Risk Reduction Measures/Methods In Manufacturing

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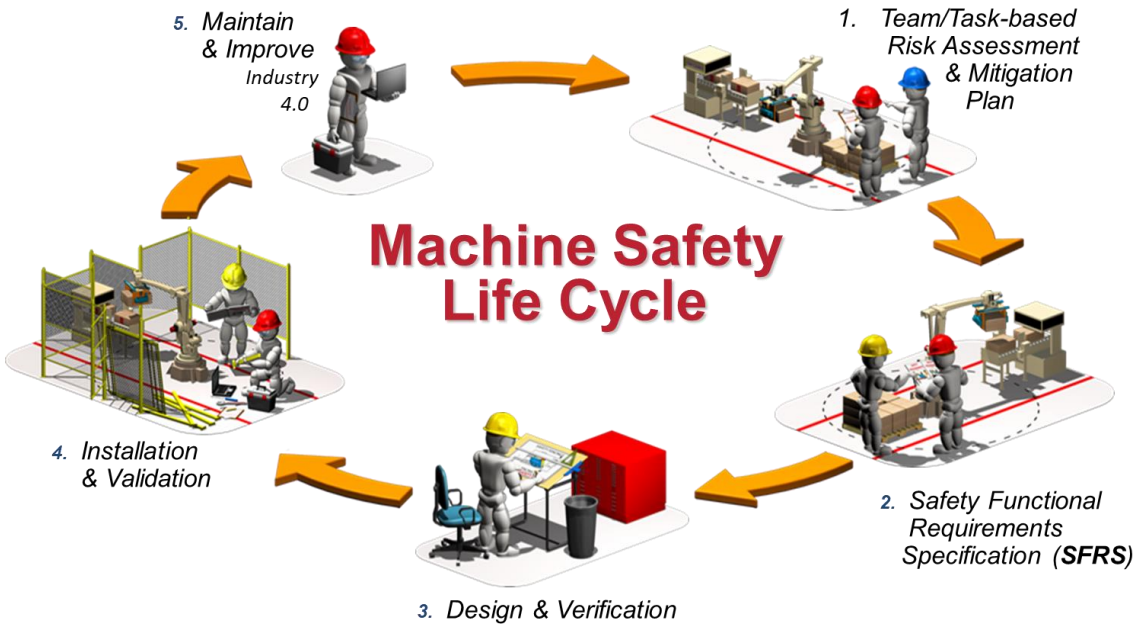
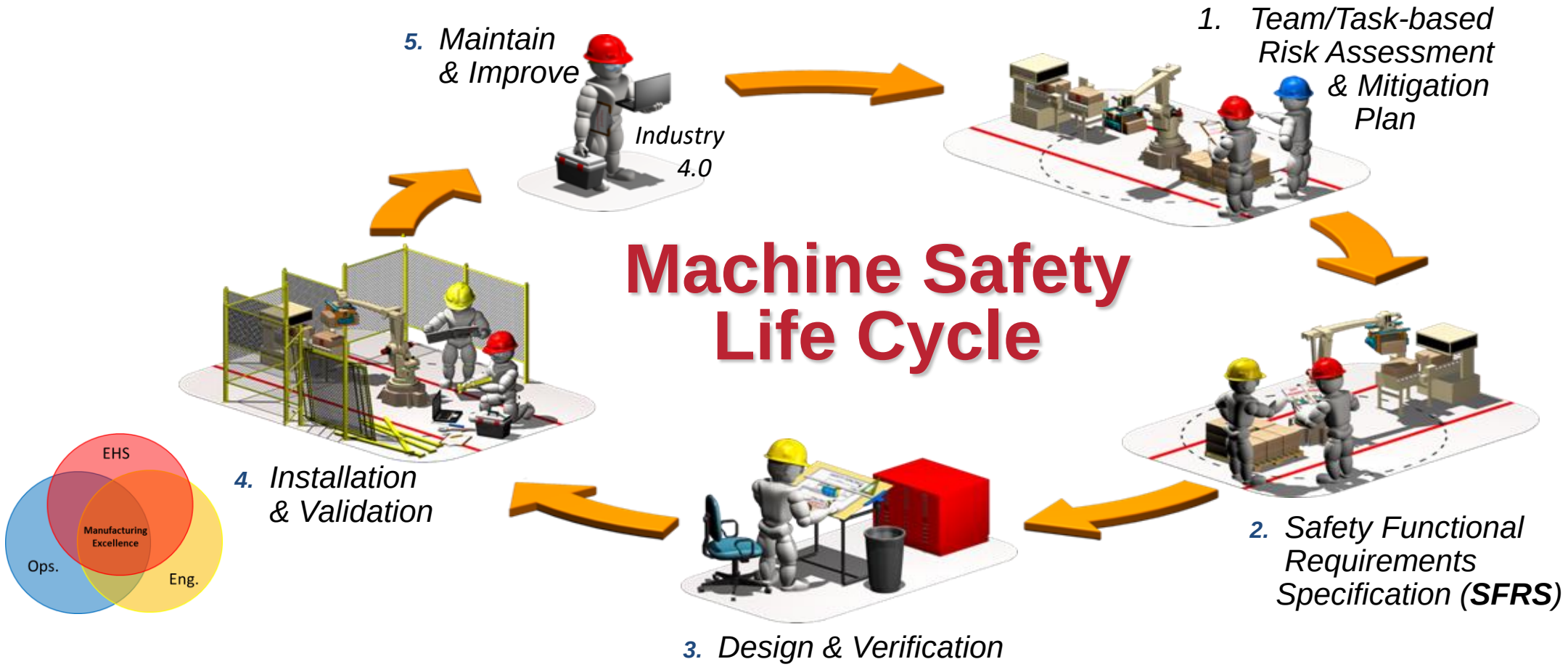


ISO, IEC, ANSI, RIA, etc.
Functional Safety Life Cycle



Risk Estimation/Score in three states

Machine Task/Hazard-Based Risk Assessment

Three machine state version: without, existing, and future risk reduction measures.

Name & Company	Titles/Roles:	Name & Company	Titles/Roles:
Al Bino	Plant Eng	Harry Azorac	Plant Elect. Eng.
Lee Nover	Plant Eng - Portage, IN	Kareem O'Weet	Process Tech.
Berry McCokinner	Lead Elect. Maint.		
Haywood Jablomi	Pickle Line - Trainer		
Pat Myaz			
Michael Hunt			
Mark Eitzman - IMS			

Cross-functional team

Machine Info.		Assessment Info.	
Name / ID:	Client/machine info	Date(s) of Assessment:	20-Jul-20
Plant:	Coil finishing	Revision:	0
Department:	Shipping	Risk Assessment Scope and limits:	Specific area, production line or machine

). Third party validation

Zone/Area	x.x.x.x Person Task Step Hazard	Person	Task	Steps	Potential Hazards	Ref pic	Initial Risk Estimate (without Risk Reduction Measures) ANSI/RIA TR R15.306-2016 Scoring System: Severity	Exposure	Avoidance	Risk Level	Is a Control Circuit required?	Minimum Functional Performance Required			Existing Estimate (with existing Risk Reduction Measures): Design	Engineering Controls	Administrative Controls	Existing Actions / Measures	Existing Risk Estimate ANSI/RIA TR R15.306-2016 Scoring System: Severity	Exposure	Avoidance	Risk Level	Future Estimate (with proposed Risk Reduction Measures): Design	Engineering Controls	Administrative Controls	Future Actions / Measures	Future Risk Estimate ANSI/RIA TR R15.306-2016 Scoring System: Severity	Exposure	Avoidance	Risk Level
Coil Prep	5.5.5.1	Operator 1	Transfer coil from "hot band saddles" the blocker rolls	Position coil car under the center of the coil on the hot band saddle	Crushing between the moving coil car and the stationary parts of the pit and saddles	1	S3	E2	A3	Very High	Yes	e	4	Control Reliable	X	X	X	Ops station's location positions operator far enough away from the hazard, Training and awareness. A non-safety rated photo eyes wired to standard logic hardware to detect presence around edge integrated with standard logic in the PLC and stops non-safety rated actuators controlling hazardous motion	S3	E2	A2	High	X	X		perimeter guard along the east & wes side of the pit, proper access control via perimeter guard and gate access control - trap key on Ops station's location with access key for gate access interlocked with safety rated controls	S3	E0		Low
Coil Prep					under coil that may fall off of ar	1	S2	E1		Medium	Yes	d	2	Control	X	X	X	Training/Awareness, PPE	S2	E1		Medium				physical retainment barrier impractical for protection (47 ton max coil)	S2	E0		Low
Coil Prep	5.5.10.2	Operator 1	Transfer coil from "hot band saddles" the blocker rolls	Raise the coil car to lift the coil off of the hot band saddle and jog it into position	Struck by coil										X	X						2 Low	X	X		physical retainment barrier impractical for protection (47 ton max coil)	S1	E0		Negligible
Coil Prep	5.5.15.1	Operator 1	Transfer coil from "hot band saddles" the blocker rolls	Rotate the coil on the blocker rolls to position the tail under the coil so that it is pinned by both rollers	In running nip of the coil rotating on the blocker rolls	3	S3	E2	A1	High	Yes	d	3	Control Reliable	X	X	X	Ops station's location positions operator far enough away from the hazard, Training and awareness. A non-safety rated photo eyes wired to standard logic hardware to detect presence around edge integrated with standard logic in the PLC and stops non-safety rated actuators controlling hazardous motion	S3	E1		High				location with access key for gate access interlocked with safety rated controls				
Coil Prep	5.5.15.2	Operator 1	Transfer coil from "hot band saddles" the blocker rolls	Rotate the coil on the blocker rolls to position the tail under the coil so that it is pinned by both rollers	Crushing due to coil falling off of the blocker roll	2	S3	E2	A3	Very High	Yes	e	4	Control Reliable	X	X	X	Ops station's location positions operator far enough away from the hazard, Training and awareness. A non-safety rated photo eyes wired to standard logic hardware to detect presence around edge integrated with standard logic in the PLC and stops non-safety rated actuators controlling hazardous motion	S3	E1		High				none other than awareness - physical retainment barrier impractical for protection (47 ton max coil)	S3	E1		High
Coil Prep	5.5.15.3	Operator 1	Transfer coil from "hot band saddles" the blocker rolls	Rotate the coil on the debanding rolls to position the tail under the coil so that it is pinned by both rollers	Struck or cut by a broken band	2	S2	E2	A2	High	Yes	d	3	Control Reliable	X	X	X	Ops station's location positions operator far enough away from the hazard, Training and awareness. A non-safety rated photo eyes wired to standard logic hardware to detect presence around edge integrated with standard logic in the PLC and stops non-safety rated actuators	S2	E1		Medium	X	X		perimeter guard along the east & west side of the pit. An opening in the perimeter guard on the west side at the blocker rolls will detect a person with a safety area scanner. The scanner is interlocked with the coil ears, blocker rolls, hold down roll and	S2	E0		Low

