Robots and Robot Systems

1. Purpose / Background

The purpose of this document is to provide information and procedures to assure that robots and robot systems are used safely per the MIT Environmental, Health and Safety (EHS) Policy and the Guiding Principles in Support of the EHS Policy. To view the EHS Policy and Guiding Principles, go to http://ehs.mit.edu/site/content/ehs-policy.

Industrial robots are programmable multifunctional mechanical devices designed to move material, parts, tools, or specialized devices through variable programmed motions to perform a variety of tasks. Robots are generally used to perform unsafe, hazardous, highly repetitive, and unpleasant tasks. They have many different functions such as material handling, assembly, welding, machine tool load and unload functions, painting, spraying, and so forth.

Studies indicate that many robot accidents occur during non-routine operating conditions, such as programming, maintenance, testing, setup, or adjustment. During many of these operations the worker may temporarily be within the robot’s working envelope where unintended operations could result in injuries.

The Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Health and Safety (NIOSH), and the American National Standards Institute (ANSI) recommend the implementation of safety measures to protect robot operators from preventable injuries. Additionally, the International Standard has developed safety requirements for industrial robots and robotic devices (ISO 10218-1).

NIOSH has stated that various studies have shown that most robot accidents occur during adjustment of the robot or work-piece, programming, maintenance, repair, testing, or setup. Injuries have occurred at MIT during robot operation when personnel have placed fingers or hands in the robot’s operating area to adjust a part without shutting down the robot.

The OSHA Technical Manual provides some examples of robot incidents that have occurred:

- **Impact or collision accidents** when the robot’s arm made unexpected movements or program changes.
- **Crushing and trapping accidents** when a worker’s limb or body became trapped between a robot’s arm and walls, poles, or other equipment.
- **Pinch point accidents** when personnel placed fingers or hands in the robots operating area to adjust a part without shutting down the robot.

According to OSHA, the sources of some robot hazards include:

- Human errors, such as, placing hands in a robot’s operating area while the robot is in operation; incorrect activation of the “teach pendant” or the control panel; or personnel placing themselves in a hazardous position.
- Unauthorized access into a robot’s safeguarded area when personnel are unfamiliar with the safeguards in place.
- Improper installation, design, and layout of a robot creating inherent safety issues, such as, installing too close to poles, equipment, or other freestanding objects.
- Control errors including errors in software, electromagnetic or radio frequency interference, or faults in the hydraulic, pneumatic, or electrical sub controls.
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When the robot is operating automatically, all safeguarding devices must be activated, and at no time should any part of the operator’s body be within the robot’s safeguarded area.

Limiting devices minimize the total distance a robot can travel. Floors or working surfaces should have clearly visible marks that indicate the zones of movement of the robot.

Interlocked barriers are gates with interlocks that stop all automatic operations of the robot when any gate is open. Restarting the operation requires closing the gate and reactivating a control outside of the barrier.

Additional physical barriers should be installed between robots and any freestanding objects, such as posts that limit robot arm movement, so that workers cannot get between any part of the robot and the “pinch points”.

Presence-sensing devices, such as pressure mats or light curtains, are used to stop all motion of the robot if a person steps or reaches into a hazardous area of the robot.

Awareness devices, such as flashing lights, signs, whistles, and horns, are used to augment the above safeguarding devices.

4.1.3 Working within the Safeguarded Area (Programmer/Teacher, Maintenance and Repair Personnel)
For work that must be performed within the safeguarded or restricted area, the robot should be at slow speed (250 mm/sec or 10 in/sec), in the teach mode, and the worker should have full control of the robot. Employing the buddy system, with a second worker outside of the safeguards who can turn off the robot in an emergency, is also recommended.

4.1.4 Emergency Stops
Readily accessible emergency stops that override all other controls should be located in all zones where needed. The portable programming control device should contain an emergency stop. Robot movement should be arrested by dynamic braking systems rather than simple power cut-off. Cutting off all power could create additional hazards such as a sudden dropping of a robot’s arm or work piece.

