# Intro to Collaborative Robots & Robotics Safety

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**GE Global Research**

NH General Industry Roundtable
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# TOPICS

- Collaborative Robots
- Standards
- Risk Assessments
- Resources

# Collaborative Robots

## ‘Cageless Robots’

Safe co-operation between people and robots

# Human / Robot Collaboration

**Drivers**

- Safety
- Simple installation & programming
- Affordability

**Enablers**

- Sensors
- Light Weight
- Safety Standards revised

**Implications**

- Reduce Floor Space
- Cost saving of installation
- More Flexibility

Source: Universal Robotics

# What is a Cobot?

Collaborative robots, or Cobots, are complex machines which work hand in hand with human beings.

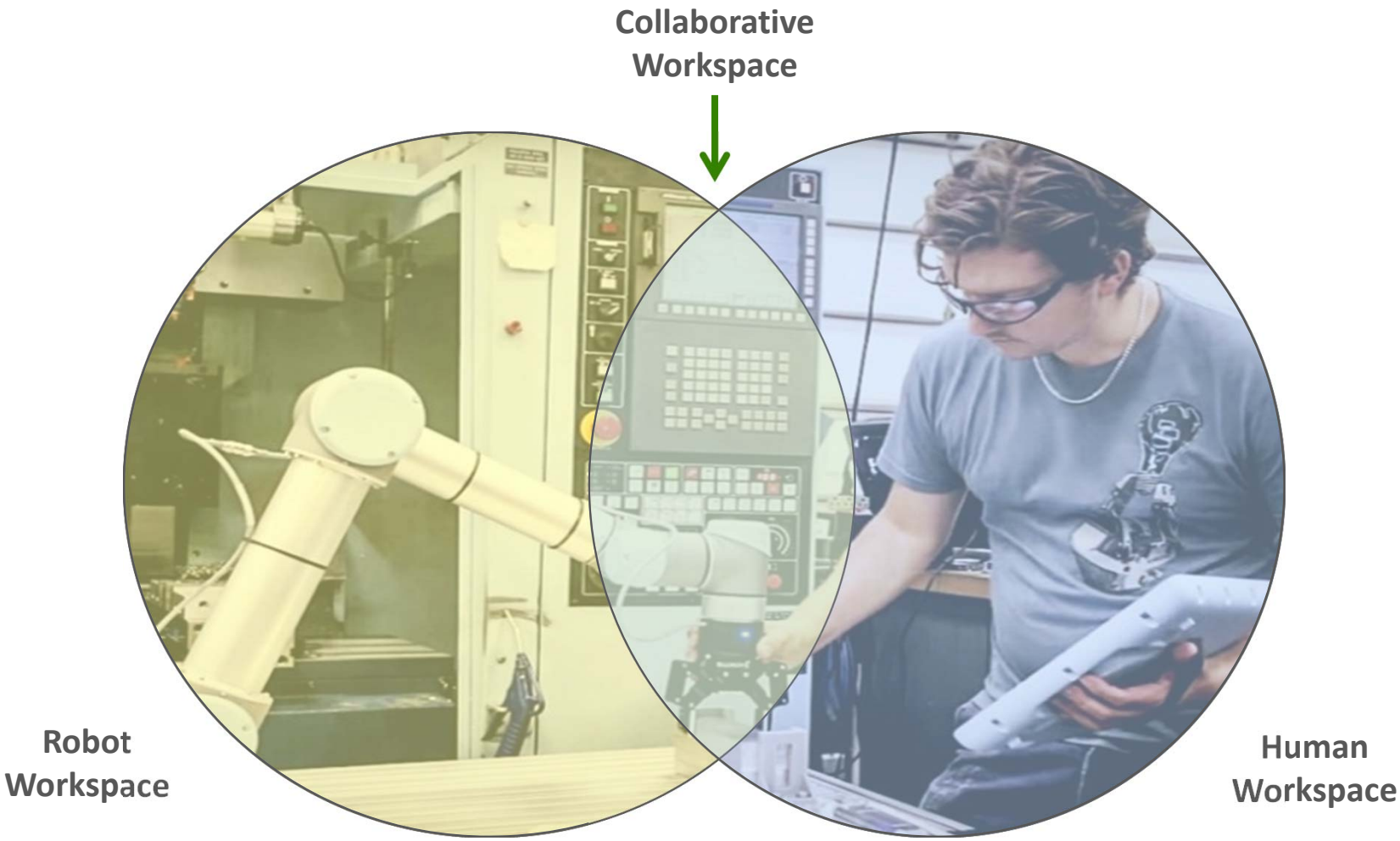
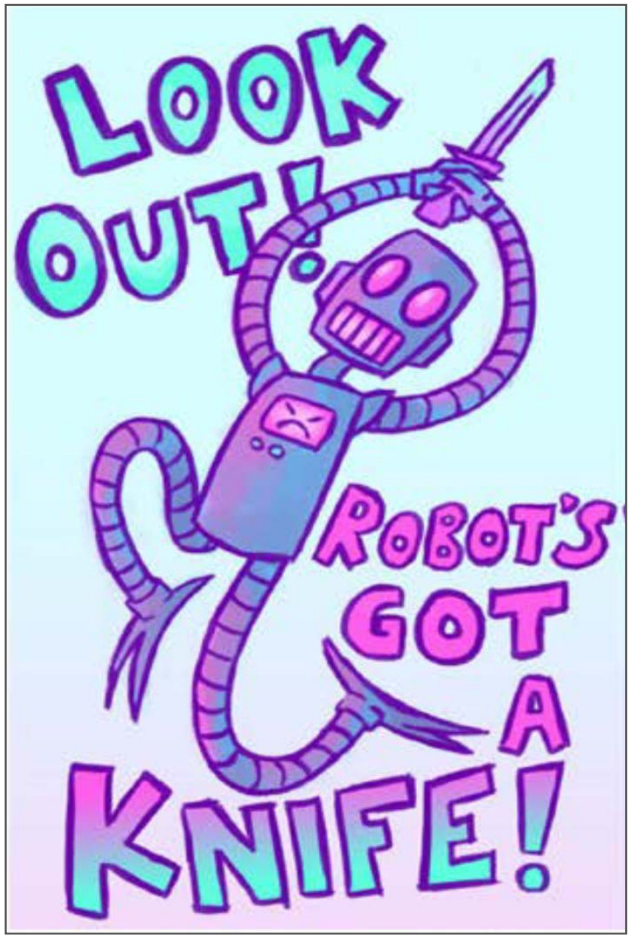



Image source: Robotiq

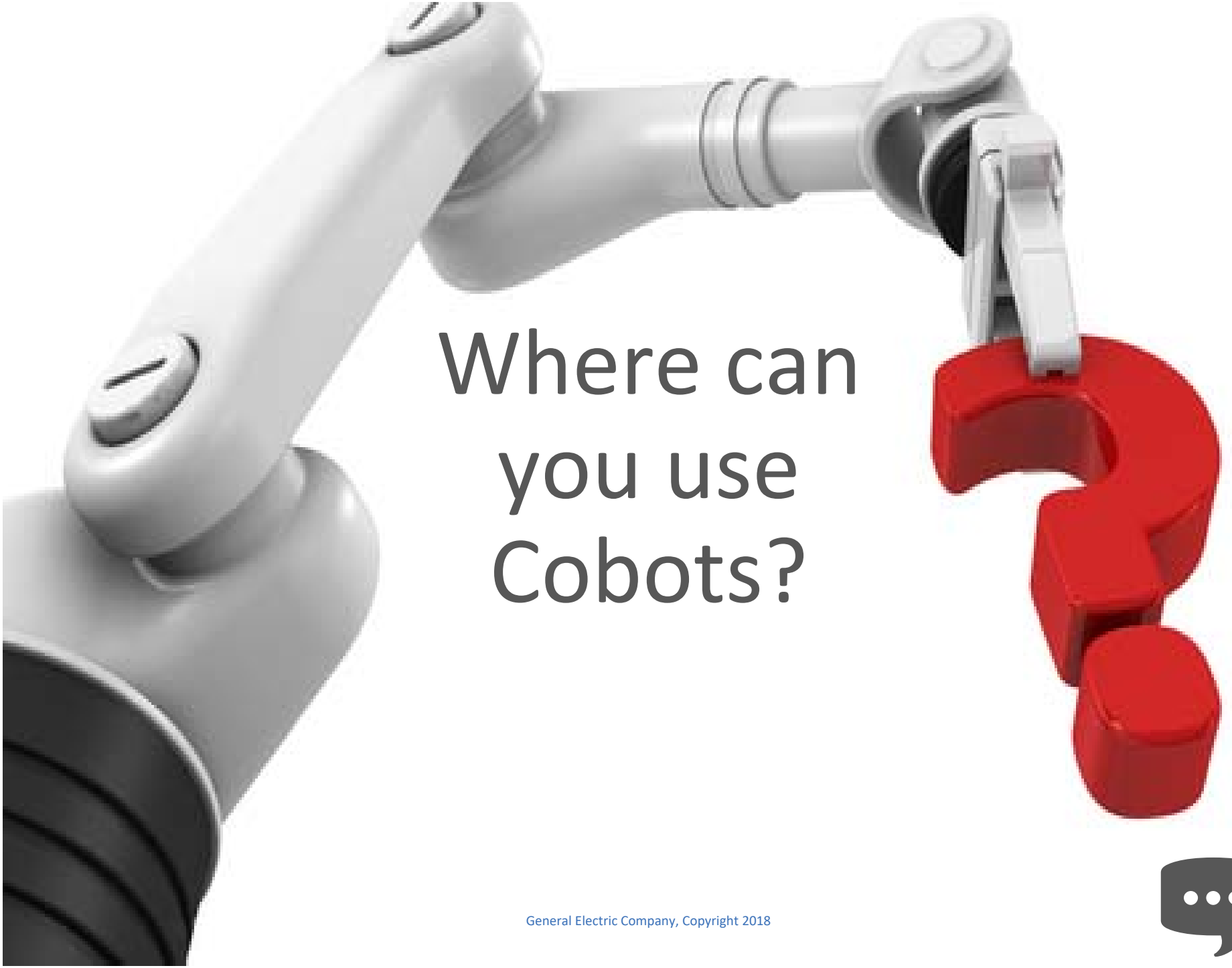
# A collaborative robot is defined by ….




The **task** the robot is performing; and

The **space** in which the task is being performed …

… and not the **robot** itself!

