during an observation period, then dividing the number of exertions by the duration of the observation period, measured in minutes. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box. *NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet: Efforts per Minute = number of exertions / total observation time (min) = nearly static exertion, therefore = 3.0	**Rating Criterion**	**Rating**	**Multiplier**
	< 4	1	0.5
	4 - 8	2	1.0
	9 -14	3	1.5
	15 -19	4	2.0
	> or = 20	5	3.0
Efforts per Minute Multiplier			**3.0**

Table 17. Shipfitter Grinding Strain Index (continued)

4. Hand/ Wrist Posture: An estimate of the position of the hand or wrist relative to neutral position. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.						
Rating Criterion	**Wrist Extension** *(Stetson et al, 1991)*	**Wrist Flexion** *(Stetson et al, 1991)*	**Ulnar Deviation** *(Stetson et al, 1991)*	**Perceived Posture**	**Rating**	**Multiplier**
Very Good	0 -10 degrees	0 - 5 degrees	0 - 10 degrees	perfectly neutral	1	1.0
Good	11 - 25 degrees	6 - 15 degrees	11 -15 degrees	near neutral	2	1.0
Fair	26 -40 degrees	16 - 30 degrees	16 - 20 degrees	non-neutral (*estimated, based on RULAs performed)	3	1.5
Bad	41 - 55 degrees	31 - 50 degrees	21 -25 degrees	marked deviation	4	2.0
Very Bad	> 60 degrees	> 50 degrees	> 25 degrees	near extreme	5	3.0
Hand/ Wrist Posture Multiplier						**1.5**

5. Speed of Work: An estimate of how fast the worker is working. Mark the rating on the far right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.				
Rating Criterion	**Compared to MTM** *(observed pace is divided by MTM's predicted pace and expressed as %)*	**Perceived Speed**	**Rating**	**Multiplier**
Very Slow	< or = 80%	extremely relaxed pace	1	1.0
Slow	81 - 90%	"taking one's own time"	2	1.0
Fair	91 -100%	"normal" speed of motion	3	1.0
Fast	101-115%	rushed, but able to keep up	4	1.5
Very Fast	> 115%	rushed, barely or unable to keep up	5	2.0
Speed of Work Multiplier				**1.0**

Table 17. Shipfitter Grinding Strain Index (continued)

6. Duration of Task per Day: Either measured or obtained from plant personnel. Mark the rating on the right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.			
Worksheet:	***Rating Criterion***	***Rating***	***Multiplier***
Duration of Task per Day (hrs) = duration of task (hrs) + duration of task (hrs) + ... = (estimate @ 2-4 hrs)	< or = 1 hrs	1	0.25
	1 - 2 hrs	2	0.50
	2 - 4 hrs	3	0.75
	4 - 8 hrs	4	1.00
	> or = 8 hrs	5	1.50
Duration of Task per Day Multiplier			**0.75**

7. Calculate the Strain Index (SI) Score: Insert the multiplier values for each of the six task variables into the spaces below, then multiply them all together.							
Intensity of Exertion	**Duration of Exertion**	**Efforts per Minute**	**Hand/ Wrist Posture**	**Speed of Work**	**Duration of Task**	=	**SI SCORE**
6.0 X	**2.0 X**	**3.0 X**	**1.5 X**	**1.0 X**	**0.75**		**40.5**

SI Scores are used to predict Incidence Rates of Distal Upper Extremity injuries per 100 FTE:
- SI Score < 5 is correlated to an Incidence Rate of about 2 DUE injuries per 100 FTE;
- SI Score of between 5-30 is correlated to an Incidence Rate of about 77 DUE injuries per 100 FTE;
- SI Score of between 31-60 is correlated to an Incidence Rate of about 106 DUE injuries per 100 FTE;
- SI Score > 60 is correlated to an Incidence Rate of about 130 DUE injuries per 100 FTE.

