

Intro to Collaborative Robots & Robotics Safety

Jim Biaglow, MS, CSP, CHMM

Sr Safety Engineer
GE Global Research



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



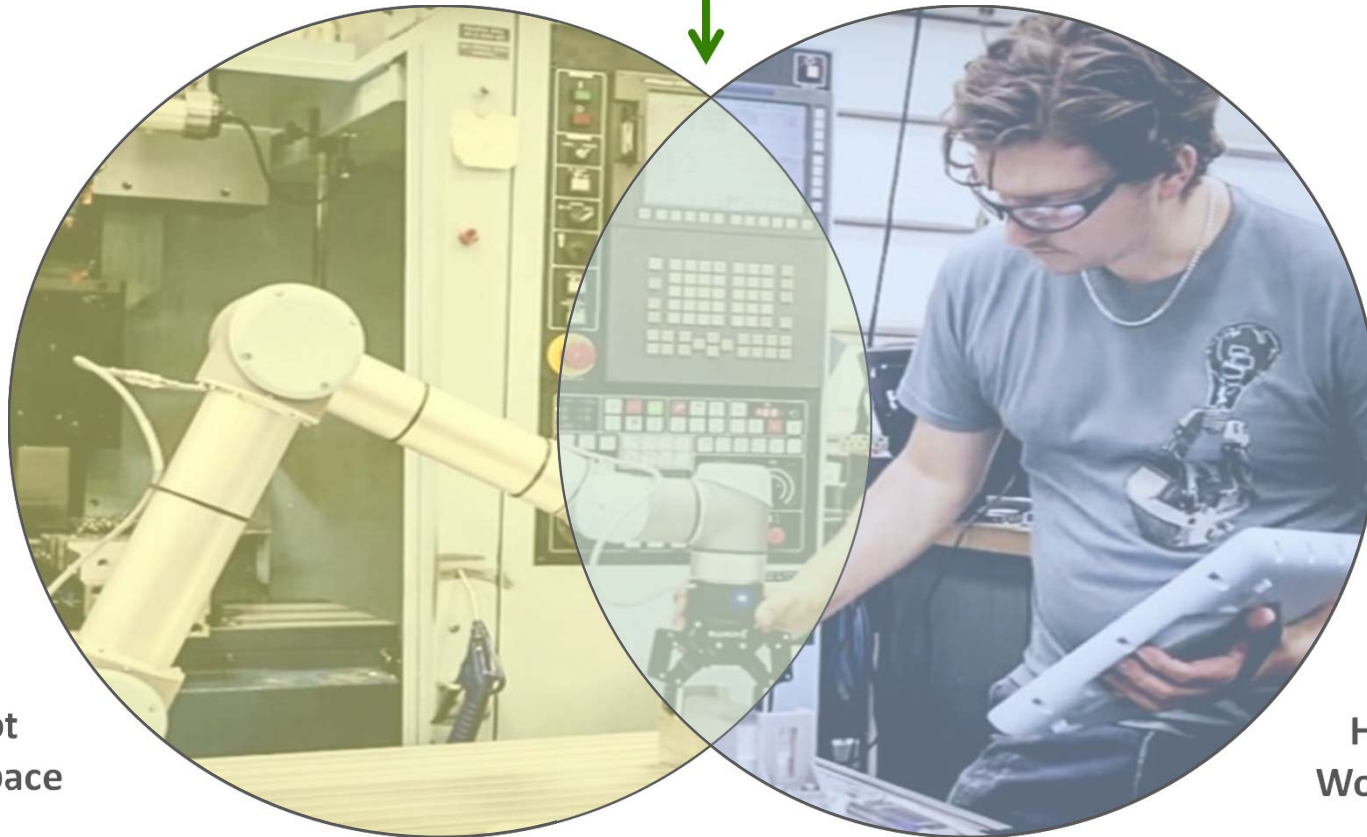
Source: Universal Robotics

What is a Cobot?