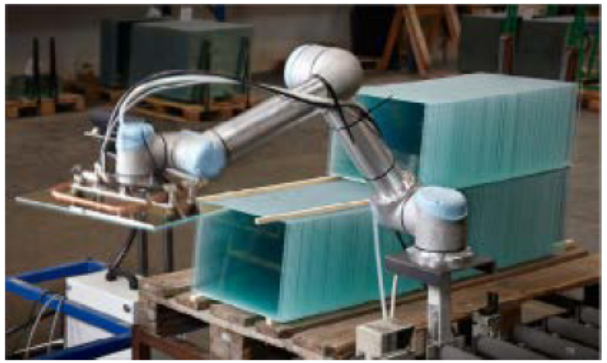


# Where can you use Cobots?

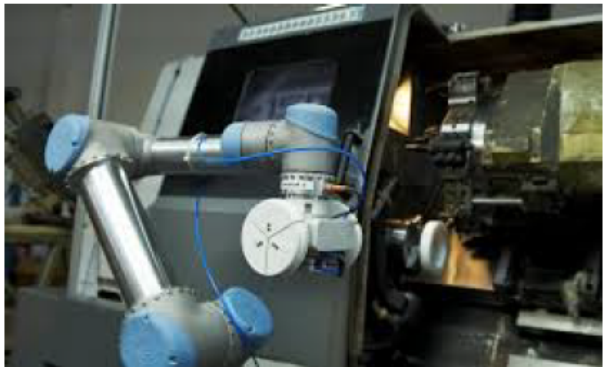
Automotive Assembly

Packaging/Palletizing

Pharmaceutical



Glass Handling



Machine Tending

Automotive Inspection

# ReThink Sawyer

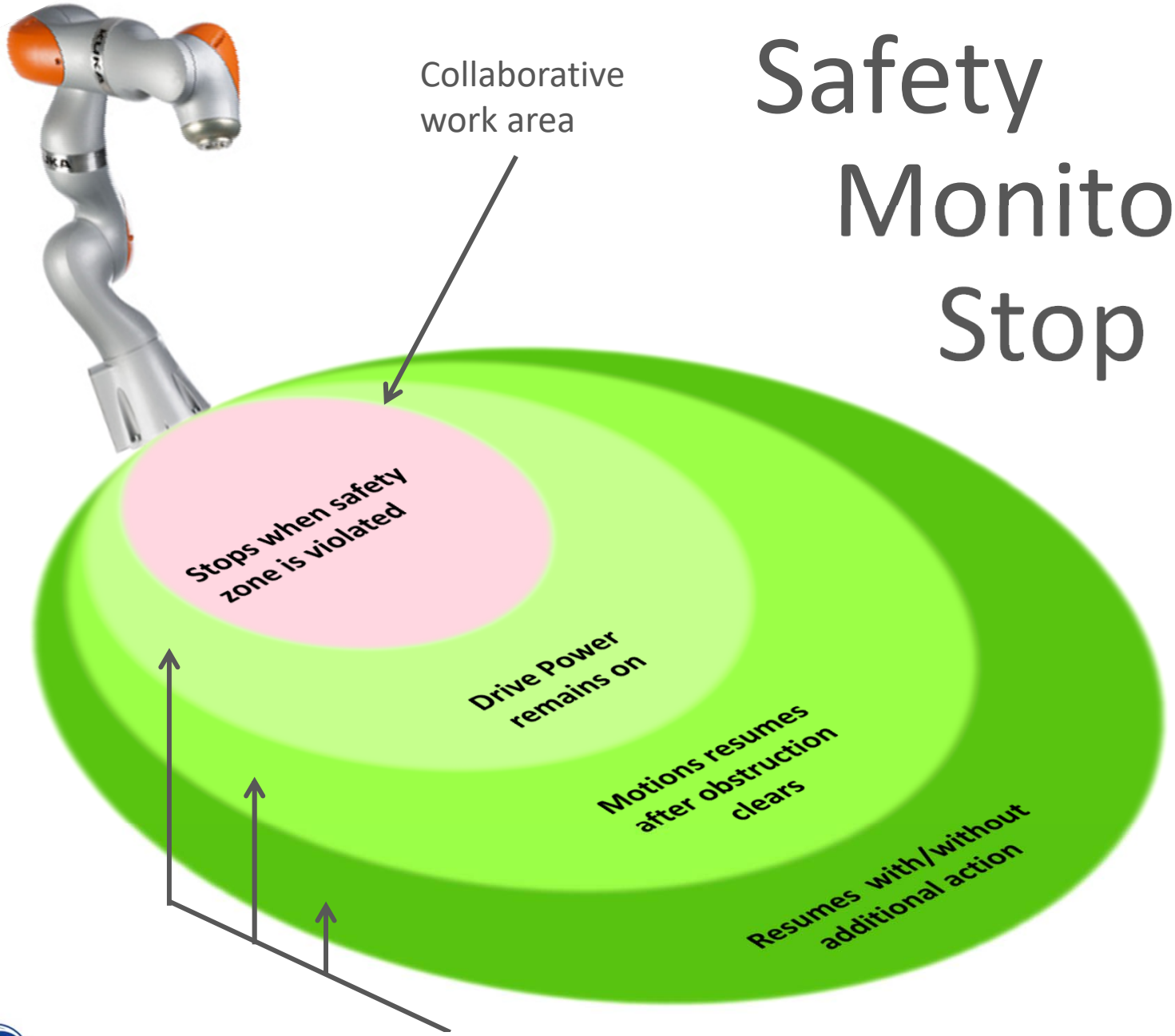
https://www.youtube.com/watch?v=7WtAoys5mNo

imagination at work

# 4 Types of Collaboration

| | |
|---|---|
| Safety Monitored Stop | • Robot stops when a human is in the collaborative workspace |
| Hand Guiding | • End-of-arm tooling (EOAT) is equipped with an e-stop and an enabling device |
| Speed & Separation Monitoring | • Robot maintains a determined speed and separation distance from the operator |
| Power & Force Limiting | • Robot limits dynamic power output, static force and speed or energy |

# Safety Monitored Stop



# Safety Monitored Stop

https://www.youtube.com/watch?v=-KDpbLT8dM8

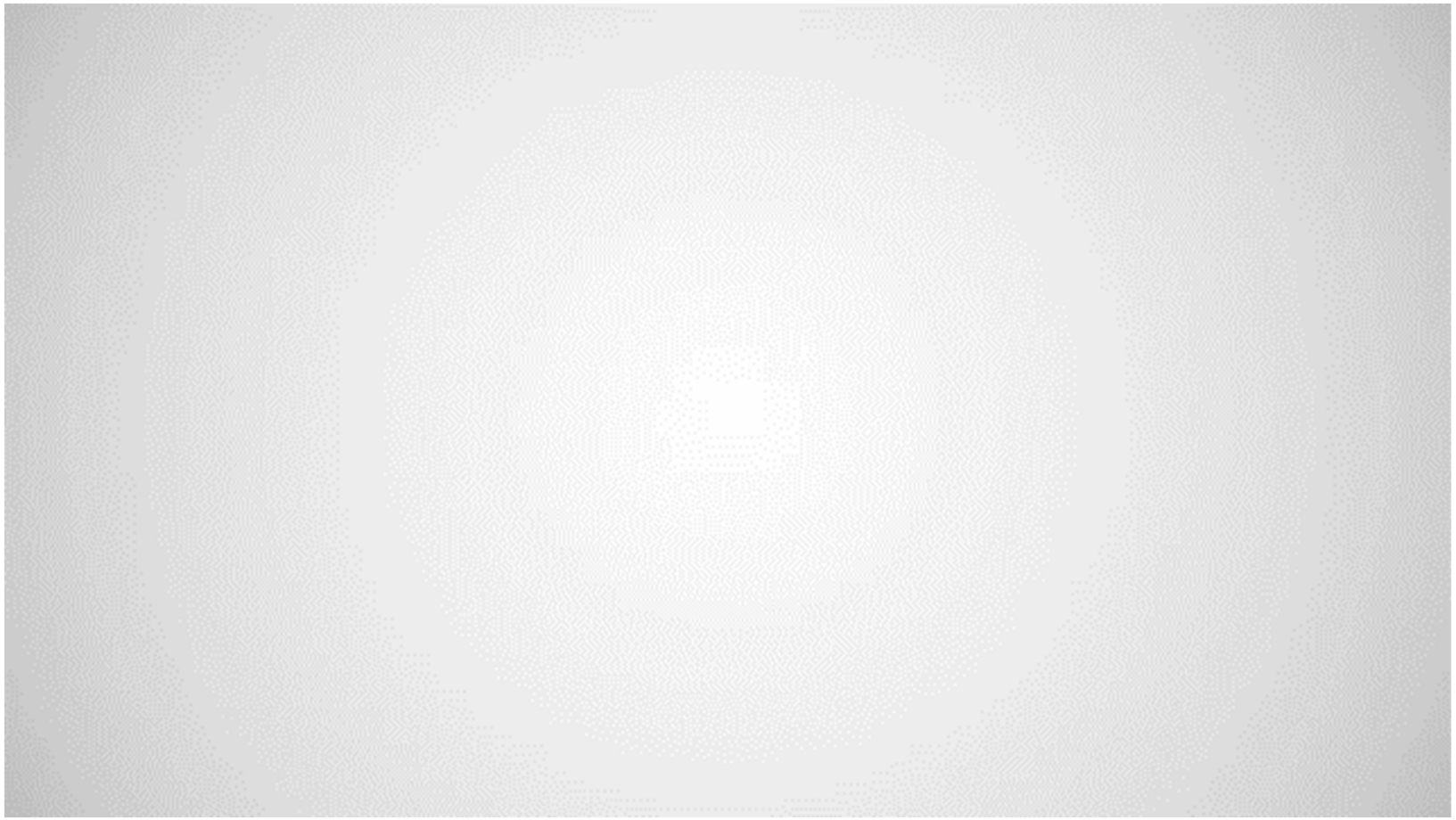
Source: SICK, Inc.