Table 18. Shipfitter Grinding UE CTD Checklist

Michigan Checklist for Upper Extremity Cumulative Trauma Disorders
Lifshitz and Armstrong (1986)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Shipfitter Grinding Area/ Shop: Onboard Vessel
* "No" responses are indicative of conditions associated with the risk of CTD's

Risk Factors	No	Yes
1. Physical Stress		
1.1 Can the job be done without hand/ wrist contact with sharp edges		Y
1.2 Is the tool operating without vibration?	N	
1.3 Are the worker's hands exposed to temperature >21degrees C (70 degrees F)?	N	Y
1.4 Can the job be done without using gloves?	N	
2. Force		
2.1 Does the job require exerting less than 4.5 kg (10lbs) of force?	N	
2.2 Can the job be done without using finger pinch grip?		Y
3. Posture		
3.1 Can the job be done without flexion or extension of the wrist?	N	
3.2 Can the tool be used without flexion or extension of the wrist?	N	
3.3 Can the job be done without deviating the wrist from side to side?	N	
3.4 Can the tool be used without deviating the wrist from side to side?	N	
3.5 Can the worker be seated while performing the job?		Y
3.6 Can the job be done without "clothes wringing" motion?		Y
4. Workstation Hardware		
4.1 Can the orientation of the work surface be adjusted?	N	
4.2 Can the height of the work surface be adjusted?	N	
4.3 Can the location of the tool be adjusted?	N	
5. Repetitiveness		
5.1 Is the cycle time longer than 30 seconds?	N	
6. Tool Design		
6.1 Are the thumb and finger slightly overlapped in a closed grip?	N (elec. grind.)	
6.2 Is the span of the tool's handle between 5 and 7 cm (2-2 3/4 inches)?	N (elec. grind.)	
6.3 Is the handle of the tool made from material other than metal?		Y
6.4 Is the weight of the tool below 4 kg (9lbs)?		Y
6.5 Is the tool suspended?	N	
TOTAL	**15 (68.1%)**	**7 (31.8%)**

Table 19. Shipfitter Grinding OWAS

OWAS: OVAKO Work Analysis System
Louhevaara and Suurnäkki (1992)

Procedure: Observe workers at intervals of 30-60 seconds. Record postures and forces over a representative period (~ 45 minutes)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Shipfitter Grinding Area/Shop: Onboard Vessel

Risk Factor	**Work Phase1 Grind surface**	**Work Phase 2 Repo-sition body**	**Work Phase 3 Repo-sition/ adjust tool**	**Work Phase 4 Inspect, rest**	**Work Phase 5 Torch cut**	**Work Phase 6 De-slag**
TOTAL Combination Posture Score	**3**	**1**	**2**	**2**	**3**	**2**
Common Posture Combinations (collapsed across work phases)						
Back	2	2	1			
Arms	3	1	1			
Legs	1	1	7			
Posture Repetition (% of working time)	35	31	24			
Back % of Working Time Score	2	2	1			
Arms % of Working Time Score	2	1	1			
Legs % of Working Time Score	1	1	1			

ACTION CATEGORIES:
1 = no corrective measures
2 = corrective measures in the near future
3 = corrective measures as soon as possible
4 = corrective measures immediately

Table 19. Shipfitter Grinding OWAS (continued)

Risk Factor	**Work Phase1** **Grind surface**	**Work Phase 2** **Repo-sition body**	**Work Phase 3** **Repo-sition/ adjust tool**	**Work Phase 4** **Inspect, rest**	**Work Phase 5** **Torch cut**	**Work Phase 6** **De-slag**
Posture						
Back 1 = straight 2 = bent forward, backward 3 = twisted or bent sideways 4 = bent and twisted or bent forward and sideways	2	1	2	2	2	2
Arms 1 = both arms are below shoulder level 2 = one arm is at or above shoulder level 3 = both arms are at or above shoulder level	3	1	1	1	3	1
Legs 1 = sitting 2 = standing with both legs straight 3 = standing with the weight on one straight leg 4 = standing or squatting with both knees bent 5 = standing or squatting with one knee bent 6 = kneeling on one or both knees 7 = walking or moving	1	7	1	1	1	1
Load/ Use of Force						
1 = weight or force needed is = or <10 kg (<22lbs)	2	1	1	1	2	1
2 = weight or force > 10 but < 20kg (>22lbs < 44 lbs)						
3 = weight or force > 20 kg (>44 lbs)						
Phase Repetition						
% of working time (0,10,20,30,40,50,60,70,80,90,100)	11	24	18	12	24	1