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



**Collaborative
Workspace**

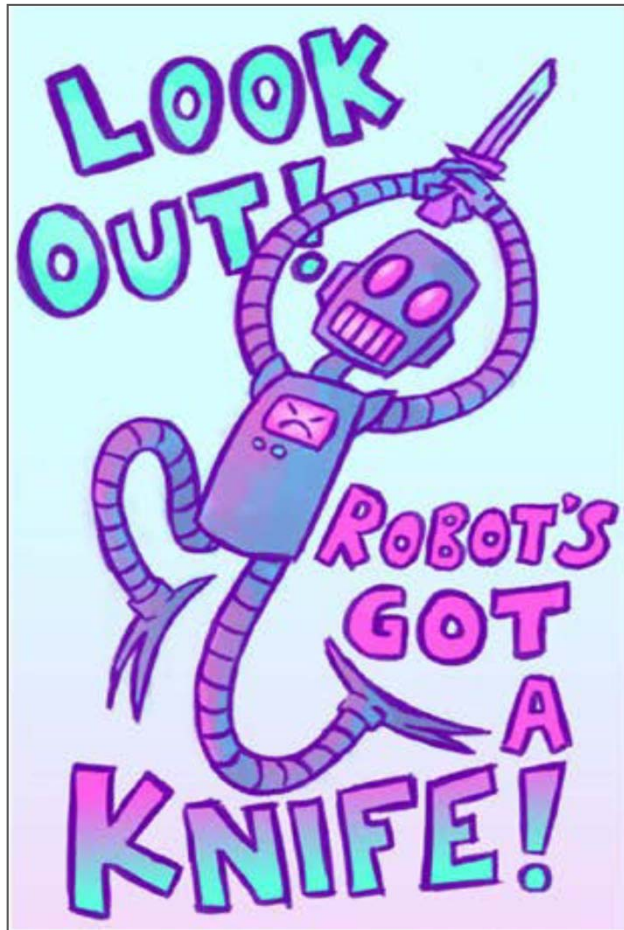


**Robot
Workspace**

**Human
Workspace**

Image source: Robotiq

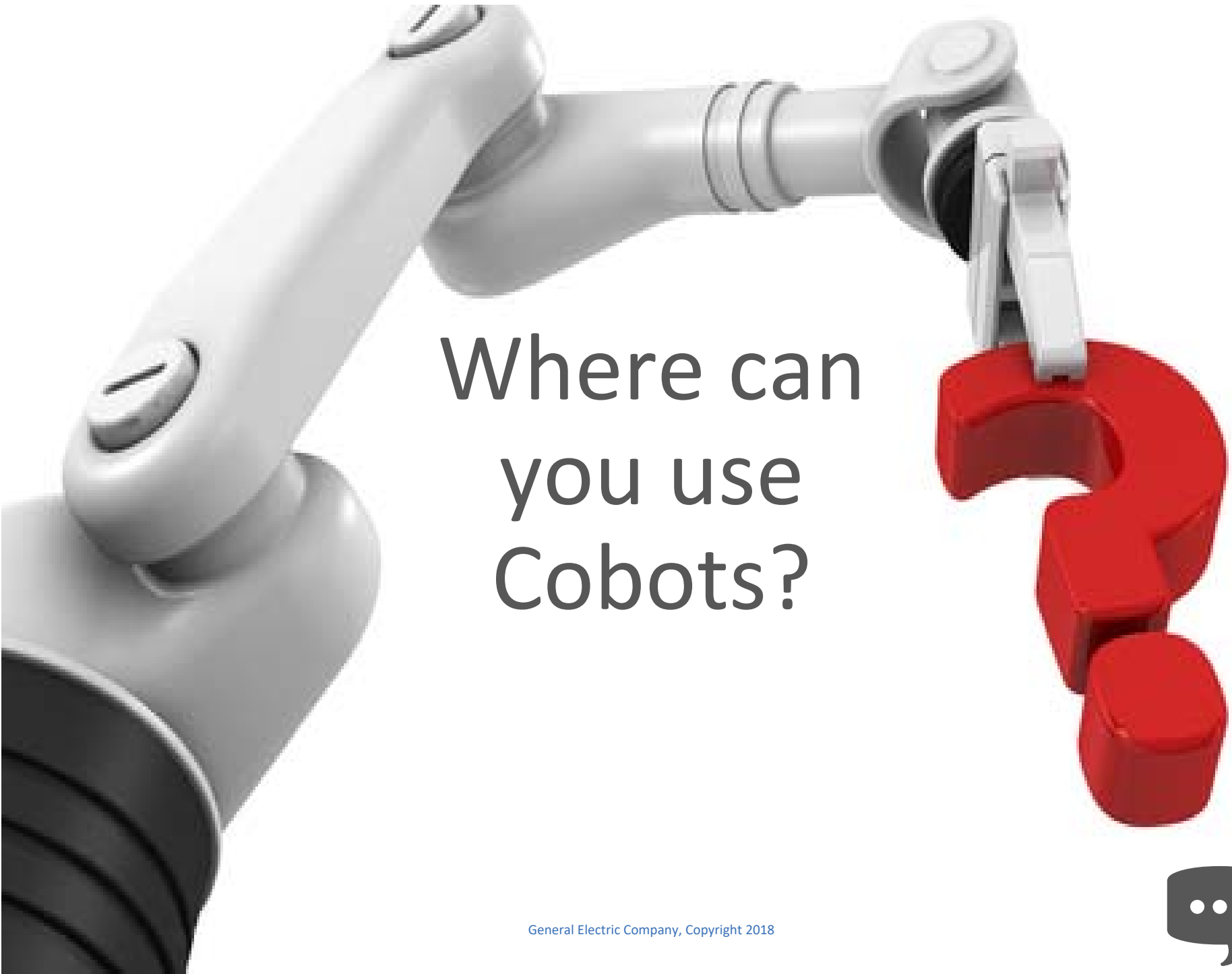
A collaborative robot is defined by



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

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

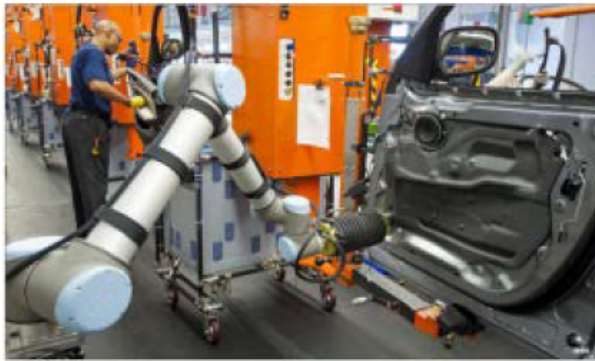
... and not the **robot** itself!

A white robotic arm is shown from the left, reaching towards the center. Its gripper is holding a large, 3D red question mark. The background is plain white.

Where can you use Cobots?