# Hand Guiding

Safety Monitored Stop → Operator grasps enabling device → Robot responds to operators commands → Non-collaborative operation resumes when operator leaves

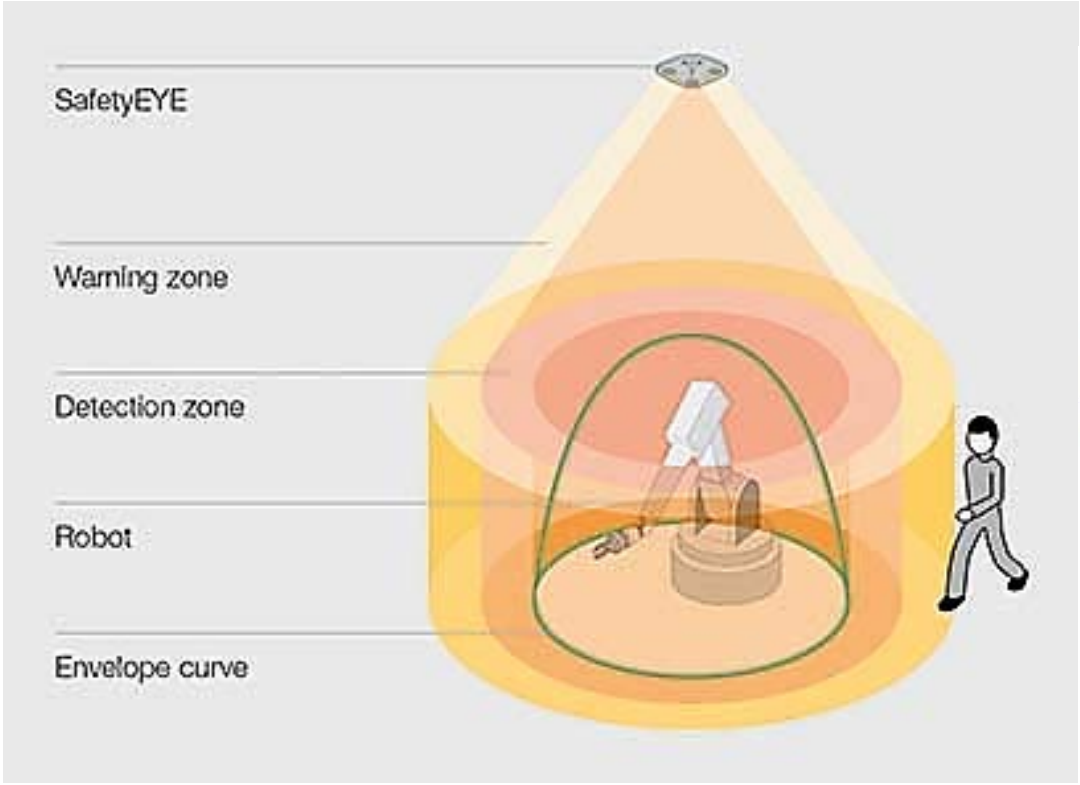
# Universal Robotics

https://www.youtube.com/watch?v=j51XCuQCR_8

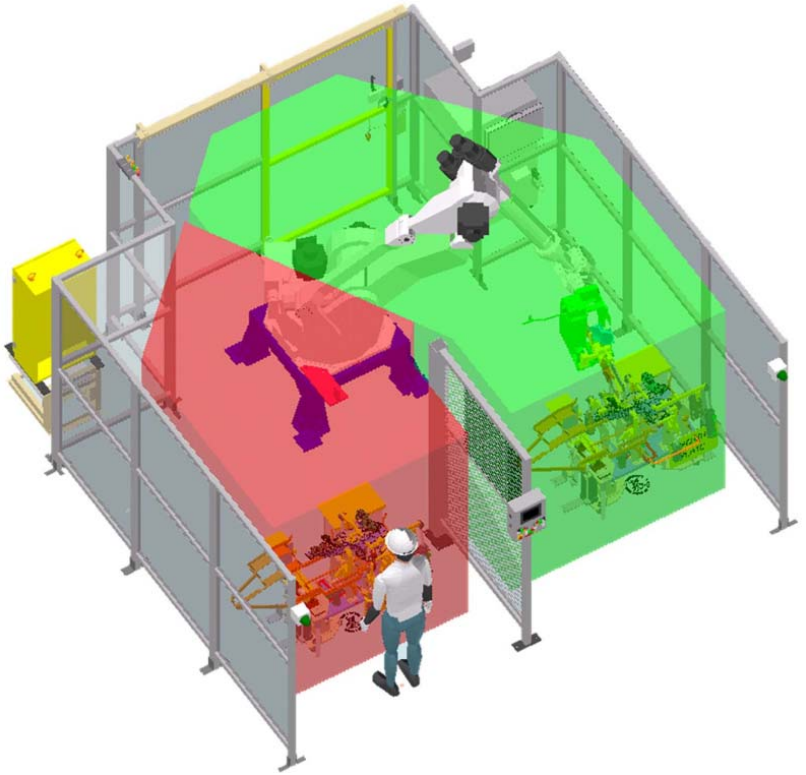


Source: Robotiq

# Speed & Separation Monitoring




Pilz SafetyEYE



# Speed & Separation Monitoring

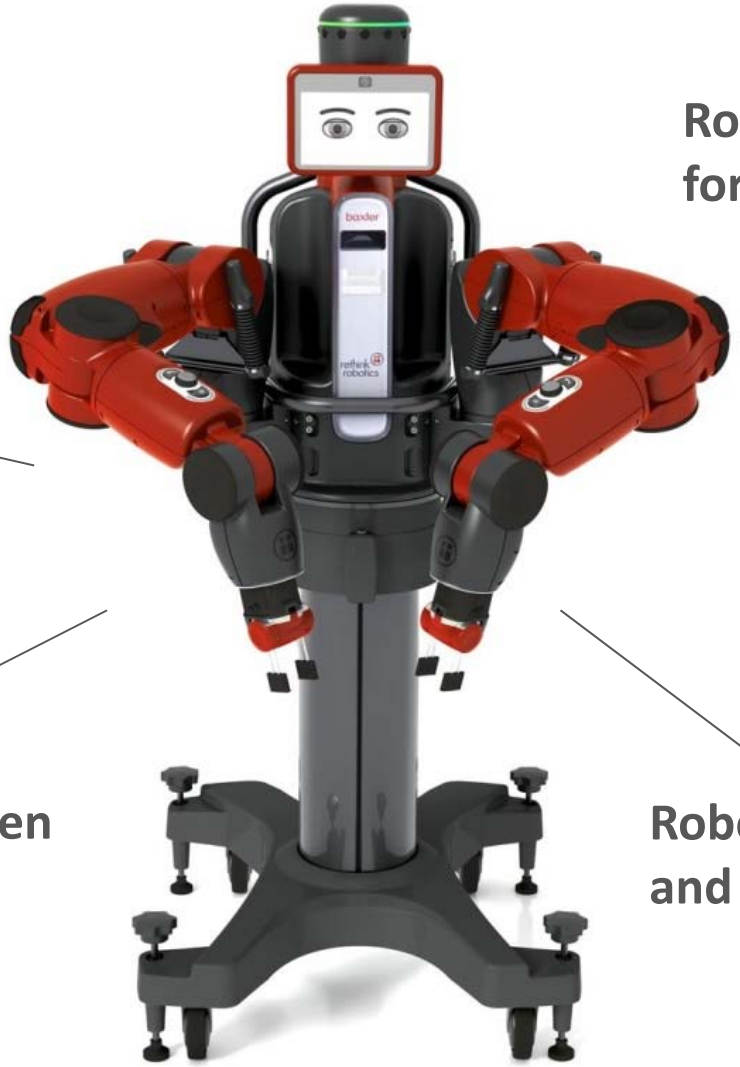
https://www.youtube.com/watch?v=O3QgMzmg5HI

Source: SICK, Inc.

