

draft standard

for Intelligent Assist Devices — Personnel Safety Requirements

Publication of this draft standard for trial use and comment has been approved by the ASC T15 Committee. Distribution of this draft standard for comment shall not continue beyond 12 months from the date of publication. It is expected that following this 12 month period, this draft standard, revised as necessary, will be submitted to the American National Standards Institute for approval as an American National Standard. Suggestions for revision should be directed to the T15 Committee in care of the Robotic Industries Association.



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Draft Standard for Trial Use
for Intelligent Assist Devices —

Personnel Safety Requirements

Secretariat
Robotic Industries Association

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Foreword (Not part of Draft Standard BSR/T15.1)

The objective of this draft standard is to enhance the safety of personnel using Intelligent Assist Devices by establishing requirements for their manufacture, installation, safeguarding methods, maintenance and repair.

The Intelligent Assist Device or IAD is a single or multiple axis device that employs a hybrid programmable computer-human control system to provide human strength amplification and may include path limiters. These multifunctional manipulators and lift assist devices are designed for material handling and assembly tasks under the direct control of a human operator. The IAD is considered to be a new development in technology, and though it exhibits some robotic characteristics, it is not considered to be a manipulating industrial robot. To assure the safety of personnel assigned to use the IAD, industry approached the Robotic Industries Association requesting assistance in developing appropriate standards for the IAD. The operational scope and characteristics of an IAD are significantly different than other equipment and machines, particularly as they require persons to be in the proximity of the device while drive power is available. To satisfy the standards development requirement, the RIA agreed to sponsor the Accredited Standards Committee T15 on Intelligent Assist Devices.

To assist in the interpretation of this draft standard, the Committee intended that the manufacturer, the installer, and the end user have specific responsibilities. From a practical standpoint, the ultimate responsibility for safeguarding of persons associated with any industrial machinery lies with the person(s) themselves. A book cannot regulate safety; rather safety must be a conscious effort on the part of all parties (manufacturer, integrator, and user.) Necessary components in every safeguarding system are the maintenance of and adherence to the system design. Personnel skills, training, and attitude are important factors in a safety program. This standard only serves to provide guidelines to a safe operation.

Terms that are defined in clause 3 appear in **bold** type when used in other definitions, and the first time they are used in context within each clause. The words “shall” and “will” are intended to be prescriptive, and required to be in compliance with this standard. The words “should” and “may” are meant to be recommendations and good practices.

Industry standards, including this draft, are voluntary. The T15 Committee and Robotic Industries Association make no determination with respect to whether any IAD, associated safety devices, manufacturer, or user is in compliance with this draft standard.

This draft standard contains four (4) annexes, all of which are informative.

This draft standard is issued for trial use to allow all persons associated with the use of the IAD to determine the appropriateness, suitability, and completeness of the conditions contained in this draft standard. Suggestions for improvement of the standard are welcome and encouraged. Comments should be sent to the:

ASC T15 on Intelligent Assist Devices
c/o Robotic Industries Association
P. O. Box 3724
Ann Arbor, MI 48106

Consensus for approval of this draft standard for use was achieved by balloting of the T15 Committee on Intelligent Assist Devices (an accredited standards committee). Committee approval of this draft standard for use does not necessarily imply that all committee members voted for its approval. At the time it approved this standard, the T15 Committee had the following members:

Tom Pearson, Chairman

<i>Organization Represented</i>	<i>Name of Representative</i>
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Draft Standard for Trial Use for Intelligent Assist Devices –

Personnel Safety Requirements

0 Introduction

Intelligent Assist Devices (IAD) are force based control devices that range from single axis payload balancing to multiple degree of freedom articulated manipulators. IADs may have multiple modes of operation including:

- a) Hands-on-controls mode – powered motion of the IAD when the operator is in physical control and contact with the IAD primary controls;
- b) Hands-on-payload mode – a selectable powered motion of the IAD in response to the operator positively applying forces to the payload or tooling, when the operator's hand(s) are not on the primary controls;
- c) Hands-off mode – powered motion of the IAD that is not in response and proportion to forces applied by the operator.

Within each of these modes the IAD may employ features such as force amplification, **virtual guiding surfaces**, and line tracking technologies. General safety features of the IAD will ensure that any reasonably foreseeable failure will result in a safe condition for the operator and other personnel in the work envelope, task envelope or both. Compliance will be determined by performing a documented risk assessment at each stage of development and implementation.

1 Scope, purpose, application and exclusions

1.1 Scope

This safety standard applies to the design, manufacture, remanufacture, rebuild, installation, **safeguarding**, start-up conditions, operations, and training of operator and maintenance personnel for Intelligent Assist Devices (IAD).

1.2 Purpose

The purpose of this standard is to provide the safety requirements for Intelligent Assist Devices for use in an industrial environment and the methods of safeguarding for safety of personnel associated with the operation and maintenance of the IAD.

1.3 Application

The requirements of this standard shall be applied to the manufacture and use of IADs deployed after the approval date of this standard.

Exclusions include but are not limited to:

- a) systems covered by a separate safety standard
- b) non-hybrid manual manipulators or manual assist devices
- c) systems used in a non-industrial or non-manufacturing environment

- d) tele-operated or remotely controlled systems; Automated Guided Vehicles; hoists
- e) portions of an Intelligent Assist Device that are covered by other applicable safety standards
- f) robotic systems
- g) specific mechanical design features and mechanical specifications of the IAD

This Standard applies to Intelligent Assist Devices only. Examples of devices that are not considered Intelligent Assist Devices include, but are not limited to: tele-operated manipulators, prosthetics and other aids for the handicapped, and service assist devices.

2 Normative references

The following standards contain provisions, which, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

ANSI/B56.5-1993 — *Safety Standards for Guided Industrial Vehicles and automated functions of manned vehicles*

ANSI/NFPA 79-1997 — *Electrical standard for industrial machinery*

ANSI/UL 1740-1998 — *Safety standard for robots and robotic equipment*

OSHA 1904.12 — *Recording and reporting occupational injuries and illnesses - Definitions*

OSHA 1910.147 — *Control of hazardous energy (Lockout/Tagout)*

OSHA 1910 Subpart O — *Machinery and Machine Guarding*

UL1998 — *Safety related software*

3 Definitions

The definitions below are particular to this standard. Any other terms are explained as they are used in the document, or would be found in a dictionary.

3.1 **actuator**: A mechanism used to cause, impact, initiate, or create motion. A power mechanism that converts electrical, hydraulic or pneumatic energy to effect motion.

3.2 **awareness barrier**: A means that warns a person of a potential or present hazard.

3.3 **awareness signal**: A warning to a person of a potential or present hazard by an audible, visible or tactile means.

3.4 **context based safety stop**: A controlled interrupt that selectively removes power from appropriate **actuators** based on recognition of a defined set of conditions.

3.5 **cycle**: The single execution of a task.

3.6 **drive power**: The **energy source** or sources for the motion of the IAD's **actuators**.

3.7 **emergency stop**: The operation of a circuit that overrides all other controls, removes **drive power**, causes all moving parts to stop, and removes power from other hazardous functions present in the **operating space** of the IAD but does not cause additional hazards.

3.8 **enabling device**: A device which when activated, permits controlled motion.

- 3.9 **end-effector**: An auxiliary device or tool specifically designed to be integrated with the IAD to enable the IAD to perform its intended task. (Examples may include gripper, spot weld gun, or any other application tools.)
- 3.10 **energy source**: Any electrical, mechanical, hydraulic, pneumatic, chemical, thermal, potential, kinetic, human or other sources of power or movement.
- 3.11 **hazard**: A potential source of physical harm to persons.
- 3.12 **hazardous motion**: Any movement that is likely to cause personal physical harm.
- 3.13 **Intelligent Assist Device (IAD)**: A single or multiple axis device that employs a hybrid programmable computer-human control system to provide **human strength amplification**, guiding surfaces, or both. These multifunctional assist devices are designed for material handling, process and assembly tasks that in normal operation involve a human presence in its workspace.
- 3.14 **Human strength amplification**: Application of additional force to a payload, in response or proportion to the force applied by the human operator.
- 3.15 **interlock**: An arrangement whereby the operation of one control or mechanism allows, or prevents the operation of another.
- 3.16 **pendant**: A hand-held device linked to the control system with which an IAD can be programmed or moved.
- 3.17 **risk assessment**: A comprehensive evaluation of the potential injury or damage to health in order to select appropriate **safeguards** to mitigate risk.
- 3.18 **safeguard**: A barrier guard, device or safety procedure designed for the protection of personnel.
- 3.19 **safeguarding**: The act of protecting personnel from potential **hazards**.
- 3.20 **safeguarding device**: A means that reduces or eliminates exposure to a **hazard**.
- 3.21 **safety rated**: Tested, evaluated, and proven to operate in a reliable and acceptable manner when applied in a function critical to health and welfare of personnel.
- 3.22 **single point of control**: The ability to operate the IAD such that initiation of motion from one source of control is only possible from that source and cannot be overridden from another source.
- 3.23 **singularity**: A condition caused by the collinear alignment of two or more axes resulting in unpredictable motion and velocities.
- 3.24 **space**: The three dimensional volume encompassing the range of motions of all IAD parts including the **end-effector**, workpiece and attachments.
- 3.24.1 **maximum space**: The volume of **space** encompassing the maximum designed movements of the IAD including the **end-effector**, attachments, and the work piece.
- 3.24.2 **restricted space**: That portion of the **maximum space** to which an IAD is restricted by limiting devices. The maximum distance that the IAD, **end-effector**, and work piece can travel after the limiting device is actuated defines the boundaries of the **restricted space** of the IAD.
- 3.24.3 **operating space**: That portion of the **restricted space** to which the IAD is confined by software; all **space** reachable by the IAD during normal operation.
- 3.24.4 **safeguarded space**: The **space** defined by the perimeter **safeguarding devices**.
- 3.25 **teach**: Manually programming an IAD, including but not limited to: manually leading the IAD **end-effector**; or manually leading a mechanical simulating device; or using a **pendant** to instruct or move the IAD through critical points.

3.26 **teach mode**: The control state that allows the generation, storage and playback of instructional and positional data points, particularly for the definition of the **virtual guiding surfaces**.

3.27 **user**: An entity which uses IADs, and is responsible for the personnel associated with the IAD operation.

3.28 **virtual guiding surfaces**: Software-defined paths or surfaces that constrain or direct the motion of the payload, for the purpose of guidance.

4 Modes of operation

4.1 Hands-on-controls mode

Hands-on-controls operation is powered motion of the IAD when the operator is in physical control of the IAD from a designated control interface; the powered motion is in response to operator inputs on the control interface.

Motion under operator control shall not exceed speeds of 2.0 m/s (6.56 ft/sec) and shall not accelerate to that speed at a rate faster than the rate intended by the human operator. Acceleration shall not exceed 1g, and under no condition shall the acceleration or deceleration permit the load to be released, or permit the load to shift in position relative to the tool. Release or removal of the operator's physical contact with the IAD shall be monitored, and result in the IAD and payload being brought safely to a stop. Such devices include, but are not limited to: handles with hands-present switches, light beam interrupters, enabling devices and touch detection.

