Introduction

Risk assessment has been identified as one of the key attributes and skills that safety professionals need to possess. This need is evidenced by the recent creation of ASSE’s Risk Assessment Institute. Risk assessment in regards to industrial machinery has been recommended for years in the American National Standards Institute (ANSI) B11 series relating to machine tools safety requirements and British Standards/International Organization for Standardization.

This presentation is designed to identify some methods for analyzing and documenting machine guarding risk assessments that have been effective in the machine guarding effort for Babcock & Wilcox Nuclear Operations Group – Lynchburg, Virginia (NOG-L).

Tool Box References

An important part of risk assessment is having effective and valuable references of information and methods to perform an effective assessment and substantiate results. Prevention through Design (PtD) principles calls these references “tool boxes”. It has been our experience that several sources of information are frequently needed to properly describe hazards, assess them, recommend solutions options and document the process. Appendix A contains references that have shown to be valuable tool-box additions. These references are regulations, standards, publications and statistics. Each reference’s benefits and comments are provided. It must be noted prior to the release of newly updated ANSI B11.0-2010, Safety of Machinery - General Requirements and Risk Assessment and ANSI B11.19-2010, Performance Criteria for Safeguarding, these references were previously more valuable, but important none-the-less.

The Risk Assessment Process at B&W NOG-L

The risk assessment process at NOG-L is depicted in Figure 1. This process is a tailored version of the ANSI B11.TR3-2000, Risk Assessment/Reduction Process, designed to fit our applications. While this figure defines our process, it does not describe the groundwork needed to begin the start the journey.
The goal of risk assessment processes at NOG-L is to recommend safeguards that will reduce risks to acceptable/tolerable levels or identify those that may not so they can be acknowledged by management for consideration as an acceptable risk or a risk that requires more attention to resolve.

Figure 1. Modified ANSI B11.TR3-2000 Risk Assessment/Reduction Process

Risk Assessment Preparation

For the purpose of this paper, the ultimate goal of risk assessment is to assure safe use of industrial machinery and to reduce regulatory enforcement and liability concerns to arrive at an “acceptable” risk or “tolerable” risk. ANSI B11.0-2010 defines acceptable risk as “the risk level achieved after risk reduction measures have been applied.” This definition, as the standard points out, is an accepted or tolerable risk that is influenced by many factors including culture,
technological and economic feasibility and the degree of protection achieved through the use of implemented risk reduction measures.

One of the methods available at the time NOG-L’s risk assessment effort was started was published in ANSI B11.TR3-2000, Risk Assessment and Risk Reduction – A guide to Estimate, Evaluate and Reduce Risks Associated with Machine Tools. This methodology was modified to the flowchart found in Figure 1 to demonstrate the risk assessment process and how it is incorporated at NOG-L.

The paragraphs to follow identify the risk assessment/reduction methodology and processes used at NOG-L.

**Setting the Assessment Limit or Depth**

A management decision was made to meet the requirements of the US Occupational Safety and Health Administration (OSHA) point-of-operation regulations. Per OSHA, this requires “guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by the point of operation, ingoing nip points, rotating parts, flying chips and sparks.”³ One or more guarding methods may be used to accomplish this requirement including those identified below:

- Fixed barriers types shall be affixed to the machine where possible and prevent personnel from reaching over, under, around or through a barrier and require a tool to remove it.
- Interlocked guards shall remove or disengage power and prevent starting of machine when guard is opened; and requires machine to be stopped before worker can reach into danger area.
- “The guarding device shall be in conformity with any appropriate standards or in the absence of applicable, specific standards, shall be designed and constructed as to prevent the operator from having any part of their body in the danger zone during the operating cycle.”⁴

In addition, and in accordance with the spirit of the ANSI standards, guarding effect on the following issues were also addressed.