# Power & Force Limiting

**Robot exterior is designed for human contact**

**Robot can respond to contact forces while performing work**



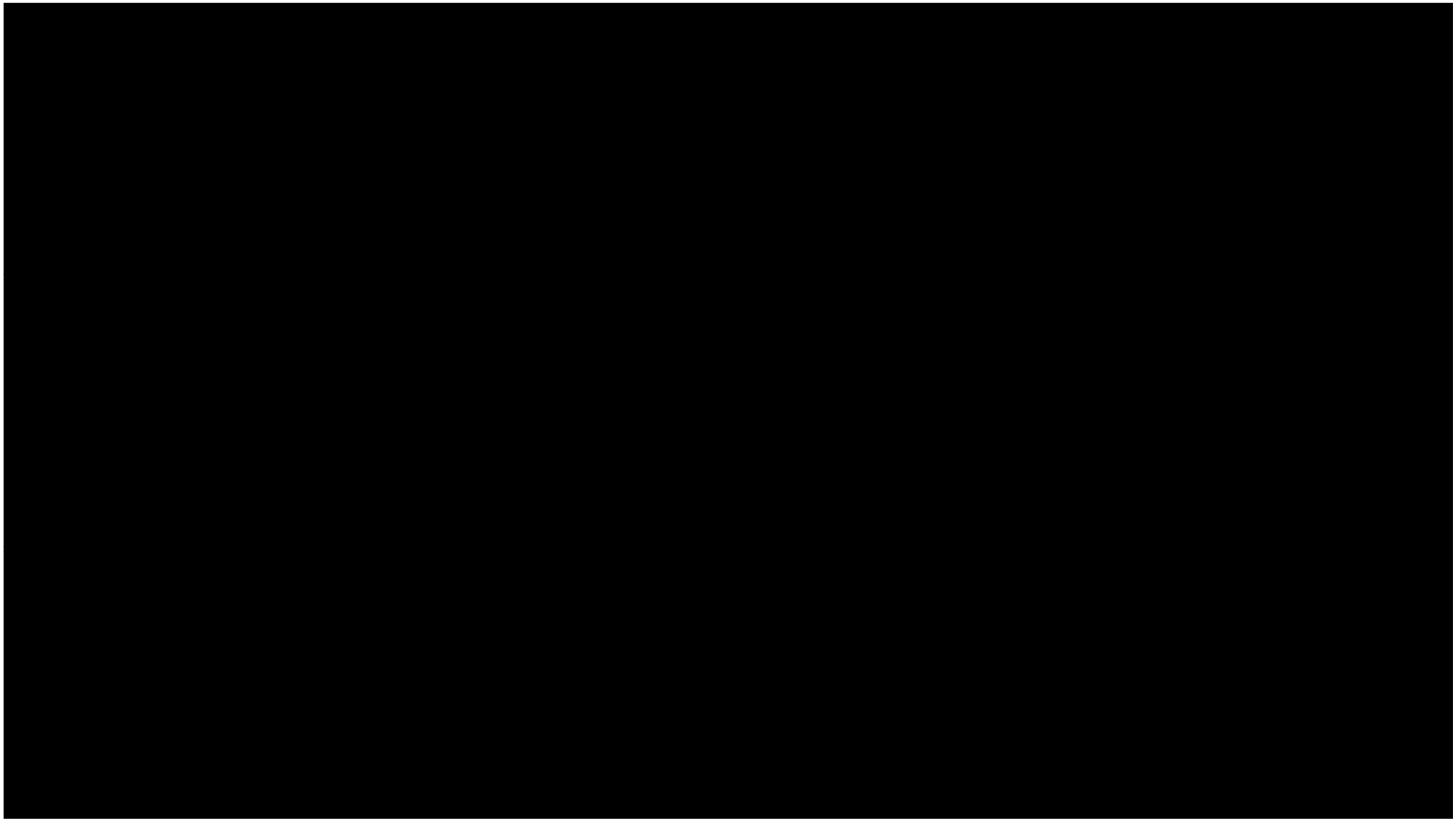
**Stop or Slow Down when Touched**

**Robot can safely limit speed and work area**

Baxter by Rethink Robotics

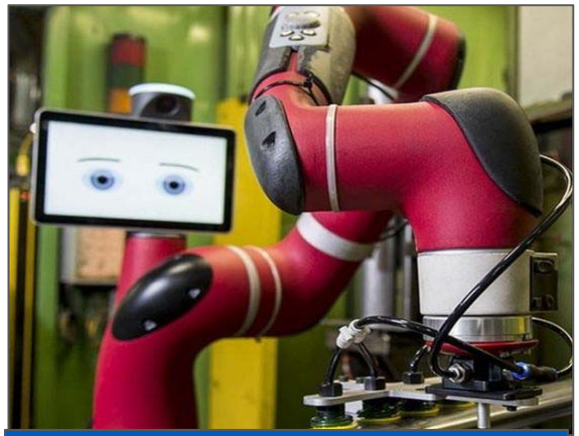
# ReThink Baxter

https://www.youtube.com/watch?v=Y-uyVF1kYyA

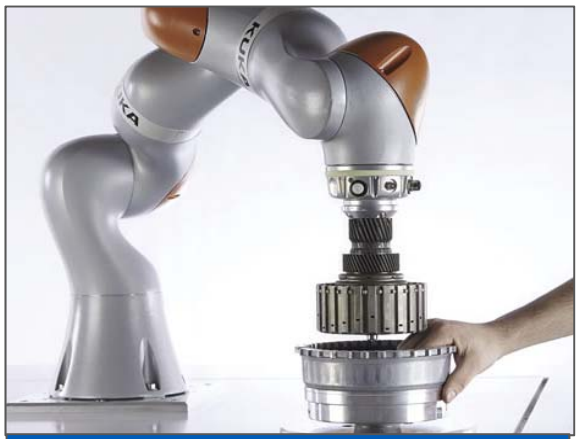


# Force Limited Robots

- Inherently safe
- Reduces pressure applied
- Padded surfaces



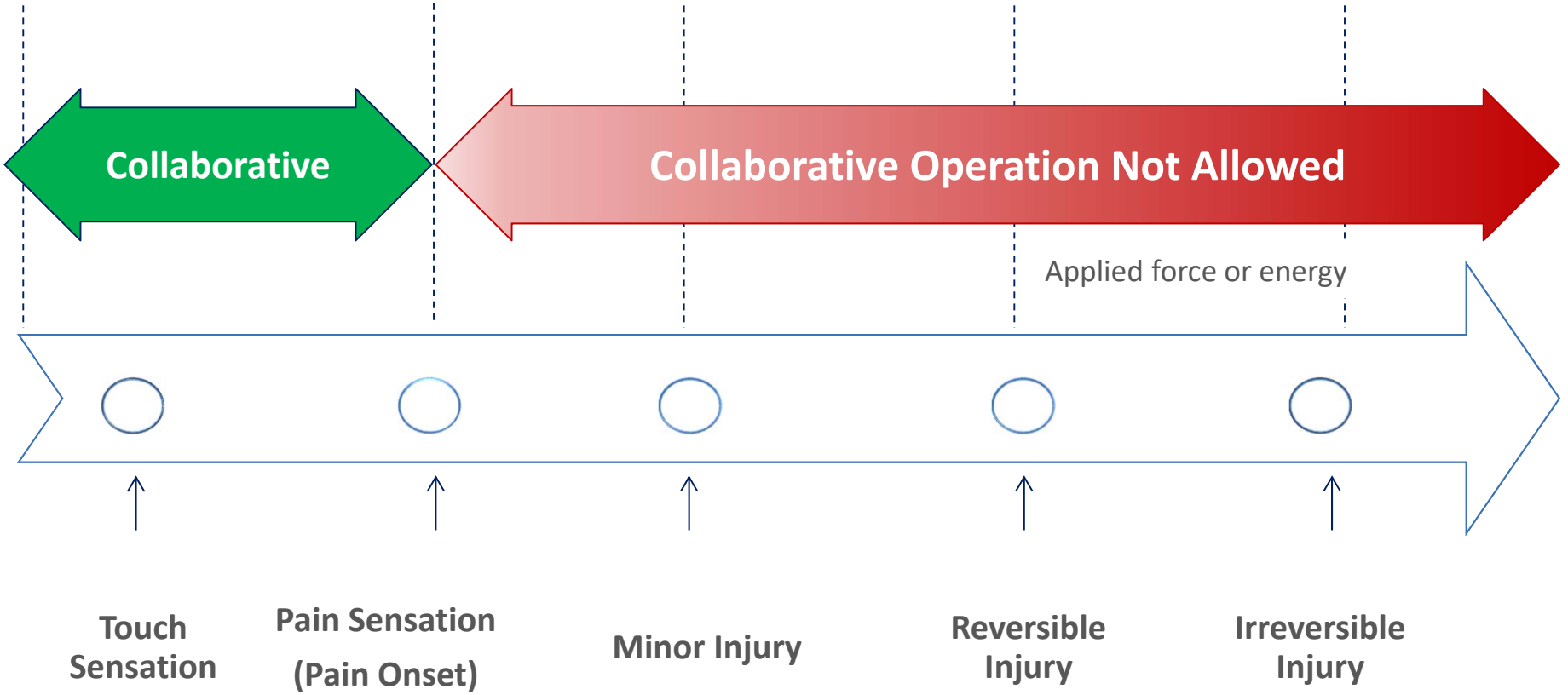
- Force torque sensors
- No need for fencing or other safety devices



- Programmed with hand guiding
- Compact, light weight design
- Minimal impact on production line

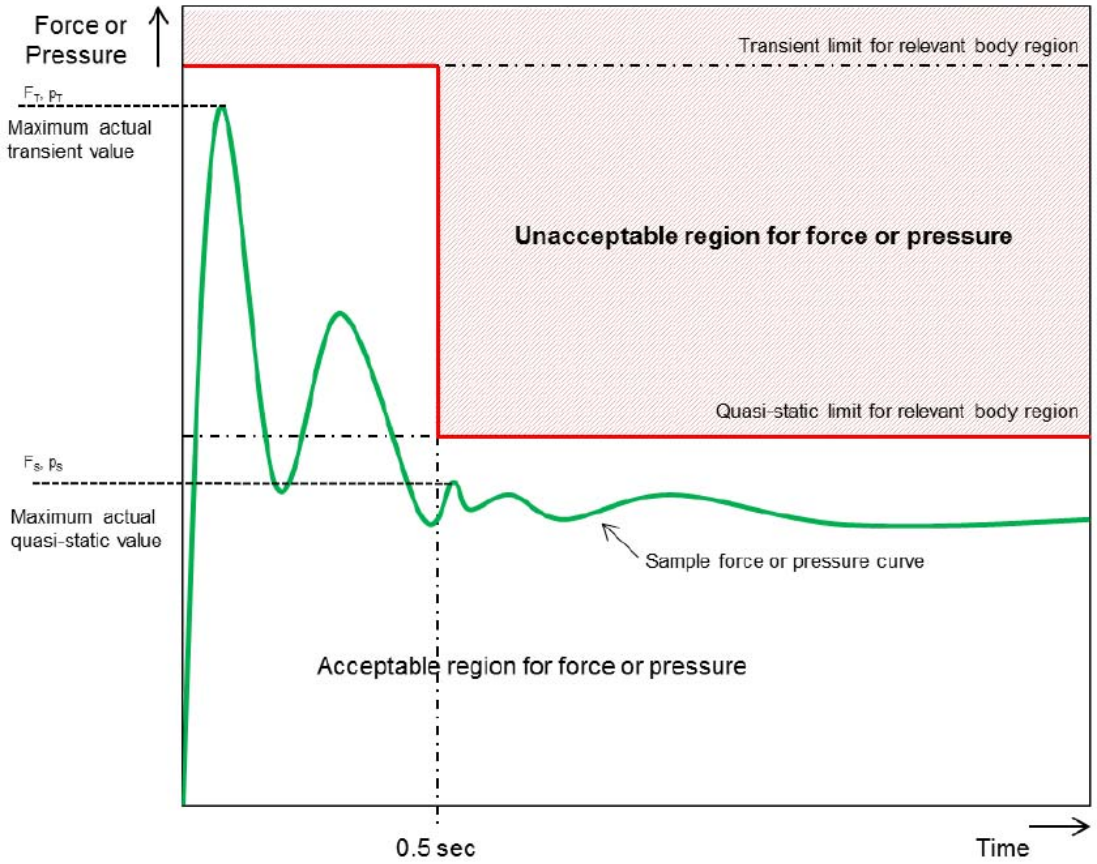
# Biomechanical Limit Criteria

## ISO TS 15066 – Onset of Pain Study



# Onset of Pain Study

## Study by University of Mainz




ISO TS 15066:2016 figure 3

imagination at work

# Biomechanical Limits

## ISO TS 15066:2016 TableA.2

**Table A.2 — Biomechanical limits**

| Body Region | | Specific Body Area | Quasi-Static Contact | | Transient Contact | |
|---|---|---|---|---|---|---|
| | | | Maximum Allowable Pressure $p_c$ [N/cm2] (see NOTE 1) | Maximum Allowable Force [N] (see NOTE 2) | Maximum Allowable Pressure Multiplier $P_T$ (see NOTE 3) | Maximum Allowable Force Multiplier $F_T$ (see NOTE 3) |
| Skull and forehead | 1 | Middle of forehead | 130 | 130 | N/A | N/A |
| | 2 | Temple | 110 | | N/A | |
| Face | 3 | Masticatory muscle | 110 | 65 | N/A | N/A |
| Neck | 4 | Neck muscle | 140 | 150 | 2 | 2 |
| | 5 | Seventh neck muscle | 210 | | 2 | |
| Back and shoulders | 6 | Shoulder joint | 160 | 210 | 2 | 2 |
| | 7 | Fifth lumbar vertebra | 210 | | 2 | 2 |
| Chest | 8 | Sternum | 120 | 140 | 2 | 2 |
| | 9 | Pectoral muscle | 170 | | 2 | |
| Abdomen | 10 | Abdominal muscle | 140 | 110 | 2 | 2 |
| Pelvis | 11 | Pelvic bone | 210 | 180 | 2 | 2 |
| Upper arms and elbow joints | 12 | Deltoid muscle | 190 | 150 | 2 | 2 |
| | 13 | Humerus | 220 | | 2 | |
| Lower arms and wrist joints | 14 | Radial bone | 190 | 160 | 2 | 2 |
| | 15 | Forearm muscle | 180 | | 2 | |
| | 16 | Arm nerve | 180 | | 2 | |
| Hands and fingers | 17 | Forefinger pad D | 300 | 140 | 2 | 2 |
| | 18 | Forefinger pad ND | 270 | | 2 | |
| | 19 | Forefinger end joint D | 280 | | 2 | |
| | 20 | Forefinger end joint ND | 220 | | 2 | |
| | 21 | Thenar eminence | 200 | | 2 | |
| | 22 | Palm D | 260 | | 2 | |
| | 23 | Palm ND | 260 | | 2 | |
| | 24 | Back of the hand D | 200 | | 2 | |
| | 25 | Back of the hand ND | 190 | | 2 | |
| Thighs and knees | 26 | Thigh muscle | 250 | 220 | 2 | 2 |
| | 27 | Kneecap | 220 | | 2 | |
| Lower legs | 28 | Middle of shin | 220 | 130 | 2 | 2 |
| | 29 | Calf muscle | 210 | | 2 | |