NOTE – Some deceleration conditions may exceed 1G (instantaneous) if required for safe operations.

Speed limits should be reduced to the extent practical as determined by a risk assessment.

Multi-axis IADs constructed from rigid structures (e.g. articulated arms) shall use an over-force or overload device or technique that can reliably detect an impulse force of 267 N (60 lbf)¹ maximum applied to the IAD at the normal point of operator control (e.g., handles). In the event of an impulse loading, this over-force device shall provide protection resulting in a **context based safety stop**. This requirement does not apply to non-powered axes or to IAD configurations providing less than 267 N force.

4.2 Hands-on-payload mode

Hands-on-payload mode is an operator selectable mode that permits powered motion of the IAD in response to forces applied by the operator directly to the payload or tooling. The input does not come from a designated control interface (e.g. Control Handle).

The same speed and acceleration limits as in 4.1 apply.

IADs having a designated control interface shall enter hands-on-payload mode only by an intentional authorizing action by the operator, (e.g. a switch or control logic sequence.) This does not apply to non-powered, and IAD configurations providing less than 267 N force.

When motion in hands-on-payload mode ceases for a period of time, hands-on-payload mode should be terminated and revert to hands-on-controls mode until it is again authorized by the operator.

NOTE – The period of time should be adjustable to allow for **user** selection of either short or longer periods of inactivity.

¹ The power level required for a 5th percentile female to stop motion by overpowering the actuators

Multi-axis IADs of rigid construction that permit a hands-on-payload mode, shall use an over-force or overload device (breakaway) or technique that can reliably detect an impulse force of 267 N (60 lbf) maximum applied to the IAD at any reasonable point of application on the payload or tooling [all axes]. In the event of an impulse loading, this over-force device or technique shall provide protection resulting in a context based safety stop.

4.3 Hands-off control mode

A mode of operation where powered motion of the IAD on a pre-determined path is not in response to forces applied by the operator.

An IAD shall commence hands-off operation only by a positive authorizing action by the operator, (e.g. by depressing a switch). This mode is allowed for a single **cycle** for each activation. However, if a **risk assessment** shows that hands-off motion is justified without specific action of the operator (e.g. line tracking or disengagement with a moving line); then motion may be initiated by another control input for each task cycle.

Motion of the IAD when initiated shall be under slow speed control of 250mm/sec (10 in/sec) or less unless appropriate **safeguarding** is installed. When **safeguards** are not installed, the IAD shall travel along a known and marked route, employ audible (and optionally visual) enunciators, provide a warning of impending motion, and employ safety circuit sensors to initiate controlled stops when objects obstruct the IAD path.

4.4 Line tracking

IADs may be designed to work with moving assembly lines and to track the line's motion automatically in any of the above modes. Variations on line tracking include but are not limited to:

- a) Floating tracking: An electro-mechanical mode where the IAD has velocity (float) that follows the line. The operator still has control to influence velocity. The IAD may also interact with virtual constraints that float with the line being tracked;
- b) Fixed tracking: A mechanical mode where an (active or passive) **actuator** is engaged between the IAD and the assembly line to propel the IAD synchronous with the line speed.

NOTE - See 5.2.5 for end of reach conditions.

Risk assessment may indicate the need for the IAD to be interlocked with the line being tracked.

4.5 Single point of motion initiation

The IAD control system shall be designed so that when the IAD is placed in the hands-on-controls mode or hands-on-payload mode, initiation of the IAD motion shall be prevented from any remote source.

4.6 Communication of IAD mode to operator

As IADs are intended for close interaction with human operators, unambiguous communication of IAD mode to the operator is of particular importance. IAD mode selectors (when provided) shall be clearly marked and the selected mode signaled by a continuous indication readily visible to the operator and to other personnel in or near the IAD's workspace. Furthermore, attention should be paid to design of the operator's controls such that inadvertent or mistaken changes of mode are minimized.

When lights are employed, the following color scheme should be used:

RED: A red indicator means the IAD is faulted, no **drive power** is available to actuators, or both.

GREEN: A green indicator means the IAD is ready, and may be operated in the hands-on-controls mode. (Hands-on-controls mode)

BLUE: A blue indicator means that operator forces applied to the payload or tooling may cause IAD motion. (Hands-on-payload mode).

YELLOW: A yellow (or amber) indicator means that drive power is available to the actuators but a mode has not been selected.

FLASHING YELLOW: A flashing yellow (or amber) indicator means that the IAD may move automatically without operator force applied to the control-interface, payload, or tooling. (Hands-off mode)

5 General performance and design features

5.1 Safety controls performance

Safety Controls (electric, pneumatic, hydraulic) shall meet one or more of the performance criteria listed in 5.1.1 thru 5.1.4 based on a completed **risk assessment**.

5.1.1 Basic safety controls

Basic safety controls shall be hardware based or comply with 5.1.4. These controls are to include components that shall be **safety rated**, be used in compliance with manufacturers' recommendations and proven circuit designs.

5.1.2 Safety controls with monitoring

Safety controls with monitoring shall include all the requirements for basic safety controls standards and specifications, and:

- a) The check of the safety function (s) shall be performed:
 - at machine start-up
 - periodically during operation, such as change of mode to hands-off operation, stop conditions, interrupted operation, process stops, etc.
- b) The check shall either:
 - allow operation in the absence of a fault
 - generate a stop signal if a fault is detected. A warning shall be provided if a **hazard** remains after cessation of motion.
- c) The check itself shall not cause a hazardous situation
- d) Following the detection of a fault, a safe state shall be maintained until the fault is cleared.

5.1.3 Control reliable

Control reliable safety controls shall be dual channel with monitoring designed, constructed and applied such that any single component failure shall not prevent the stopping action of the IAD.

These controls shall be hardware based or comply with 5.1.4, and include automatic monitoring at the system level.

- a) The monitoring shall generate a stop signal if a fault is detected. A warning shall be provided if a hazard remains after cessation of motion;
- b) Following detection of a fault, a safe state shall be maintained until the fault is cleared.
- c) Common mode failures shall be taken into account when the probability of such a failure occurring is significant.
- d) The single fault should be detected at time of failure. If not practicable, the failure shall be detected at the next demand upon the safety function.

5.1.4 Safety related software and firmware based controllers

Software and firmware-based controllers used in place of hardware-based components with safety related devices shall:

- a) be designed such that any single safety related component, software or firmware failure shall:
 - lead to the shutdown of the system in a safe state
 - maintain a safe load position
 - prevent subsequent automatic operation until the component failure has been corrected.
- b) supply the same degree of safety achieved by using hardwired hardware components per 5.1. For example, this degree of safety may be achieved by using microprocessor redundancy, microprocessor diversity, and self-checking.

The manufacturer shall follow the risk assessment procedure and may elect to have their safety related software and firmware based controllers certified by a nationally recognized testing laboratory (NRTL) to an approved standard applicable for safety devices.

5.2 IAD Stopping Controls

Every IAD shall have stopping functions providing for one or more **emergency stop** devices. This shall include an emergency stop circuit and may include a **context based safety stop** circuit.

5.2.1 Emergency Stop

Emergency stop engagement shall stop all **hazardous motion** and remove all **drive power** from the IAD device. It shall not be possible to restart the IAD until the emergency stop device has been reset. Resetting the emergency stop device shall not cause the IAD and associated equipment to operate without a second independent non-automatic controlled action.

NOTE – Some IAD designs may maintain power on steerage drives to facilitate moving the IAD when power has been removed from the drive axes. The steerage drives in this case must not cause motion of payload or tooling.

5.2.2 Emergency stop devices

An emergency stop device shall be readily accessible to the operator. Control stations not located directly on the IAD, including remote **pendants** capable of initiating IAD motion, shall have manually initiated emergency stop devices.

5.2.3 Emergency stop device design

Push buttons that activate an emergency stop circuit shall be readily accessible to the operator and shall be configured as follows:

- a) red in color with a yellow background
- b) unguarded
- c) palm or mushroom head type
- d) the type requiring manual resetting
- e) installed such that resetting the button shall not initiate a restart

5.2.4 Context based safety stop

An IAD may have one or more context based safety stop circuits. When used, inputs should be provided to allow application-specific external devices to initiate context based safety stops. Outputs shall be provided to allow application-specific actions or signaling devices to be coordinated with IAD context based safety and emergency stops.

One or more on-board safety controls may halt IAD motion and remove power from the drive **actuators** until the unsafe condition has been cleared. Once the condition has been cleared and automatic verification of safety circuit performance has been completed, power may be restored to the IAD drive actuators without additional inputs. Context based safety stops in this mode can be hardware or software based limits or constraints. (e.g. over-travel limit switches, virtual wall or surfaces boundary limits etc.)

5.2.5 Line tracking end-of-reach conditions

Line tracking end-of-reach conditions or extreme limits of workspace envelope of the IAD must be clearly defined and communicated to the operator in a timely manner. A context based safety stop shall be initiated to enable the operator sufficient time to move the IAD from the potential hazard or take other evasive action designed to prevent an end-of-reach emergency stop from occurring.

5.2.6 Motion intent sensor and interpretation system

The operator's intent for motion (force and direction) is communicated to the IAD by one or more sensors including software and firmware. The failure of such sensors or sensor systems shall result in a context based safety stop.

5.3 End Effectors

End effectors are the tooling designed to interface between the IAD and the part or component being handled or manipulated. End effectors should be designed to reduce hazards associated with unintentional human contact. Edges should be smooth, feature edge radius details, be padded where practical, and avoid small or sharp profiles.

NOTE – Multi-axis IAD end effectors should be equipped with sensors in compliance with section 4.2 that will halt the IAD prior to contact with a person in the path of travel under hands-off operation.

5.4 Additional personnel in the workspace

IAD systems are designed to permit interaction, collaboration and sharing between IAD systems, and personnel in a workspace. A Risk Assessment shall be used to determine necessary **safeguarding** required to protect the additional personnel in all modes of IAD operations (e.g. both the hands-on and hands-off operations modes.)

NOTE – In hands-on-controls and hands-on-payload modes it is the responsibility of the operator to operate the IAD in a safe and responsible manner to protect other personnel in the workspace.

5.5 Failures

IADs shall be designed and constructed so that any reasonably foreseeable failure shall not cause a hazard.

5.6 Virtual Guiding Surfaces

Virtual Guiding surfaces provide the **user** with positional repeatability and are generally used as a positioning aid. While the existence of a guiding surface may provide additional safety to the operator it shall not be used as a primary safety device.