Person.Task.Steps.Hazards

Initial/No Risk Reduction

Existing Measures

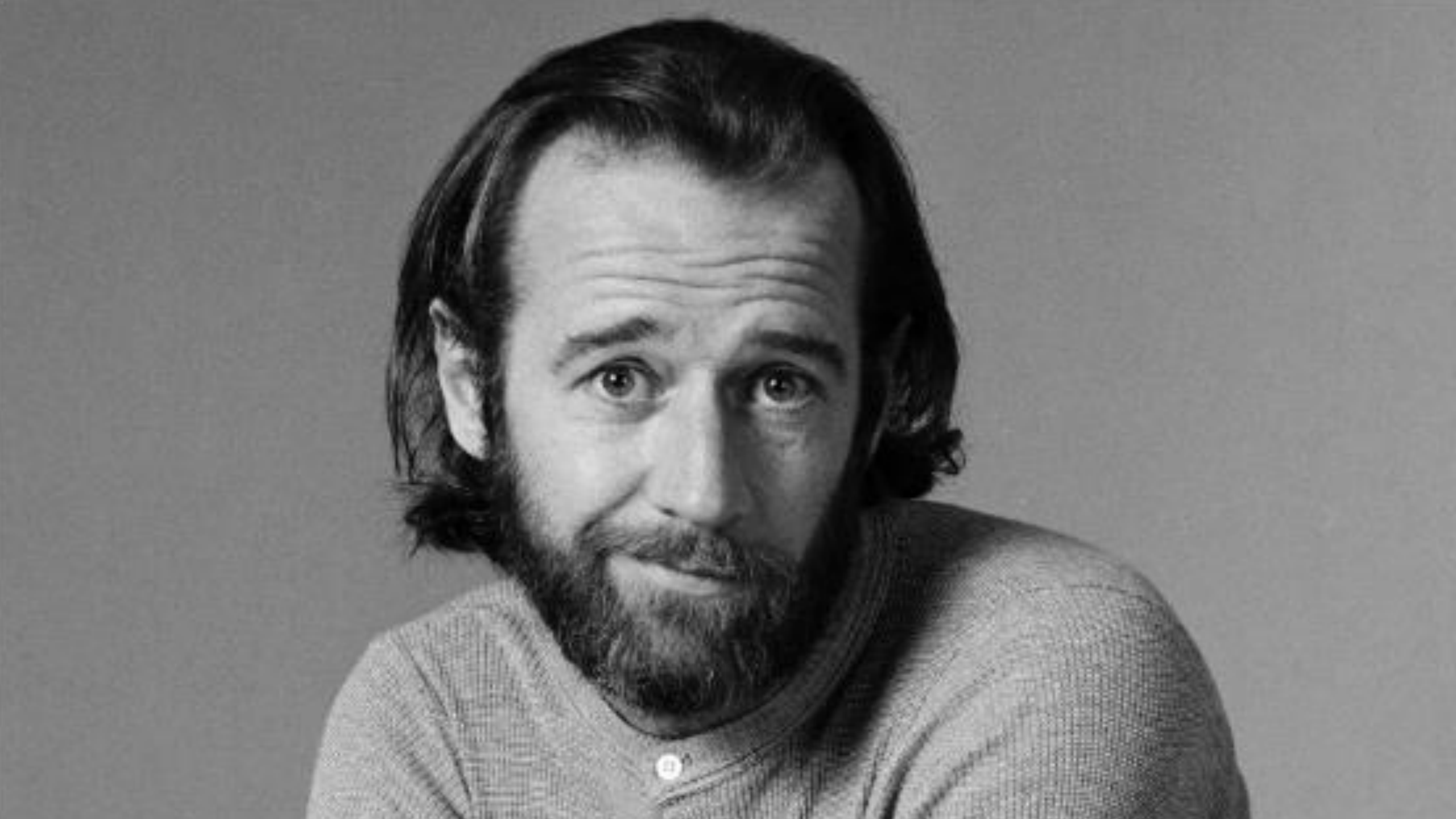
Future Measures/Residual

Definition

SAFETY is…. Freedom from unacceptable **RISK**

RISK is… a combination of **SEVERITY** and **PROBABILITY**

ACCEPTABLE RISK is… **UP TO YOU!**



Risk Estimation & Risk Reduction Methods

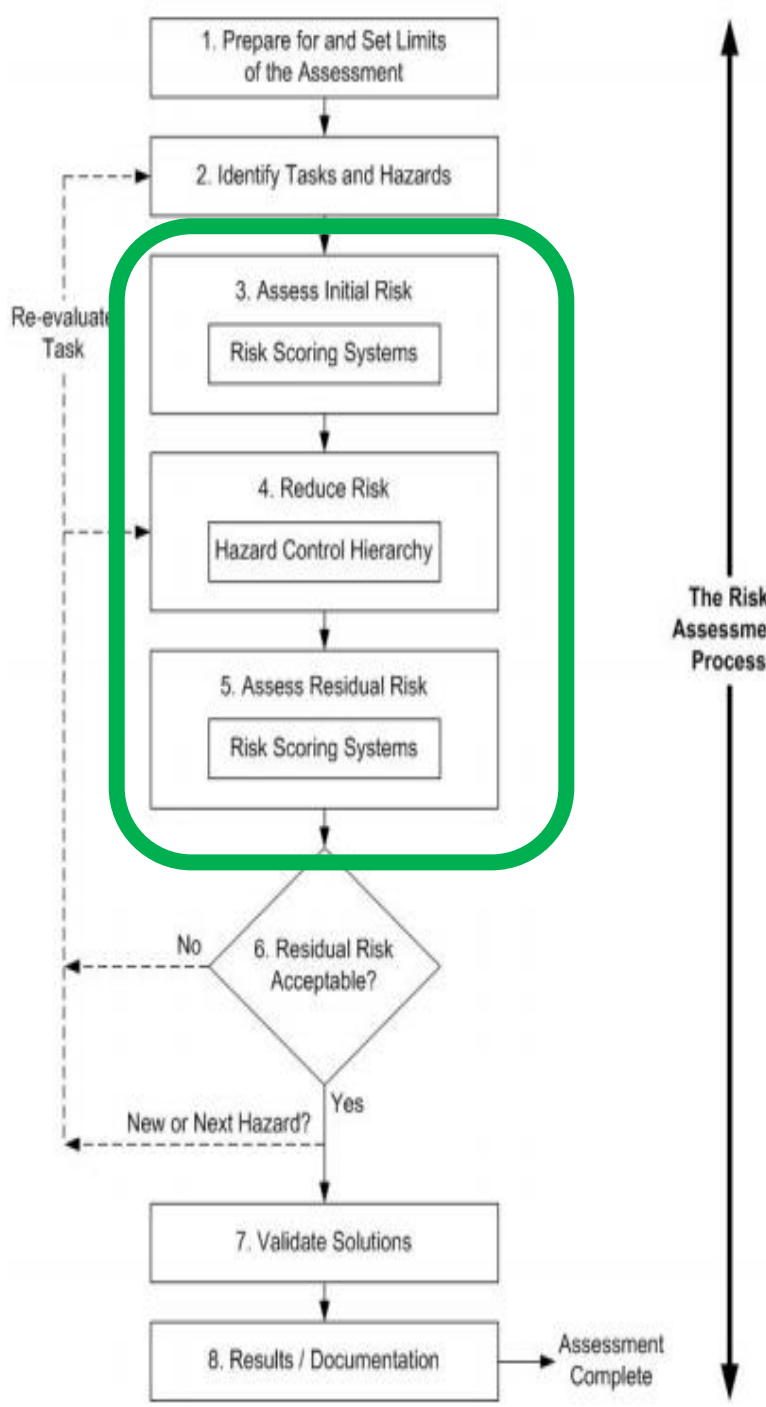
A clear and consistent means to determine a risk level

Risk Level				
VERY HIGH	HIGH	MEDIUM	LOW	NEGLIGIBLE

Hazard + People = Risk

Risk Estimation is the combination of the;

- **Severity of harm + Probability of occurrence**
- **Probability is frequency of exposure + avoid-ability**



Redesign the machine or change the process

Guarding, gates, sensors, controls

Lights, signs, rules, training, LOTO, PPE

Most Preferred

Least Preferred

Table 6 — Potential Effects/Additional Characteristics of Risk Reduction Measures

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability			Failure	Error / Misuse
Classification	Type			Expo-sure	Avoid-ance	Occur-rence		
Inherently Safe by Design (Redesign)	Limiting Interaction	modify the process to eliminate/reduce human interaction		•		•		•
	Elimination	replace task, increase clearance	•	•				
		energy magnitude reduction	•			•	•	
	Substitution	automated material handling	•	•	•	•	•	•
		use less hazardous chemicals	•			•		•
		reduce force, speed, etc. through selection of inherently safe components	•		•			
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	
Administrative Controls	Awareness Means (Warnings & Instructions)	awareness barriers		•	•	•		•
		awareness signals (audible and/or visible)			•	•	•	•
		awareness signs / markings			•	•		•
	Information for Use (Training & Procedures)	safe work procedures, training			•	•		•
	Administrative Methods	safe-holding safeguarding method			•	•		•
	Supervision	supervisory control of configurable elements			•	•		•
	Control of hazardous energy	isolation of hazardous energy	•	•		•		•
	Tools	hand tools	•		•	•	•	•
	PPE	safety glasses, hearing protection, gloves	•		•	•	•	•

Risk estimation/rating determines the recommended **primary** risk reduction measure

RIA TR R15.306-2016

Risk Reduction Measure	Risk Level				
	VERY HIGH	HIGH	MEDIUM	LOW	NEGLIGIBLE
Elimination	Use of one or a combination of these risk reduction measures are required as a primary means to reduce risks.			Any of the risk reduction measures that would reduce risks to an acceptable level may be used.	
Substitution					
Limit Interaction					
Safeguarding/ SRP/CS					
Complementary Protective Measures	Use of one or a combination of these risk reduction measures may be used in conjunction with the above risk reduction measures but shall not be used as the primary risk reduction measure.				
Warnings and Awareness Means					
Administrative Controls					
PPE					

More preferred

Less preferred

Risk Reduction Measures		
Hierarchy		Examples
Classification	Type	
Inherently Safe by Design (Redesign)	Limiting Interaction	modify the process to eliminate/reduce human interaction
	Elimination	replace task, increase clearance
		energy magnitude reduction
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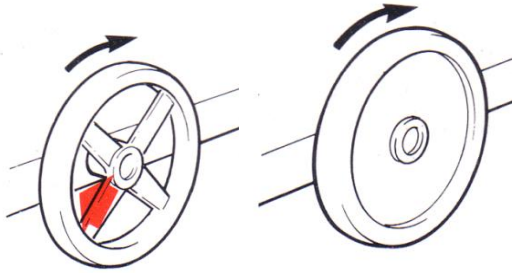
Inherently Safe by Design (Redesign)	Limiting Interaction	modify the process to eliminate/reduce human interaction		•		•		•
	Elimination	replace task, increase clearance	•	•				
		energy magnitude reduction	•			•	•	
	Substitution	automated material handling	•	•	•	•	•	•
		use less hazardous chemicals	•			•		•
		reduce force, speed, etc. through selection of inherently safe components	•		•			
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	
Administrative Controls	Awareness Means (Warnings & Instructions)	awareness barriers		•	•	•		•
		awareness signals (audible and/or visible)			•	•	•	•
		awareness signs / markings			•	•		•
	Information for Use (Training & Procedures)	safe work procedures, training			•	•		•
	Administrative Methods	safe-holding safeguarding method			•	•		•
	Supervision	supervisory control of configurable elements			•	•		•
	Control of hazardous energy	isolation of hazardous energy	•	•		•		•
	Tools	hand tools	•		•	•	•	•
	PPE	safety glasses, hearing protection, gloves	•		•	•	•	•