Table 20. Shipfitter Grinding PLIBEL

PLIBEL Checklist, Kemmlert (1995)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Shipfitter Grinding Area/ Shop: Onboard Vessel

Section I: Musculoskeletal Risk Factors
Methods of Application:
1) Find the injured body region, answer yes or no to corresponding questions
2) Answer questions, score potential body regions for injury risk

Musculoskeletal Risk Factor Questions	Body Regions				
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
1: Is the walking surface uneven, sloping, slippery or nonresilient?			Y	Y	Y
2: Is the space too limited for work movements or work materials?	Y	Y	Y	Y	Y
3: Are tools and equipment unsuitably designed for the worker or the task?	Y	Y	Y	Y	Y
4: Is the working height incorrectly adjusted?	Y				Y
5: Is the working chair poorly designed or incorrectly adjusted?	Y				Y
6: If work performed standing, is there no possibility to sit and rest?			N	N	N
7: Is fatiguing foot pedal work performed?			N	N	
8: Is fatiguing leg work performed? e.g. ...					
a) repeated stepping up on stool, step etc..			N	N	N
b) repeated jumps, prolonged squatting or kneeling?			N	N	N
c) one leg being used more often in supporting the body?			N	N	N
9: Is repeated or sustained work performed when the back is:					
a) mildly flexed forward?	Y				Y
b) severely flexed forward?	N				N
c) bent sideways or mildly twisted?	N				N
d) severely twisted?	N				N

Table 20. Shipfitter Grinding PLIBEL (continued)

10: Is repeated/sustained work performed with neck:					
a) flexed forward?	N				
b) bent sideways or mildly twisted?	N				
c) severely twisted?	N				
d) extended backwards?	Y				
11: Are loads lifted manually? Note important factors:					
a) periods of repetitive lifting	N				N
b) weight of load	N				N
c) awkward grasping of load	N				N
d) awkward location of load at onset or end of lifting	N				N
e) handling beyond forearm length	Y				Y
f) handling below knee length	N				N
g) handling above shoulder height	Y				Y
12: Is repeated, sustained or uncomfortable carrying, pushing or pulling of loads performed?	Y	Y			Y
13: Is sustained work performed when one arm reaches forward or to the side without support?	Y				
14: Is there a repetition of:					
a) similar work movements?	Y	Y			
b) similar work movements beyond comfortable reaching distance?	Y	Y			
15: Is repeated or sustained manual work performed? Notice factors of importance as:					
a) weight of working materials or tools	N	N			
b) awkward grasping of working materials or tools	Y	Y			
16: Are there high demands on visual capacity?	N				
17: Is repeated work, with forearm and hand, performed with:					
a) twisting movements?		N			
b) forceful movements?		Y			
c) uncomfortable hand positions?		Y			
d) switches or keyboards?		N			

Table 20. Shipfitter Grinding PLIBEL (continued)

Musculoskeletal Risk Factors Scores					
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
SUM	13	8	3	3	9
PERCENTAGE	50.0	72.7	37.5	37.5	42.9
Section II: Environmental / Organizational Risk Factors (Modifying) **Answer below questions, use to modify interpretation of musculoskeletal scores**					
18: Is there no possibility to take breaks and pauses?	N				
19: Is there no possibility to choose order and type of work tasks or pace of work?	N				
20: Is the job performed under time demands or psychological stress?	N				
21:Can the work have unusual or expected situations?	N				
22: Are the following present?					
a) cold	Y				
b) heat	Y				
c) draft	Y				
d) noise	Y				
e) troublesome visual conditions	Y				
f) jerks, shakes, or vibration	Y				
Environmental / Organizational Risk Factors Score					
SUM	6				
PERCENTAGE	60.0				