5.7 Required information

The following information shall be provided to users by the manufacturer or integrator, as appropriate, for all IADs and additional equipment furnished:

- a) Instructions/Procedures
 - 1) Operational capabilities
 - 2) Emergency movement and operation of the IAD with and without drive power
 - 3) Emergency recovery procedure
 - 4) Lifting procedures and precautions
 - 5) Lockout procedures
 - 6) Operating instructions
 - 7) Slow speed control functional testing
 - 8) Start-up and testing procedures
 - 9) Set up procedures
- b) Warnings/Cautions
 - 1) Precautionary information (including appropriate labels on the equipment)
- c) Specifications/Technical Information
 - 1) Function and location of all controls
 - 2) Specifications including range and load capacity
 - 3) Information required for installation
 - 4) Safety hardware
 - 5) Number, location, and range of adjustment of hard stops
 - 6) Safety performance standards: Stopping time and distance or angle (from initiation of stop signal at full rated speed, maximum extension and maximum load).
 - 7) Safety features incorporated in IAD software. The number and location of non-mechanical limiting means.
 - 8) Additional safety features incorporated in IAD hardware controls. The safety control performance the IAD meets per 5.1.
- d) Certifications/Qualifications
 - 1) A list of the standards with which the IAD complies
 - 2) a list of the standards to which the IAD is third party certified
 - 3) Information on appropriate standards and related documents

- e) Maintenance
 - 1) Maintenance information, including preventative maintenance schedules
- f) System Requirements
 - 1) Structural, utilities (electrical, hydraulic, or pneumatic), environmental requirements
 - 2) Special environmental requirements including but not limited to, Electromagnetic Interference (EMI), Radio Frequency Interference (RFI) and Electro-Static Discharge (ESD), water, humidity, corrosive, hazardous environment.
- g) Miscellaneous Information (subject to mutual agreements)
 - 1) Safety related failure mode effect analysis (FEMA) information

6 Safeguarding of personnel - Introduction

Safeguarding personnel against **hazards** that could cause personal injury is the responsibility of all persons involved in the design, integration, and use of **intelligent assist devices**. The **user** shall ensure that appropriate **safeguards** are in place, functioning, and that personnel are trained to use them as intended.

6.1 Implementation

Safeguarding shall be implemented by conducting a **risk assessment** and installing the appropriate **safeguarding devices** determined to be necessary to provide a safe working environment for personnel. Eliminating hazards by design changes in the application is preferred to the use of engineering controls (Figure B.9). The workspace should be designed to enable personnel to accomplish their jobs in a safe manner.

6.1.1 Implementation stages

Safeguarding shall be required at each of the following stages:

- a) design/development
- b) integration/installation (commissioning)
- c) verification/testing
- d) production operation
- e) maintenance
- f) training
- g) research and development
- h) re-application (re-commissioning)

6.1.2 Conducting the risk assessment

IAD manufacturers, system integrators and end-users shall conduct and document a risk assessment per Clause 7. The risk assessment documentation shall be provided to each successive level of development or deployment. The objective of conducting the risk assessment is to develop an overall safety strategy focused on personnel in the workspace and the immediate vicinity of the IAD.

- a) The manufacturer shall conduct a risk assessment of the base device, including internal hardware and software components. This risk assessment shall be performed before the

commercial introduction of the product, and the results recorded. It shall be a living document available to integrators and users.

- b) The system integrator shall conduct an application specific risk assessment for every system supplied or delivered to an end user. This document shall be recorded and provided to end-users.
- c) The user shall conduct an application specific risk assessment, either independently or together with the integrator, focusing primarily on the safety of the operator and other personnel in the immediate vicinity of the workspace. This document shall be recorded, preserved, and updated when changes are made.

6.2 Sources of hazards

Hazards shall be identified in all aspects of the installation, including but not limited to:

- a) equipment (conveyors, safeguards, ancillary hardware);
- b) installation (pinch points, mounting, positioning);
- c) process hazards, hazards from the IAD interaction with other equipment, or from interaction of persons within the IAD work area.

NOTE – Examples of sources of hazards are in Annex A

6.3 Failures

IADs shall be installed so that in normal use and conditions any single reasonably foreseeable failure shall not result in an unsafe condition. The user is responsible for complying with installation and use guidelines provided by the manufacturer.

7 Safeguarding of personnel – Safety risk assessment

As required for new installations, a **risk assessment** shall be performed. The risk assessment shall take into account the stage of development, intended use of the IAD, anticipated skill and training of operators, additional risk exposure and processes. A number of methodologies are available to do a risk assessment. Any method is acceptable which prescribes **safeguarding** equivalent to or more stringent than the requirements of this clause.

7.1 Requirements

- a) The manufacturer shall perform the risk assessment at the time of initial design to determine minimum safeguarding requirements and to develop an overall safety strategy (see Figure B.1). This assessment shall be revised and updated as the design process matures prior to integration of the IAD system, and provided to the integrator or **user**.
- b) Additional risk assessments shall be performed by the integrator or user when designing a system and upon final installation and configuration, and again each time the system configuration changes. The user shall maintain the documentation of the most recent risk assessment(s).
- c) The first step of a risk assessment shall assume only integral **safeguards** are available and include:
 - 1) task and **hazard** identification per 7.2;
 - 2) risk estimation per 7.3;

NOTE – Designed in safety devices shall be delineated and included in the documentation for the IAD risk assessment.

- d) The second step of a risk assessment shall select additional safeguards based on requirements of 7.4 and 7.5.
- e) The third step of the risk assessment is to assume that all safeguards are installed and validates the selection (7.6).

NOTE – Annex B offers an example of a risk assessment method that has been demonstrated to achieve the required results.

7.2 Task and hazard identification

- a) Describe the application/process and a definition of the limits associated with its intended use;
- b) Identify all reasonably foreseeable tasks associated with the IAD system and the stage of development;
- c) Identify all reasonably foreseeable hazards associated with the IAD system and the stage of development.

7.3 Risk estimation

For each task and hazard combination, determine level of risk using severity, event probability, and avoidance per Table 1. Where multiple criteria can apply, use the most restrictive criteria.

Factor	Category		Criteria
Severity	S2	Serious Injury	Normally irreversible; or fatality; or requires more than first-aid as defined in OSHA §1904.12
	S1	Slight Injury	Normally reversible; or requires only first-aid as defined in OSHA §1904.12
Event Probability	E2	High probability	The likelihood that an identified failure mode will cause exposure to the hazard.
	E1	Low probability	The likelihood that an identified failure mode will not cause exposure to the hazard.
Avoidance	A2	Not Likely	Cannot move out of way; or inadequate reaction time; or speed greater than 250 mm/sec
	A1	Likely	Can move out of way; or sufficient warning/reaction time; or speed less than 250 mm/sec

Table 1 – Hazard Severity/Event Probability/Avoidance Categories

NOTE – Event probability can be affected by either a change in the frequency that the task is performed or by the application of an index R2 risk reduction safeguard or application of lockout to control the hazard by removal of the **energy source** that reduces exposure to the hazard. Determining event probability can require judgment decisions by the person(s) performing the risk assessment. When determining proper safeguards, it should be noted that serious injuries have resulted from infrequent tasks.

Avoidance can be affected by: a) reducing the speed of the hazard to give sufficient warning/reaction time, or b) through the application of an index R2 risk reduction safeguard, or c) installation of awareness devices.

7.4 Risk reduction determination

Using the Avoidance, Severity and Event probability criteria for each task and hazard combination obtained from Table 1, follow across Table 2 to determine the risk reduction index.

SEVERITY OF INJURY	EVENT PROBABILITY	AVOIDANCE	RISK REDUCTION INDEX
S2 Serious Injury More than First-aid	E2 High	A2 Not Likely	R1
		A1 Likely	R2A
	E1 Low	A2 Not Likely	R2B
		A1 Likely	R2B
S1 Slight Injury First-aid	E2 High	A2 Not Likely	R2B
		A1 Likely	R3
	E1 Low	A2 Not Likely	R3
		A1 Likely	R4

Table 2 – Risk reduction decision matrix prior to safeguard selection

NOTE – This table assumes that no external safeguards are installed.

7.5 Safeguard selection

Using the risk reduction index determined by Table 2, follow across Table 3 to determine the minimum required safeguard performance and controls performance.

INDEX	SAFEGUARD PERFORMANCE	CONTROLS PERFORMANCE
R1	Hazard elimination or hazard substitution (7.5.1)	Control reliable (5.1.3)
R2A	Engineering controls preventing access to the hazard, or stopping the hazard (7.5.2), e.g. interlocked barrier guards, light curtains, safety mats, or other presence sensing devices.	
R2B		
R3	Non-interlocked barriers, clearance, procedures and equipment (7.5.3)	Basic safety controls (5.1.1)
R4	Awareness means (7.5.4)	

Table 3 – Safeguard Selection Matrix

NOTE – Application of the Safeguard Selection Matrix (Table 3) and Safeguard Selection Validation Matrix (Table 4) are primarily intended for machinery and equipment related task and hazard combinations. Certain task and hazard combinations such as material related tasks that include exposure to sharp parts, thermal and ergonomic hazards require the application of the highest level of feasible safeguarding based on the hierarchy of controls (Table B.9) and fall outside the scope of Tables 3 and 4. Appropriate standards and regulations should also be consulted.

7.5.1 Index R1 risk reduction

Risk reduction shall be accomplished by hazard elimination or hazard substitution that does not create an equal or greater hazard. When hazard elimination or substitution is not possible, all provisions of an index R2 risk reduction shall apply and provisions of indexes R3 and R4 shall be used for safeguarding residual risk.

7.5.2 Index R2 risk reduction

Safeguarding shall be by means that prevent access to the hazard, or cause the hazard to cease. Provisions of indexes R3 and R4 may be used for safeguarding residual risk.

7.5.3 Index R3 risk reduction

Safeguarding, at a minimum, shall be by means of non-**interlocked** barriers, clearance from the hazard, written procedures, and personal protective equipment if applicable. Provisions of index R4 may also be used for safeguarding residual risk.

7.5.4 Index R4 risk reduction

Safeguarding, at a minimum, shall be by administrative means, awareness means including audio/visual warnings and training.

7.6 Selection validation

Once safeguards are selected based on Table 3 requirements and installed in accordance with Clause 8, the process in 7.2 and 7.3 must be repeated to determine if each identified hazard has been protected so that the remaining risk is tolerable. Re-evaluate the Avoidance, Severity and Event probability criteria for each task and hazard combination using Table 1. Then follow across Table 4 to determine the risk reduction index. Apply the appropriate additional safeguards to control residual risk. If the risk reduction index is now tolerable (R3 or R4), the risk reduction for that task and hazard combination is complete. If the risk reduction index is not an R3 or R4, install appropriate safeguards and repeat this step.