4.1.5 Control Devices
Control devices should have the following characteristics:
- Guarded against accidental operation
- Equipped with a separate circuit breaker than can be locked only in the “off” position
- Equipped with an anti-restart device to prevent a robot from restarting upon restoration of power after an electrical power failure
- Allow the manual movement of the robot on any of its axes without using the system drive power
- Clearly marked and labeled as to device purpose and operating status
4.1.6 Training
Personnel who program, operate, maintain, or repair robots should receive hands-on-training in the following:
- The control of the robot.
- The proper operating procedure of the robot and associated equipment.
- Use of slow robot operation speeds and hazardous location avoidance while working within the restricted area of the robot while it is energized.
- A review of the robot’s emergency stops
- Familiarization with the robot’s potentially hazardous energy sources and procedures to effectively lock out these sources when needed.
- A description and identification of the hazards and an awareness of all conceivable pinch points, such as poles, walls, and other equipment in the robot’s operational area
- How safeguards, including awareness and presence-sensing devices, provide protection and the hazards for which they are intended.
- Reporting to a supervisor if a safeguard is damaged, missing, or unable to provide adequate protection.
- Consequences of operating without guards and placing fingers in a robot’s operating area without powering down the robot.
- Protocols (SOPs) for maintenance, operation, adjustment, set-up, repairs, testing or programming.

4.1.7 Maintenance
Documented manufacturer-recommended inspection and maintenance programs are essential for minimizing the hazards from component malfunction and unexpected movements by the robot. Periodic checks of all safety-critical equipment should be performed. A lockout procedure must be established and enforced for preventive maintenance or repair operations. Those who service or maintain robots must comply with OSHA’s Lockout/Tagout Standards (29 CFR 1910.147 and 1910.333).

4.2 Design and Installation Guidelines
4.2.1 Temporary safeguarding devices and practices should be used to minimize the hazards associated with the installation of new equipment.
Before installation, the following should be considered:
- installation specifications
- physical and electrical facilities
- the action of peripheral equipment integrated with the robot
- control and emergency stop requirements
- special robot operating procedures or conditions
- identification requirements.

4.2.2 To ensure safe installation, complying with Section 6, Installation of Robots and Robot Systems, of the ANSI/RIA R15.06-2009 standard, is recommended.
4.2.3 To ensure safe design, it is recommended that robots comply with Section 4, Manufacturing, Remanufacture, and Rebuild of Robots, of the ANSI/RIA R15.06-2009 standard.

Prior to purchasing a new robot, a design review should be conducted to ensure compliance with Section 4.

5. Roles & Responsibilities

5.1 The EHS Office is responsible for:
- Providing General Robot Training that includes information contained in this SOG.
- Maintaining up to date guidance pertaining to robots.
- Addressing questions or concerns pertaining to robots.
- Assisting with inspections of robots and robot incidents.

5.2 PI’s/Supervisors are responsible for:
- Ensuring that SOPs specific to each robot are developed including lock out / tag out, maintenance, operation, adjustment, set-up, repairs, testing or programming SOPs.
- Ensuring that those individuals that they supervise who work with robots receive adequate training (see Section 6.0 for training requirements.)
- Ensuring that robots are used safely in the laboratory/work areas that they supervise.
- Ensuring that a design review is conducted prior to purchasing a new robot to ensure that the robot complies with ANSI/RIA R1.5.06-2009 Section 4, Manufacturing, Remanufacture, and Rebuild of Robots.
- Ensuring that appropriate safeguarding devices are in place and functioning on the robots in the work areas that they supervise.

5.3 The DLC EHS Coordinator is responsible for:
- Addressing questions or concerns regarding the use of robots, and consulting with the EHS Office if necessary.
- Inspecting robots and notifying the PI/Supervisor of problems found so that they can be corrected or prevented.

5.4 The EHS Representatives are responsible for:
- Assisting the PI/Supervisors with the safe use of robots as directed. Specific duties may include periodically inspecting robots to ensure that safeguarding devices are in place and working.