- Risk/reduction benefit
- Technological feasibility
- Economic feasibility
- Productivity, fire safety and quality
- Durability and maintainability
- Usability

It was determined that risk assessments should be performed under the following circumstances:

- For machines that present more than an unacceptable or tolerable risk to personnel.
- When there is a potential personnel exposure to hazard zone – Assessment would then include, but would not be limited to frequency and duration of hazardous situation; extent of exposure; number of persons exposed, personnel level of training, skill and experience.
- Where there is a history of incidents related to the machine or task - Assessment would then include reliability and other statistical data; history of harm and near misses; risk comparison; etc.
- For machinery designed by NOG-L.
For machines that incorporate presence-sensing devices.
For used machinery purchased by the company

Establishment of a “Machine Guarding Committee”
NOG-L ultimately selected the Manager of Manufacturing Improvement Engineering as the chairperson. This manager has oversight and expertise in the majority of machines found at NOG-L and has the influence and resources to get goals accomplished. The rest of the committee is composed of representatives from industrial engineering, an electronics and controls expert, product engineering, industrial safety and health, and from tooling and design. Machine operators, their management and area personnel opinions were sought to temporarily serve on the committee for acted on the committee to the users’ perspective.

The Committee’s charter is to:
- Perform machine guarding assessments of existing machinery in accordance with regulatory requirements and guidance and best industry practices
- Recommend machine safeguards and operating methods to protect personnel, and company resources
- Contribute to site regulatory compliance and training programs
- Assist management and supervision accomplish their safety and health goals

If so desired machine guarding risk assessment fits nicely with the implementation of OSHA’s Voluntary Protection Program (VPP), International Organization for Standardization (ISO) 18001 Occupational Health and Safety Management System, Job Safety Analyses (JSAs), formal equipment evaluation should these endeavors be considered.

Committee Documentation
It was determined that like-kind machines (machine categories boring, milling, cutting machines, etc.) would be evaluated as a group with results published as in phases. Figure 2 contains an example of what this document may resemble. Where several guarding methods were offered, the Committee would publish a risk assessment that is the main focus of this paper found on the pages to follow.

<table>
<thead>
<tr>
<th>PHASE I: Lathes, Vertical Milling Centers, Drill Press</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager &amp; Area</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>P.T. Quagmire Bldg. 1</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td>Mill</td>
</tr>
</tbody>
</table>
Figure 2. Machine Guarding Committee Documentation Example

Communication
Sometimes some convincing is needed to address possible resistance to change philosophies of seasoned workers and management. Their tribal knowledge and culture and the fact that some machines are old and have “always” been operated that way may have to be overcome. The machine guarding effort was communicated to the site in a prepared statement that described the effort and the importance of assisting the Machine Guarding Committee obtain an accurate understanding of machine-related processes. Machine operators and area personnel were informed that they may be asked to describe and/or demonstrate their tasks so that representative evaluations could be made. From the evaluations, recommendations for improvement were to be offered if required.

One of the team’s products for a selected type of machines was the launching of a machine guarding pilot program. Several machines were outfitted with guards. A trail period was established that permitted personnel opportunities to use and test guards and provide feedback to the Committee. An example of the form used to collect feedback is found in Figure 3.

| operation | assessment required | P.T. Quagmire Total | $1000 | Phase I TOTAL | 13 | $4500 | 24 hrs | 45 hrs |

Figure 3. Pilot Program Evaluation Form Example
Establishing Rank and Priority for Performing Risk Assessments and Action
The method identified in Figure 4 was used to determine the order in which machines should be addressed and risk assessments would be performed. It considers injury severity, exposure, ability to avoid hazards, required resources, effect on production and cost estimates. This method was fashioned after the assessment techniques published in ANSI/RIA R15.06-1999, American National Standard for Industrial Robots and Robot Systems—Safety Requirements.  