EVENT PROBABILITY	AVOIDANCE	SEVERITY OF INJURY	RISK REDUCTION INDEX
E 2 High	A2 Not Likely	S2 Serious Injury	R1
		S1 Slight Injury	R2B
	A1 Likely	S2 Serious Injury	R2A
		S1 Slight Injury	R3
E1 Low	A2 Not Likely	S2 Serious Injury	R2B
		S1 Slight Injury	R3
	A1 Likely	S2 Serious Injury	R3
		S1 Slight Injury	R4

Table 4 – Safeguard selection validation matrix with safeguards installed

7.7 Documentation

The manufacturer, integrator, and user shall document the risk assessment. At a minimum the risk assessment must contain lists of tasks, hazards, risk reduction index, and safeguards selected, to validate and record the risk assessment requirements of 7.1 through 7.6. This assessment shall be passed on to the successor level responsible for installation/integration; and be incorporated in the risk assessment accomplished at the next stage. The user shall maintain a file documenting the most recent risk assessment(s) for each IAD in use (see Annex B for sample formats).

8 Installation and Safeguarding

The **user** of an IAD or IAD systems shall ensure that the IAD systems and appropriate **safeguards** are installed in accordance with 8.1 through 8.15 of this standard.

8.1 Installation specification

The IAD or IAD systems shall be installed consistent with a **risk assessment** performed in accordance with Clause 7 and specifications of the manufacturer.

8.2 Environmental conditions

Environmental conditions shall be evaluated to ensure compatibility of the IAD with the anticipated operational conditions. These conditions include, but are not limited to, explosive mixtures, corrosive conditions, humidity, dust, temperature, Electromagnetic Interference (EMI), Radio Frequency Interference (RFI) and Electro-Static Discharge (ESD).

8.3 Power enable controls

Controls that allow **drive power** to be enabled to the IAD shall be constructed or located so as to protect against inadvertent operation. Additionally, a visual awareness means shall be installed in a conspicuous location to indicate that drive power is enabled to the IAD.

NOTE – Examples of protection that prevents inadvertent operation include but are not limited to guarded switches and key selector switches. The awareness means should be an amber light per NFPA 79.

8.4. Limiting IAD motion

Limiting IAD motion may be accomplished by means integral to the IAD, or by external limiting devices. Limiting devices are used to re-define the **space** for an IAD to perform its task, e.g. the **operating space** is made smaller than the **maximum space** by installation of limiting devices.

8.4.1 Mechanical limiting devices

Mechanical limiting devices, including mechanical stops integral to the IAD, shall be capable of stopping motion at rated load, maximum speed conditions, and at maximum and minimum extension for the device.

8.4.2 Non-mechanical limiting devices

Devices such as, but not limited to, limit switches, light curtains, proximity or position sensors, and scanners may be utilized provided the device and associated controls (hardware based or compliant with 5.1.3) are capable of stopping the IAD motion under maximum load and speed conditions. Non-mechanical limiting devices shall be integrated in accordance with 5.1.

Non-mechanical limiting devices that do not physically stop motion shall be tested, after installation, to determine the boundaries of the **restricted space** when the device is actuated. Testing shall be performed under maximum speed and maximum anticipated load conditions at full and minimum extension. Control activated mechanical limiting devices that physically stop IAD movement shall be engineered to meet the performance criteria of mechanical stops.

8.5 Awareness means

Awareness means include barriers or signal devices used to call attention to the existence of potential **hazards**. They should be used in addition to, but shall not be as a substitute for, the **safeguarding devices** in 8.8. Awareness means shall be used to identify residual risks not protected by other safeguards.

NOTE – Where the hazards cannot be totally or physically removed or controlled by design, awareness means should be used. Awareness means are not intended to be used in place of engineering controls, such as barriers and presence sensing safeguarding devices.

8.5.1 Awareness barrier

An **awareness barrier** (where required by risk assessment) shall be, located, and installed so that a person entering the operating space of an IAD will be aware of the potential hazard(s).

NOTE – An awareness barrier need not impede motion; examples include floor markings, chains, and signs at entrances and on equipment.

8.5.2 Awareness signal

An **awareness signal** shall be designed and located such that it shall provide a recognizable audible or visual signal to individuals of an approaching or present hazard. When visual awareness light signals are used to warn of hazards within a **safeguarded space**, they shall be designed and located so that an individual approaching the safeguarded space can see the light (see also 8.3). Audible awareness devices shall have a distinctive sound and a greater decibel level or different frequency than the surrounding ambient noise.

8.5.3 Operating space identification

The operating space for the IAD should be conspicuously identified. Areas where the IAD will operate in the hands-off mode shall be clearly marked unless a barrier is installed.

NOTE – Marking is particularly important in areas where the IAD will meet or **interlock** with other equipment.

8.6 Clearance

The IAD system (including end-effector tooling and payload) shall be installed to provide a minimum clearance from the operating space of 0.5 m (20 inches)² from areas of building, structures, utilities, other machines and equipment not specifically supporting the IAD function that may create trapping or a pinch point. Where this minimum clearance is not provided, additional safeguarding devices to IAD motion shall be provided while personnel are within 0.5m (20 inches) of the trapping or pinch hazard. This does not include those areas that are not readily accessible except by climbing over, around or under an obstruction unless access is required for the **teaching** function

NOTE – The 0.5 m (20 in) dimension is derived from rigid installation designs. A cable-based system may require a different dimension that must be addressed in the risk assessment.

8.7 Power requirements

All sources of power provided shall meet the specifications of the manufacturer and applicable codes.

8.7.1 Grounding requirement

Electrical ground shall be provided in accordance with the specifications of the manufacturer and applicable codes.

8.7.2 Power disconnect

Each installation shall have a means to shut off power to the IAD consistent with requirements to control hazardous energy; e.g. with integral lockout/tagout provisions. This means shall be

² NASA (1978) Anthropomorphic studies

located within line of sight to the operating space and shall be accessible without creating a hazard.

8.7.3 Associated equipment shutdown

The IAD system shall be installed so that shutdown of associated equipment shall not result in a hazard, e.g. conveyor interlocks must be tested prior to initial operation.

8.7.4 End-effector power loss or change

End-effectors shall be designed and constructed so that loss or change of electrical, hydraulic, pneumatic or vacuum power shall not result in a hazard. If this is not feasible, then other methods of safeguarding shall be provided to protect against hazards.

8.7.5 Emergency recovery procedure

A means shall be provided for the emergency movement (without drive power) for the IAD mechanisms and for other foreseeable fault recovery of related equipment.

8.8 Safeguarding devices

Safeguarding devices shall be used consistent with the manufacturers instructions; and shall be applied to the IAD system to:

- a) prevent exposure to the hazard,
- b) cause the hazard to cease before exposure,
- c) prevent unintended operation,
- d) contain parts and tooling (e. g. loose objects, flying projectiles),
- e) control other process hazards (e. g. noise, laser, radiation.)

NOTE – Each safeguarding device may not address each criteria a-e, depending on the hazard being protected.

8.8.1 Safeguarding device selection

Devices selected for safeguarding IAD and IAD system applications shall comply with the requirements contained herein. The selection of the safeguarding devices or combination of devices shall provide automatic protection against hazards associated with tasks such as normal production, teaching, troubleshooting, and maintenance. Safeguarding shall be accomplished by the use of one or more but not limited to the following safeguarding devices:

- a) barriers, fixed and interlocked;
- b) one or two hand **enabling device**;
- c) presence sensing safeguarding devices:
 - 1) safety light curtains/screens
 - 2) safety mat systems
 - 3) area scanning safeguarding systems
 - 4) radio frequency (RF)/capacitance sensing safety systems
 - 5) single and multiple safety beams

NOTE – Additional information and assistance in selecting safeguarding devices is contained in Annex C.

8.8.2 Requirements of safety circuit performance

The ultimate design requirement for safety systems is that, should they fail, the associated hazard is left in a safe state.

- a) Safety related parts of control systems shall be designed, constructed, selected, and assembled for the intended application and can withstand:
 - 1) the expected operating stresses,
 - 2) the influence of the processed material,
 - 3) other relevant external influences.
- b) The performance criteria listed in 5.1 shall be used in the design of the safety circuit consistent with the associated level of hazard.
- c) Safeguarding devices shall be integrated into the **context based safety stop** circuitry per 5.2.

8.8.3 Start and Restart

Starting and restarting the IAD shall require deliberate actions by the operator. The IAD shall not restart in the hands-off mode of operation without a specific additional instruction from the operator.

8.8.4 Bypassing safeguarding devices

Bypassing refers to the manual interruption of the normal function of a safeguarding device that signals or causes a stop by designed-in controls or by temporary means.

- a) Bypassing in hands-off mode - The IAD system shall not be operated in hands-off mode with any of the safeguards bypassed unless alternate safeguards are provided which provide an equivalent level of protection from the hazard.
- b) Bypassing for maintenance - When a means to bypass safeguarding devices is provided for maintenance, the following requirements shall be met:
 - 1) for designed-in bypass controls, it shall not be possible to enter hands-off mode with the bypass activated.
 - 2) the bypass means shall be located in clear view of the device bypassed.
 - 3) the bypass control shall be designed and installed consistent with the circuit performance of the device being bypassed.
 - 4) visual indication that safety devices are bypassed shall be provided at the bypass control, and the affected operator stations, if any.
- c) Bypassing for teach - When a control device to bypass safety devices is provided for teach, the following requirements shall be met:
 - 1) it shall not be possible to enter hands-off operation with the bypass control device activated.
 - 2) the teacher shall be fully trained in which safeguarding devices have been bypassed.
 - 3) the bypass control shall be designed and installed consistent with the circuit performance of the device being bypassed.
 - 4) visual indication that safety devices are bypassed shall be provided at the bypass control, and the affected operator stations, if any.
- d) Bypassing shall not be used as a substitute for lockout/tagout.

8.8.5 Muting

Muting is the temporary automatically controlled deactivation of the function of a safeguarding device during a portion of the IAD, or IAD system's **cycle**. Muting may be used in conjunction with any safeguarding device that signals a stop.

Muting is permitted when:

- a) personnel are not exposed to the hazard;
- b) the hazard cannot be accessed without a stop being initiated;
NOTE – Physical barriers or obstructions can prevent access.
- c) the muting system is designed and installed consistent with the safety circuit performance required of the device being muted. In the event of a failure subsequent muting shall be prevented until the failure is corrected.

8.9 Procedures and training

When risk has been reduced to an acceptable level, procedures and training shall be used in addition to, but not as a substitute for the safeguarding devices.

8.10 Safeguarding the teacher

The teacher is the person assigned to “teach”, or program the IAD. When teaching, safeguards are required to protect the teacher from hazards as determined by the risk assessment.

8.10.1 Training

The user shall ensure that the teacher is trained in accordance with Clause 11.

8.10.2 Preparation

Before teaching an IAD, the teacher shall visually check the IAD and operating space to ensure that conditions that may cause hazards do not exist. The **emergency stop** and motion controls of the operator interface unit (e.g. **pendant** or hand controls) shall be functionally tested to ensure proper operation. Any damage or malfunction shall be repaired prior to commencing the teaching operation.

8.10.3 Functional safeguards

Before entering the operating space, the teacher shall ensure that all safeguards are in place and functioning as intended in the **teach mode**.

8.10.4 Protection from adjacent hazards

The teacher shall be safeguarded from the motion of adjacent IADs and other associated equipment that may present a hazard.