A5. Semi-Automatic Welder

Table 21. Semi-Automatic Welder RULA

Rapid Upper Limb Assessment (RULA), Matamney and Corlett (1993)

Day/Time: 4/13/00 Facility: Todd Pacific
Task: Semi-Automatic Welder Area/Shop: Onboard Vessel

RULA: Posture Sampling Results				
RULA Component	**Frame # 46650 Prepare machine**		**Frame # 48870 Welding**	
	Specific	***RULA Score***	***Specific***	***RULA Score***
Shoulder Extension/ Flexion	mod flex	3	mod flex	3
Shoulder is Raised (+1)		1		0
Upper Arm Abducted (+1)		1		0
Arm supported, leaning (-1)		0		-1
Elbow Extension/ Flexion	neut	2	ext	1
Shoulder Abduction/ Adduction	mod abd	1	add	1
Shoulder Lateral/ Medial	lat	1	mod med	1
Wrist Extension/ Flexion	flx	2	neut	1
Wrist Deviation	neut	0	neut	0
Wrist Bent from Midline (+1)		0		0
Wrist Twist (1) In mid range Or (2) End of range		1		1
Arm and Wrist Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		0		1
Arm and Wrist Force/Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		0		1

Table 21. Semi-Automatic Welder RULA (continued)

RULA Component	**Frame # 46650 Prepare machine**		**Frame # 48870 Welding**	
	Specific	***RULA Score***	***Specific***	***RULA Score***
Neck Extension/ Flexion		4		2
Neck Twist (+1)		1		0
Neck Side-Bent (+1)		1		0
Trunk Extension/ Flexion	mod flx	3	mod flx	3
Trunk Twist (+1)		1		0
Trunk Side Bend (+1)		1		0
Legs If legs and feet are supported and balanced: (+1); If not: (+2)		1		1
Neck, Trunk, and Leg Muscle Use Score If posture mainly static (i.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		0		1
Neck, Trunk, and Leg Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		1		1
Total RULA Score	**7**		**5**	

1 or 2 = Acceptable
3 or 4 = Investigate Further
5 or 6 = Investigate Further and Change Soon
7 = Investigate and Change Immediately

B6. Wire Welder

Table 22. Wire Welder RULA

Rapid Upper Limb Assessment (RULA), Matamney and Corlett (1993)

Day/Time: 4/13/00 Facility: Todd Pacific
Task: Wire Welder Area/Shop: Onboard Vessel

RULA: Posture Sampling Results												
RULA Component	**Frame # 15000 Welding kneeling**		**Frame # 25440 Welding standing**		**Frame # 16410 De-Slag**		**Frame # 28920 Prepare to weld**		**Frame # 16140 Change tool**		**Frame # 17280 Inspect**	
	Specific	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***
Shoulder Extension/ Flexion	mod flex	3	sl flex	2	mod flex	3	neut	1	neut	1	sl flex	2
Shoulder is Raised (+1)		1		0		1		0		0		0
Upper Arm Abducted (+1)		1		1		0		0		0		0
Arm supported, leaning (-1)		0		-1		0		0		0		-1
Elbow Extension/ Flexion	neut	2	neut	2	neut	2	ext	1	ext	1	neut	2
Shoulder Abduction/ Adduction	mod abd	1	mod abd	1	neut	0	neut	0	neut	0	neut	0
Shoulder Lateral/ Medial	lat	1	lat	1	neut	0	neut	0	neut	0	neut	0
Wrist Extension/ Flexion	ext	2	ext	2	neut	1	neut	1	neut	1	neut	1
Wrist Deviation	ulnar	1	ulnar	1	ulnar	1	neut	0	neut	0	neut	0
Wrist Bent from Midline (+1)		0		0		0		0		0		0
Wrist Twist (1) In mid range Or (2) End of range		1		1		1		1		1		1
Arm and Wrist Muscle Use Score If posture mainly static (I.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		1		0		0		0		0
Arm and Wrist Force/ load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		2		2		1		0		1		0