Inherently Safe by Design or Redesign
Elimination of the hazard

- Eliminate human interaction or exposure
  - Eliminate the task
  - Relocate the operator
- Mechanical or process alteration
  - Automate material handling, robotics
- Modify the machine
  - Elimination of shear points or offset edges
- Product substitution
  - raw material or “support product” like lubricant
- Reducing the energy available/accumulated
  - Kinetic, potential, electrical



For new machines

- **Inherently Safe by Design**
- Suggest that this is in contractual layout (Ts & Cs)
  - Infuse risk assessments and mitigation into the process/contract
  - Collaboration of Supplier/User of Equipment/Machine
  - Risk assessed & mitigated at each stage
  - Specify standards
    - ANSI B11.0-2020 (Risk Assessment)
    - ANSI B11.19-2019 (Mitigation)

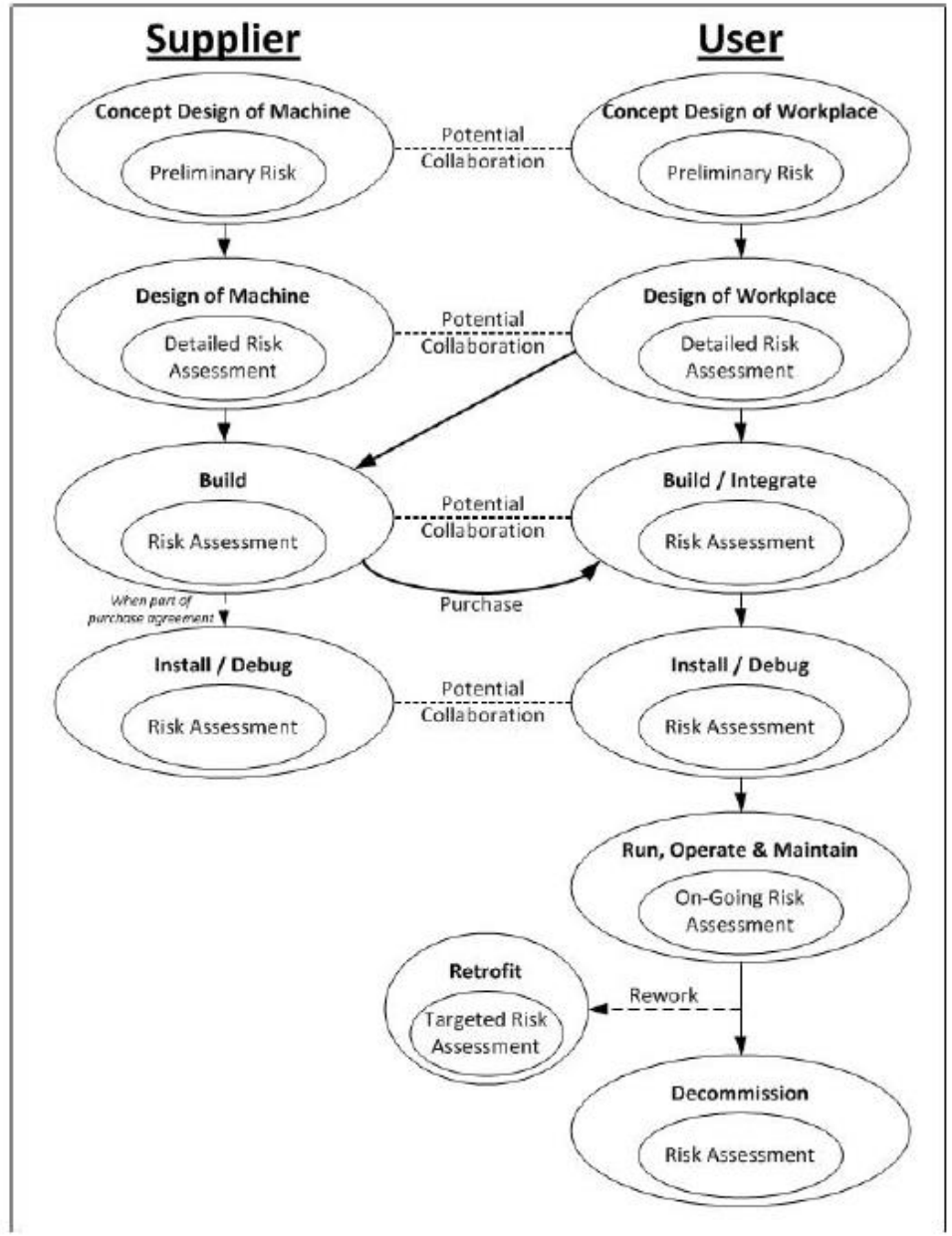
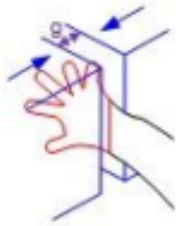
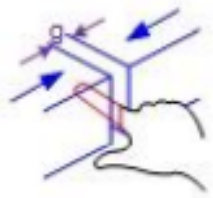


Figure 5 — Example of Machinery Lifecycle Responsibilities

Inherently Safety by Design
ANSI B11.19-2019

- **Inherently safe by design**: A design measure that reduces risk, which is not susceptible to a malfunction that will increase the risk of harm.
- Prevention though design
  - **Safe-opening safeguarding method**
    - When work piece is in place, no room for human (in part or whole)
    - Typically includes an engineered control (guard)
  - **Safe-location safeguarding method**
    - Put hazard out of normal reach (horizontal/vertical)
    - Separate area/room/vault
  - **Maximum gaps to avoid exposure to hazards**
    - ANSI - US = 1/4” (~6mm)
    - ISO – EU = 4mm (~5/32”)
  - **Minimum gaps to avoid crushing of parts of the human body**
    - ANSI B11.19-2019 Table 1





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	Elimination	replace task, increase clearance	•	•				
		energy magnitude reduction	•			•	•	
	Substitution	automated material handling	•	•	•	•	•	•
		use less hazardous chemicals	•			•		•
		reduce force, speed, etc. through selection of inherently safe components	•		•			
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
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	Supervision	supervisory control of configurable elements			•	•		•
	Control of hazardous energy	isolation of hazardous energy	•	•		•		•
	Tools	hand tools	•		•	•	•	•
	PPE	safety glasses, hearing protection, gloves	•		•	•	•	•

Engineering Controls

Machine Guarding

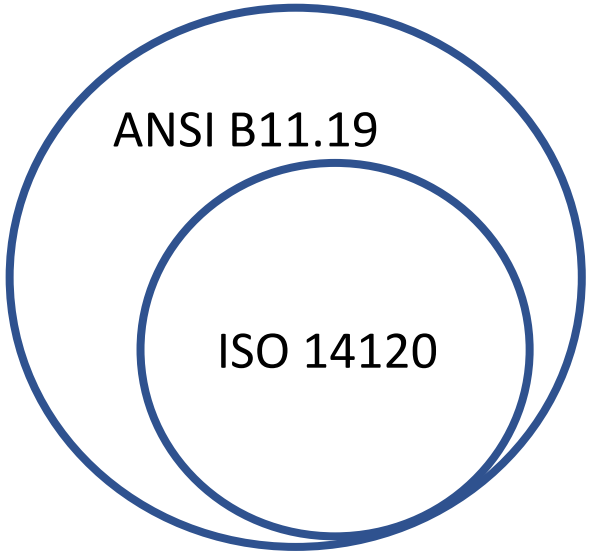
Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

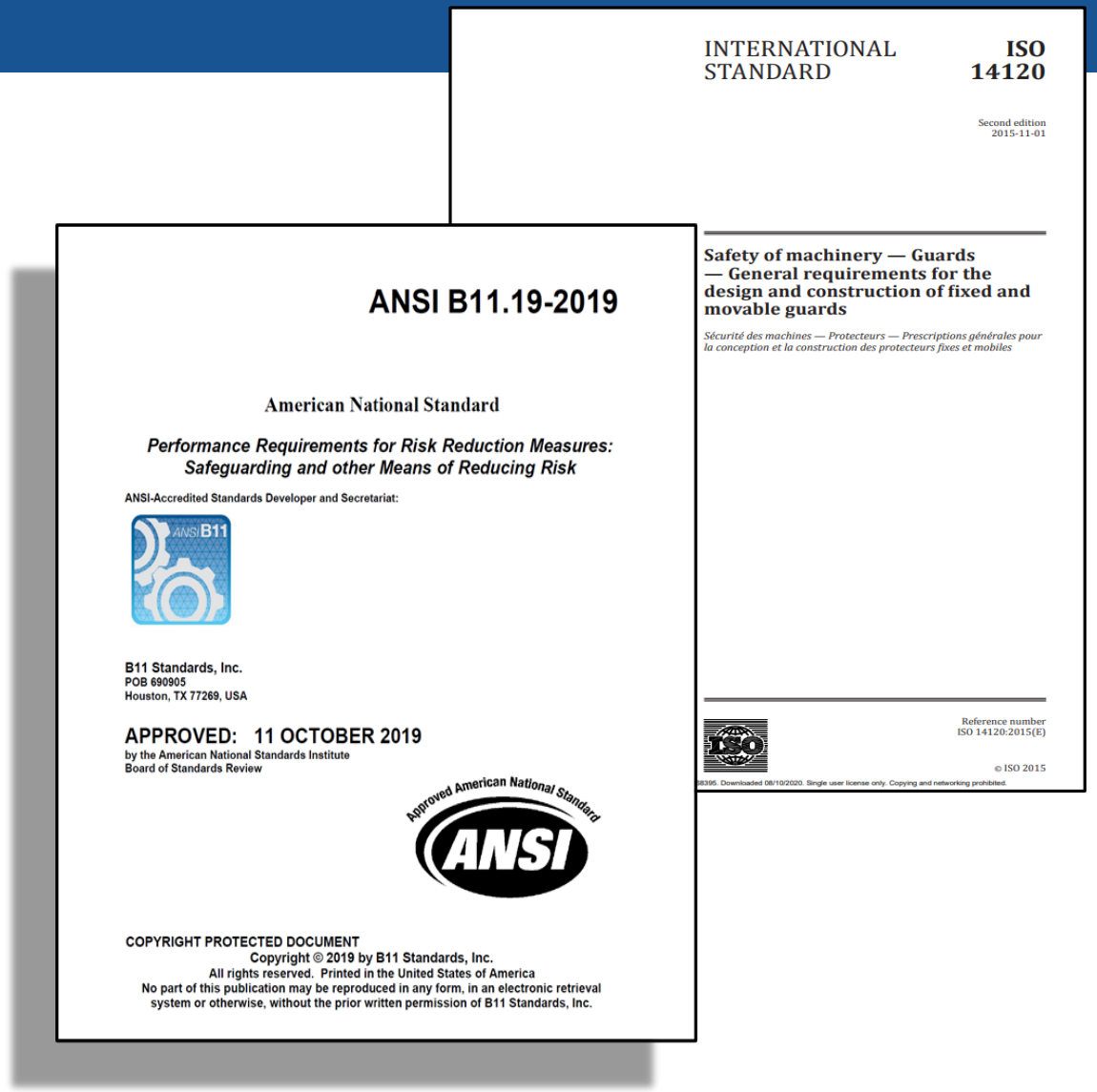
US Law = Requirements

- 1910.212(a)*Machine guarding.*
1910.212(a)(1)*Types of guarding.* One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks. Examples of guarding methods are-barrier guards, two-hand tripping devices, electronic safety devices, etc.
1910.212(a)(2)*General requirements for machine guards.* Guards shall be affixed to the machine where possible and secured elsewhere if for any reason attachment to the machine is not possible. The guard shall be such that it does not offer an accident hazard in itself.