8.10.5 Selecting teach mode

When the teach mode is selected, the following conditions shall be met:

- a) the teacher shall be provided with and use a pendant or other control which has **single point of control** of the IAD. Additionally the teacher shall have sole control of initiating motion of any associated equipment which may present a hazard;

- b) when operating in teach mode, slow speed control shall be in effect for hands-off mode (see 4.3). The actual speed shall be selected such that the teacher has sufficient time to either withdraw from **hazardous motions** or stop the IAD;
- c) all IAD system emergency stop devices shall remain functional.

8.11 Safeguarding the operator

The user of an IAD system shall ensure that safeguards are established for each operation associated with the IAD system as determined by the risk assessment.

- a) Operators of IAD systems shall be trained in accordance with Clause 11.
- b) Operators shall be instructed in the proper operation of the control **actuators** for the IAD system and shall be instructed in how to respond to recognized hazards.
- c) Operators shall be safeguarded by the safeguards determined necessary by a risk assessment in accordance with Clause 7.

8.12 Safeguarding maintenance personnel

Personnel that maintain IAD systems shall be safeguarded from injury due to hazardous motion and be trained in accordance with Clause 11.

NOTE – Tasks covered by this clause include routine servicing, troubleshooting failures, component repair and replacement.

8.12.1 Control of hazardous energy

a) Maintenance with no drive power available

A procedure for hazardous energy control shall be followed that includes lockout/tagout of sources of hazardous energy and releasing or blocking hazardous stored energy.

b) Maintenance with drive power available

While the drive power is available, and a full lockout/tagout procedure is not used, means of alternate safeguards or safeguarding procedures shall be established and used to prevent injury from hazardous energy. Personnel shall be additionally protected by providing the necessary clearance from potential rear swing or side motion of IAD components such as the shoulder, counterweight, drives or accessory structures that create a pinch point to adjacent equipment.

8.12.2 Control of IAD and IAD system

Personnel performing maintenance tasks within the operating space when drive power is available shall have total control of the IAD or IAD system. This shall be accomplished by the following:

- a) the lead person shall be provided with and use a pendant or other control which has single point of control of the IAD. Additionally, that person, shall have sole control of initiating motion of any associated equipment which may present a hazard;
- b) all IAD system emergency stop devices shall remain functional;
- c) to restore hands-off operation the following shall be required:
 - 1) restore safeguards required for hands-off operation;
 - 2) initiate deliberate start-up procedure.

8.12.3 Additional safeguarding methods

Additional safeguarding methods may be provided as follows:

- a) certain maintenance tasks can be performed without exposing personnel to trapping or pinching points by placing IAD into a predetermined position;
- b) the utilization of devices such as blocks or pins can prevent potentially hazardous motion of the IAD and IAD systems.

8.12.4 Alternate safeguards

If, during maintenance, it becomes necessary to disconnect or otherwise render inoperative any safeguards, alternative safeguarding shall be provided. Any inoperative safeguards shall be identified and shall be returned to their original effectiveness when the maintenance task is complete.

8.13 Safeguarding verification

Following the installation of safeguarding devices the system shall be tested and verified to ensure an adequate level of safety has been achieved. This review shall include, at a minimum, the following:

- a) all safeguarding devices must be tested under reasonably foreseeable conditions of use to ensure they are functioning as intended and protect personnel from hazards. Modifications must be made to correct deficiencies;
- b) the tasks must be reviewed to ensure that safeguarding does not inhibit task performance and encourage personnel to defeat the devices;
- c) safeguarding devices must be reviewed to ensure that they are not easily defeated or bypassed;
- d) determining if all tasks can be performed with the safeguarding devices in place. For those tasks that cannot be performed with safeguards in place alternative methods such as lockout must be used

8.14 Precautionary labels

Where precautionary labels provided on the IAD are not visible due to some application or process, other means of precautionary notice shall be provided.

8.15 Requirements during hands-off mode

Additional requirements exist for personnel safety when the IAD is operating in the hands-off control mode.

8.15.1 Warnings

Prior to initiation of IAD movement without direct operator contact, a warning device shall be activated and will be either audible, visual, or a combination thereof to indicate the imminent movement of the IAD under automatic control. The IAD shall provide a similar, continuous warning during all automatic motion.

8.15.2 Object detection

During hands-off mode object detection must be provided. If bumpers are used as an emergency sensing device, bumpers shall not exert a force greater than 30 lb (133 N)³ applied

³ 30 lbf data taken from B56.5a-1994 section 8.10.4

parallel to and opposing the direction of travel with respect to the bumper. Activation of the bumper shall cause a context based safety stop within the collapsible range of the bumper.

8.15.3 Abnormal condition sensing

During hands-off mode the emergency control functions and devices shall include the following items: detection of loss of speed control; detection of unplanned loss of guide path reference or path of intended travel; and failure detection of power sources that are critical to safety performance.

8.15.4 Emergency stop

Emergency stop switches shall be located on the IAD and accessible to personnel.

8.16 Required information

The applicable information as listed in 5.7 for IAD shall be provided for all IADs and IAD systems.

9 Safety Testing

Operational testing shall verify the safety functions, as applicable, for each IAD.

9.1 Equipment Manufacturer, Integrator and User

The IAD and any supplied accessories (such as end effectors and sensors) shall be tested to verify operation of safety critical functions at each stage of development, from manufacture to final installation. Such functions include, but are not limited to, safety related hardware and software, enabling system, **emergency stop**, and safety sensors as applicable to each system.

Safety verification procedures shall include, but not necessarily be limited to, the following:

- a) Before applying power, verify that the following have been installed as intended:
 - 1) mechanical mounting and stability;
 - 2) appropriate power sources (e.g. electric, pneumatic, hydraulic);
 - 3) **energy sources** - incoming and disconnect means, lockout/tagout connections;
 - 4) utility connections;
 - 5) communications connections;
 - 6) peripheral equipment and systems;
 - 7) limiting devices for restricting the **maximum space**;
 - 8) emergency procedures.
- b) Equipment manufacturer and **user** safety verification [initially no one in area]: All personnel, except the teacher or operator, shall exit the workspace prior to applying **drive power**.
- c) After applying power, verify:
 - 1) motion shall not be initiated without deliberate operator action;
 - 2) motion initiation shall be from a single point (see 4.5);
 - 3) IAD responds as expected to basic operating system motion commands - including **pendant** and operator control station panel controls, as applicable (see Clause 4);

check each IAD operating function such as, "hands-on-control", "hands-off", standby, return to home, transition (of phases) between operating modes;

- 4) each axis moves and is restricted as intended;
- 5) limit switches and similar devices and systems that define limits of travel for each axis (see 8.4);
- 6) all **safeguarding devices** [or interim **safeguards**] function;
- 7) operational check of emergency stop circuits, devices and e-stop system reset (see 5.2);
- 8) verification of systems status lamps and warning devices (as applicable);
- 9) slow speed control. **Teach mode** speed shall not exceed slow speed limits;
- 10) operation of safety **interlocks**;
- 11) verification of sensors, such as contact with payload, force sensors (see 5.2.6);
- 12) end effector operation (see 5.3);
- 13) user interface for input/output signals;

In addition to items c)1 - 12 above, the user shall verify:

- 14) line tracking and potential interference points with programmed workspace, as applicable (see 4.3 and 4.4).

9.2 Recommended daily operational safety checks

Daily, prior to use, the end user shall verify:

- a) motion does not initiate without deliberate operator action;
- b) motion initiation shall be from a single point (see 4.5);
- c) IAD responds as expected to basic operating system motion commands - including pendant and operator control station panel controls, as applicable; check each IAD operating function such as, "hands-on-controls", "hands-off", standby, return to home, transition (of phases) between operating modes;
- d) each axis moves and is restricted as intended;
- e) all safeguarding devices [or interim safeguards] function;
- f) verification of systems status lamps and warning devices (as applicable);
- g) user interface for input/output signals.

9.3 Recommended periodic user checks

Periodic user checks shall include, but not be limited to:

- a) limit switches and similar devices and systems that define limits of travel for each axis (see 8.4);
- b) slow speed control. Teach mode speed shall not exceed slow speed limits;
- c) verification of sensors, such as contact with payload, force sensors (see 5.2.6);
- d) end-effector operation (see 5.3);
- e) operational check of emergency stop circuit controls, devices and e-stop system reset (see 5.2);

- f) operation of safety interlocks;
- g) potential interference points with programmed workspace, as applicable.
- h) line tracking

10 Maintenance protections

The **user** of an IAD system shall establish a maintenance program as required for the continued safe operation of the IAD system. The inspection and maintenance programs shall consider the recommendations of the manufacturer of the IAD system and local application specific requirements.

10.1 Preventive

The user shall establish a preventive maintenance program following the equipment manufacturer's guidelines. This program should ensure that all recommended components are inspected at regular intervals, all safety and warning systems are operational, and all manufacturer supplied plates, tags and decals are maintained in legible condition.

10.2 Diagnosis and Repair

The user shall ensure that all required maintenance actions are performed. Any repairs or modifications which would affect the safety of the IAD must be documented and any warning or other awareness signs be changed to reflect the current configuration of the IAD.

NOTE – Maintenance actions should use manufacturer recommended instructions, procedures and parts.

10.3 Testing and start-up

The applicable manufacturer's recommended procedures shall be followed during the start-up and testing of IAD systems after maintenance or relocation. These procedures apply to IAD systems after software or hardware changes and after maintenance that could affect their safe operation.

NOTE – This applies only to the IAD operating system, not user programs or normal daily or shift start-up procedures.

No personnel shall be allowed in the **restricted space** during the initial application of power to the IAD system.

NOTE – This is especially critical during initial power-on to ensure that the IAD and equipment move/operate in the expected manner.

10.4 Documentation

The user shall be able to demonstrate through documentation that an effective inspection and maintenance program is in place.

11 Safety training of personnel

The **user** shall ensure and document that any person who programs, operates, or maintains IADs or associated equipment is trained on safety issues related to assigned tasks. Additionally, persons who may come in casual contact with IADs shall be instructed on basic safety issues related to the IAD operation, tasks, or associated processes. Retraining will be accomplished if any part of the system setup changes. Qualified personnel shall conduct training.

NOTE – This training is best presented when integrated with operational training.

11.1 Training objectives

The objective of a training program is to provide information on:

- a) the purpose of safety devices and their function;
- b) procedures, specifically those dealing with health and safety;
- c) **hazards** presented by and capabilities of the IAD system;
- d) tasks associated with a specific IAD application;
- e) safety concepts.

11.2 Training requirements

Training may be accomplished through classroom training, on the job training, or a combination of both. Training documentation will include at a minimum a description of the training, attendees, and date conducted.

Training shall include:

- a) industry standards and instructions designed for the protection of personnel;
- b) the IAD supplier safety recommendations;
- c) procedures that contain steps related to safety actions;
- d) hazardous energy control procedures including lockout/tagout and alternative procedures;
- e) emergency procedures;

and the following content specific training program, content based on assigned tasks of the personnel (e.g. operator, maintainer, other personnel in casual contact).