Table 22. Wire Welder RULA (continued)

RULA Component	**Frame # 15000 Welding kneeling**		**Frame # 25440 Welding standing**		**Frame # 16410 De-Slag**		**Frame # 28920 Prepare to weld**		**Frame # 16140 Change tool**		**Frame # 17280 Inspect**	
	Specific	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***	***Specific***	***RULA Score***
Neck Extension/ Flexion		4		2		2		2		3		2
Neck Twist (+1)		0		0		0		0		0		0
Neck Side-Bent (+1)		0		0		0		0		0		0
Trunk Extension/ Flexion	neut	1	sl flx	2	sl flx	2	sl flx	2	sl flx	2	sl flx	2
Trunk Twist (+1)		0		0		0		0		0		0
Trunk Side Bend (+1)		0		0		0		0		0		0
Legs If legs and feet are supported and balanced: (+1); If not: (+2)		1		1		1		1		1		1
Neck, Trunk, and Leg Muscle Use Score If posture mainly static (i.e. held for longer than 10 minutes) or; If action repeatedly occurs 4 times per minute or more: (+ 1)		1		1		0		0		0		0
Neck, Trunk, and Leg Force/ Load Score If load less than 2 kg (intermittent): (+0) If 2kg to 10 kg (intermittent): (+1) If 2kg to 10 kg (static or repeated): (+2) If more than 10 kg load or repeated or shocks: (+3)		1		2		1		1		1		1
Total RULA Score	**6**		**7**		**4**		**3**		**3**		**3**	

1 or 2 = Acceptable
3 or 4 = Investigate Further
5 or 6 = Investigate Further and Change Soon
7 = Investigate and Change Immediately

Table 23. Wire Welder Strain Index

Strain Index: Distal Upper Extremity Disorders Risk Assessment
Moore and Garg (1995)

Date/ Time 4/13/00 Facility: Todd Pacific
Task : Wire Welder Area/ Shop: Onboard Vessel

1. Intensity of Exertion: An estimate of the strength required to perform the task one time. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.					
Rating Criterion	**% MS** *(percentage of maximal strength)*	**Borg Scale** *(Compare to Borg Cr-10 Scale)*	**Perceived Effort**	**Rating**	**Multiplier**
Light	< 10%	< or = 2	barely noticeable or relaxed effort	1	1.0
Somewhat hard	10 - 29%	3	noticeable or definite effort	2	3.0
Hard	30 - 49%	4 - 5	obvious effort; unchanged facial expression	3	6.0
Very Hard	50 - 79%	6 - 7	substantial effort; changes to facial expression	4	9.0
Near Maximal	> or = 80%	> 7	uses shoulder or trunk to generate force	5	13.0
Intensity of Exertion Multiplier					**3.0**

Table 23. Wire Welder Strain Index (continued)

2. Duration of Exertion (% of cycle): Calculated by measuring the duration of all exertions during an observation period, then dividing the measured duration of exertion by the total observation time and multiplying by 100. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box.*NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet: % Duration of Exertion = 100 x duration of all exertions (sec) / Total observation time (sec) = 100 x 584 (sec)/ 751 (sec) = 37	**Rating Criterion**	**Rating**	**Multiplier**
	< 10	1	0.5
	10 - 29	2	1.0
	30 - 49	3	1.5
	50 -79	4	2.0
	> or = 80	5	3.0
Duration of Exertion Multiplier			**1.5**

3. Efforts per Minute: Measured by counting the number of exertions that occur during an observation period, then dividing the number of exertions by the duration of the observation period, measured in minutes. Use the worksheet below and mark the appropriate rating according to the rating criterion, then fill in the corresponding multiplier in the bottom far right box. *NOTE: If duration of exertion is 100% (as with some static tasks), then efforts/ minute multiplier should be set to 3.0			
Worksheet: Efforts per Minute = number of exertions / total observation time (min) = 12/12.52 = 0.95 but welding is nearly static exertion, therefore, compromise at = 1.5	**Rating Criterion**	**Rating**	**Multiplier**
	< 4	1	0.5
	4 - 8	2	1.0
	9 -14	3	1.5
	15 -19	4	2.0
	> or = 20	5	3.0
Efforts per Minute Multiplier			**1.5**