General Electric Company, Copyright 2018





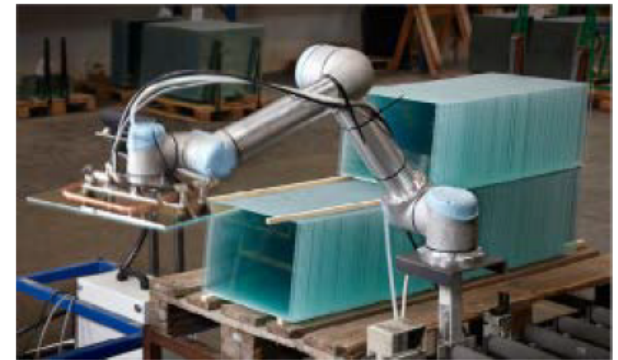
Automotive Assembly

Packaging/Palletizing



Pharmaceutical

Glass Handling



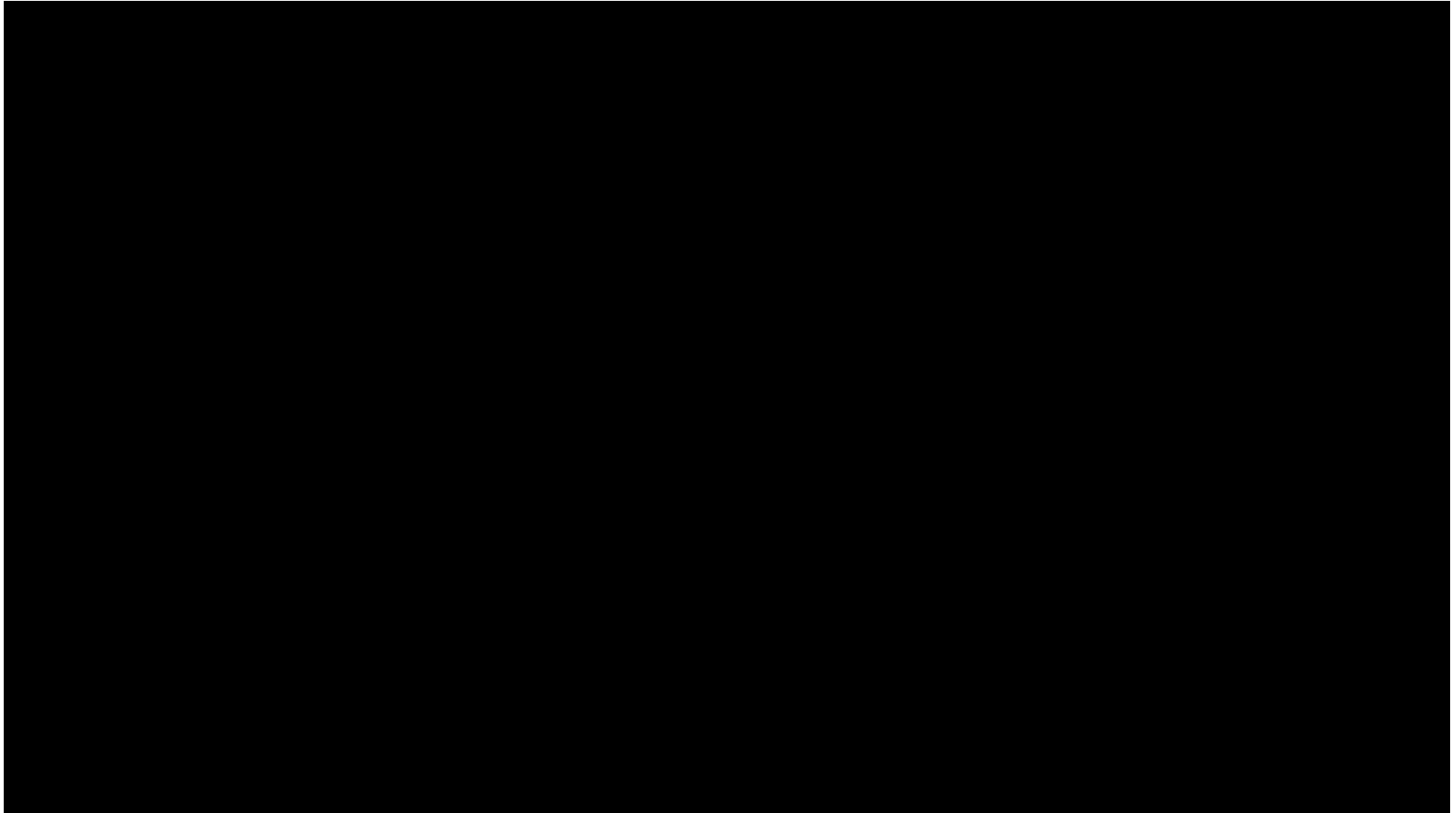
Machine Tending

Automotive Inspection



ReThink Sawyer

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