Machine Guarding Requirements

- **ANSI B11.19 – 2019** *-Performance Requirements for Risk Reduction Measures*
  - **ISO 14120-2015** *General requirements for the design and construction of fixed and movable guards*




INTERNATIONAL STANDARD **ISO 14120**

Second edition
2015-11-01

Safety of machinery — Guards — General requirements for the design and construction of fixed and movable guards

Sécurité des machines — Protecteurs — Prescriptions générales pour la conception et la construction des protecteurs fixes et mobiles

Reference number
ISO 14120:2015(E)

ANSI B11.19-2019

American National Standard

Performance Requirements for Risk Reduction Measures: Safeguarding and other Means of Reducing Risk

ANSI-Accredited Standards Developer and Secretariat:

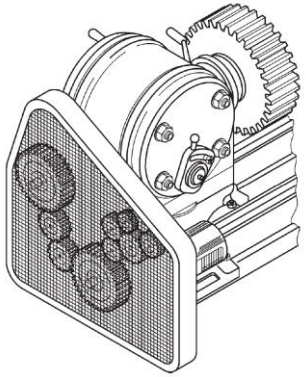
B11 Standards, Inc.
POB 690905
Houston, TX 77269, USA

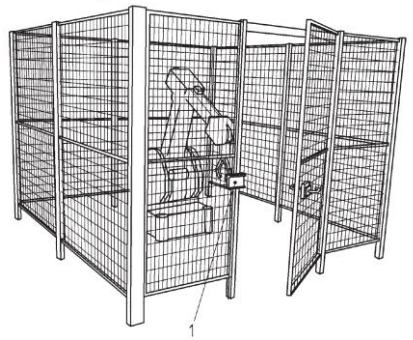
APPROVED: 11 OCTOBER 2019
by the American National Standards Institute
Board of Standards Review

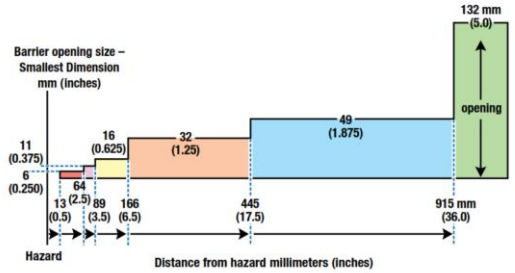
Approved American National Standard
ANSI

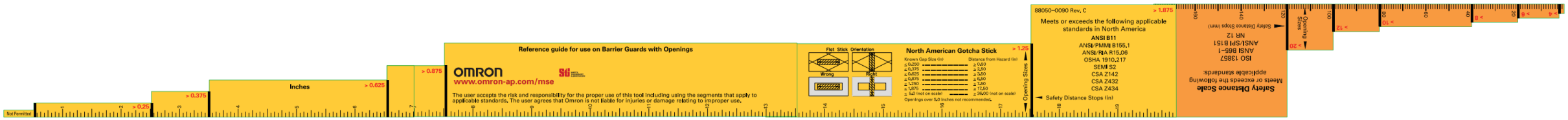
Fixed Guards

- On-machine or perimeter
- Welded or fasteners that require a tool
- Withstand impact forces
- Reasonably foreseeable misuse
- Maintain visibility
- **AUTO** test, **A**round, **U**nder, **T**hrough or **O**ver the guard to access a hazard
  - Depth of Penetration Test (gotcha stick)



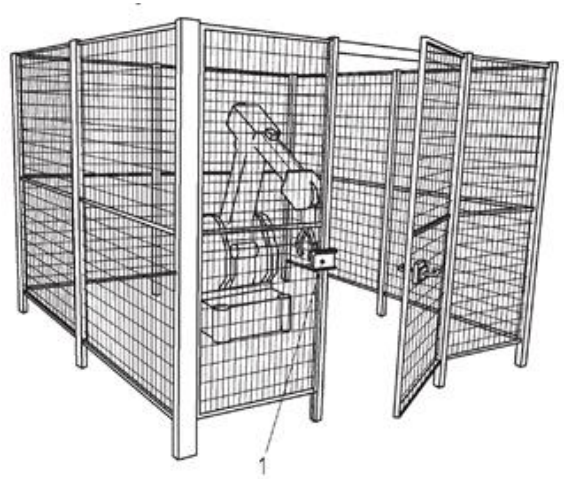






Movable Guards

- On machine or perimeter
  - Gates and Panels
- Most of the same requirements as fixed guards
- Switches & Interlocking Devices & Control Functions
- Safety Distance & Stop Time Calculations



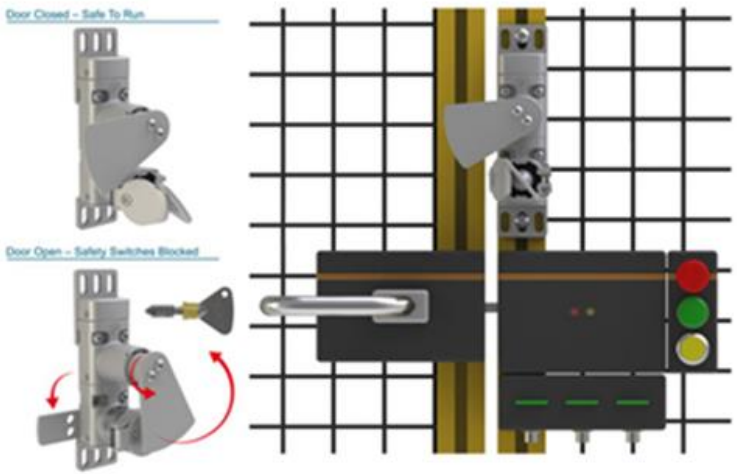


Table E.2 – Horizontal reaching distance when accessing over a protective structure

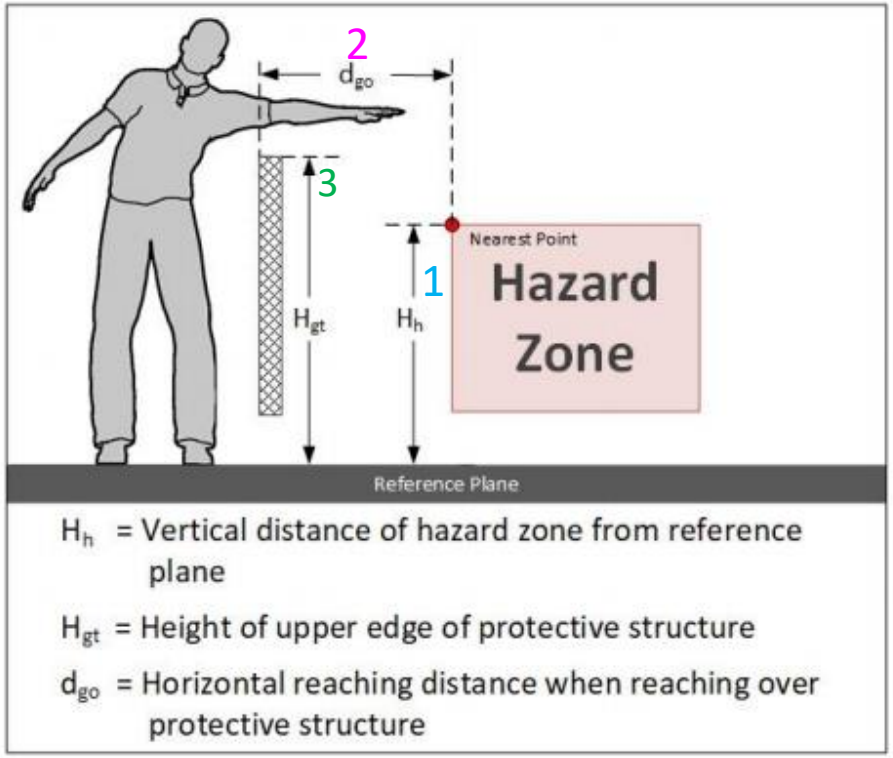
1 Vertical distance of hazard zone from reference plane [3] H_h	3 Height of upper edge of protective structure [1] H_{gt}									
	1 000 mm (39.37") [2]	1 200 mm (47.24") [2]	1 400 mm (55.12")	1 600 mm (62.99")	1 800 mm (70.87")	2 000 mm (78.74")	2 200 mm (86.61")	2 400 mm (94.49")	2 500 mm (98.43")	2 700 mm (106.30")
	2 Horizontal reaching distance toward hazard zone over a protective structure d_{go}									
2 700 mm (106.30")	0	0	0	0	0	0	0	0	0	0
2 600 mm (102.36")	900 mm (35.43")	800 mm (31.50")	700 mm (27.56")	600 mm (23.26")	600 mm (23.62")	500 mm (19.69")	400 mm (15.75")	300 mm (11.81")	100 mm (3.94")	0
2 400 mm (94.49")	1 100 mm (43.31")	1 000 mm (39.37")	900 mm (35.43")	800 mm (31.50")	700 mm (27.56")	600 mm (23.62")	400 mm (15.75")	300 mm (11.81")	100 mm (3.94")	0
2 200 mm (86.61")	1 300 mm (51.18")	1 200 mm (47.24")	1 000 mm (39.37")	900 mm (35.43")	800 mm (31.50")	600 mm (23.62")	400 mm (15.75")	300 mm (11.81")	0	0
2 000 mm (78.74")	1 400 mm (55.12")	1 300 mm (51.18")	1 100 mm (43.31")	900 mm (35.43")	800 mm (31.50")	600 mm (23.62")	400 mm (15.75")	0	0	0
1 800 mm (70.87")	1 500 mm (59.06")	1 400 mm (55.12")	1 100 mm (43.31")	900 mm (35.43")	800 mm (31.50")	600 mm (23.62")	0	0	0	0
1 600 mm (62.99")	1 500 mm (59.06")	1 400 mm (55.12")	1 100 mm (43.31")	900 mm (35.43")	800 mm (31.50")	500 mm (19.69")	0	0	0	0
1 400 mm (55.12")	1 500 mm (59.06")	1 400 mm (55.12")	1 100 mm (43.31")	900 mm (35.43")	800 mm (31.50")	0	0	0	0	0
1 200 mm (47.24")	1 500 mm (59.06")	1 400 mm (55.12")	1 100 mm (43.31")	900 mm (35.43")	700 mm (27.56")	0	0	0	0	0
1 000 mm (39.37")	1 500 mm (59.06")	1 400 mm (55.12")	1 000 mm (39.37")	800 mm (31.50")	0	0	0	0	0	0
800 mm (31.50")	1 500 mm (59.06")	1 300 mm (51.18")	900 mm (35.43")	600 mm (23.62")	0	0	0	0	0	0
600 mm (23.62")	1 400 mm (55.12")	1 300 mm (51.18")	800 mm (31.50")	0	0	0	0	0	0	0
400 mm (15.75")	1 400 mm (55.12")	1 200 mm (47.24")	400 mm (15.75")	0	0	0	0	0	0	0
200 mm (7.87")	1 200 mm (47.24")	900 mm (35.43")	0	0	0	0	0	0	0	0
0	1 100 mm (43.31")	500 mm (19.69")	0	0	0	0	0	0	0	0

[1] Protective structures lower than 1 000 mm (39.37") in height are not included because they do not sufficiently restrict movement of the body.