Table 23. Wire Welder Strain Index (continued)

4. Hand/ Wrist Posture: An estimate of the position of the hand or wrist relative to neutral position. Mark the rating after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.						
Rating Criterion	**Wrist Extension** *(Stetson et al, 1991)*	**Wrist Flexion** *(Stetson et al, 1991)*	**Ulnar Deviation** *(Stetson et al, 1991)*	**Perceived Posture**	**Rating**	**Multiplier**
Very Good	0 -10 degrees	0 - 5 degrees	0 - 10 degrees	perfectly neutral	1	1.0
Good	11 - 25 degrees	6 - 15 degrees	11 -15 degrees	near neutral	2	1.0
Fair	26 -40 degrees	16 - 30 degrees	16 - 20 degrees	non-neutral (*estimated, based on RULAs performed)	3	1.5
Bad	41 - 55 degrees	31 - 50 degrees	21 -25 degrees	marked deviation	4	2.0
Very Bad	> 60 degrees	> 50 degrees	> 25 degrees	near extreme	5	3.0
Hand/ Wrist Posture Multiplier						**1.5**

5. Speed of Work: An estimate of how fast the worker is working. Mark the rating on the far right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.				
Rating Criterion	**Compared to MTM** *(observed pace is divided by MTM's predicted pace and expressed as %)*	**Perceived Speed**	**Rating**	**Multiplier**
Very Slow	< or = 80%	extremely relaxed pace	1	1.0
Slow	81 - 90%	"taking one's own time"	2	1.0
Fair	91 -100%	"normal" speed of motion	3	1.0
Fast	101-115%	rushed, but able to keep up	4	1.5
Very Fast	> 115%	rushed, barely or unable to keep up	5	2.0
Speed of Work Multiplier				**1.0**

Table 23. Wire Welder Strain Index (continued)

6. Duration of Task per Day: Either measured or obtained from plant personnel. Mark the rating on the right after using the guidelines below, then fill in the corresponding multiplier in the bottom far right box.			
Worksheet:	***Rating Criterion***	***Rating***	***Multiplier***
Duration of Task per Day (hrs) = duration of task (hrs) + duration of task (hrs) + ... = (estimate @ 2-4 hrs)	< or = 1 hrs	1	0.25
	1 - 2 hrs	2	0.50
	2 - 4 hrs	3	0.75
	4 - 8 hrs	4	1.00
	> or = 8 hrs	5	1.50
Duration of Task per Day Multiplier			**0.75**

7. Calculate the Strain Index (SI) Score: Insert the multiplier values for each of the six task variables into the spaces below, then multiply them all together.							
Intensity of Exertion	**Duration of Exertion**	**Efforts per Minute**	**Hand/ Wrist Posture**	**Speed of Work**	**Duration of Task**	=	**SI SCORE**
3.0 X	**1.5 X**	**1.5 X**	**1.5 X**	**1.0 X**	**0.75**		**7.6**

SI Scores are used to predict Incidence Rates of Distal Upper Extremity injuries per 100 FTE:
- SI Score < 5 is correlated to an Incidence Rate of about 2 DUE injuries per 100 FTE;
- SI Score of between 5-30 is correlated to an Incidence Rate of about 77 DUE injuries per 100 FTE;
- SI Score of between 31-60 is correlated to an Incidence Rate of about 106 DUE injuries per 100 FTE;
- SI Score > 60 is correlated to an Incidence Rate of about 130 DUE injuries per 100 FTE.