5.5 Individuals Using Robots are responsible for:
- Knowing the safeguarding devices that are in place and not operating the equipment if the safeguards have been removed or damaged.
- Using the robots in accordance with the training and guidance provided. Following the protocols (SOPs) for lock out / tag out, maintenance, operation, adjustment, set-up, repairs, testing or programming established for each robot in their laboratory/work area.
6. Training
All personnel working with robots are required to have hands-on training for the specific robotic equipment being used. The hands-on training can be provided by the robot vendor or by a PI/Supervisor or experienced co-worker. Hands-on-training should cover the following points:

- The control of the robot.
- The proper operating procedure of the robot and associated equipment.
- Use of slow robot operation speeds and hazardous location avoidance while working within the restricted area of the robot while it is energized.
- A review of the robot’s emergency stops.
- Familiarization with the robot’s potentially hazardous energy sources and lock out / tag out procedures.
- A description and identification of the hazards and an awareness of all conceivable pinch points, such as, poles or other equipment in the robot’s operational area
- How safeguards, including awareness and presence-sensing devices, provide protection and the hazards for which they are intended.
- Reporting to a supervisor if a safeguard is damaged, missing, or unable to provide adequate protection.
- Consequences from operating robots without guards and placing fingers in a robot’s operating area without powering down the robot.
- Protocols (SOPs) for maintenance, operation, adjustment, set-up, repairs, testing or programming.

7. Monitoring Requirements
Work areas where robots are used should be inspected at least twice a year during the Level II inspections to assure that they are being used safely and in accordance with the standard operating procedures established for the robot in the work area.

8. Record Management
All records related to the use of robots should be maintained per the SOP on Records Retention.

9. References
9.1. Standards


9.2. **Other SOP/SOGs**
Records Retention SOP

9.3. **Supplementary Documents.**
MIT EHS Policy

National Institute for Occupational Safety and Health (NIOSH) Alert Publication No. 85103. *Request for Assistance in Preventing the Injury of Workers by Robots.* National Institute for Occupational Safety and Health, Division of Safety Research, 944 Chestnut Ridge Road, Morgantown, West Virginia 26505


OSHA Technical Manual Section IV: Chapter 4, *Industrial Robots and Robot System Safety.* Occupational Safety and Health Administration, Washington, D.C.

Robotic Industries Association, 900 Victors Way, P.O. Box 3724, Ann Arbor, Michigan 48106

9.4. **Helpful Websites**
http://www.osha.gov/dts/

10. **Definitions**

**Actuator** A power mechanism used to effect motion of the robot; a device that converts electrical, hydraulic, or pneumatic energy into robot motion.

**Application Program** The set of instructions that defines the specific intended tasks of robots and robot systems. This program may be originated and modified by the robot user.

**Attended Continuous Operation** The time when robots are performing (production) tasks at a speed no greater than slow speed through attended program execution.

**Attended Program Verification** The time when a person within the restricted envelope (space) verifies the robot's programmed tasks at programmed speed.
Audible and Visible Warning Systems  Audible and visible warning systems are not acceptable safeguarding methods but may be used to enhance the effectiveness of positive safeguards. The purposes of audible and visible signals need to be easily recognizable.

Automatic Mode  The robot state in which automatic operation can be initiated.

Automatic Operation  The time during which robots are performing programmed tasks through unattended program execution.

Awareness Barrier Device  A device such as a low railing or suspended chain that defines a safety perimeter and is intended to prevent inadvertent entry into the work envelope but can be climbed over, crawled under, or stepped around. Such a device is acceptable only in situations where a hazard analysis indicates that the hazard is minimal and inter locked or fixed barrier guards are not feasible. Interlocked or fixed barrier guards provide a positive protection needed to prevent worker exposure to robotic systems hazards.

Awareness Signal  A device that warns a person of an approaching or present hazard by means of audible sound or visible light.

Axis  The line about which a rotating body (such as a tool) turns.

Barrier  A physical means of separating persons from the restricted envelope (space).