[2] Protective structures lower than 1 400 mm (55.12") should not be used without additional engineering controls.

[3] For safe-location-safeguarding method (7.4), the hazard should be 2 700 mm (106.30") or greater vertical distance above the reference plane (e.g., floor).

American National Standard B11.19–2019



Detect/Control Access

Machine Guarding

Minor Servicing Exception

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

Alternative Methods/Measures
routine, repetitive and integral to the operation of the machine

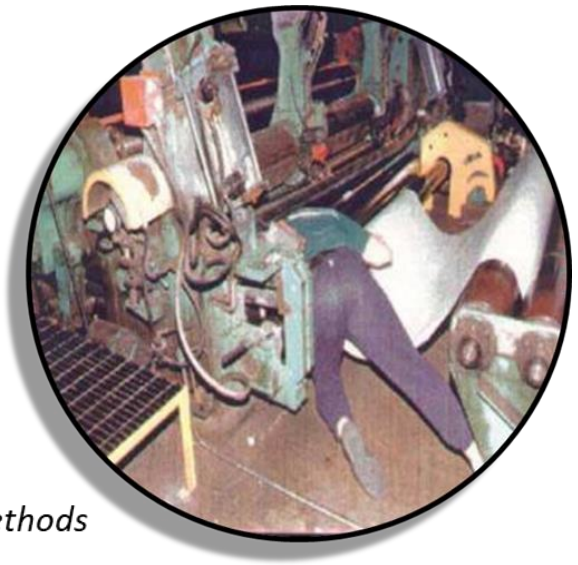
Tasks - Minor Servicing Exception

1910.147 (a)(2)(ii)(B)

https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.147

Note: ***Exception to paragraph (a)(2)(ii):*** Minor tool changes and adjustments, and other minor servicing activities, which take place during normal production operations, are not covered by this standard if they are routine, repetitive, and integral to the use of the equipment for production, provided that the work is performed using alternative measures which provide effective protection (See Subpart O of this Part).

1. The task is performed during normal operations
2. Is routine, repetitive and integral to the use of the equipment for production
3. Alternative measures are just as effective – does not increase risk
4. * Shall provide justification and a team/task-based risk assessment (documentation).

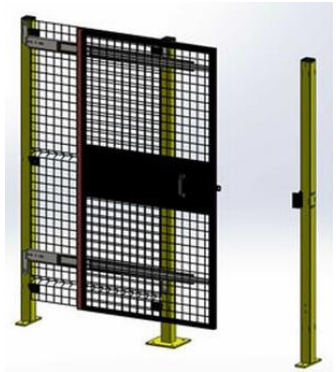


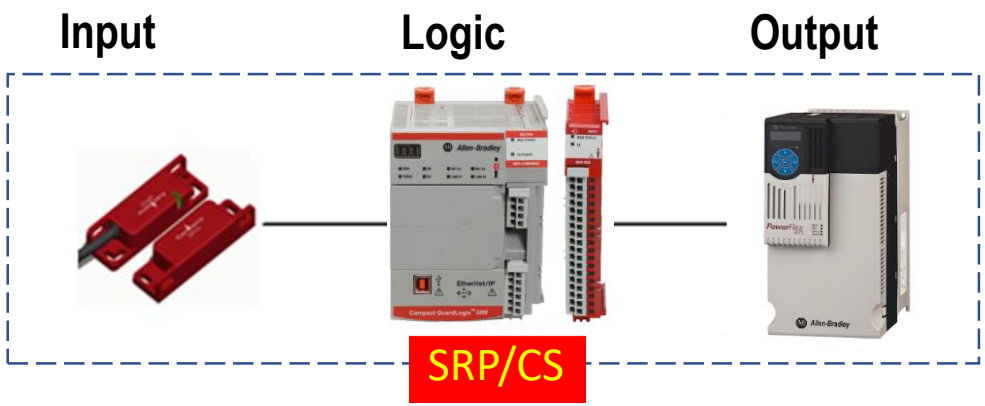
* ANSI/ASSE Z244.1 *Control of Hazardous Energy - Lockout/Tagout and Alternative Methods*

Functional Safety – *Safety Rated Part of the Control System (SRP/CS)*

- **Functional Safety** of machinery are those parts of the machine control system that are specifically used to reduce risk, particularly with regard to human safety
  - An example of Functional Safety is a simple interlock circuit.

Access Gate (Movable Guard)





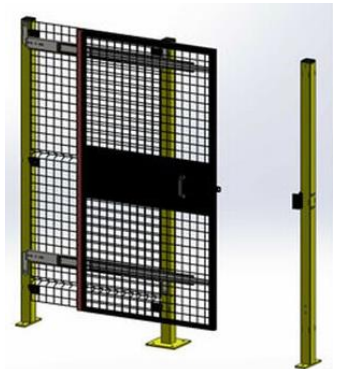
- The **Safety Function** could be described as follows:
  - *The Safety Gate is opened, causing the gate monitoring sensor to turn off (input). The Monitoring Safety Relay (logic) detects this change of state and de-energizes the contactors (output), thus stopping the associated motor and hazardous motion.*

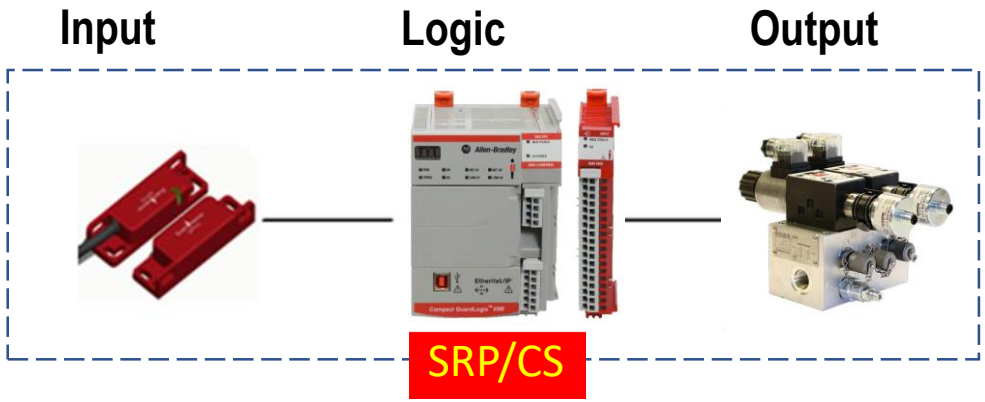
Functional Safety – *Safety Rated Part of the Control System (SRP/CS)*

- **Functional Safety** of machinery are those parts of the machine control system that are specifically used to reduce risk, particularly with regard to human safety
  - An example of Functional Safety is a simple interlock circuit.

Fluid Power!

Access Gate (Movable Guard)





Hydraulic Actuator

- *The Safety Gate is opened, causing the gate monitoring sensor to turn off (input). The Monitoring Safety Relay (logic) detects this change of state and commanding the safety valve to the block and dump position (output), thus stopping the hydraulic actuator and hazardous motion.*

Stops - *cessation of machine motion*

- **Normal stop** - The stopping of a machine, initiated by the control system, at the completion of a cycle.
- **Emergency stop** - The stopping of a machine, manually initiated, for emergency purposes.
- **Protective or safety stop** - The stopping of a machine initiated by an engineering controls device for risk reduction purposes.

- These definitions are harmonized across all of the standards

9.4.4 Comparison of Stop Functions

B11.19–2019

Table 2 offers an explanatory comparison of the different types of stop functions.

Table 2 — Comparison of stop, emergency stop, and protective stops (Informative)

	Normal Stop	Emergency Stop	Protective Stop
ANSI B11.19 reference	3.101.3; 9.4.1	3.101.2; 9.4.2; 10.12	3.101.4; 9.4.3
Location	Personnel have quick, unobstructed access. Required on all operator stations	Personnel have quick, unobstructed access. Required on all operator stations and other locations as determined by a risk assessment	Located such that an individual cannot access the hazard. Determined by the safety distance formula (see also, 9.6 and Annex H).
Initiation of stop signal	Manual or automatic	Manual only	Manual or automatic
Stop category**	0, 1 or 2	0 or 1 only	0, 1, or 2
Circuit performance	As determined by a documented risk assessment		
	Typically single channel (non safety-rated)	Minimum single channel safety rated controls. Greater performance may be required	Typically control reliable, see also, 9.2
Circuit reset	Manual only	Manual only	Manual or automatic (hardware or software)
Manual suspension and mute	Allowed (for cycle completion, etc.)	Not allowed	Allowed (for muting, modes of operation, set up, etc.)
Use frequency	Variable; frequent (every cycle) to infrequent	Infrequently; only in emergency situations or for other immediate stop purposes	Variable; frequent (every cycle) to infrequent. Typically a stop command is only issued when a safe condition is not present
Effect	De-energize the relevant circuit and override related start functions	Remove all energy sources to hazards in the span of control and override all other functions and operations in all modes	Remove or control energy sources to the hazard in the span of control and override all other functions and operations in all modes associated with the hazard in the span of control
Final removal of power	Electromechanical or solid-state components	Electromechanical components or solid-state components designed for safety functions	Electromechanical or solid-state components designed for safety functions

Stop Categories

- **Category 0** - *an uncontrolled stop by immediately removing power to the machine actuators. (Additional braking can be necessary)*
- **Category 1** - *a controlled stop with power to the machine actuators available to achieve the stop then power is removed when the stop is achieved.*
- **Category 2** - *a controlled stop with power left available to the machine actuators.*

- These definitions are harmonized across all of the standards.
- Applies to all controllable power sources electric, hydraulic and pneumatic that produce motion.
- Type and category applied is determined by the risk assessment.