Table 24. Wire Welder UE CTD Checklist

Michigan Checklist for Upper Extremity Cumulative Trauma Disorders
Lifshitz and Armstrong (1986)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Wire Welder Area/ Shop: Onboard Vessel
* "No" responses are indicative of conditions associated with the risk of CTD's

Risk Factors	No	Yes
1. Physical Stress		
1.1 Can the job be done without hand/ wrist contact with sharp edges		Y
1.2 Is the tool operating without vibration?		Y
1.3 Are the worker's hands exposed to temperature >21degrees C (70 degrees F)?	N	Y
1.4 Can the job be done without using gloves?	N	
2. Force		
2.1 Does the job require exerting less than 4.5 kg (10lbs) of force?	N	
2.2 Can the job be done without using finger pinch grip?		Y
3. Posture		
3.1 Can the job be done without flexion or extension of the wrist?	N	
3.2 Can the tool be used without flexion or extension of the wrist?	N	
3.3 Can the job be done without deviating the wrist from side to side?	N	
3.4 Can the tool be used without deviating the wrist from side to side?	N	
3.5 Can the worker be seated while performing the job?	N	
3.6 Can the job be done without "clothes wringing" motion?		Y
4. Workstation Hardware		
4.1 Can the orientation of the work surface be adjusted?	N	
4.2 Can the height of the work surface be adjusted?	N	
4.3 Can the location of the tool be adjusted?	N	
5. Repetitiveness		
5.1 Is the cycle time longer than 30 seconds?	N	
6. Tool Design		
6.1 Are the thumb and finger slightly overlapped in a closed grip?		Y
6.2 Is the span of the tool's handle between 5 and 7 cm (2-2 3/4 inches)?		Y
6.3 Is the handle of the tool made from material other than metal?		Y
6.4 Is the weight of the tool below 4 kg (9lbs)?		Y
6.5 Is the tool suspended?	N	
TOTAL	**13 (59%)**	**9 (41%)**

Table 25. Wire Welder OWAS

OWAS: OVAKO Work Analysis System
Louhevaara and Suurnäkki (1992)

Procedure: Observe workers at intervals of 30-60 seconds. Record postures and forces over a representative period (~ 45 minutes)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Wire Welder Area/Shop: Onboard Vessel

Risk Factor	**Work Phase 1** **Welding kneeling**	**Work Phase 2** **Welding standing**	**Work Phase 3** **De-Slag**	**Work Phase 4** **Prepare to weld**	**Work Phase 5** **Change tool**	**Work Phase 6** **Inspect**
TOTAL Combination Posture Score	**1**	**2**	**2**	**2**	**2**	**2**
Common Posture Combinations (collapsed across work phases)						
Back	1	2				
Arms	3	1				
Legs	6	2				
Posture Repetition (% of working time)	11	86				
Back % of Working Time Score	1	3				
Arms % of Working Time Score	1	1				
Legs % of Working Time Score	1	2				

ACTION CATEGORIES:
1 = no corrective measures
2 = corrective measures in the near future
3 = corrective measures as soon as possible
4 = corrective measures immediately

Table 25. Wire Welder OWAS (continued)

Risk Factor	**Work Phase 1** **Welding kneeling**	**Work Phase 2** **Welding standing**	**Work Phase 3** **De-Slag**	**Work Phase 4** **Prepare to weld**	**Work Phase 5** **Change tool**	**Work Phase 6** **Inspect**
Posture						
Back 1 = straight 2 = bent forward, backward 3 = twisted or bent sideways 4 = bent and twisted or bent forward and sideways	1	2	2	2	2	2
Arms 1 = both arms are below shoulder level 2 = one arm is at or above shoulder level 3 = both arms are at or above shoulder level	3	1	1	1	1	1
Legs 1 = sitting 2 = standing with both legs straight 3 = standing with the weight on one straight leg 4 = standing or squatting with both knees bent 5 = standing or squatting with one knee bent 6 = kneeling on one or both knees 7 = walking or moving	6	2	2	2	2	2
Load/ Use of Force						
1 = weight or force needed is = or <10 kg (<22lbs)	2	2	1	1	1	1
2 = weight or force > 10 but < 20kg (>22lbs < 44 lbs)						
3 = weight or force > 20 kg (>44 lbs)						
Phase Repetition						
% of working time (0,10,20,30,40,50,60,70,80,90,100)	11	19	1	41	5	20