CRITICAL ZONE

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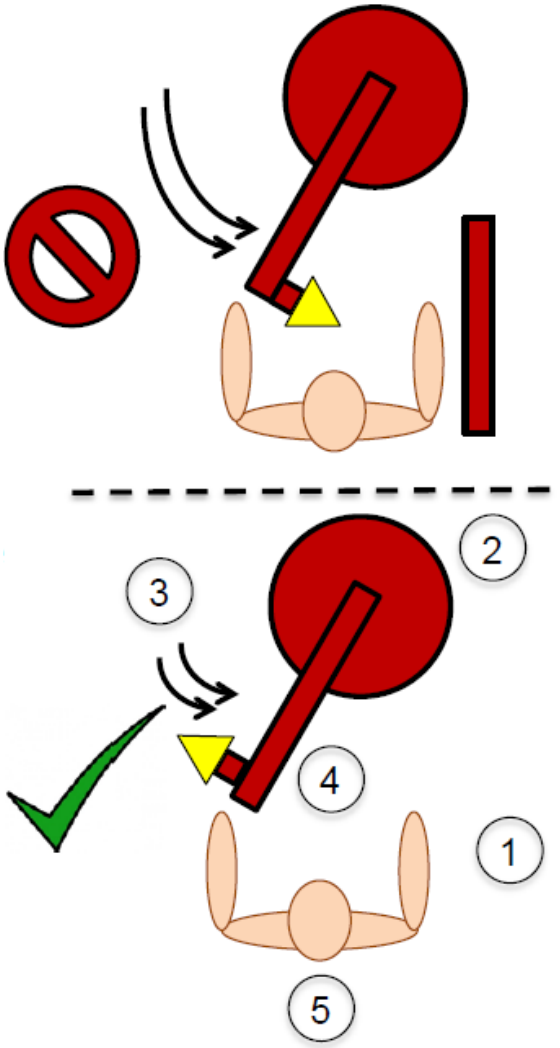
**Power and force limits can be affected or modified by:**

1) Eliminating pinch points
2) Reducing inertia or mass
3) Reducing velocity
4) Modifying posture
5) Avoiding sensitive body areas



Collaborative robots with Power & Force Limiting **does not mean:**

- Remove fences without further considerations
- “Safe” robot will render entire application “safe”
- Requires a higher safety performance than standard industrial robots
- Too slow for productive applications

# Robot Safety Standards

# ANSI/RIA R15.06 - 2012


- Update to **ANSI/RIA R15.06-1999**
- National adoption of **ISO 10218-1&2**

**KEY ASPECTS:**

- **Terminology**
- **Regulatory Compliance**
- **Safety Rating Qualification**
- **Floor Space optimization**
- **Collaborative Operation**
- **Global Acceptance**

# Terminology

| | |
|---|---|
| Robot | Does not include end effector |
| Robot System | Robot and end effector and any task equipment |
| Robot Cell | Robot System and safeguarding |
| Slow speed | Reduced speed |
| Safety Stop | Protective stop |
| Teach Mode | MANUAL reduced speed mode (teach is a task using manual mode) |
| APV | MANUAL high speed mode |
| Operator | All personnel |

# Terminology

## Know your verb usage:

| | |
|---|---|
| Shall | Normative or mandatory requirement |
| Should | Recommendation or good practice |
| May | Permissive or allowed |
| Can | Possible or capable – statement of fact |

NOTE — Notes appear throughout the document. All notes are informative and are used to provide additional information or explanation of concepts.

# Regulatory Compliance

OSHA® Occupational Safety and Health Administration

# ANSI & OSHA Standards Comparison

Source: Matt Epperson, Compliance Safety and Health Officer, OSHA

**OSHA General Duty Clause:** *"Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees…"*

| | ANSI Standards | OSHA Standards |
|---|---|---|
| Compliance Requirement: | Voluntary | Mandatory |
| Comprehensive: | Yes | No* |
| Periodically Updated: | Yes | No |

* limited to mechanical power presses, forging machines, cooperage machines, etc.

**Compliance to ANSI standards can be used as a**

- Means of complying with OSHA requirements of a safe workplace but NOT presumption of conformity or compliance.
- Civil legal defense for providing a safe workplace based on current practices.

# Who do standards concern?

Source: Matt Epperson, Compliance Safety and Health Officer, OSHA

| | ANSI | ISO | OSHA |
|---|---|---|---|
| **Manufacturer** | X | X | |
| **Integrator** | X | X | |
| **User** | X | | X |

- **ANSI standards** typically provide guidance to **Manufacturers**, **Integrators** and **Users** of industrial machinery.
- **ISO standards** do not provide guidance to **Users** of industrial machinery, under the assumption that each country will have its own regulatory safety requirements.
- **OSHA standards** provide guidance only to **Users** of industrial machinery.

# OSHA and Robots

Source: https://www.osha.gov/SLTC/robotics/

**"There are currently no specific {OSHA} standards for the robotics industry."**

Several General Industry (29 CFR 1910) requirements do apply

- **1910 Subpart J,** General environmental controls
  - **1910.147,** The control of hazardous energy
- **1910 Subpart O,** Machinery and machine guarding
- **1910 Subpart S,** Electrical

Several national consensus standards (ANSI, ISO, CSA) are recognized as ***providing guidance*** related to worker protection

- (References are out of date)

Source: Matt Epperson, Compliance Safety and Health Officer, OSHA

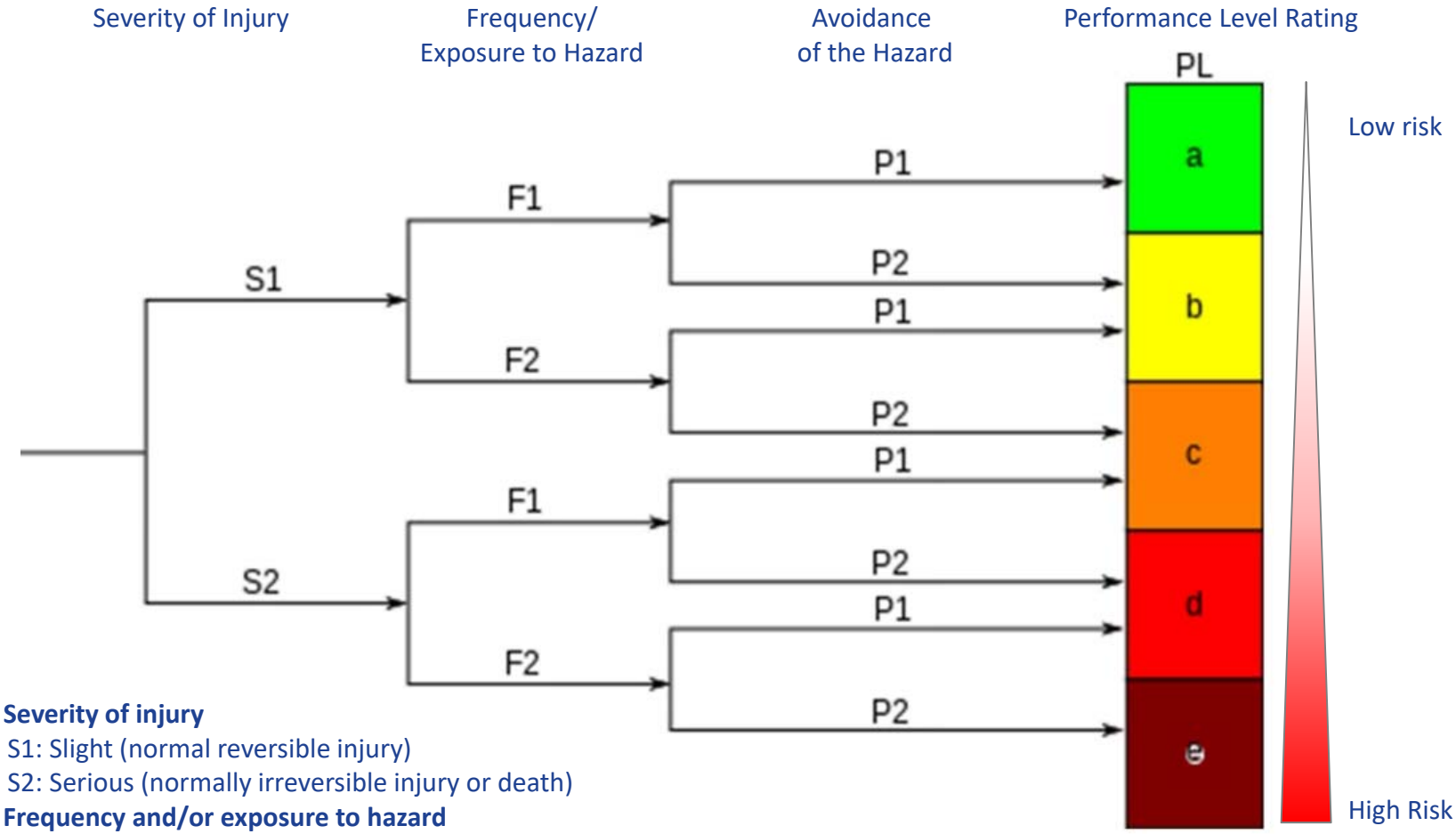
# What to Provide to OSHA if Inspected

- Risk Assessments
- Job Hazard Analysis/Job Safety Analysis
- Drawings & Schematics
- Safety device specifics
- Minor servicing task list and justification
- Lock out tag out program and procedures
- The employer needs to know their system and know how to explain to OSHA and the compliance officers.
- The employer needs to know with confidence how their system functions and why it is safe.

Source: Matt Epperson, Compliance Safety and Health Officer, OSHA

OSHA® Occupational Safety and Health Administration

# Safety Rating Qualification




**S: Severity of injury**
- S1: Slight (normal reversible injury)
- S2: Serious (normally irreversible injury or death)

**F: Frequency and/or exposure to hazard**
- F1: Seldom to less often and/or exposure time is short
- F2: Frequent to continuous and/or exposure time is long

**P: Possibility or avoiding hazard or limiting harm**
- P1: Possible under specific conditions
- P2: Scarcely possible

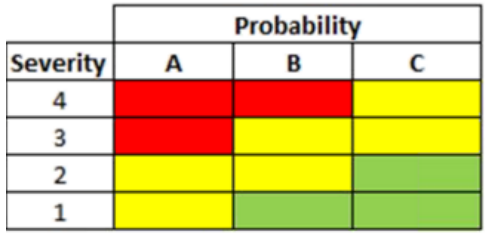
# Safety Rating Qualification

- ISO 13849-1:2006 and IEC 62061 provide performance metrics for Functional Safety
  - Can quantify performance, determine requirements, and validate compliance
- "Control Reliable" is a concept written in the 1999 standard
- A controls system meeting a PL=d and structure category 3 meets the requirements set forth in the prior control reliability language:
  1. A single fault does not lead to the loss of the safety function;
  2. The fault shall be detected before the next safety function demand;
  3. When the fault occurs, the safety function is performed and a safe state shall be maintained until the detected fault is corrected;
  4. Reasonably foreseeable faults shall be detected.