Reset and Restart

- **Reset** – rearms the estop or protective stop function – allows the potential to return to normal production
- **Restart** – return to normal operation/production

Detect/Control Access

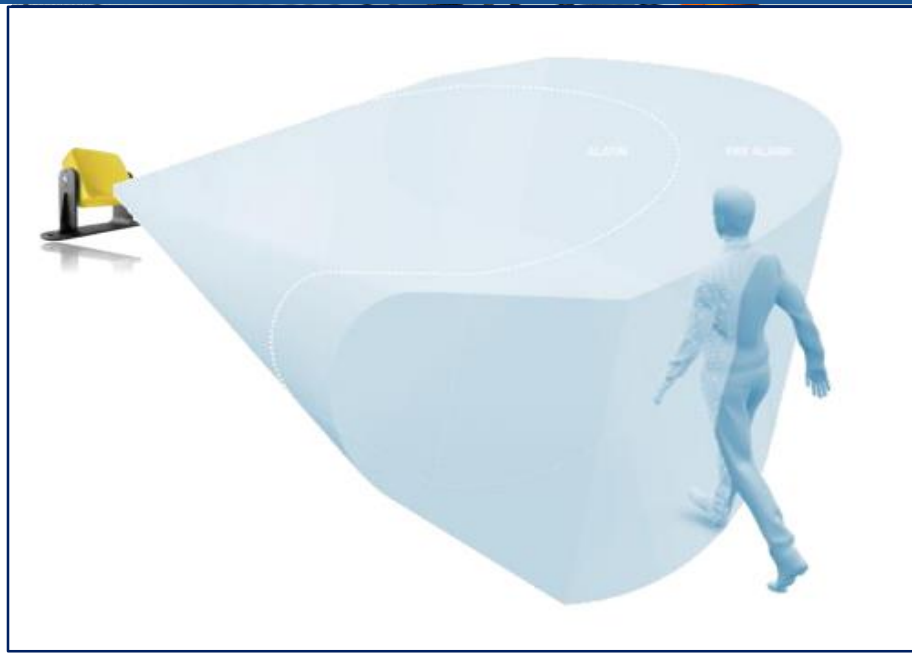
Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

Minor Servicing Exception

Alternative Methods/Measures
routine, repetitive and integral to the operation of the machine

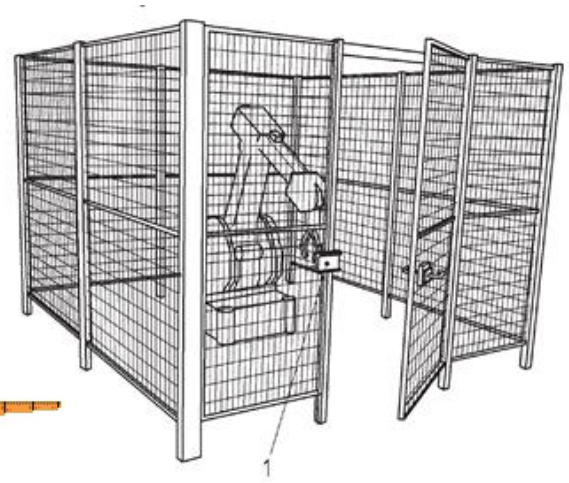
Detect - interlocked
(formally "non-separating safeguarding")

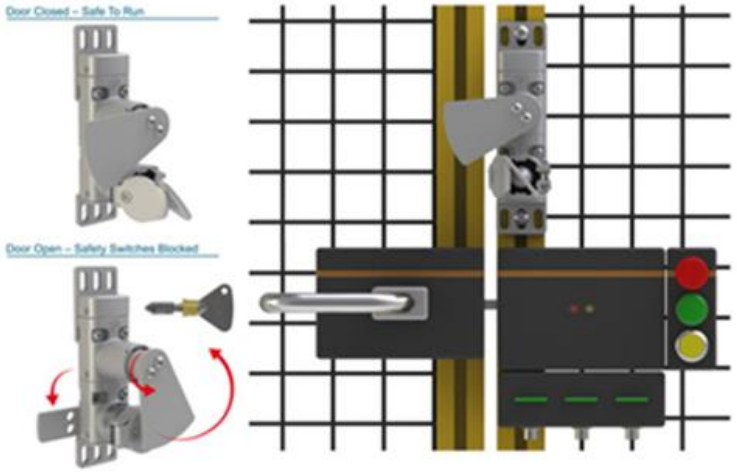
- **Detection device must:**
  - Prevent contact with the hazard
  - Secure – tamper-proof, not easily by-passed
  - Create no new hazard
  - Not impede worker's task
  - Allow safe operation of the machine without the need to:
    - Remove
    - Modify
    - Bypass



Access Control
(formally "separating safeguarding")

- Movable physical gates, panels or shields
- Switches & interlocking control functions
  - Interlock or guard lock
- *Safety Distance & Stop Time Calculations*



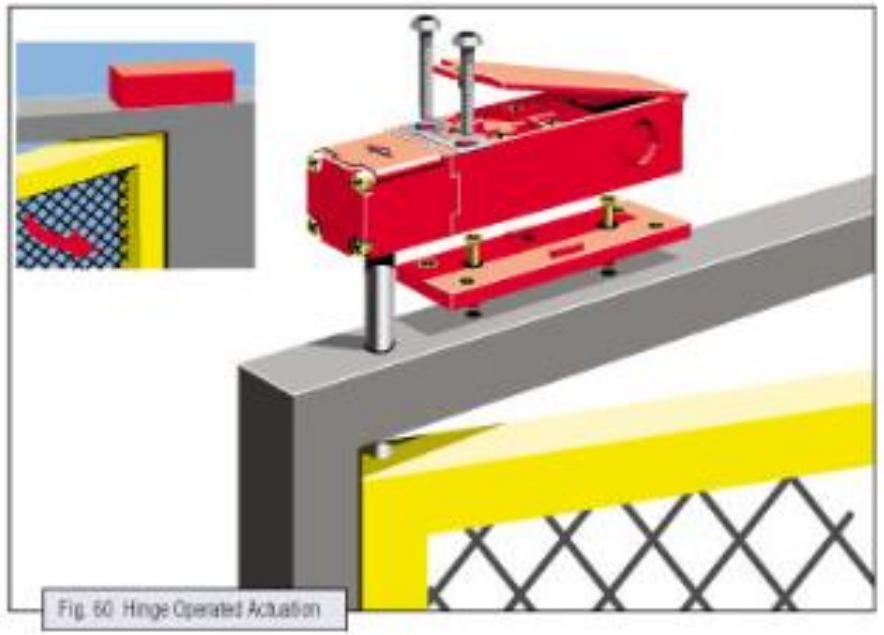


Interlocked access control

- Opening/removing the guard triggers the safety function
- Unique RFID code and/or uncommon key

Interlocked guard

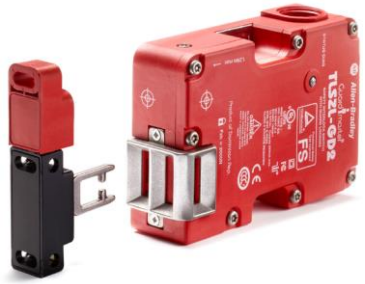
- Hinge switch
  - Electric or pneumatic



pneumatic

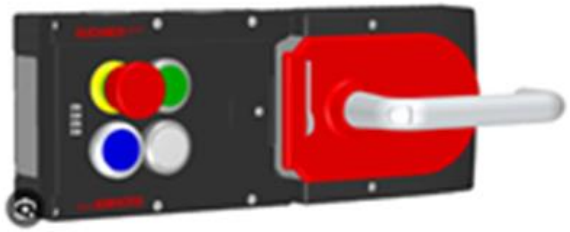
Guard locked (also interlocked)

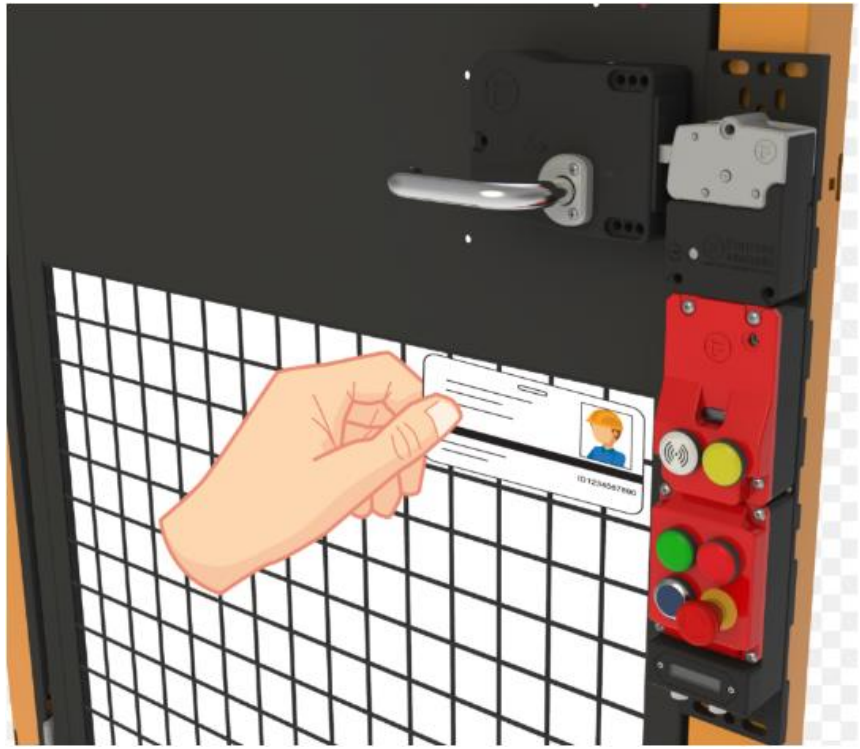
- Guard door remains locked until safe state is attained
- Controlled by the safety logic device (PLC or relay)
  - Actual safe state via feedback or timer (assumption)
- Mechanical or magnetic locks



Guard locked (also interlocked)

- Multifunction Gate Access Control
  - Typically networked vs hard wired





Band Saw – interlock or guard lock?