11.2.1 Safeguard training

Training on **safeguarding devices** shall include, but not be limited to:

- a) types of safeguarding devices;
- b) capabilities/options of safeguarding devices;
- c) description of devices selected for a specific application;
- d) function of the selected devices;
- e) functional test of the device;
- f) limitations of the selected device.

11.2.2 Training for application setup

Training for application setup shall include, but not be limited to: (if applicable)

- a) motion control;
- b) **safeguards** which are bypassed during application setup;
- c) **pendant** or programming interface operation;
- d) **single point of control**;
- e) process safety/control;

- f) response to abnormal/unexpected events;
- g) hazards during application setup;
 - 1) pinch point locations
 - 2) observation points
 - 3) IAD motion in hands-on operation
 - 4) IAD performance restrictions
 - 5) **singularity**
 - 6) hands-off operation playback,
 - 7) line tracking (if applicable)
 - 8) virtual surfaces (if applicable)
 - 9) programmable performance parameters (if applicable)
 - 10) procedures
 - 11) path
 - 12) process materials
 - 13) failure modes
 - 14) alternative safeguards
 - 15) obstacle detection;
- h) auxiliary equipment.

11.2.3 Training the operator

Training of the operator shall include, but not be limited to:

- a) IAD operational tasks;
 - 1) mode transition
 - 2) hands-on
 - 3) hands-off
 - 4) normal startup and shut down
- b) hazards related to each task;
- c) response to abnormal/unexpected events;
- d) orientation changes
- e) recovery of operation;
- f) auxiliary equipment;
- g) mode/phase change;
- h) requirements and procedures
- i) changes to programmed motion.

11.2.4 Training maintenance personnel

Training maintenance personnel shall include, but not be limited to:

- a) applicable tasks in 11.1.1 and 11.2.3 relating to developing the application setup and training the operator;
- b) hazards involving:
 - 1) preventive maintenance/calibrations
 - 2) troubleshooting
 - 3) repair
 - 4) operational checks
 - 6) failed safety devices
 - 7) failed communication systems
 - 8) process variables
- c) emergency operations;
- d) hazards involved in procedures on live IADs versus IADs disabled by lockout/tagout;
- e) hazards involving auxiliary equipment.

11.3 Retraining requirements

Retraining shall be provided as necessary to cover such items as system changes, personnel changes, or other event which may affect safe operation.

NOTE – These changes may include, but are not limited to:

- a) personnel assignments
- b) system set-up changes
- c) program changes
- d) after an accident.

Annex A
(Informative)
Sources of Hazards

Hazards need to be identified in all aspects of the design, installation, and use of the IAD. The following is a list of hazards that should be considered when reviewing an IAD application. This example list is intended to be a starting point for consideration of hazards and is not all-inclusive. Potential hazards include but are not limited to:

- Motion: moving mechanical components causing striking, trapping or crushing; individually (by themselves), in conjunction with other parts of the system, or other equipment in the work area; line tracking; speed of device
- Potential energy: release of stored energy in moving parts; mechanical, electrical, air or fluid power components; gravity
- Power sources: electrical; hydraulic; pneumatic, thermal
- Environmental: hazardous atmospheres, materials, or conditions; explosive or combustible; radioactive; extreme high or low temperature; noise (acoustical)
- Interference: electromagnetic, electrostatic, radio frequencies; vibration and shock;
- Loose objects: dropped or flying projectiles (e.g. failures of fixtures, grippers, or other mechanical parts retention devices); loss of equipment stability; equipment overload; cable slack
- Ergonomics: posture, body position; location of controls; configuration of work cell; personal exertion
- Fall: slips or tripping on the same level; falls from elevated locations
- Human errors in: design, development and construction including ergonomic considerations; installation and commissioning including access, lighting, and noise; functional testing; application and use; programming and program verification; set-up including work handling/holding and tooling; troubleshooting and maintenance; safe working procedures;
- Configuration: moving, handling, or replacing of the IAD system or associated components.
- Failures or faults of: protective means (e.g. devices, circuits, components), including removal or disassembly; power sources or means of distribution; control circuits, devices or components including input and output devices or controls;
- Inadvertent operation caused by equipment failure; loss of virtual guiding surfaces; entanglement in equipment
- Actions or misuse by personnel, either unintended or deliberate

Annex B

(Informative)

An example risk assessment method

General Considerations

This sample risk assessment has been adapted from the risk assessment methodology developed by the Robotic Industries Association and contained in the Robot Safety Requirements standard, ANSI/RIA R15.06-1999. The process described herein has been validated and has been found to provide an acceptable and reliable means to conduct a risk assessment.

Organizing your Risk Assessment

One of the main keys to performing a successful risk assessment that captures all of the tasks and hazards associated with the IAD is the participation of those individuals who routinely work with the IAD. As a minimum this should include the following types of personnel:

- Operator(s), others interfacing with the IAD
- Maintenance personnel (skilled trades)
- System Process Engineer, Safety Engineer and or Design Engineer, and management

Optimum group size would be 4-8 persons from the above categories.

The other key player is the person performing the risk assessment. This individual should have experience in working with groups and have a familiarity with the IAD, and the process being evaluated.

The best process to solicit input from this group is to organize them as a team to “brainstorm” inputs.

Suggested set up

The best setting is a conference room or classroom. A useful tool to assist in collecting task and hazard combinations is a flip chart or white board and colored markers. A risk assessment form in either hard copy or in electronic form will be needed to capture and document the information once collected. Sample forms and templates are included throughout this example.

Risk Assessment Flow Chart

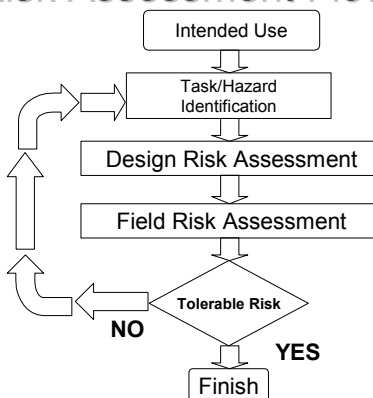


Figure B.1

Step 1

Using the brainstorming technique, develop a list of all tasks performed on the IAD, application or process. Include all operator, maintenance, clean-up and quality tasks. Include all tasks done daily, weekly, monthly, quarterly, semi-annually, annually, bi-annually, etc.

Once developed, sequentially number each task and place this in a location convenient for everyone to refer to (such as on the wall if using a flip chart) during the remaining steps in the process. See examples in Figure B.2.

	TASKS	HAZARDS	NOTES
1	Operator picks part		
2	Maneuver to location		
3	Disengage end-effector and home		
	Continue identifying all tasks.		

Figure B.2 – Sample data gathering of Tasks

Continuing the same brainstorming technique, select the first task off the task list and develop a comprehensive list of all hazards associated with that specific task. Sequentially number each hazard. See examples in Figure B.3.

	HAZARD	SEVERITY	EVENT PROBABILITY	AVOIDANCE
1	Unexpected IAD motion			
2	Impact other person in work area			
3	Slip/fall same level			
4	High speed device motion			
5	Pinch point between IAD and product rack			
	Continued list of potential hazards			

Figure B.3 – Sample data gathering of Hazards

For each hazard have the group, using consensus, identify the severity, event probability and probability of avoidance, based on the criteria in Table B.1. See examples in Figure B.4.

	HAZARD	SEVERITY	EVENT PROBABILITY	AVOIDANCE
1	Unexpected IAD motion	S2	E2	A1
2	Impact other person in work area	S2	E2	A1
3	Slip/fall same level	S1	E2	A1
4	High speed device motion	S2	E1	A2
5	Pinch point between IAD and product rack	S2	E2	A1
	Continued list of potential hazards			

Figure B.4 – Sample determination of severity, event probability, and avoidance

Factor	Category		Criteria
Severity	S2	Serious Injury	Normally irreversible; or fatality; or requires more than first-aid as defined in OSHA §1904.12
	S1	Slight Injury	Normally reversible; or requires only first-aid as defined in OSHA §1904.12
Event Probability	E2	High probability	The likelihood that an identified failure mode will cause exposure to the hazard.
	E1	Low probability	The likelihood that an identified failure mode will not cause exposure to the hazard.
Avoidance	A2	Not Likely	Cannot move out of way; or inadequate reaction time; or speed greater than 250 mm/sec
	A1	Likely	Can move out of way; or sufficient warning/reaction time; or speed less than 250 mm/sec

Table B.1 – Hazard Severity/Event Probability/Avoidance Categories

NOTE – Event probability can be affected by either a change in the frequency that the task is performed or by the application of an index R2 risk reduction safeguard or application of lockout to control the hazard by removal of the energy source that reduces exposure to the hazard. Determining event probability can require judgment decisions by the person(s) performing the risk assessment. When determining proper safeguards, it should be noted that serious injuries have resulted from infrequent tasks.

Avoidance can be affected by: a) reducing the speed of the hazard to give sufficient warning/reaction time, or b) through the application of a category R2 risk reduction safeguard, or c) installation of awareness devices.

Next go back to the task list and add the associated hazards and identify any changes to severity, event probability or avoidance based on the specific task. See examples in Figure B.5.

	TASKS	HAZARDS	NOTES
1	Operator picks part	1,3,5	
2	Maneuver to location	1,2,3,5	
3	Disengage end-effector and home	1,2,3,4,5	
	Continue identifying all tasks.		

Figure B.5 – Sample data gathering of task and hazard combinations

Step 2

For each task and hazard combination, and prior to applying any additional safeguards, follow the matrix in Table B.2 to identify the risk reduction index. See examples in Figure B.6.

Sequence No.	Task Description	Hazards	Prior to safeguard selection				Solution	After safeguard installation			
			Severity	Event probability	Avoidance (Speed) (Blind Spots) (Environment)	Risk Index		Event probability	Avoidance (Speed) (Blind Spots) (Environment)	Severity	Risk Index
			S1 or S2	E1 or E2	A1 or A2			E1 or E2	A1 or A2	S1 or S2	
1	Operator picks part	Unexpected IAD motion	S2	E2	A1	R2A					
1	Operator picks part	Slip/fall same level	S1	E2	A1	R3A					
1	Operator picks part	Pinch point IAD/product rack	S2	E2	A1	R2A					
2	Maneuver to location	Unexpected IAD motion	S2	E2	A1	R2A					
2	Maneuver to location	Impact other person in work	S2	E2	A1	R2A					
2	Maneuver to location	Slip/fall same level	S1	E2	A1	R3A					
2	Maneuver to location	Pinch point IAD/product rack	S2	E2	A1	R2A					

Figure B.6 – Sample documentation of risk reduction index

SEVERITY OF INJURY	EVENT PROBABILITY	AVOIDANCE	RISK REDUCTION INDEX
S2 Serious Injury More than First-aid	E2 High	A2 Not Likely	R1
		A1 Likely	R2A
	E1 Low	A2 Not Likely	R2B
		A1 Likely	R2B
S1 Slight Injury First-aid	E2 High	A2 Not Likely	R2B
		A1 Likely	R3
	E1 Low	A2 Not Likely	R3
		A1 Likely	R4

Table B.2 – Risk reduction decision matrix prior to safeguard selection

NOTE – This table assumes that no additional safeguards are installed.