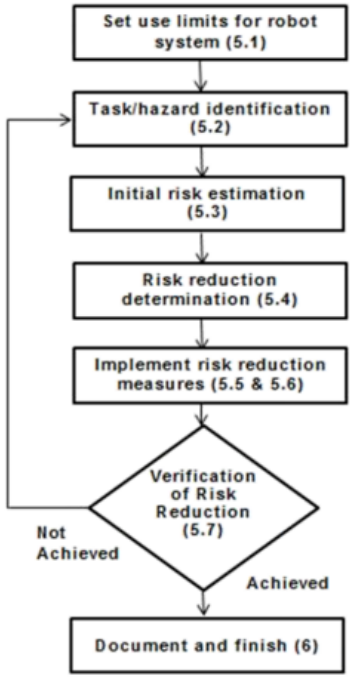
# Floor Space Optimization

The Robot Cell Footprint can be reduced bb following these steps:

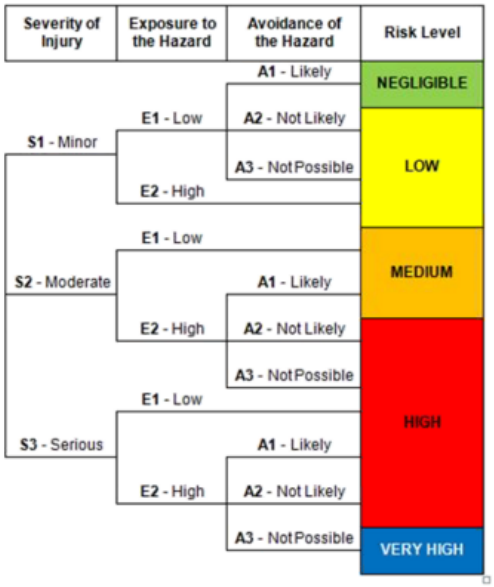
1. Conducting a **risk assessment** to identify tasks & hazards with all phases of operation and to identify **protective measures**




ISO 12100/ANSI B11.0



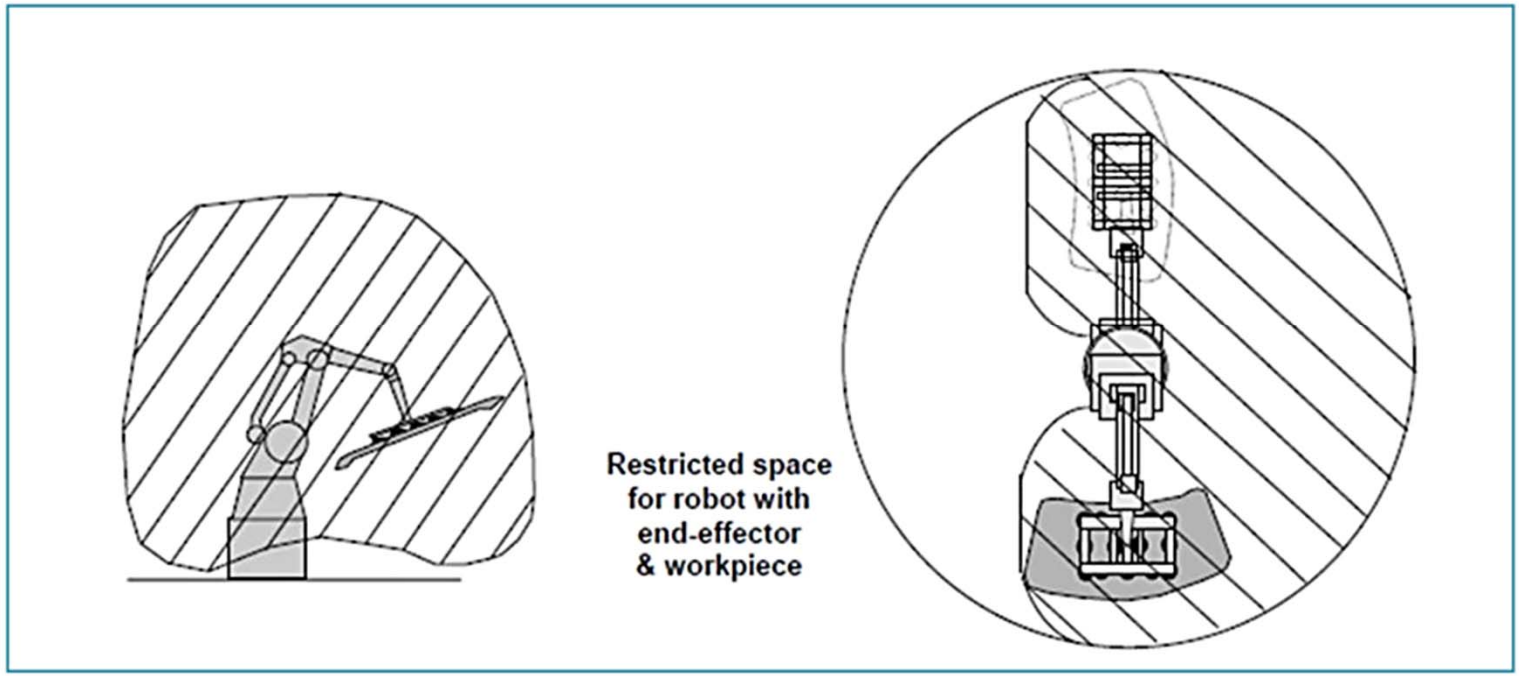

Typical flow chart




RIA TR R15.306
(based on
ISO 13849-1:2006)

# Floor Space Optimization

2. Use **'safety-rated soft axis** and **space limiting**' to reduce the size of your restricted space



# Floor Space Optimization

3. Apply **safeguarding**, providing **operator clearance** only where tasks inside the safeguarded space occur
   - No Task → no need for clearance
   - 2012: 20 inch clearance required for high speed manual
   - 1999: 18 inch clearance form the operating space was required.

# Collaborative Robot System

**https://www.youtube.com/watch?v=B6SwSPa0IQ4**

## Applying Urethane to Automotive Glass – Esys Automation

# Risk Assessment

# RISK

## How Bad?

CONCSEQUENCES

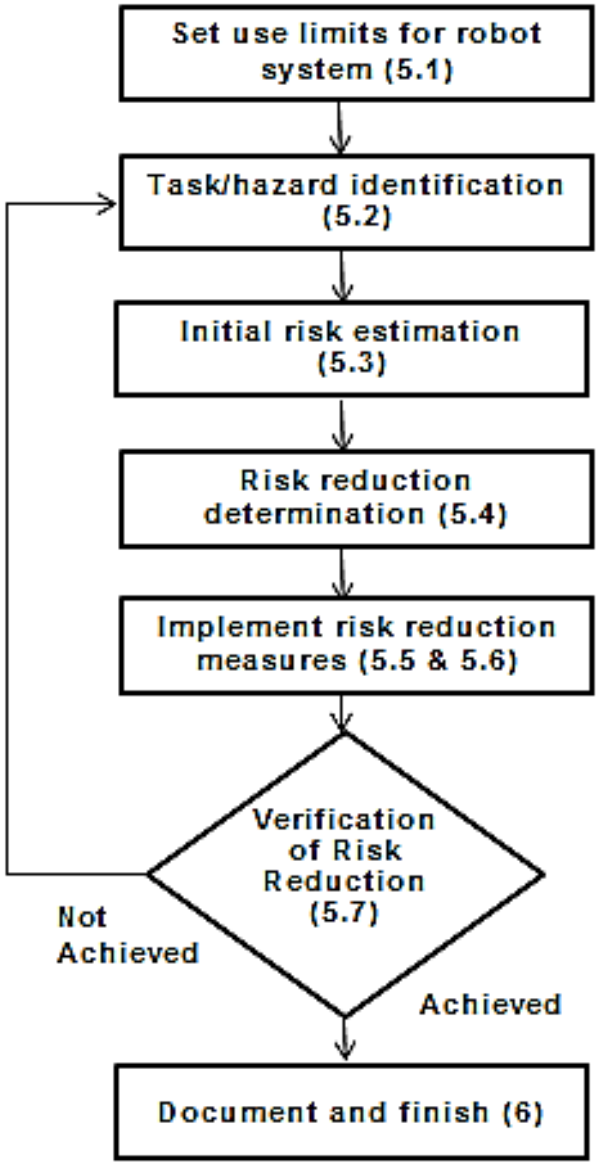
## How Often?

FREQUENCY

## How Likely?

AVOIDANCE

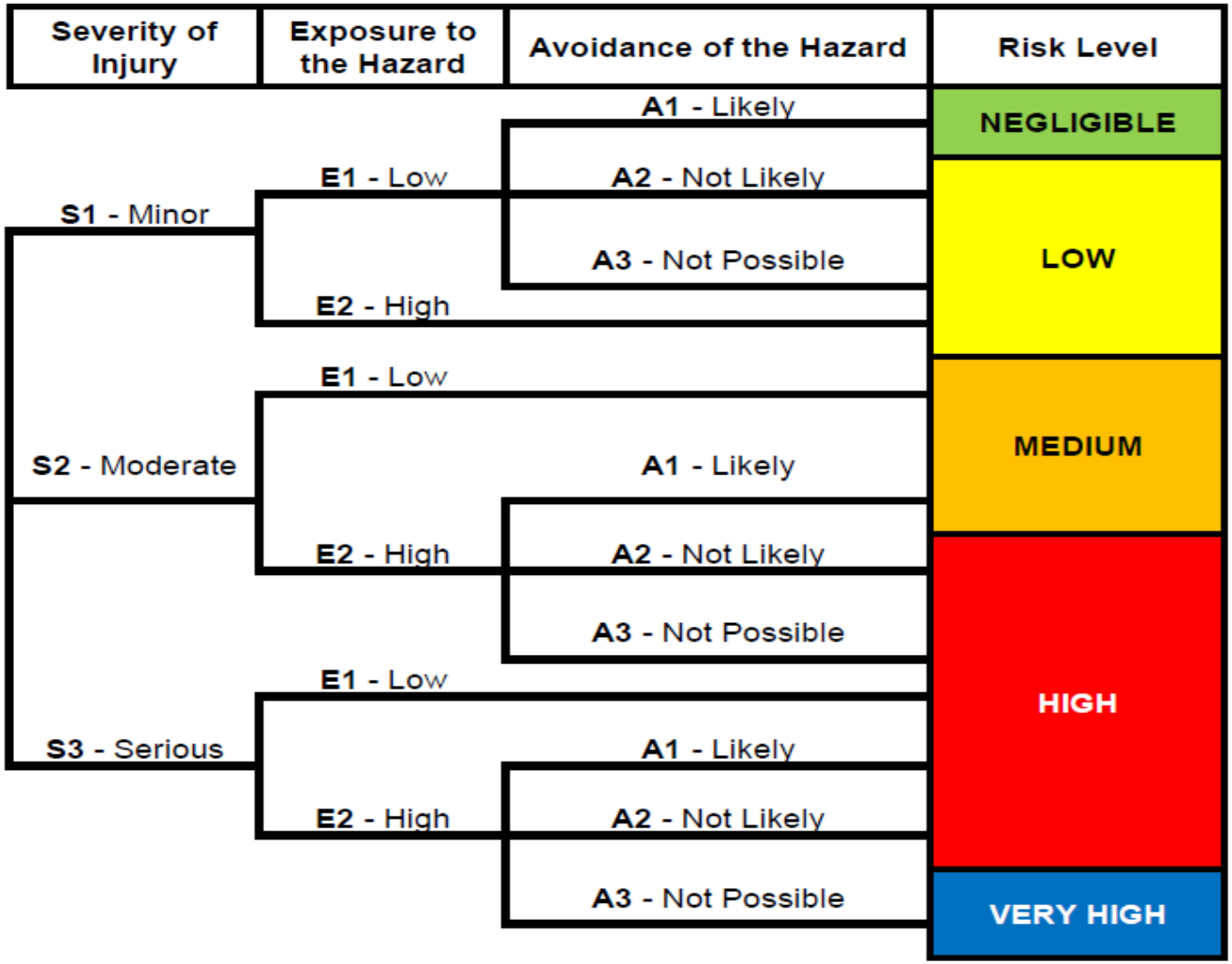
*There are MANY risk assessment methodologies!*