![Figure 4. Method to Establish Risk Assessment Performance Priority](image)

Conducting Risk Assessments
As stated earlier, several organizations participated in the Machine Guarding Assessment Committee to help assure different perspectives and expertise are considered and incorporated. Committee representatives included Electronics, Industrial Engineering, Manufacturing Engineering, Tooling, Tool Design and Industrial Health and Safety. Assistance of responsible supervision, machine operators and area employees was requested to gain acceptance to help address operational compatibility. Occasionally assistance from other organizations such as environmental engineering and Human Performance Improvement Employee Teams (HPET) were requested to again additional perspectives. HPETs are employee-driven, “teams” originally conceived by the Institute for Nuclear Power Operations (INPO). They establish goals and action plans using corporate goals, compliance trending data, program evaluations, and/or improvement
initiatives to develop and submit solutions for area concerns that may include safety, compliance, security, quality control, production, etc. particularly associated with human performance issues.

**Responsibilities**
Specific risk assessment responsibilities associated with risk assessment are summarized Figure 5.

<table>
<thead>
<tr>
<th>Department</th>
<th>Responsibilities</th>
</tr>
</thead>
</table>
| **Purchasing Department** | - Requests hazard assessment from international market machinery manufacturers' per BS EN ISO 12100:2010  
- Provides documentation to the machine/process owner and safety department as required. |
| **Machine/Process Owner** | - Provides documentation to Safety Department:  
  - Equipment specifications new purchased, leased, rented or leased machines  
  - Intended usage of equipment  
  - Materials used and/or produced  
  - Ancillary equipment (control systems, cooling systems, dip tanks, etc.)  
  - Interaction with existing process  
  - Services provided by the supplier regarding industrial machinery |
| **Safety Department** | - Reviews machinery specifications  
- Performs machinery assessment  
- Distributes copies of machine assessment to the Machine Guarding Committee (MGC) for review and approval. |
| **MGC** | - Reviews assessment and incorporates as required.  
- Coordinates issues as required.  
- Distributes to responsible management |
| **MGC** | - Schedules a meeting with responsible management to discuss assessment requirements and recommendations. |
| **Employees** | - Utilizes guards, procedures and other applicable assessment recommendations. |
| **Safety Department** | - Incorporates MGC comments as applicable.  
- Distributes assessment to:  
  - Appropriate management for accuracy and analysis confirmation, comment and implementation.  
  - Industrial Engineering (IE) for safeguard installation and maintenance procedure development. |
| **Safety Department** | - Files, updates and maintains assessments as required and files as a Technical Work Record.  
- Reviews assessments as required to assure the assessment remains practical and current. |

**Figure 5. Risk Assessment Responsibilities**
Identification of Machine, Processes, and Hazards

All of the referenced standards provide examples of hazards and hazardous situations. Below are the criteria used by the machine guarding committee as published in ANSI B11.TR3-20006 and other references identified below.

- Exposure to hazard zone – Frequency and duration of hazardous situation; extent of exposure; number of persons exposed
- Personnel who perform tasks – Level of training, skill and experience
- Machine/task history – Reliability and other statistical data; history of harm; history of near hits/misses; risk comparison; etc.
- Workplace environment – Housekeeping; workplace layout; walking/working surfaces, ladders, stairs, platforms, lighting; noise; ventilation; temperature, humidity; etc.
- Human Factors – Errors resulting from omitting steps, adding steps or performing steps out of sequence; application of ergonomic principles in the design of machines and their effects in reducing risk; interaction between persons; awareness of hazards and their risks; motivation to deviate from established safe work practices; effects of accumulated exposure; reduced vision; increased noise; characteristics of personnel; etc.
- Reliability of safety functions – mechanical, electrical, electronic, hydraulic and pneumatic control systems, etc and protective devices and measures.
- Reasonable foreseeable misuse – Incentives to defeat/circumvent protective measures include the protective measure’s potential to prevent task performance, potential to slow down production or interfere with task, difficulty to properly use, etc.
- Ability to maintain protective devices and measures

Manufacturers who manufacture for international markets are responsible for conducting, documenting and distributing risk assessments for their industrial machinery produced in accordance with International Organization for Standardization (ISO) standard BS EN ISO 12100:2010.7 When performed for machinery procured by NOG-L, it is requested that these manufacturer-conducted assessments be obtained from the manufacturer. A form letter was created to request risk assessments if performed from applicable manufacturers. The assessments would be used to analyze/verify risk and develop/implement safeguards on these machines to address identified hazards and to help assure manufacturer’s instructions are observed to help assure machine warranties are maintained.