Repeat this process until all tasks and hazards are listed. Add any additional hazards in a sequential order. Be aware that the event probability and avoidance may change for the same hazard based on the different tasks.

Step 3

Select an appropriate safeguard for each task and hazard combination based on the Risk Reduction Index determined from Table B.2. Use Table B.3 to determine the safeguard and controls performance required based on severity, event probability and avoidance criteria. Select appropriate safeguards from those listed in Annex C. Select overall safeguarding for the IAD based on the highest risk reduction index of task and hazard combinations. See examples in Figure B.7.

Sequence No.	Task Description	Hazards	Prior to safeguard selection				Solution	After safeguard installation			
			Severity	Event probability	Avoidance (Speed) (Blind Spots) (Environment)	Risk Index		Event probability	Avoidance (Speed) (Blind Spots) (Environment)	Severity	Risk Index
			S1 or S2	E1 or E2	A1 or A2			E1 or E2	A1 or A2	S1 or S2	
1	Operator picks part	Unexpected IAD motion	S2	E2	A1	R2A	Install interlocked operator safety sensor				
1	Operator picks part	Slip/fall same level	S1	E2	A1	R3	Install breakaway device				
1	Operator picks part	Pinch point IAD/product rack	S2	E2	A1	R2A	Install safety mat where clearance is not provided				
2	Maneuver to location	Unexpected IAD motion	S2	E2	A1	R2A	Install interlocked operator safety sensor				
2	Maneuver to location	Impact other person in work	S2	E2	A1	R2A	Install human presence detector				
2	Maneuver to location	Slip/fall same level	S1	E2	A1	R3	Install breakaway device				
2	Maneuver to location	Pinch point IAD/product rack	S2	E2	A1	R2A	Install safety mat where clearance is not provided				
3	Disengage & home	High speed device motion	S2	E1	A2	R2B	Install monitored interlock on speed control				

Figure B.7 – Sample documentation of safeguard selection

INDEX	SAFEGUARD PERFORMANCE	CONTROLS PERFORMANCE
R1	Hazard elimination or hazard substitution	Control reliable (5.1.3)
R2A	Engineering controls preventing access to the hazard, or stopping the hazard, e.g. interlocked barrier guards, light curtains, safety mats, or other presence sensing devices	
R2B		
R3	Non-interlocked barriers, clearance, procedures and equipment	Basic safety controls (5.1.1)
R4	Awareness means	

Table B.3 – Safeguard Selection Matrix

NOTE – Application of the Safeguard Selection Matrix (Table B.3) and Safeguard Selection Validation Matrix (Table B.4) are primarily intended for machinery, equipment, and process related task and hazard combinations. Certain task and hazard combinations such as material related tasks that include exposure to sharp parts, thermal and ergonomic hazards require the application of the highest level of feasible safeguarding based on the hierarchy of safety (Figure B.9) and fall outside the scope of Tables B.3 and B.4. Appropriate standards and regulations should also be consulted.

Step 4

After all safeguards are identified repeat steps 1-3 using Table B.4 to ensure each hazard has been addressed, and identify any remaining hazards. Determine that any risks from remaining hazards are at a “tolerable” level. This is considered residual risk. See examples in Figure B.8.

NOTE – Determining “tolerable” will vary by user or organization, and is a subjective value of acceptance of potential harm.

Sequence No.	Task Description	Hazards	Prior to safeguard selection				Solution	After safeguard installation			
			Severity S1 or S2	Event probability E1 or E2	Avoidance (Speed) (Blind Spots) (Environment) A1 or A2	Risk Index		Event probability E1 or E2	Avoidance (Speed) (Blind Spots) (Environment) A1 or A2	Severity S1 or S2	Risk Index
1	Operator picks part	Unexpected IAD motion	S2	E2	A1	R2A	Install interlocked operator safety sensor	E1	A1	S2	R3
1	Operator picks part	Slip/fall same level	S1	E2	A1	R3	Install breakaway device	E1	A1	S1	R4
1	Operator picks part	Pinch point IAD/product rack	S2	E2	A1	R2A	Install safety mat where clearance is not provided	E1	A1	S2	R3
2	Maneuver to location	Unexpected IAD motion	S2	E2	A1	R2A	Install interlocked operator safety sensor	E1	A1	S2	R3
2	Maneuver to location	Impact other person in work	S2	E2	A1	R2A	Install human presence detector	E1	A1	S2	R3
2	Maneuver to location	Slip/fall same level	S1	E2	A1	R3	Install breakaway device	E1	A1	S1	R4
2	Maneuver to location	Pinch point IAD/product rack	S2	E2	A1	R2A	Install safety mat where clearance is not provided	E1	A1	S2	R3
3	Disengage & home	High speed device motion	S2	E1	A2	R2B	Install monitored interlock on speed control	E1	A1	S2	R3

Figure B.8 – Sample documentation of safeguard validation

EVENT PROBABILITY	AVOIDANCE	SEVERITY OF INJURY	RISK REDUCTION INDEX
E 2 High	A2 Not Likely	S2 Serious Injury	R1
		S1 Slight Injury	R2B
	A1 Likely	S2 Serious Injury	R2A
		S1 Slight Injury	R3
E1 Low	A2 Not Likely	S2 Serious Injury	R2B
		S1 Slight Injury	R3
	A1 Likely	S2 Serious Injury	R3
		S1 Slight Injury	R4

Table B.4 – Safeguard selection validation matrix with additional safeguards installed

NOTE – See note with Table B.1 for additionally cautionary information.

Step 5

Keep completed risk assessment on file. Example formats are in Figures B.10-11. Use these files to feedback safeguarding selections into the design-in process for future IAD applications. The user should verify the effectiveness of the risk assessment and the safeguards that were selected.

Most Effective	1) Elimination or Substitution	<ul style="list-style-type: none"> • eliminate hazard in the process • eliminate pinch points (increase clearance) • automated material handling
↓	2) Engineering Controls (Safeguarding Technology)	<ul style="list-style-type: none"> • mechanical hard stops • barriers • interlocks • presence sensing devices • two hand controls
↓	3) Awareness Means	<ul style="list-style-type: none"> • lights, beacons and strobes • computer warnings • signs • restricted space painted on floor • beepers • horns • labels
↓	4) Training and Procedures (Administrative Controls)	<ul style="list-style-type: none"> • safe job procedures • safety equipment inspections • training • lockout
↓	5) Personal Protective Equipment	<ul style="list-style-type: none"> • safety glasses • ear plugs • face shields • gloves • hard hats
Least Effective		

Figure B.9 – Hierarchy of Safeguarding Controls

RISK ASSESSMENT REPORT		
Company:	Location:	Date:
Device/Cell Identification:	Accomplished by:	
Manufacturer and Model Number:	Approved by:	Date:
Date of Manufacture:	Review/revision dates:	
General description of application (Narrative):		
General comments:		

To be accomplished in accordance with Draft BSR T15.1

Figure B.10 – Sample risk documentation, cover

Annex C

(Informative)

Guidelines for safeguard device installation

C.1 General requirements for safeguarding devices that signal a stop

Safeguarding devices which initiate a stop signal should:

- a) be interfaced with the control system such that the detection of an intrusion into the hazard area would cause the hazard to cease;
- b) be installed and arranged so that persons cannot enter the hazardous area without the intrusion being detected, and cannot reach a hazard before the hazardous conditions have ceased;
- c) not allow the restart of automatic operation by the removal of the intrusion without a deliberate action outside the safeguarded space;

NOTE – This would not apply if the device is functioning in a Presence Sensing Device Initiation mode.

- d) provide for control over adjustments or settings being made by other than authorized personnel.

have a readily observable indication that the device is functioning;

NOTE – Indicator lamps compliant with ANSI/NFPA 79 should be provided for all presence-sensing devices to indicate that the device is functioning. The lights may be integral to the device or part of the interface to the system control.

Where color blindness is a consideration, unambiguous positioning, patterning, labeling, or flashing of the indicator may be an effective method of providing indication.

C.2 Safety light curtains/screens

Safety light curtains/screens should:

- a) meet the requirements of C.1;
- b) be installed at a safety distance that accounts for the increased object sensitivity, when blanking (fixed or floating) is used unless the opening is completely obstructed;
- c) visibly indicate the fixed blanked area, or the user should verify that blanking is being used (or not used) as intended, including the number, size and location of the blanked beams;
- d) visibly indicate the number of floating beams or object sensitivity, otherwise the user should verify that floating blanking is being used as intended.

NOTE – Fixed and Floating Blanking creates holes in the light curtain's coverage that are needed in some applications. If an obstruction does not fill the "holes", then the light curtain is installed at a greater safety distance due to the increased object sensitivity. Without visible indication of the blanked area or the number of floating beams enabled, the configuration may be changed with indication. If only one floating beam is allowed, a single specific floating beam indicator would indicate the number of floating beams. Although the changes would require access, it is desirable to verify that the installation integrity is as expected.

- e) be installed so reflective surfaces do not cause the device to fail to respond to the presence of personnel.

C.3 Area scanning safeguarding devices

Area scanning safeguard devices should:

- a) meet the requirements of C.1;
- b) be installed for a safety distance and detecting plane height that accounts for the detection zone's maximum object sensitivity and also includes the device's total range measurement tolerance in the safety distance calculation, see Table C.1

NOTE – Object sensitivities greater than 70 mm may not detect ankles, so the height above floor is an important installation consideration.

- c) have a visibly identifiable detection area;
- d) be tested to ensure that the device is able to detect all objects and personnel entering the detection area;

NOTE – For example, dark clothing may be detected only with devices having specific diffused reflectance detection capabilities. These devices operate on a principle of transmitting beams(s) of light to form a detection zone. When an object enters the detection zone, it reflects the transmitted light back to the device, which then evaluates the object's position. The amount of reflected light (degree of reflectance in percent) that can be reliably detected typically ranges from 1.8% to over 90%.

- e) have the detection area verified upon installation, replacement, or changes within the detection area for proper size and coverage before the device will allow the hazardous motion to start or restart.

NOTE – This verification can be accomplished manually by using a programming device, by verifying the marked or intended detection area, or using an operation mode commonly called "test-on-startup", which may require an intrusion into the detection area before the device can be reset. This verification can also be accomplished automatically if the control system can identify that the device has not been moved, relocated, or replaced.

C.4 Radio frequency (RF)/capacitance safeguarding devices

RF/capacitance safeguarding devices should:

- a) meet the requirements of C.1;
- b) have their sensitivity properly set;
- c) be verified, by the user, for proper sensitivity adjustment setting on a routine basis.