Safety Distance Calculation
ex. ANSI B11.19-2019, Annex H

Ds = [K x (Ts + Tc + Tr)] + Dpf + Z

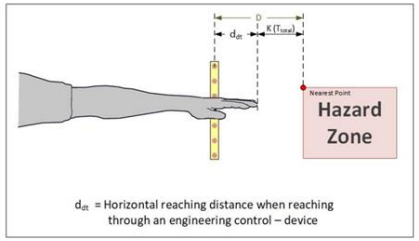


Figure I.5 – Reaching through a vertical sensing field with $d_x \leq 64$ mm (2.52")

- **Ds** = the minimum safe distance between safeguarding device and the hazard
- **K**= speed constant; 1.6 m/sec (63”/sec) walking
  2m/sec (78 ¾”/sec) hand, reaching
- **Ts** = machine/equipment stopping time
- **Tc** = control system stopping time
- **Tr** = detecting device response time
- **Dpf** = maximum travel towards the hazard within the presence sensing safeguarding devices (PSSD) field that may occur before a stop is signaled
- **Z** = Supplemental distance factor

ex. [K x (Ts + Tc + Tr)] + Dpf + Z = Ds
[1600mm x (.3sec + .01sec + .080sec)] + 23.8mm + 10mm = 657.8mm

Detect/Control Access

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

Minor Servicing Exception

Alternative Methods/Measures
routine, repetitive and integral to the operation of the machine

Control Hazardous Motion

Two hand/single actuating

- Simultaneous actuation
- Repositions the operator
  - All or part (hands)
- Stop time/safe distance
  - Ds = [K x (Ts + Tc + Tr)] + Dpf + Z

- Anti tie down buttons

Control Hazardous Motion

Enabling Device – Jog Controls

- 3-position – center on
- Exclusive control of hazardous motion
- Enable the machine to operate while within parameters
  - safety speed/torque/direction
  - typically within the hazard area
- In proximity to the hazard

Detect/Control Access

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
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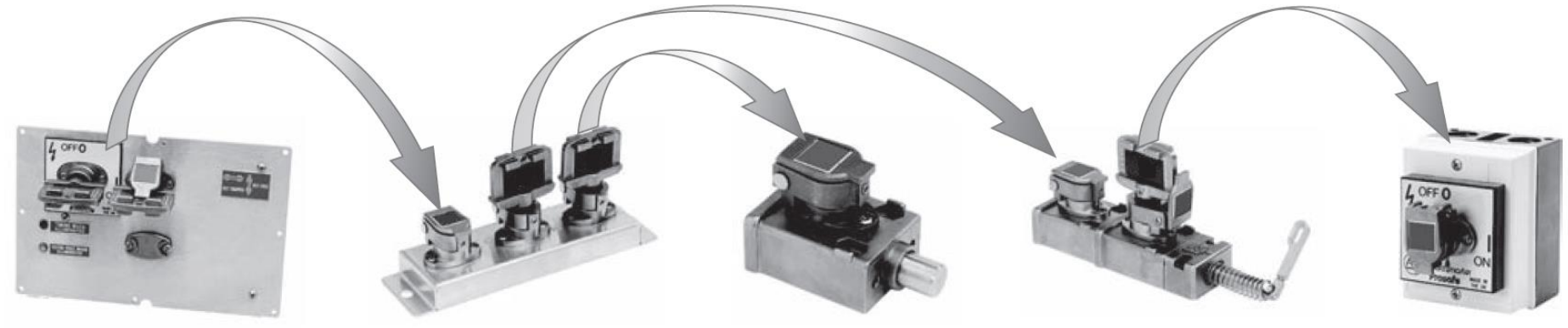
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

Minor Servicing Exception

Alternative Methods/Measures
routine, repetitive and integral to the operation of the machine

Restricting Operation (typically associated with access control – interlocked or guard locking)

Illustrated Principles of Trapped Key Interlocking



AA
ETU
Isolator with timed delay key release

AA AB AB
KEX
Trapped key 'AA'
Locking off ETU,
Release access door lock, key 'AB'.

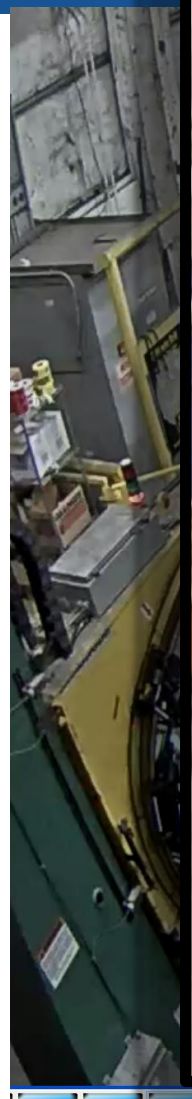
AB
SBL
'AB' key in to retract bolt from guard door.

AB AC
DAL
'AB' key in then 'AC' key out to open guard door.

AC
RKS
To energize robot teach mode.

Trapped-key

- **Access Key** – triggers the safety function
- **Safety** and/or **Enabling Key**
  - “Exclusive control”



Speed/force limiting (monitored)

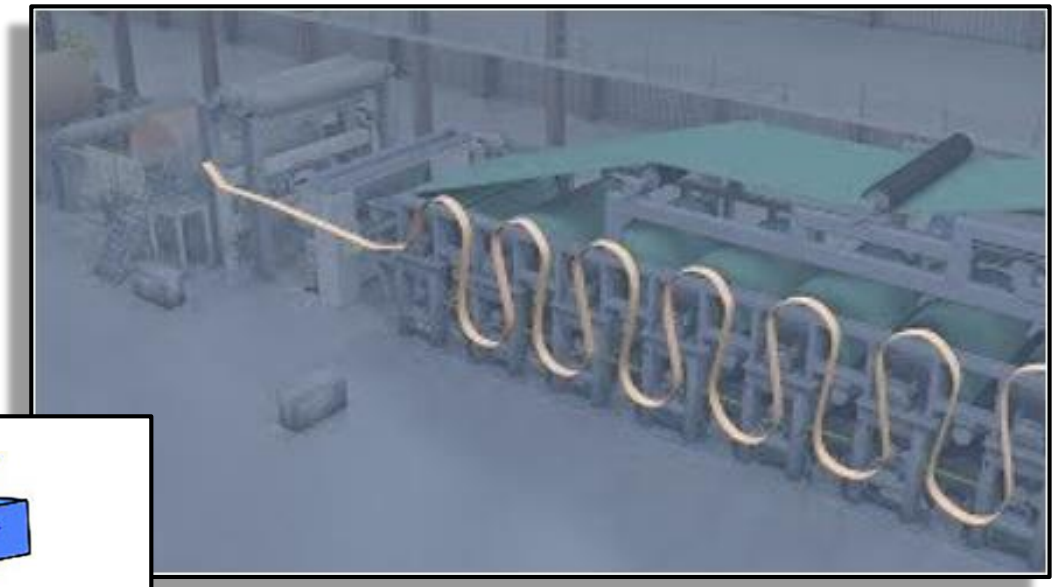
Minor Servicing Exception

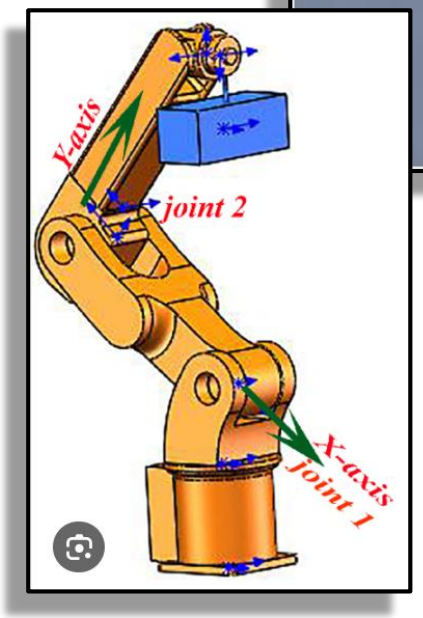
Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

Alternative Methods/Measures
routine, repetitive and integral to the operation of the machine

Speed/Force Monitoring and Limiting
(+ access control and control of hazardous motion)

- Usually not actually stopped
  - Category 2 “stop”
- Reduce the severity
- Sophisticated controls/safety function
  - Minimum PLd
- Many variations
  - Threading as slow speed
  - Suspended load
  - Safe direction





11.19–2019 Annex L – Safety Functions for Power Drive Systems - Speed/Force Monitoring and Limiting

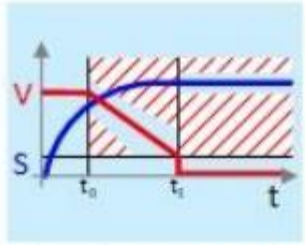


Figure L.5 – Safe Stop 2 Ramp Monitored (SS2-r)
(V = velocity; S = position; t = time)

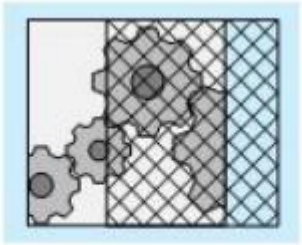


Figure L.18 – Safe Door Locking (SDL)

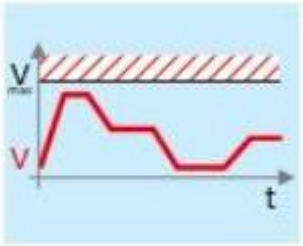
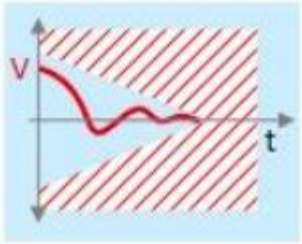


Figure L.16 – Safe Maximum Speed (SMS)
(V = velocity; t = time)



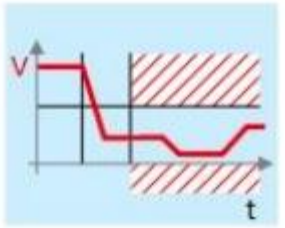


Figure L.13 – Safe Direction (SDi)
(V = velocity; t = time)

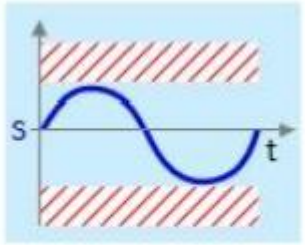


Figure L.11 – Safely-Limited Position (SLP)
(S = position; t = time)

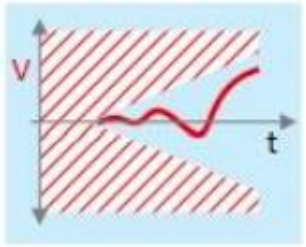


Figure L.7 – Safely-Limited Acceleration (SLA)
(V = velocity; t = time)

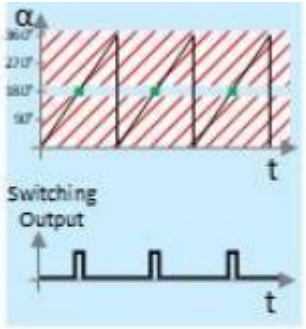


Figure L.14 – Safe Cam (SCa)
(α = shaft position; t = time)

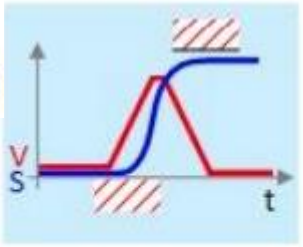


Figure L.12 – Safely-Limited Increment (SLI)
(V = velocity; S = position; t = time)

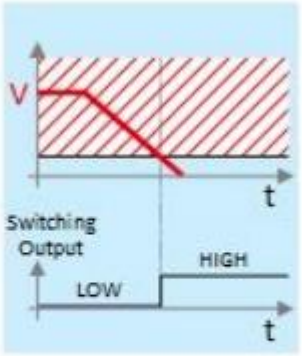


Figure L.15 – Safe Speed Monitor (SSM)
(V = velocity; t = time)

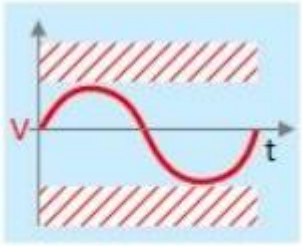


Figure L.10 – Safely Speed Range (SSR)
(V = velocity; t = time)