4 Types of Collaboration



imagination at work

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

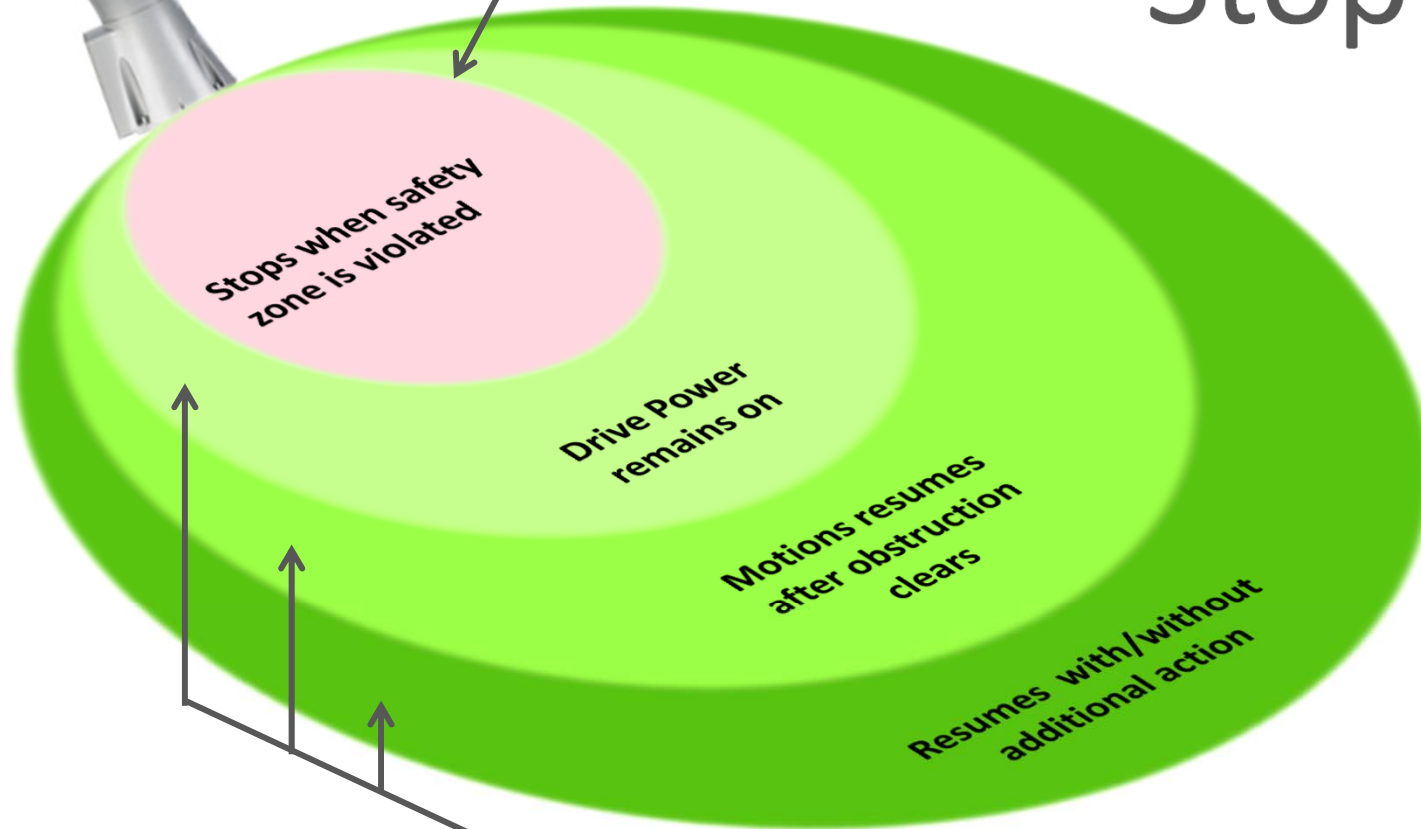
Power & Force Limiting

- Robot limits dynamic power output, static force and speed or energy

Safety Monitored Stop



Collaborative