C.5 Safety mat systems

Safety mat systems should:

- a) meet the requirements of C.1;
- b) be of sufficient size and geometry to detect intrusion from all places of access;
- c) be securely mounted such that it cannot be inadvertently moved or removed;

NOTE – Means to prevent inadvertent movement may be but are not limited to: secured edging, secured trim, fasteners, recessed, size and weight of large mats.

- d) be installed to minimize tripping hazards;
- e) not exceed minimum object sensitivity where multiple mats are installed together to form a single sensing surface;
- f) have a maximum response time which is less than 100 ms over the system operating temperature range;

NOTE – A total mat system response time of greater than 100 ms may allow a person to step lightly and quickly over the mat's sensing surface without being detected.

- g) have a construction suitable for the application and environment;
- h) be routinely inspected, and function tested per manufacturers recommendations;
- i) be installed and arranged such that reset of the safety function requires removal of the obstruction from the sensing surface followed by a separate and deliberate action outside of the sensing surface, when used as the sole means of safeguarding;
- j) be installed at a safety distance such that the edge of the safety mat sensing surface which is furthest from the hazard is at or beyond the safety distance from the hazard, unless the safety mat is being used solely to prevent start/restart of automatic operation or for pinch point protection where clearance requirements are not met.
- k) the system (mat, controller, wiring between mat and controller) should comply with 8.8.2c

C.6 Single and multiple beam safety systems

Single and multiple beam safety systems should:

- a) meet the requirements of C.1;
- b) be installed so reflective surfaces do not cause the device to fail to respond to the presence of personnel;
- c) not be used for finger or hand detection in a point-of-operation installation.

C.7 Two hand control systems

Two hand control systems when used as the primary means of personnel safeguarding should:

- a) be designed to prevent accidental or unintentional operation;
- b) have the individual operator's hand controls arranged by design, construction, or separation to require the use of both hands within 500 ms to initiate/cycle the system;
- c) require individual hand controls for each operator when multiple operators are safeguarded by two hand controls;
- d) require each operator two hand control station to be concurrently operated before initiation to cycle the robot system, and be maintained during the hazardous portion of the cycle and signal a stop if one or both hands are removed from the controls when the two hand control system is the only means of safeguarding;
- e) require supervisory personnel to deselect operator two hand controls when more than one operator control is provided;
- f) prevent cycling of the system if all operator stations are deselected;
- g) be designed to require the release of all selected operator's hand controls and the re-activation of all operator's hand controls before a system cycle can be initiated;
- h) have all operator's hand controls located in clear view of the hazard for which the operator hand control is being used;
- i) have all operator's hand controls located such that the person operating the controls is located at a safe distance;
- j) provide other safeguarding means for personnel other than those using the two hand controls.

NOTE – Two hand controls only provide protection for the personnel using them.

The following tables provide graphic aid in selecting the proper safeguarding devices.

$$D_s = [K \times (T_s + T_c + T_r)] + D_{pf}$$

where:

D_s = minimum safe distance between safeguarding device and the hazard

K = speed constant: 1.6 m/sec (63 inches/sec) minimum based on the movement being the hand/arm only and the body being stationary

NOTE – A greater value may be required in specific applications and when body motion must also be considered.

T_s = worst stopping time of the machine/equipment

T_c = worst stopping time of the control system

T_r = response time of the safeguarding device including its interface

D_{pf} = maximum travel towards the hazard within the presence sensing safeguarding devices (PSSD) field that may occur before a stop is signaled. Depth penetration factors will change depending on the type of device and application.

Figure C.1 – Safety Distance Formula

	Purpose	Typical Application	Typical Limitations	Considerations
Barriers				Withstand forces needed, no sharp edges
Fixed	Prevents access and contains parts and tools	Perimeter guarding	Does not allow access	Guard opening table, provide visibility for troubleshooting and observation when possible
Interlocked	Signals a stop and contains parts and tools	Access in guarding	Open access	Guard opening and safety distance formula Test & verify that it is still installed as intended
Pins/Mech Locks	Prevent motion	Blocking/locking	Not automatic	Identification, training and procedures
2 Hand Control	Initiates cycle and signals a stop	Prevent start or restart & Signal a stop	Protects one person per two hand control Not for automatic operation	Safety Distance Formula All other access safeguarded
Safety Light Curtain / Screen			May be nuisance stops if used over large area and coverage not obvious Does not contain parts/tools	Safety Distance Formula All other access safeguarded Traffic areas & people gesturing – nuisance stops? Test & verify that it is still installed as intended
Object sensitivity: less than 2.5"	Signals a stop If PSDI then also initiate movement	Prevent start or restart & signal a stop (point of operation)	Does not contain parts/tools	Same as above – plus check blanking
Object sensitivity: greater than 2.5"	Signal a stop	Prevent start or restart & signal a stop (area / perimeter guarding)	Does not contain parts/tools Often not usable to signal a stop due to 36" min Dpf (more space required)	Same as above
Horizontal use	Signal a stop	Prevent start or restart & signal a stop (area guarding)	Does not contain parts/tools Often not usable to signal a stop due to up to 48" Dpf (more floor space)	Same as above
1 / Multiple Beams	Signal a stop	Prevent start or restart & signal a stop	Does not contain parts/tools Not for point of operation guarding	Same as above
Safety Mat System	Signals a stop	Prevent start or restart & signal a stop (area guarding)	Does not contain parts/tools Often not usable to signal a stop due to up to 48" Dpf (more floor space required)	Same as above and Select mat to best withstand installed environment Inspect mat for damage/wear that may affect operation
Scanning Safety Device	Signals a stop	Prevent startup or restart & signal a stop Variable or unusual geometry guarding easily done AGV safeguarding	Does not contain parts/tools Protected area not visible (only w/PC) Object sensitivity and response time varies with program and distance May not detect some clothing (dark) Flashlights may cause nuisance stops (some lighting conditions)	Same as above and identify/mark the safeguarded area Test detection of clothing/colors Compared to other safeguards, requires greater knowledge / expertise to use properly Only 1 size vs many with light curtains and safety mats

Figure C.3 – Safeguarding Selection Aide

	Barriers		Pins/Mech Locks	2 Hand Control	Safety Light Curtain / Screen Object sensitivity			1 / Multi Beams	Safety Mat System	Scanning Safety Device
	Fixed	Interlocked			< 2.5"	> 2.5"	Horizontal			
HOW DOES THE SAFEGUARD WORK?										
Contains Hazards (projectiles or fluids/gases)	X	X								
Electrically signals a stop / the hazard to cease		X		X	X	X	X	X	X	X
Accessibility										
Prevents Access	X									
Fairly Easy to Access		X	X							
Very Easy to Access				X	X	X	X	X	X	X
Protects only 1, not many, per safeguard device				X						
TYPICAL APPLICATIONS										
Access Required										
No access is needed, at all	X									
Limited access is needed		X								
Easy & frequent access is needed			X	X	X	X	X	X	X	X
Prevent motion / hazard by performing procedure	X		X							
Point of operation Safeguard								NO		
Automatic operation										
No access needed	X									
Some access needed		X								
Easy & close access		X			X					
Needed and there is limited space (for Dpf)		X			X					Depends
Needed, but space is available for Dpf		X			X	X	X	X	X	X
Typically manual feed (load/unload)										
Close, and quick access needed		X		X	X					
Close & quick access not needed (large Dpf OK)						X	X		X	X
Perimeter or Area Guarding										
Floor space not available (space is issue for large Dpf)		X			X					Depends
Floor space available (large Dpf OK)		X			X	X	X	X	X	X
Prevent Start / Re-start			X		X	X	X	X	X	X
Unusual shape / geometry of guarding										X

OTHER APPLICATION ISSUES	Barriers		Pins/Mech Locks	2 Hand Control	Safety Light Curtain / Screen Object sensitivity			1 / Multi Beams	Safety Mat System	Scanning Safety Device
	Fixed	Interlocked			< 2.5"	> 2.5"	Horizontal			
Notes						Large Dpf	Large Dpf	Large Dpf	Large Dpf	Sensing field not visible
Safety Distance:										
Guard Opening Table	X	X								
Safety Distance Formula		X		X	X	X	X	X	X	X
Depth Penetration Factor adder to Safety Distance					X	X	X	X	X	X
Muting Allowed		X		X	X	X	X	X	X	X

Figure C.3 – Safeguarding Selection Aide (concluded)

Annex D
(Informative)
Bibliography

The following standards contain additional and related information relative to applications in which Intelligent Assist Devices may be used but are not essential for the completion of the requirements of this standard. When superseded by an approved revision, the revised standard shall apply. The American National Standards Institute, 25 West 43rd Street, New York, NY 10036 (212) 642-4900 offers electronic versions of ANSI, ISO, and IEC standards through its Electronic Standards Store on the Internet at www.ansi.org

ANSI B11.1-1988 (R1994), *Mechanical power presses*
ANSI B11.2-1995, *Hydraulic presses*
ANSI B11.3-1982 (R1994), *Power press brakes*
ANSI B11.4-1993, *Shears*
ANSI B11.6-1984 (R1994), *Lathes*
ANSI B11.8-1983 (R1994), *Drilling, milling and boring machines*
ANSI B11.9-1975 (R1997), *Grinding machines*
ANSI B11.10-1990 (R1998), *Metal sawing machines*
ANSI B11.11-1985 (R1994), *Gear-cutting machines*
ANSI B11.19-1990 (R1996), *Safeguarding performance criteria*
ANSI B11.20-1991 (R1996), *Safety requirements for flexible manufacturing systems/cells*
ANSI Z136.1-1993, *Safe use of lasers*
ANSI Z244.1-1982 (R1993), *Safety Requirements for the Lock Out/Tag Out of Energy Sources*
ANSI Z535.1-1998, *Safety Color Code*
ANSI Z535.2-1998, *Environmental and Facility Safety Signs*
ANSI Z535.3-1998, *Criteria for Safety Symbols and Labels*
ANSI Z535.4-1998, *Product Safety Signs and Labels*
ANSI Z535.5-1998, *Accident Prevention Tags (for Temporary Hazards)*
ANSI/UL508-1988, *Industrial Control Equipment*
ANSI/UL969-1991, *Standard for safety - marking and labeling systems*
UL 991 - *Tests for safety-related controls employing solid-state devices*

The following list of other documents may be of additional assistance to the user of this Standard but is not all inclusive.

Accident Prevention Manual for Business & Industry: Administration & Programs — 11th ed.

Available from the National Safety Council, 1121 Spring Lake Dr., Itasca, IL 60143 (630) 285-1121

Hard copies of standards produced by ANSI, ISO, IEC, CEN, CENELEC, Underwriters Laboratory and other standards developers may be obtained from:

Global Engineering Documents
15 Iverness Way East
Englewood, CO 80112

Phone (800) 854-7179 (U.S. and Canada), (303) 397-7956 (International), FAX (303) 397-2740, and on the internet at <http://global.ihs.com>

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