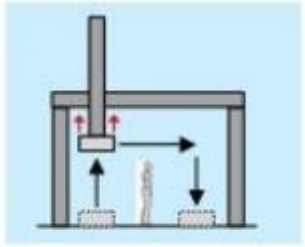


Figure L.17 – Safe Braking and Holding System (SBS)

Speed/Force Monitoring and Limiting
(+ access control and control of hazardous motion)

Direction / Speed of Rolls

- Input – Speed / Direction Sensors
- Input – Enable switch
- Logic – Speed / direction
- Output – Advanced Drive

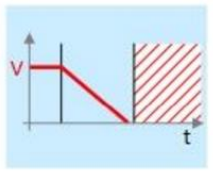


Figure L.2 – Safe Stop 1 Deceleration Controlled (SS1-d)
(V = velocity; t = time)

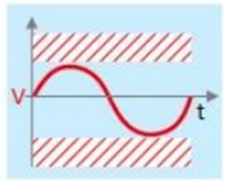


Figure L.10 – Safely Speed Range (SSR)
(V = velocity; t = time)

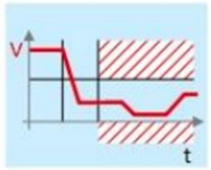


Figure L.13 – Safe Direction (SDi)
(V = velocity; t = time)

Speed/force limiting (monitored)

Minor Servicing Exception

E-stop

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

Alternative Methods/Measures
routine, repetitive and integral to the operation of the machine

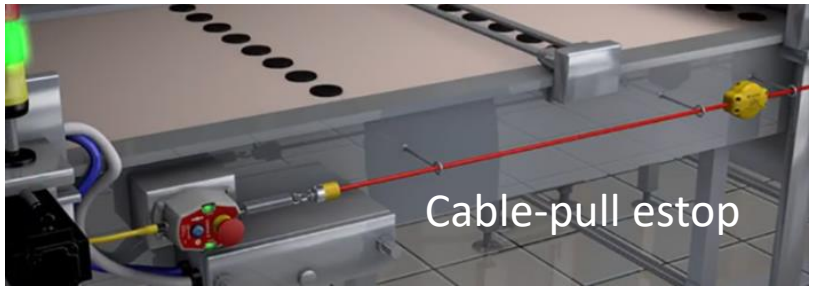
Emergency Stop Function – General Requirements

ISO 13850:2015(E) 4.1.1

- Immediate succession of hazard (motion)
- Is to be initiated by a single human action
- Shall be available and operational at all times
- It shall be maintained until it is manually reset
- Hazardous movements and operations of the machine are stopped in an appropriate manner
  - Cat 0, 1
  - Reversal or limitation of motion, rate of braking, etc.
- Actuation shall not create any new hazards

Emergency Stop - locations

- At each operator control station
- At other locations, as determined by the risk assessment, e.g.:
  - at entrance and exit locations;
  - at locations where intervention to the machinery is needed, e.g. operations with a hold-to-run control function;
  - at all places where a man / machine interaction is expected by design (loading / unloading zone for example).
  - could also be portable and wireless a device on a person



Wireless,
on-person estop

Estop – shrouds or covers?

Estop covers, locking accessories? Substitute for LOTO?

Speed/force limiting (monitored)

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Expo-sure	Avoid-ance	Occur-rence	Failure	Error / Misuse
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	

E-stop

Alternative Methods/Measures
routine, repetitive and integral to the operation of the machine

Table 6 — Potential Effects/Additional Characteristics of Risk Reduction Measures

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability			Failure	Error / Misuse
Classification	Type			Expo-sure	Avoid-ance	Occur-rence		
Inherently Safe by Design (Redesign)	Limiting Interaction	modify the process to eliminate/reduce human interaction		•		•		•
	Elimination	replace task, increase clearance	•	•				
		energy magnitude reduction	•			•	•	
	Substitution	automated material handling	•	•	•	•	•	•
		use less hazardous chemicals	•			•		•
		reduce force, speed, etc. through selection of inherently safe components	•		•			
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	
Administrative Controls	Awareness Means (Warnings & Instructions)			•	•	•		•
					•	•	•	•
					•	•		•
	Information for Use (Training & Procedures)				•	•		•
	Administrative Methods				•	•		•
	Supervision				•	•		•
	Control of hazardous energy		•	•		•		•
	Tools		•		•	•	•	•
	PPE		•		•	•	•	•

Most Preferred

Least Preferred

Administrative Controls

No actual risk reduction in the RIA standard

Redesign the machine or change the process

Machine Guarding

Minor Servicing Exception

E-stop

Signs, lights, horns, training

Training/Awareness

Boss, keys, cameras

Lockout/Tagout

Safety glasses, hardhat, tools

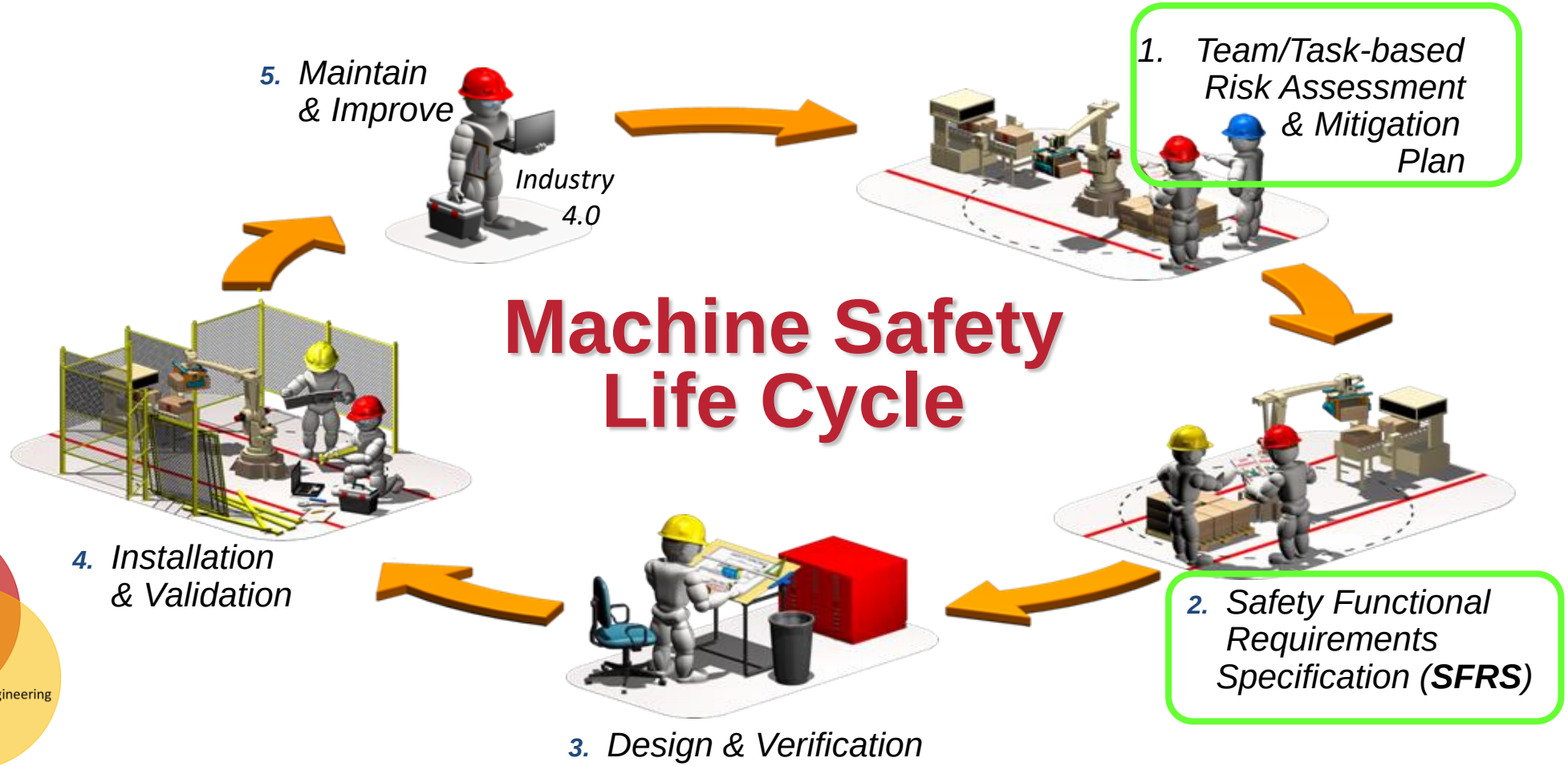
Most Preferred

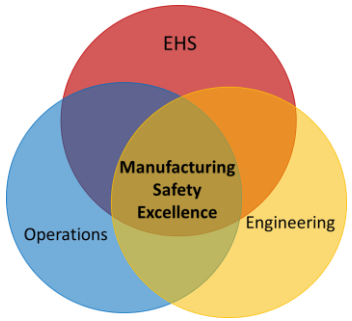
Least Preferred

Table 6 — Potential Effects/Additional Characteristics of Risk Reduction Measures

Risk Reduction Measures			Possible Effect on Risk Factors				Possibly susceptible to: (even when properly applied)	
Hierarchy		Examples	Severity	Probability				
Classification	Type			Exposure	Avoidance	Occurrence	Failure	Error / Misuse
Inherently Safe by Design (Redesign)	Limiting Interaction	modify the process to eliminate/reduce human interaction		•		•		•
	Elimination	replace task, increase clearance	•	•				
		energy magnitude reduction	•			•	•	
	Substitution	automated material handling	•	•	•	•	•	•
		use less hazardous chemicals	•			•		•
		reduce force, speed, etc. through selection of inherently safe components	•		•			
Engineering Controls (Guards, Devices and Control Functions)	Separation	fixed guards, shields		•		•	•	•
	Detect / Control Access	Interlock devices, presence sensing devices		•		•	•	•
	Control Hazardous Motion	two-hand / single actuating controls		•	•	•	•	•
		enabling devices, jog controls			•	•	•	•
	Restricting Operation	controlled selection of operating modes				•		•
	Monitor / Limit Hazards	speed / force monitoring and limiting	•		•	•	•	
	Emergency Action	emergency stop devices	•		•	•	•	
Administrative Controls	Awareness Means (Warnings & Instructions)	awareness barriers		•	•	•		•
		awareness signals (audible and/or visible)			•	•	•	•
		awareness signs / markings			•	•		•
	Information for Use (Training & Procedures)	safe work procedures, training			•	•		•
	Administrative Methods	safe-holding safeguarding method			•	•		•
	Supervision	supervisory control of configurable elements			•	•		•
	Control of hazardous energy	isolation of hazardous energy	•	•		•		•
	Tools	hand tools	•		•	•	•	•
	PPE	safety glasses, hearing protection, gloves	•		•	•	•	•

ISO, IEC, ANSI, RIA, etc.
Functional Safety Life Cycle





Risk Reduction Measures/Methods In Manufacturing

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