- Anticipates tasks and hazards then applies risk reduction measures
- Allows for safeguard customization
- Uses iterative process
- Avoids ‘one size fits all’ prescriptive measures

# Risk Matrix

TR R15.306 - Risk Level Decision Matrix

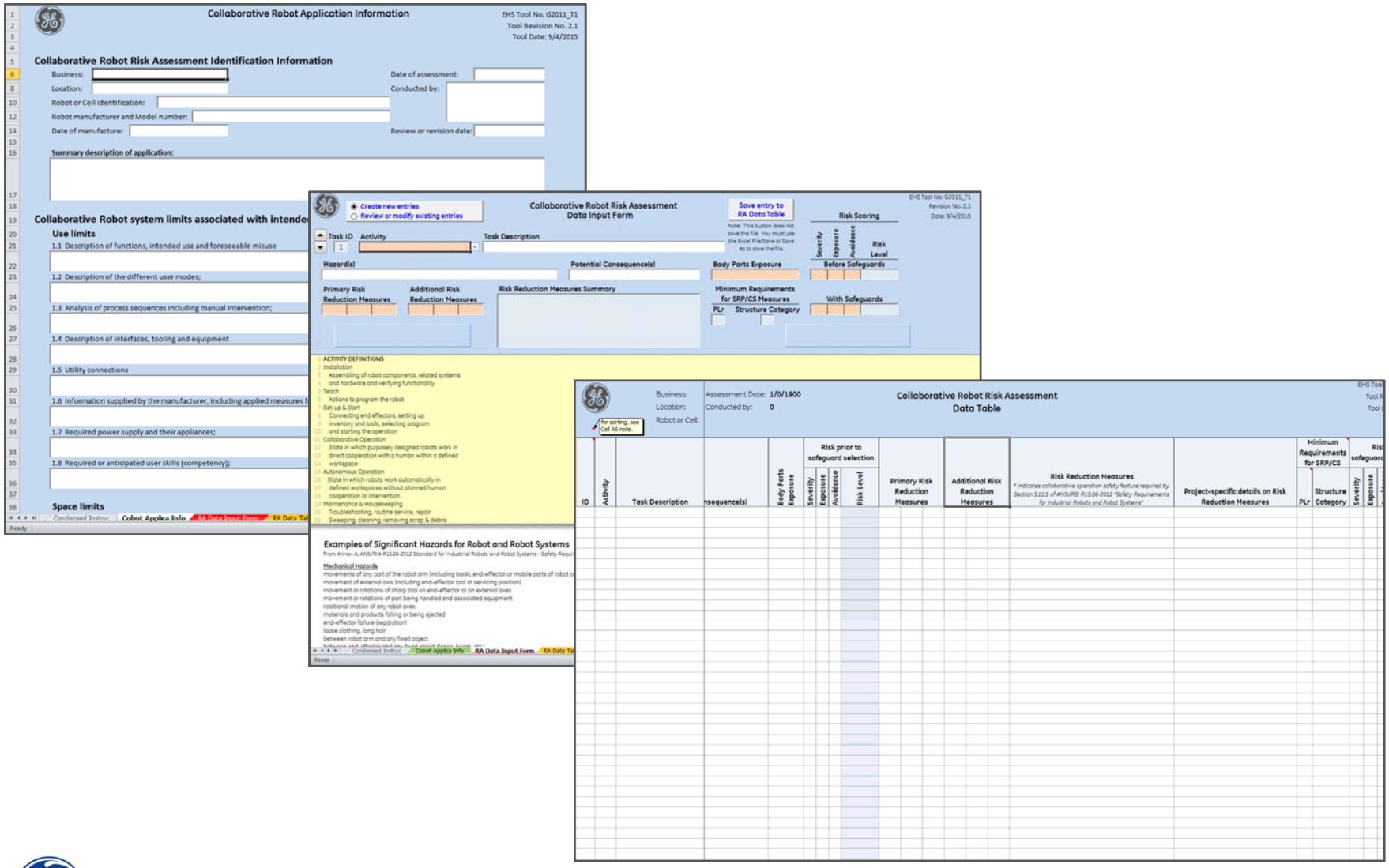


# Risk Reduction Measures

**Most preferred** → **Least preferred**

| Inherently Safe Design | | | Safeguarding & Complementary Protective Measures | | Information for Use | | |
|---|---|---|---|---|---|---|---|
| Elimination | Substitution | Limit interaction | Safeguarding & SRP/CS | Complimentary Protective Measures | Warnings & Awareness Means | Administrative Controls | Personal Protective Equipment |
| • Process design<br>• Redesign or<br>• Modifi-cation | • Less hazardous materials<br>• Intrinsically safe<br>• Reduced energy levels<br>• Reduced volumes | • Eliminate or reduce human interaction<br>• Automate tasks | • Guards<br>• Interlocks<br>• SPE<br>• Two-hand controls devices<br>• Safety controls and logic<br>• Safety-related functions and safety parameters<br>• Integration of protective devices | • Emergency Stop Devices and functions<br>• Platforms and guard railing & Safe Access<br>• Measures for escape & Rescue, isolation & energy control, handling heavy parts | Lights<br>Beacons and strobes<br>Audible alarms<br>Signs, labels or markings | • Training and safe job procedures<br>• Safety equipment inspections<br>• Job rotation<br>• Changing work schedule<br>• LOTO<br>• HazCom Confined Space Entry | • Clothing & Footwear for specific safety purposes |

# Risk Assessments



# Help!

# Standards

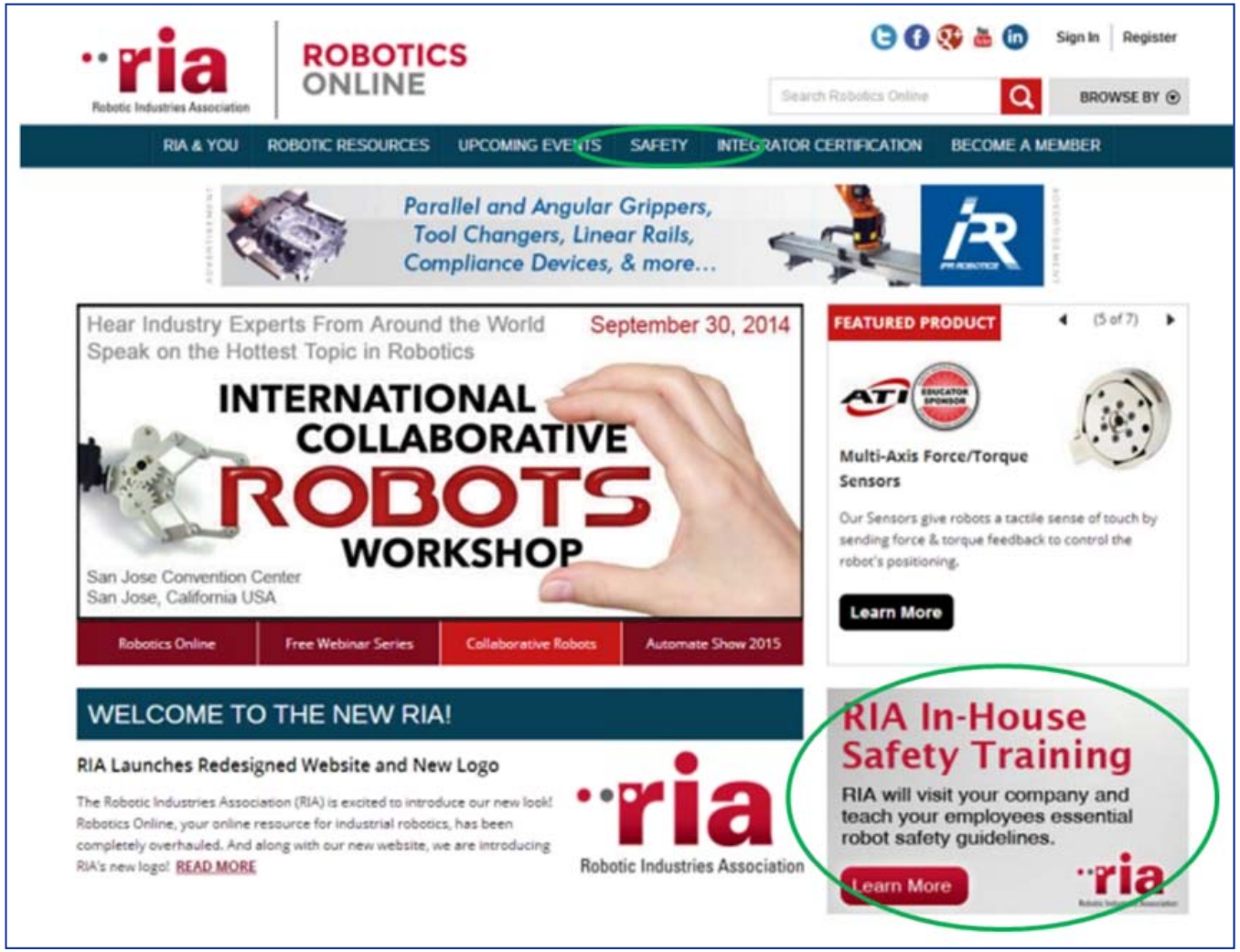
| Normative References | |
|---|---|
| ISO 10218-1:2011 | Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots |
| ISO 10218-2:2011 | Robots and robotic devices — Safety requirements for industrial robots — Part 2: Robot systems and integration |
| ISO/TS 15066 | Robots and Robotic Devices – Collaborative Robots |
| ANSI/RIA R15.06-2012 | American National Standard for Industrial Robots and Robot Systems – Safety Requirements (adopts ISO 10218-1 and ISO 10218-2 entirely) |
| RIA TR R15.306-2014 | American National Standard for Industrial Robots and Robot Systems - Task Based Risk Assessment Methodology |
| RIA TR R15.406-2014 | American National Standard for Industrial Robots and Robot Systems – Safeguarding |