Control Device  Any piece of control hardware providing a means for human intervention in the control of a robot or robot system, such as an emergency-stop button, a start button, or a selector switch.

Control Program  The inherent set of control instructions that defines the capabilities, actions and responses of the robot system. This program is usually not intended to be modified by the user.

Coordinated Straight Line Motion  Control wherein the axes of the robot arrive at their respective end points simultaneously, giving a smooth appearance to the motion. Control wherein the motions of the axes are such that the Tool Center Point (TCP) moves along a pre-specified type of path (line, circle, etc.)

Device  Any piece of control hardware such as an emergency-stop button, selector switch, control pendant, relay, solenoid valve, sensor, etc.

Drive Power  The energy source or sources for the robot actuators.

Emergency Stop  The operation of a circuit using hardware-based components that overrides all other robot controls, removes drive power from the robot actuators, and causes all moving parts to stop.

Enabling Device  A manually operated device that permits motion when continuously activated. Releasing the device stops robot motion and motion of associated equipment that may present a hazard.
End-effector  An accessory device or tool specifically designed for attachment to the robot wrist or tool mounting plate to enable the robot to perform its intended task. (Examples may include gripper, spot-weld gun, arc-weld gun, spray-paint gun, or any other application tools.)

Energy Source  Any electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other source.

Envelope (Space), Maximum  The volume of space encompassing the maximum designed movements of all robot parts including the end-effector, workpiece, and attachments.

Failure mode and effect analysis (FMEA)  A tool used to systematically analyze component failures within a system and identify the resultant effects on system operations and personal safety. While the FMEA identifies all part failure modes, its primary benefit is the early identification of all critical and catastrophic subsystem or system failure modes so they can be eliminated or minimized through design modification at the earliest point in the development effort.

Fixed Barrier Guard  A fixed barrier guard is a fence that requires tools for removal. Like the interlocked barrier guard, it prevents access through, over, under, or around the fence. It provides sufficient clearance for a worker between the guard and any robot reach, including parts held by an end-effector, to perform a specific task under controlled conditions.

Hazard  A situation that is likely to cause physical harm.

Hazardous Motion  Any motion that is likely to cause personal physical harm.

Industrial Equipment  Physical apparatus used to perform industrial tasks, such as welders, conveyors, machine tools, fork trucks, turn tables, positioning tables, or robots.

Industrial Robot  A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

Industrial Robot System  A system that includes industrial robots, the end-effectors, and the devices and sensors required for the robots to be taught or programmed, or for the robots to perform the intended automatic operations, as well as the communication interfaces required for interlocking, sequencing, or monitoring the robots.

Interlock  An arrangement whereby the operation of one control or mechanism brings about or prevents the operation of another.

Interlocked Barrier Guard  A physical barrier around a robot work envelope incorporating gates equipped with interlocks. These interlocks are designed so that all automatic operations of the robot and associated machinery will stop when any gate is opened. Restarting the operation requires closing the gate and reactivating a control switch located outside of the barrier. A typical practical barrier is an interlocked fence designed so that access through, over, under, or around the fence is not possible when the gate is closed.

Joint Motion  A method for coordinating the movement of the joints such that all joints arrive at the
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desired location simultaneously.

**Limiting Device**  A device that restricts the maximum envelope (space) by stopping or causing to stop all robot motion and is independent of the control program and the application programs.

**Maintenance**  The act of keeping the robots and robot systems in their proper operating condition.

**Mobile Robot**  A self-propelled and self-contained robot that is capable of moving over a mechanically unconstrained course.

**Muting**  The deactivation of a presence-sensing safeguarding device during a portion of the robot cycle.

**Operating Space**  That portion of the restricted envelope (space) that is actually used by the robot while performing its programmed motions.

**Operator**  The person designated to start, monitor, and stop the intended productive operation of a robot or robot system. An operator may also interface with a robot for productive purposes.

**Pendant**  Any portable control device, including teach pendants, that permits an operator to control the robot from within the restricted envelope (space) of the robot.