Risk Assessment Methods and Documentation

ANSI Z690.3-2011 identifies several types of assessment methods that can be employed. Many types of assessment techniques can be used. Two informative annexes compare assessment types and provide guidance.

Annex A of this standard compares risk assessment techniques by describing each technique’s relevance of influencing factors such as resources and capability, nature and degree of uncertainty, complexity and ability to provide quantitative output. Technique application and
factors influencing the selection of assessment techniques are addressed. Annex B provides an overview of several techniques, how to use them, required inputs, a description of the process, outputs, and strengths and limitations for each technique.

Assessment Techniques Employed by NOG-L
Assessment techniques used at NOG-L are varied depending on required detail and product desired. Each tool is a subjective, qualitative approach to define risk for tasks involving exposure to hazards and a means to recommend safeguards to abate or manage the hazards in general terms. This risk assessment process is dependent on:

- The observation of tasks being performed
- Rating the hazards personnel may be exposed to
- Assessing other criteria listed below
- Assigning the associated level of risk or the degree of hazard,
- Recommending measures to reduce and manage the risk.

Some of the techniques are copyrighted by others that were modified to provide results and presentation desired by the authors of this paper. Permission from the creators of the copyrighted work could not be obtained in time for the publishing of this paper. Most are assessments are performed as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Start the risk assessment by assuming no safety controls exist to establish a baseline.</td>
</tr>
<tr>
<td>2.</td>
<td>Identify the number of personnel exposed to the hazard.</td>
</tr>
<tr>
<td>3.</td>
<td>Determine the frequency, severity and likelihood of hazard occurrence of exposure and related affects on other criteria such as damage, production and compliance as based on established parameters identified in Table 1.</td>
</tr>
<tr>
<td>4.</td>
<td>Establish the risk category. These categories are defined in Table 1 and color coded for effect and easy identification</td>
</tr>
<tr>
<td>5.</td>
<td>Document recommended controls for implementation and evaluate them in the same manner identified above</td>
</tr>
<tr>
<td>6.</td>
<td>Determine risk improvement</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Category → Parameter ↓</th>
<th>Negligible</th>
<th>Acceptable</th>
<th>Moderate</th>
<th>Substantial</th>
<th>Intolerable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event/Outcome</td>
<td>An outcome that is not considered a significant risk</td>
<td>An outcome that is considered to be an adequate or satisfactory</td>
<td>An outcome that poses risk that must be abated</td>
<td>An outcome that presents considerable risk</td>
<td>An outcome that presents a risk that cannot be tolerated</td>
</tr>
<tr>
<td>Task Frequency</td>
<td>≤ once/year</td>
<td>≤ once/month</td>
<td>≤ once/week</td>
<td>≤ once/shift</td>
<td>&gt; once/shift</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
<td>--------------</td>
<td>-------------</td>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Severity</td>
<td>First Aid</td>
<td>Medical Treatment</td>
<td>Lost Time, Full Recovery</td>
<td>Partial Disability</td>
<td>Permanent Disability or Death</td>
</tr>
<tr>
<td>Likelihood</td>
<td>Extremely Unlikely &lt;=1x/20 yrs.</td>
<td>Unlikely 1x/10-20 yrs.</td>
<td>Possible &gt;1x/10-20 yrs.</td>
<td>Probable 1x/yr</td>
<td>Multiple &gt;1x/yr</td>
</tr>
<tr>
<td>Equipment Damage</td>
<td>No damage</td>
<td>Little to no damage</td>
<td>Damage that requires intervention to resume</td>
<td>Damage that prevents operation</td>
<td>Extensive damage requires equipment replacement</td>
</tr>
<tr>
<td>Production Effects</td>
<td>None</td>
<td>Slight recoverable delay</td>
<td>Production interruption</td>
<td>Production shutdown</td>
<td>Production shutdown</td>
</tr>
<tr>
<td>Compliance</td>
<td>Regulatory compliant</td>
<td>Regulatory compliant with Administrative Controls</td>
<td>Regulatory compliant with Engineering Controls</td>
<td>Regulatory non-compliant</td>
<td>Regulatory non-compliant</td>
</tr>
</tbody>
</table>