Table 26. Wire Welder PLIBEL

PLIBEL Checklist, Kemmlert (1995)

Date/ Time: 4/13/00 Facility: Todd Pacific
Task: Wire Welder Area/ Shop: Onboard Vessel

Section I: Musculoskeletal Risk Factors
Methods of Application:
1) Find the injured body region, answer yes or no to corresponding questions
2) Answer questions, score potential body regions for injury risk

Musculoskeletal Risk Factor Questions	Body Regions				
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
1: Is the walking surface uneven, sloping, slippery or nonresilient?			N	N	N
2: Is the space too limited for work movements or work materials?	N	N	N	N	N
3: Are tools and equipment unsuitably designed for the worker or the task?	Y	Y	Y	Y	Y
4: Is the working height incorrectly adjusted?	Y				Y
5: Is the working chair poorly designed or incorrectly adjusted?	Y				Y
6: If work performed standing, is there no possibility to sit and rest?			Y	Y	Y
7: Is fatiguing foot pedal work performed?			N	N	
8: Is fatiguing leg work performed? e.g. ...					
a) repeated stepping up on stool, step etc..			N	N	N
b) repeated jumps, prolonged squatting or kneeling?			Y	Y	Y
c) one leg being used more often in supporting the body?			N	N	N
9: Is repeated or sustained work performed when the back is:					
a) mildly flexed forward?	Y				Y
b) severely flexed forward?	N				N
c) bent sideways or mildly twisted?	N				N
d) severely twisted?	N				N

Table 26. Wire Welder PLIBEL (continued)

10: Is repeated/sustained work performed with neck:					
a) flexed forward?	N				
b) bent sideways or mildly twisted?	N				
c) severely twisted?	N				
d) extended backwards?	Y				
11: Are loads lifted manually? Note important factors:					
a) periods of repetitive lifting	N				N
b) weight of load	N				N
c) awkward grasping of load	N				N
d) awkward location of load at onset or end of lifting	N				N
e) handling beyond forearm length	Y				Y
f) handling below knee length	N				N
g) handling above shoulder height	Y				Y
12: Is repeated, sustained or uncomfortable carrying, pushing or pulling of loads performed?	N	N			N
13: Is sustained work performed when one arm reaches forward or to the side without support?	Y				
14: Is there a repetition of:					
a) similar work movements?	Y	Y			
b) similar work movements beyond comfortable reaching distance?	Y	Y			
15: Is repeated or sustained manual work performed? Notice factors of importance as:					
a) weight of working materials or tools	N	N			
b) awkward grasping of working materials or tools	Y	Y			
16: Are there high demands on visual capacity?	N				
17: Is repeated work, with forearm and hand, performed with:					
a) twisting movements?		N			
b) forceful movements?		N			
c) uncomfortable hand positions?		Y			
d) switches or keyboards?		N			

Table 26. Wire Welder PLIBEL (continued)

Musculoskeletal Risk Factors Scores					
	Neck, Shoulder, and Upper Back	Elbows, Forearms, and Hands	Feet	Knees and Hips	Low Back
SUM	11	5	3	3	8
PERCENTAGE	42.3	45.5	37.5	37.5	38.1
Section II: Environmental / Organizational Risk Factors (Modifying) **Answer below questions, use to modify interpretation of musculoskeletal scores**					
18: Is there no possibility to take breaks and pauses?	N				
19: Is there no possibility to choose order and type of work tasks or pace of work?	N				
20: Is the job performed under time demands or psychological stress?	N				
21:Can the work have unusual or expected situations?	N				
22: Are the following present?					
a) cold	Y				
b) heat	Y				
c) draft	Y				
d) noise	Y				
e) troublesome visual conditions	Y				
f) jerks, shakes, or vibration	N				
Environmental / Organizational Risk Factors Score					
SUM	5				
PERCENTAGE	50.0				