work area



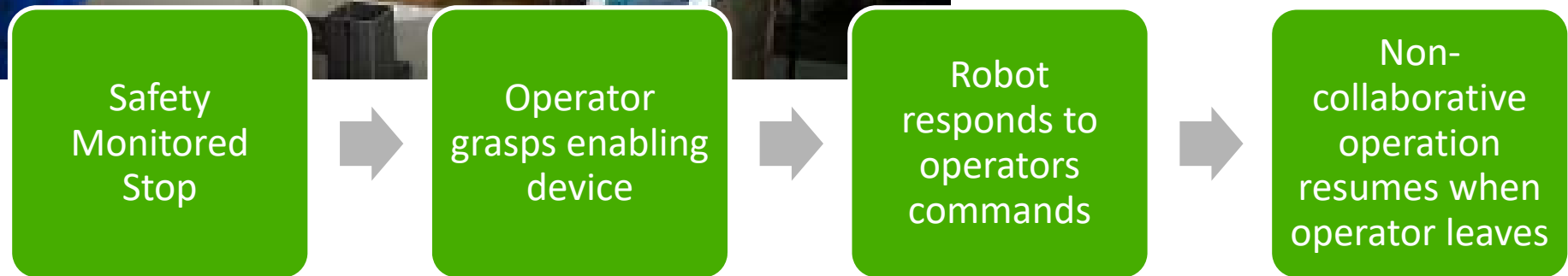
Robot functions at normal speed

Safety Monitored Stop

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

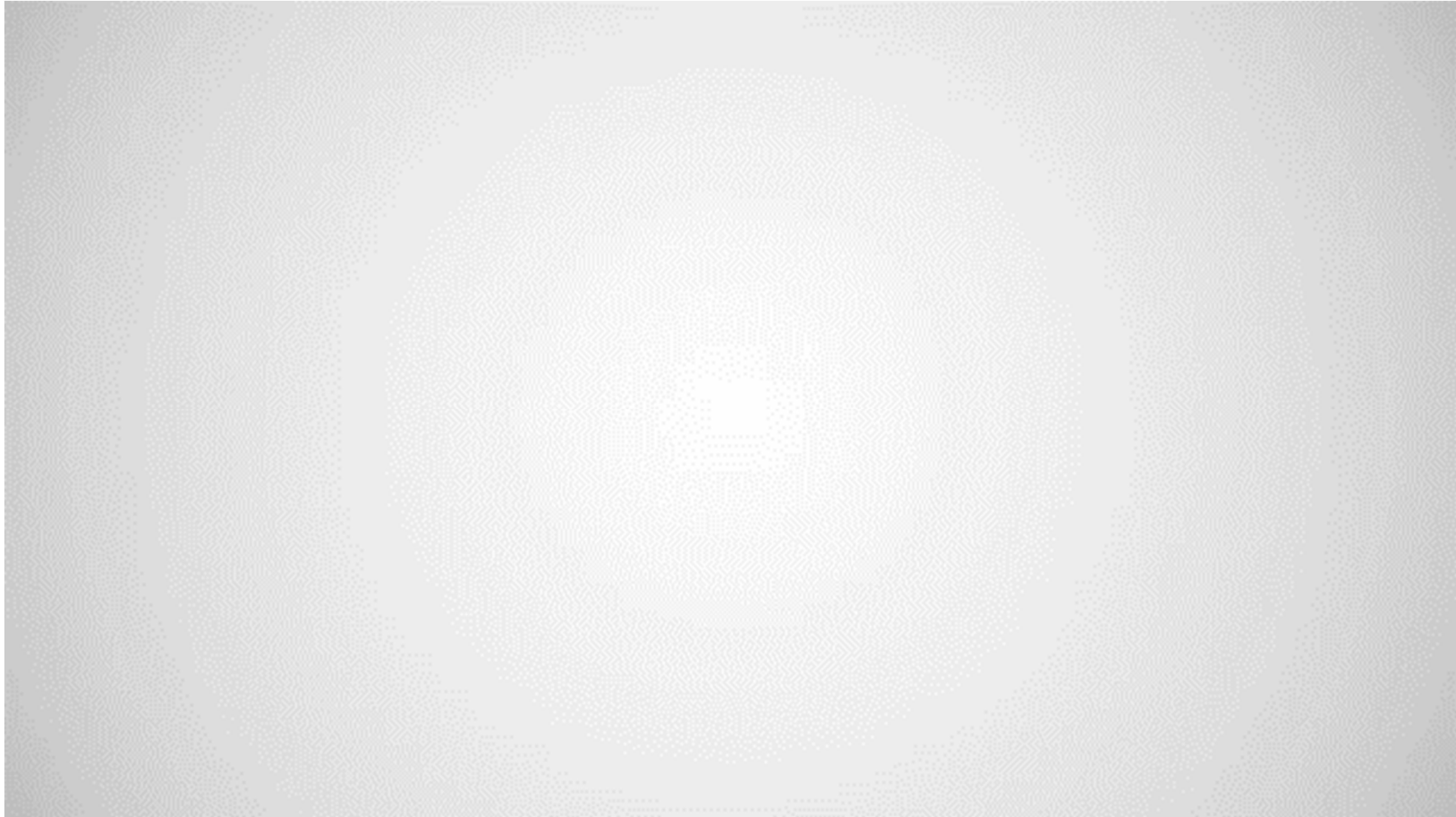


Hand Guiding

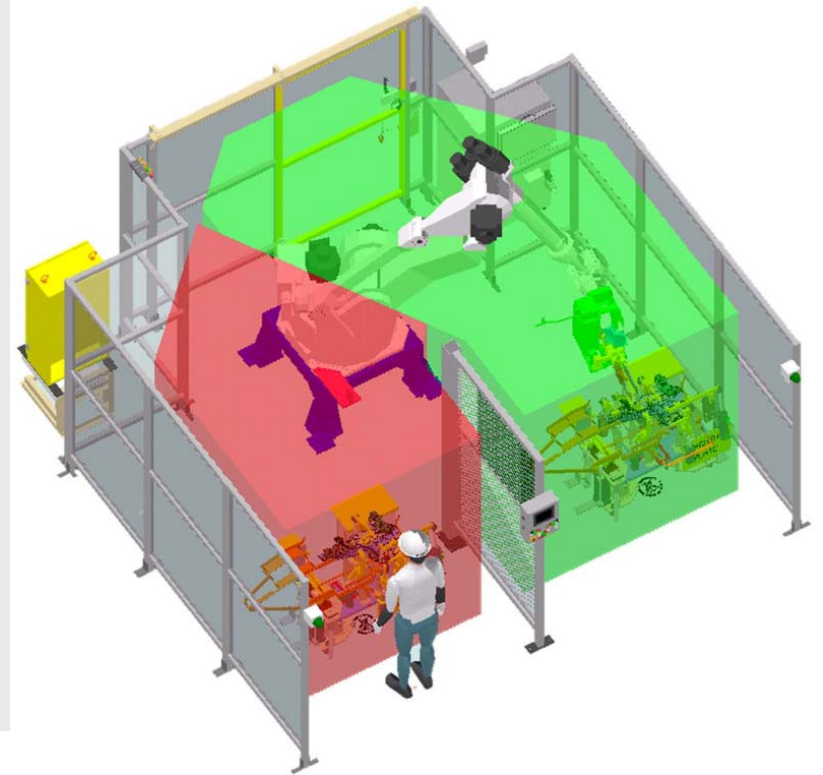
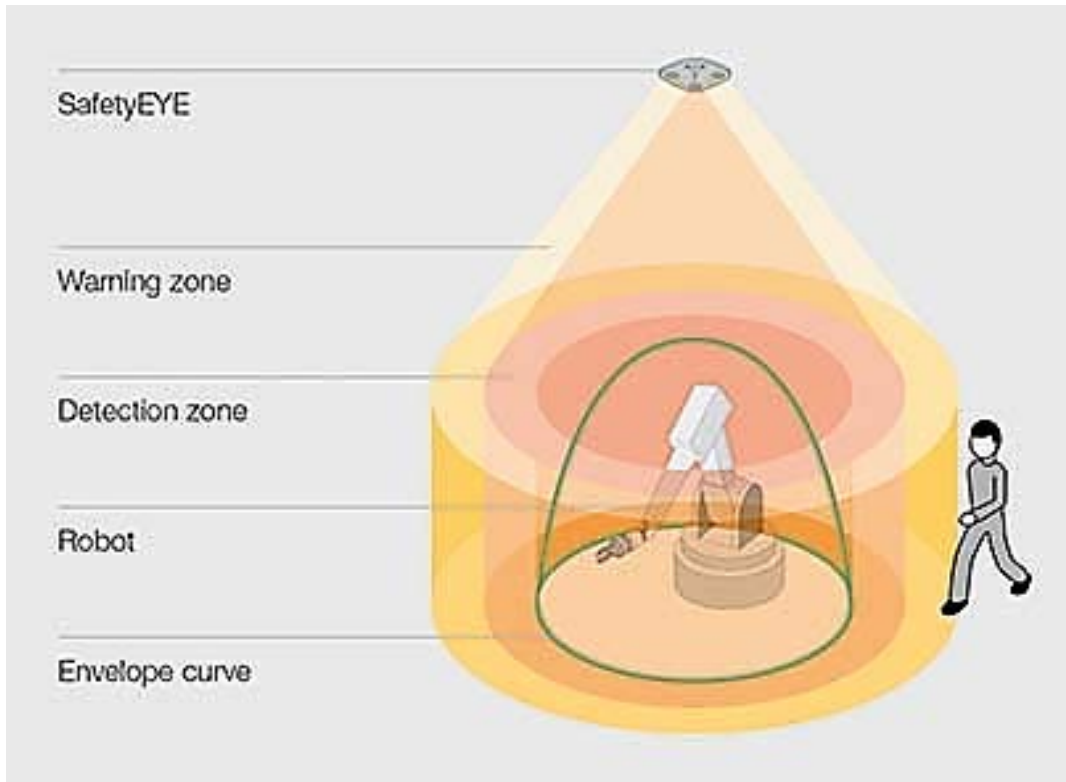