**Presence-Sensing Safeguarding Device**  Presence detectors that are most commonly used in robotics safety are pressure mats and light curtains. Floor mats (pressure sensitive mats) and light curtains (similar to arrays of photocells) can be used to detect a person stepping into a hazardous area near a robot. Proximity detectors operating on electrical capacitance, ultrasonics, radio frequency, laser, and television principles are currently undergoing reliability testing in research laboratories because of recognized limitations in their capability of detecting the presence of personnel. Although some of these devices are already available in the safety equipment marketplace, care must be used in their selection to insure adequate safety and reliability. At this time, such proximity detectors are not recommended for such use unless a specific analysis confirms their acceptability for the intended use. Effective presence sensing devices stop all motion of the robot if any part of a worker's body enters the protected zone. Also, they are designed to be fail-safe so that the occurrence of a failure within the device will leave it unaffected or convert it into a mode in which its failed state would not result in an accident. In some cases this means deactivation of the robot. Factors which are considered in the selection of such devices include spatial limitations of the field, environmental conditions affecting the reliability of the field, and sensing field interference due to robot operation.

**Program**
1. (noun) A sequence of instructions to be executed by the computer or robot controller to control a robot or robot system.
2. (verb) to furnish (a computer) with a code of instruction.
3. (verb) to teach a robot system a specific set of movements and instructions to accomplish a task.

**Rebuild**  To restore the robot to the original specifications of the manufacturer, to the extent possible.

**Remanufacture**  To upgrade or modify robots to the revised specifications of the manufacturer and
applicable industry standards.

**Repair**  To restore robots and robot systems to operating condition after damage, malfunction, or wear.

**Restricted Space**  That portion of the maximum space to which a robot is restricted by limiting devices. The maximum distance that the robot, end-effector, and work piece can travel after the limiting device is actuated defines the boundaries of the restricted space of the robot. **NOTE:** The safeguarding interlocking logic and robot program may redefine the restricted space as the robot performs its application program. (See Appendix D of the ANSI/RIA R15.06-2009 Specification).

**Robot Manufacturer**  A company or business involved in either the design, fabrication, or sale of robots, robot tooling, robotic peripheral equipment or controls, and associated process ancillary equipment.

**Robot System Integrator**  A company or business who either directly or through a subcontractor will assume responsibility for the design, fabrication, and integration of the required robot, robotic peripheral equipment, and other required ancillary equipment for a particular robotic application.

**Safeguard**  A barrier guard, device, or safety procedure designed for the protection of personnel.

**Safeguarded Space**  The space defined by the perimeter safeguarding devices.

**Safety Procedure**  An instruction designed for the protection of personnel.

**Sensor**  A device that responds to physical stimuli (such as heat, light, sound, pressure, magnetism, motion, etc.) and transmits the resulting signal or data for providing a measurement, operating a control, or both.

**Service**  To adjust, repair, maintain, and make fit for use.

**Single Point of Control**  The ability to operate the robot such that initiation or robot motion from one source of control is possible only from that source and cannot be overridden from another source.

**Slow Speed Control**  A mode of robot motion control where the velocity of the robot is limited to allow persons sufficient time either to withdraw the hazardous motion or stop the robot.

**Start-up**  Routine application of drive power to the robot or robot system.

**Start-up, Initial**  Initial drive power application to the robot or robot system after one of the following events:

- Manufacture or modification;
- Installation or reinstallation;
- Programming or program editing; and
- Maintenance or repair.
Teach  The generation and storage of a series of positional data points effected by moving the robot arm through a path of intended motions.

Teach Mode  The control state that allows the generation and storage of positional data points effected by moving the robot arm through a path of intended motions.

Teach Pendant See the definition for Pendant.

Teacher  A person who provides the robot with a specific set of instructions to perform a task.

Tool Center Point (TCP)  The origin of the tool coordinate system.