Table 1. Risk Definitions

Modified Military Standard (MIL-STD) 882D² Technique.
This assessment technique looks at the probability of occurrence of harm and estimated severity to determine a level of risk using Table 3 risk estimation table and matrix.

<table>
<thead>
<tr>
<th>Probability of Occurrence of Harm</th>
<th>Severity of Harm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Likely</td>
<td>High</td>
</tr>
<tr>
<td>Likely</td>
<td>High</td>
</tr>
<tr>
<td>Unlikely</td>
<td>Medium</td>
</tr>
<tr>
<td>Remote</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table Definitions:

- **Severity of Harm**:
  - Catastrophic – Death or permanent disabling injury or illness. (Unable to return to work). Extensive damage requires equipment replacement
  - Serious – Permanent and non-reversible injury or illness (able to return to work at some point). Severe damage requiring extensive rework.
  - Moderate – Permanent and non-reversible minor injury or illness

- **Probability of Occurrence of Harm**:  
  - Very Likely – Near certain to occur
  - Likely – May occur
• Unlikely – Not likely to occur requiring more than first aid (able to return to same job). Damage requiring attention.
• Remote – So unlikely as to be near zero
• Minor – No injury or slight injury no more than first aid (little or no lost time). Little to no damage.

Risk:
High – Requires engineered controls to abate hazard
Medium – Requires engineered controls and possible administrative controls as required to abate hazard
Low – Requires at minimum administrative controls as required to abate hazard
Negligible- Administrative controls may be adequate

Table 2. Risk Estimation Table and Matrix

ANSI/RIA R15.06 Risk Assessment Method
American National Standard Institute/Robotic Industries Association (ANSI/RIA) R15.06-1999, American National Standard for Industrial Robots and Robot Systems – Safety Requirements contains an extensive method to perform and document risk assessments. Although the standard is written for safeguarding robots and robotic systems, the assessment methodology can be used for and applies to any type of industrial machinery.

An adulterated version of this technique was utilized to establish risk and priority for machine guarding and risk assessment as found in Figure 4. NOG-L Engineering Department utilized the technique for a robot installation with excellent results.

Assessment Report
A report for each assessment is written and distributed that contains the following boilerplate information:
• Cover page with management review/approval signature block
• Assessment purpose and scope
• List of sources of information used (tool box references)
• General description of tasks performed, an overview of hazards and safeguards employed (list of controls implemented and operator training)
• Completed risk assessment work sheets
• Summary, observations and recommendations
• Appendix with risk assessment description

Abatement and Management of Risk
Hazard abatement and management of risk is varied based in assessment methods chosen with importance placed on the hazard management hierarchy. As a reminder, hazard management hierarchy includes:

• Implementation of engineering controls, the elimination or control of hazards by elimination of human interaction in the process, elimination of pinch points, use of automation, substitute materials or processes etc.
• Control of exposure to hazards by the use of guards or safeguarding devices (fixed
  guards/shields, mechanical hard stops, barriers, enclosures, interlocks, presence-sensing
  devices, two-hand controls, etc.)
• Implementation of administrative controls including awareness barriers, lights, beacon or
  strobes; computer warnings; establishment of restricted areas; safety signage; training and re-
  training; safe job procedures; safety equipment inspection; lockout/tagout; preventative
  maintenance, etc.
• Personal Protective Equipment (PPE) including, but not limited to: safety glasses and face
  shields, safety shoes, ear plugs and muffs.