Universal Robotics

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



Speed & Separation Monitoring



Pilz SafetyEYE

Speed & Separation Monitoring

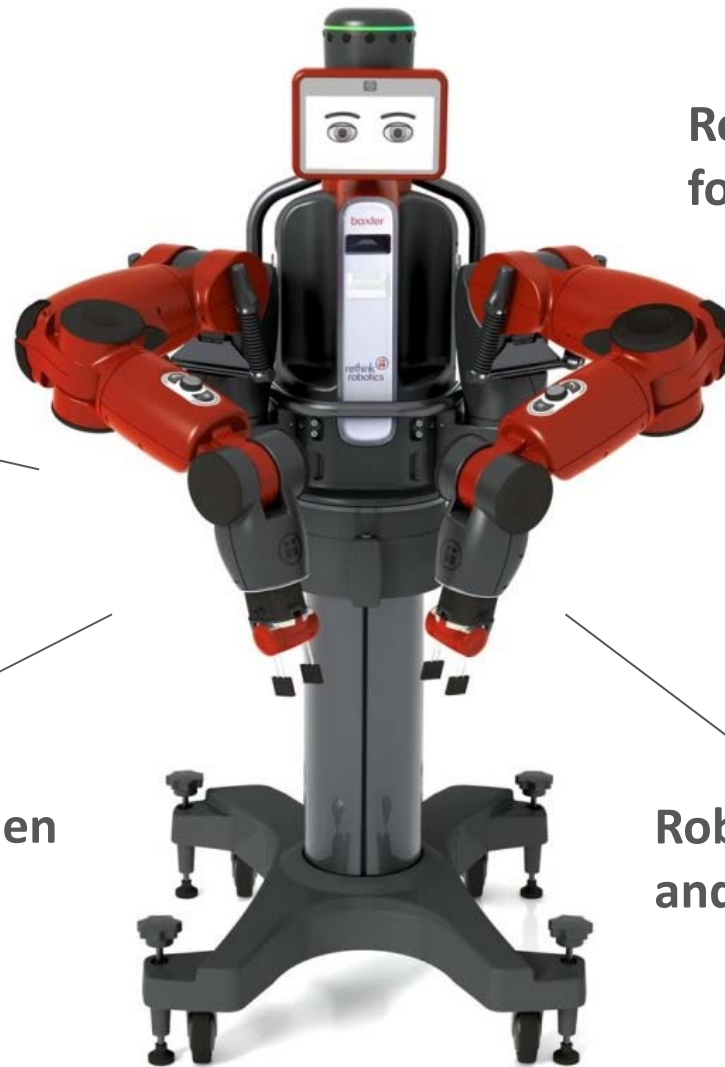
<https://www.youtube.com/watch?v=O3QgMzmg5HI>

Source: SICK, Inc.