# Resources

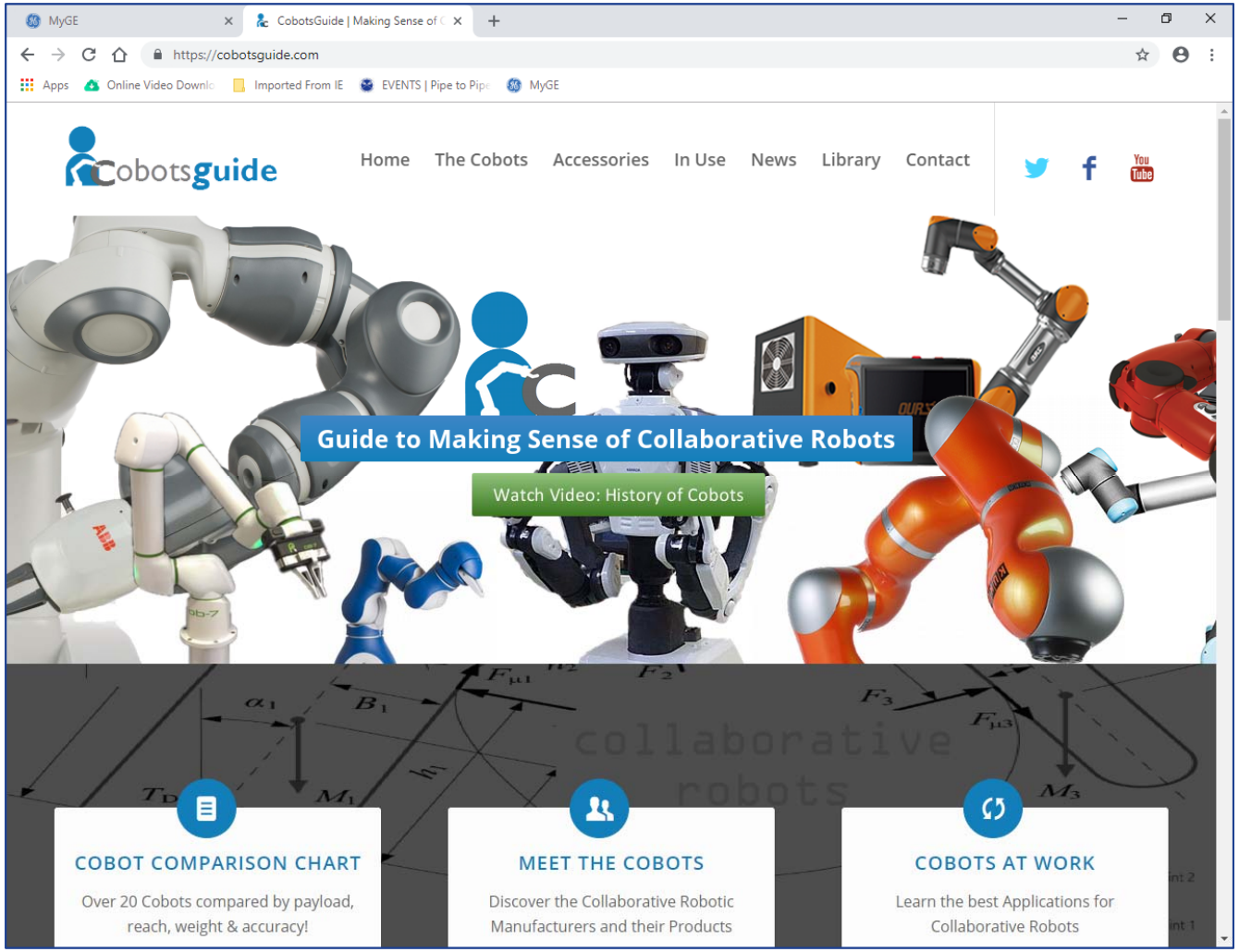
RIA Technical Reports

- **RIA TR R15.306, Task-Based Risk Assessment**
  - Updates guidance in ANSI/RIA R15.06-1999, Clause 9
- **RIA TR R15.406, Safeguarding**
  - Updates guidance in ANSI/RIA R15.06-1999, Clauses 10 and 11
- **RIA TR R15.506, Existing Systems**
  - Provides guidance as to when the guidance outlined in ANSI/RIA R15.06-2012 would apply for robot cells built to ANSI/RIA R15.06-1999 requirements

# Robotics.org



# Cobotsguide.com



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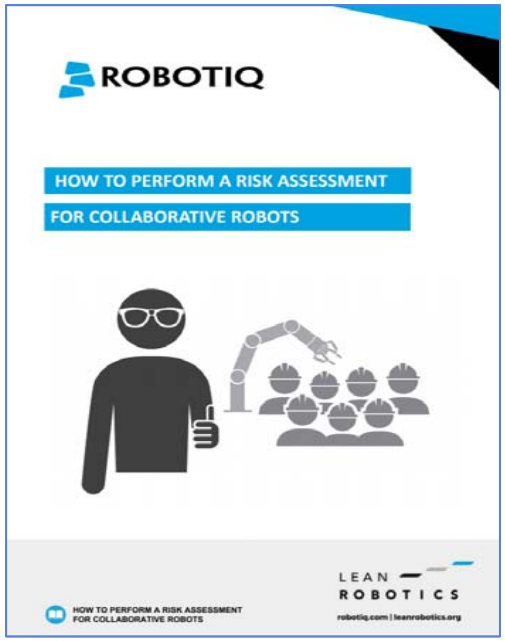


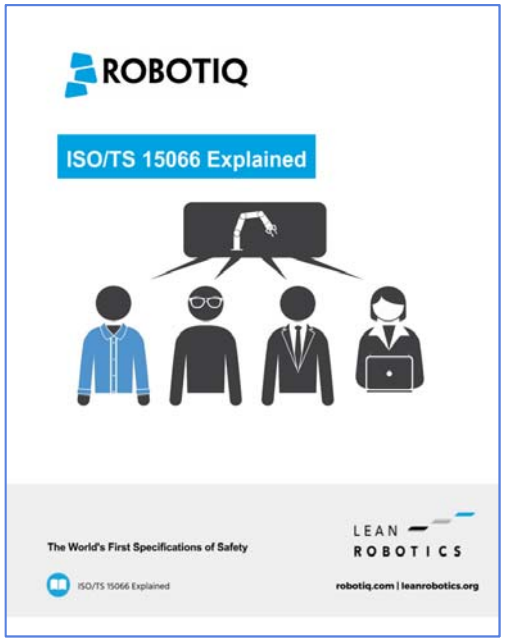


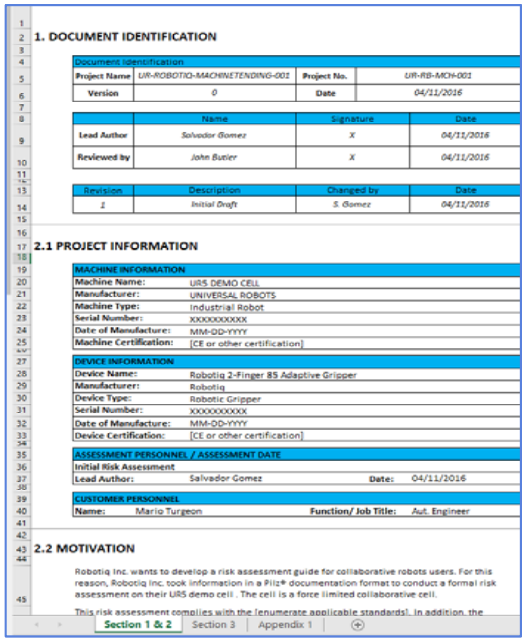

1. DOCUMENT IDENTIFICATION

| Document identification | | | |
|---|---|---|---|
| Project Name | UR-ROBOTIQ-MACHINETENDING-001 | Project No. | UR-RB-MCH-001 |
| Version | 0 | Date | 04/11/2016 |

| | Name | Signature | Date |
|---|---|---|---|
| Lead Author | Salvador Gomez | X | 04/11/2016 |
| Reviewed by | John Butler | X | 04/11/2016 |

| Revision | Description | Changed by | Date |
|---|---|---|---|
| 1 | Initial Draft | S. Gomez | 04/11/2016 |

2.1 PROJECT INFORMATION

| MACHINE INFORMATION | |
|---|---|
| Machine Name: | UR5 DEMO CELL |
| Manufacturer: | UNIVERSAL ROBOTS |
| Machine Type: | Industrial Robot |
| Serial Number: | XXXXXXXXX |
| Date of Manufacture: | MM-DD-YYYY |
| Machine Certification: | [CE or other certification] |

| DEVICE INFORMATION | |
|---|---|
| Device Name: | Robotiq 2-Finger 85 Adaptive Gripper |
| Manufacturer: | Robotiq |
| Device Type: | Robotic Gripper |
| Serial Number: | XXXXXXXXX |
| Date of Manufacture: | MM-DD-YYYY |
| Device Certification: | [CE or other certification] |

| ASSESSMENT PERSONNEL / ASSESSMENT DATE | | | |
|---|---|---|---|
| Initial Risk Assessment | | | |
| Lead Author: | Salvador Gomez | Date: | 04/11/2016 |

| CUSTOMER PERSONNEL | | | |
|---|---|---|---|
| Name: | Mario Turgeon | Function/ Job Title: | Aut. Engineer |

2.2 MOTIVATION

Robotiq Inc. wants to develop a risk assessment guide for collaborative robots users. For this reason, Robotiq Inc. took information in a Pilz® documentation format to conduct a formal risk assessment on their UR5 demo cell . The cell is a force limited collaborative cell.

This risk assessment complies with the [enumerate applicable standards]. In addition, the

Section 1 & 2 | Section 3 | Appendix 1

# Introduction: Collaborative Robot Safety: Design & Deployment

***FREE*** *Online collaborative robot safety course available to public*

coursera

University at Buffalo
The State University of New York

# Ride the Movies … on a Robot

# Harry Potter Ride Behind the Scenes https://www.youtube.com/watch?v=Kz2zSdCQCcg

# Harry Potter Ride Behind the Scenes https://www.youtube.com/watch?v=RSGpKXhnpJA

imagination at work

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