  Usually a combination of methods is required to resolve, reduce and establish an
  acceptable risk.

  Effective hazard abatement must be incorporated to machinery inspection and maintenance
  to assure the equipment not only operates safety but effectively.

  Risk assessment information has also been used to perform Job Safety Analyses, complete
  site safety evaluations, enhance personnel training and other similar applications.

  Ultimately management assumption of risk, after weighing alternatives presented by the
  safety professional and cast are the guiding force. In doing so, accurate, well thought out
  recommendations based on precise observations, correct interpretations and detailed are key on
  what can be a fine line between satisfying safety requirements and production needs.

Conclusion

Effective risk assessment is founded on assuring required resources are provided, establishing
assessment limits or depth of the review, involving individuals that provide a cross-section of
expertise and with a vested interest, using accurate references, providing good communication
and feedback, implementing assessment techniques that are accurate and detailed enough to
present rationale and permit decision making, timely documentation and incorporating knowledge
gleaned into operations, inspection, maintenance and training efforts.

Some situations require creativity to describe hazards and champion abatement rationale.
Assessors must be good listeners to extract facts from emotions and good salespersons to describe
and sell the end result.

The importance of keeping valuable tool box references cannot be understated. The
references in Appendix A helped the authors provide guidance to address situation sorely missing
from US regulations. The authors also point out the emergence of ANSI B11.0 – 2010, Safety of
Machinery – General Requirements and Risk Assessment and ANSI B19-2010, Performance
Criteria for Safeguarding as two of the most import and valuable references recently published.

In total, we hope this paper will provide some insight and assistance in developing or
enhancing risk assessment processes for machine guarding.
Endnotes


3 Occupational Safety and Health Administration (OSHA). 2010. 29 CFR 1910.212 (a) (1). General Requirements for All Machines.


Appendix A - Valuable Tool Box References

<table>
<thead>
<tr>
<th>Topic (Criteria)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>National Fire Protection Association (NFPA) 79, Electrical Standard for Industrial Machinery</td>
</tr>
<tr>
<td>Electrical Safety</td>
<td>NFPA 79, Electrical Standard for Industrial Machinery</td>
</tr>
<tr>
<td></td>
<td>NFPA 30, National Electric Code</td>
</tr>
<tr>
<td>Source</td>
<td>Details</td>
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<tr>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>and Safety Queensland;</td>
<td></td>
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<tr>
<td>Government of Queensland Australia</td>
<td></td>
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<tr>
<td>Machine Guarding Major Workplace Hazards; Government of South</td>
<td></td>
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<tr>
<td>Australia</td>
<td></td>
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<tr>
<td>National Safety Council.</td>
<td></td>
</tr>
<tr>
<td>Requirement</td>
<td>Reference</td>
</tr>
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<td>----------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Requirements CSA Z434, Industrial Robot and Robot Systems – General Safety</td>
<td></td>
</tr>
<tr>
<td>MIL-STD-882D, Department of Defense Standard Practice for System Safety</td>
<td></td>
</tr>
<tr>
<td>Safeguarding requirements for the design, construction, installation, operation and maintenance of guards, awareness devices, safeguarding methods and safe work procedures.</td>
<td>ANSI B11.19-2010, Performance Criteria for Safeguarding.</td>
</tr>
<tr>
<td>Safe Distance Safeguarding Program</td>
<td>OSHA Instruction CPL 2-1.25, Guidelines for Point of Operation of Power Presses Sheet Metal and Air-conditioning Contractors' National Association. Press Brake Compliance Kit Washington State Department of Labor &amp; Industries WAC 296-806-46508; 46504</td>
</tr>
</tbody>
</table>