Power & Force Limiting

Robot can respond to contact forces while performing work

Robot exterior is designed for human contact



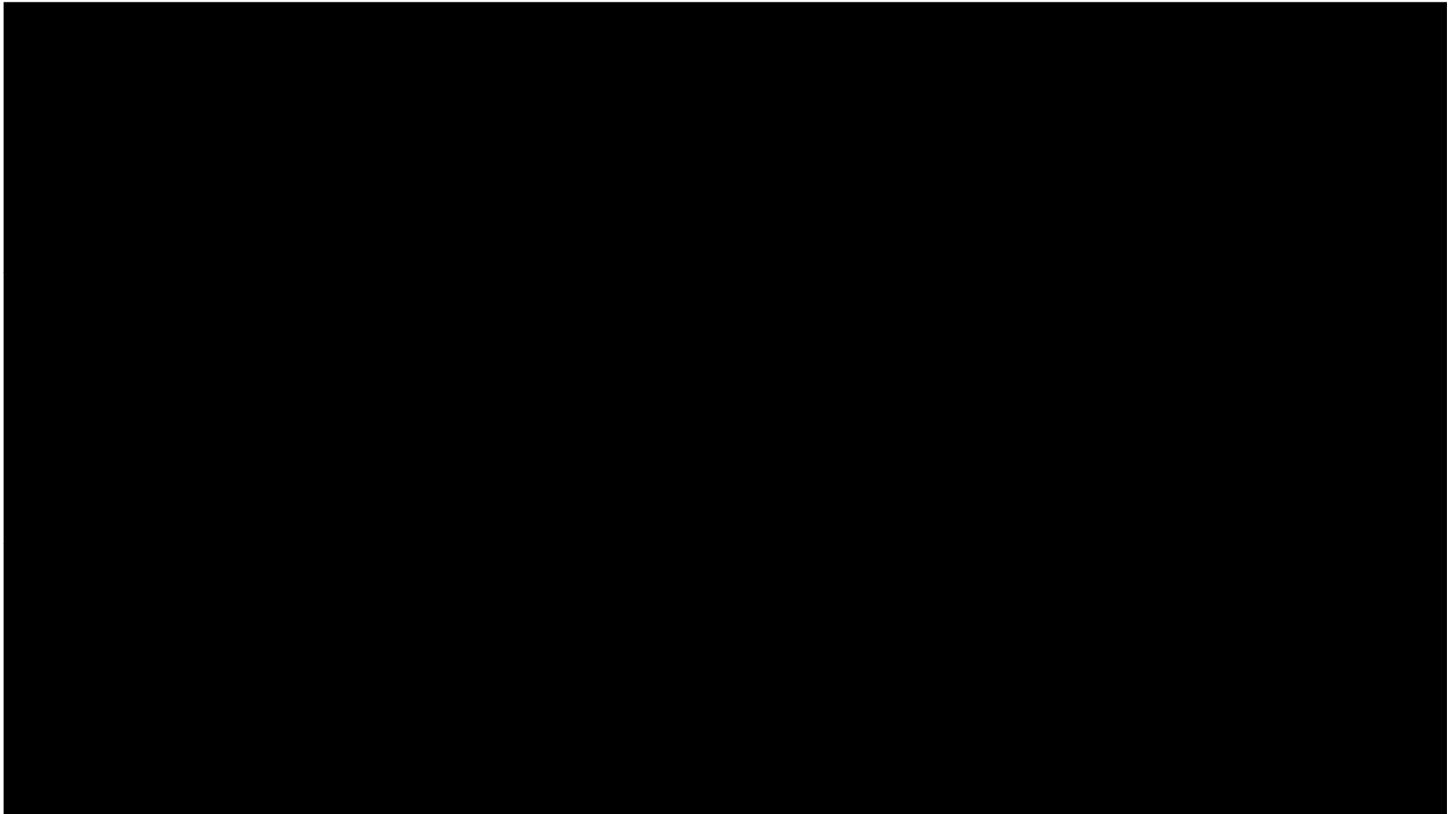
Stop or Slow Down when Touched

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



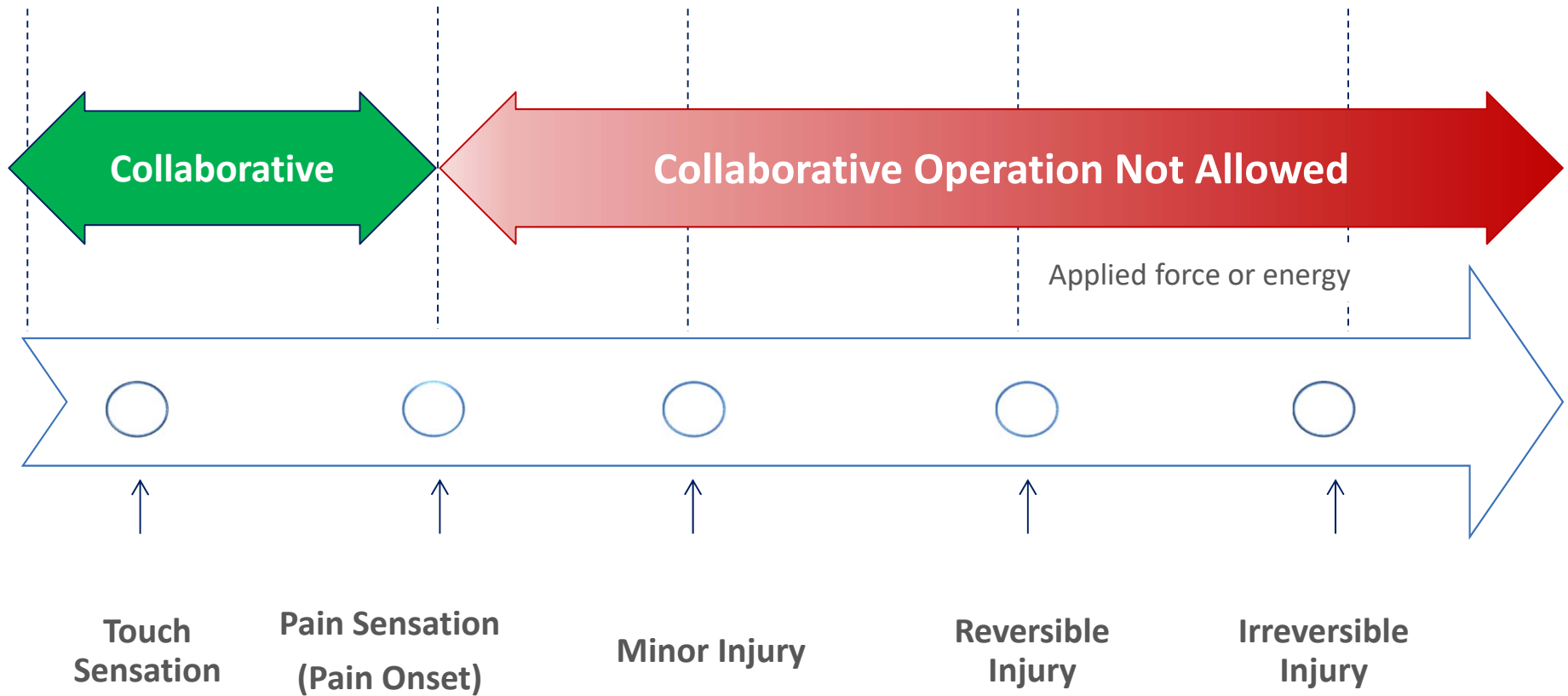
- Force torque sensors
- No need for fencing or other safety devices