User  A company, business, or person who uses robots and who contracts, hires, or is responsible for the personnel associated with robot operation.
# Appendix A  Robot Hazard Assessment Checklist

Department and Date: ________________________________________________________

<table>
<thead>
<tr>
<th>Robot</th>
<th>Safeguarding Devices</th>
<th>Emergency Stops</th>
<th>Control Devices</th>
<th>Additional Controls</th>
<th>Other Hazards and Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name/Model:</td>
<td>□ physical barriers □ interlocked barriers □ presence-sensing devices (pressure mats, light curtains) □ limiting devices □ awareness devices (signs, horns, lights) □ periodic checks performed</td>
<td>□ in all zones where needed □ on portable control device □ the emergency stop overrides all other controls □ dynamic braking system (recommended) □ power cut-off (not recommended)</td>
<td>□ guarded against accidental operation □ separate circuit breaker □ no auto-restart when power restored after failure □ clearly labeled with purpose/operating status □ auto-stop if abnormal robot speeds or traverses beyond operating envelop</td>
<td>□ documented maintenance □ periodic safety equipment checks □ risk/hazard assessments</td>
<td>□ gloves □ safety glasses or goggles □ lab coat □ local exhaust ventilation if chemical hazard □ ear plugs if noise hazard</td>
</tr>
</tbody>
</table>

| ID# or Serial #: | | | | | |

## Power

- □ plug and cord
- □ LOTO required
- □ mechanical
- □ hydraulic
- □ pneumatic
- □ bad wire insulation

## Written SOPs

- □ Maintenance SOP
- □ LOTO SOP
- □ Operation SOP
- □ Programming SOP
- □ Test/adjustment SOP
- □ Shut-down Procedures
- □ other

## Training Topics Covered

- □ proper operation and robot control
- □ how safeguards work
- □ reporting missing guards
- □ emergency stops
- □ hazardous location avoidance
- □ hazardous energy sources
- □ awareness of hazards
- □ location/content of SOPs
- □ chemical
- □ biohazards
- □ radiation hazards

## Deficiencies

- □ buddy system
- □ slow robot speed

## Recommended Actions

- □ gloves
- □ safety glasses or goggles
- □ lab coat
- □ local exhaust ventilation if chemical hazard
- □ ear plugs if noise hazard
### Appendix B: Failure Mode and Effects Analysis template

#### Failure Modes Effects Analysis

<table>
<thead>
<tr>
<th>Process or Product Name:</th>
<th>Process Owner:</th>
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<th>FMEA Date (Orig):</th>
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<table>
<thead>
<tr>
<th>Predicting potential hazards</th>
<th>Actions to reduce risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Process Step or Input</td>
<td>Potential Failure Mode</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>What is the Process Step or Input?</td>
<td>In what ways can the Process Step or Input fail?</td>
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**Key**

<table>
<thead>
<tr>
<th>SEV: Severity of effect</th>
<th>OCC: Occurrence Rating</th>
<th>DET: Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: None</td>
<td>1: Remote</td>
<td>1: Almost certain</td>
</tr>
<tr>
<td>2: Very minor</td>
<td>2: Low</td>
<td>2: Very high</td>
</tr>
<tr>
<td>3: Minor</td>
<td>3: Low+</td>
<td>3: High</td>
</tr>
<tr>
<td>4: Very Low</td>
<td>4: Moderate</td>
<td>4: Moderately high</td>
</tr>
<tr>
<td>5: Low</td>
<td>5: Moderate+</td>
<td>5: Moderate</td>
</tr>
<tr>
<td>6: Moderate</td>
<td>6: Moderate++</td>
<td>6: Low</td>
</tr>
<tr>
<td>7: High</td>
<td>7: High</td>
<td>7: Very low</td>
</tr>
<tr>
<td>8: Very High</td>
<td>8: High+</td>
<td>8: Remote</td>
</tr>
<tr>
<td>9: Hazardous with warning</td>
<td>Very High</td>
<td>9: Very remote</td>
</tr>
<tr>
<td>10: Hazardous without warning</td>
<td>Very High++</td>
<td>10: absolute uncertainty</td>
</tr>
</tbody>
</table>