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

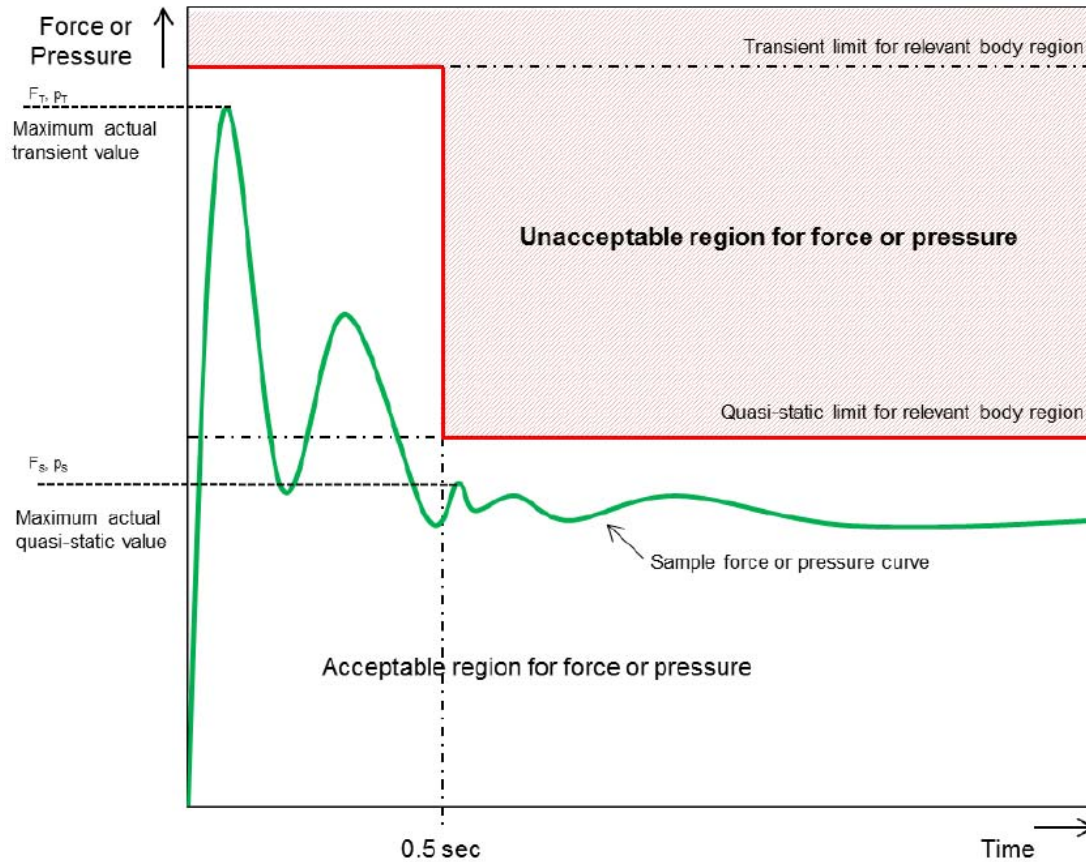
Biomechanical Limit Criteria

ISO TS 15066 – Onset of Pain Study



Onset of Pain Study

Study by University of Mainz



ISO TS 15066:2016 figure 3



Biomechanical Limits

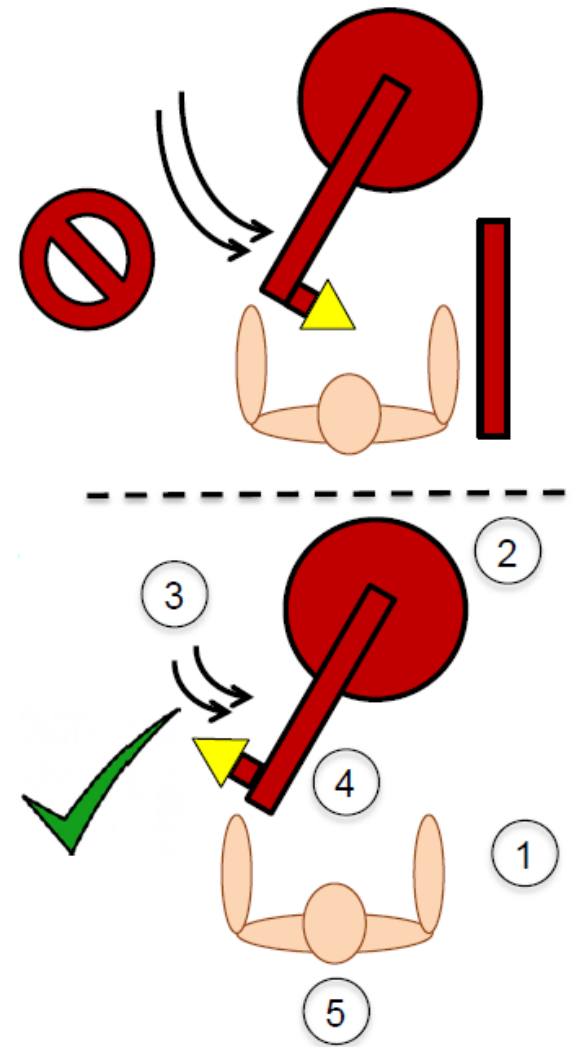
ISO TS 15066:2016 TableA.2

Table A.2 — Biomechanical limits

Body Region	Specific Body Area	Quasi-Static Contact		Transient Contact	
		Maximum Allowable Pressure P_s [N/cm ²] (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			
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	
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	

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

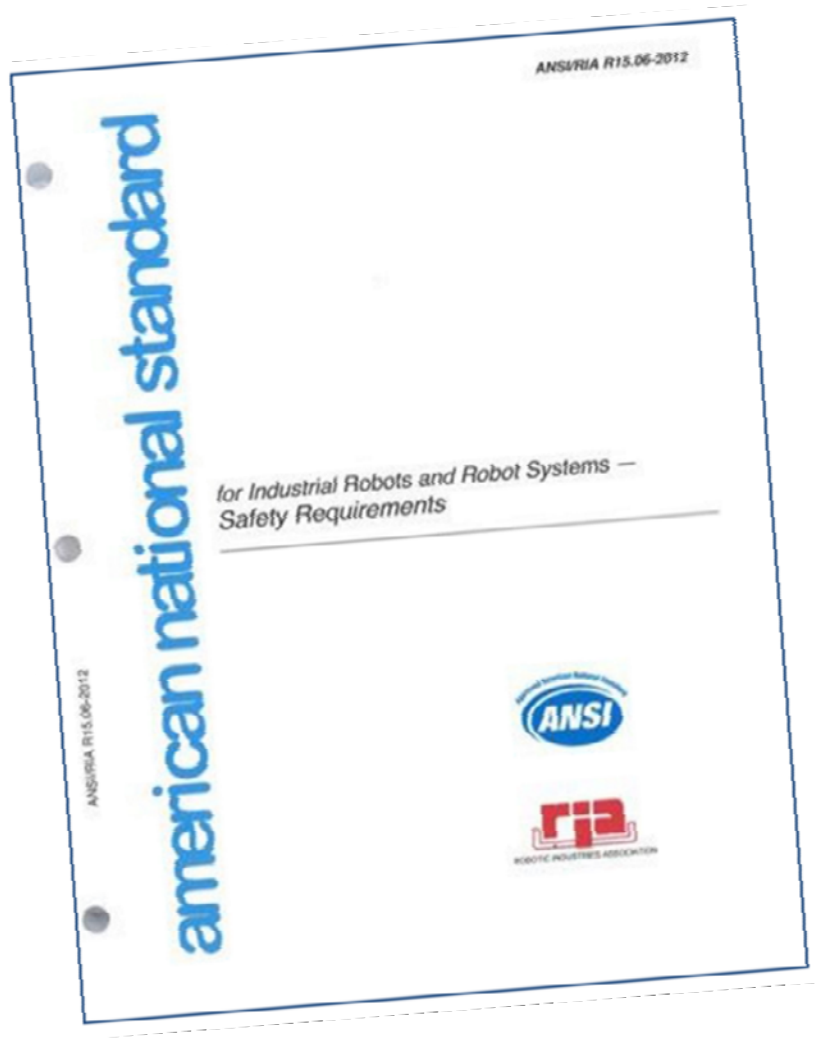


Robot Safety Standards



imagination at work

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



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

	<u>ANSI</u>	<u>ISO</u>	<u>OSHA</u>
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)

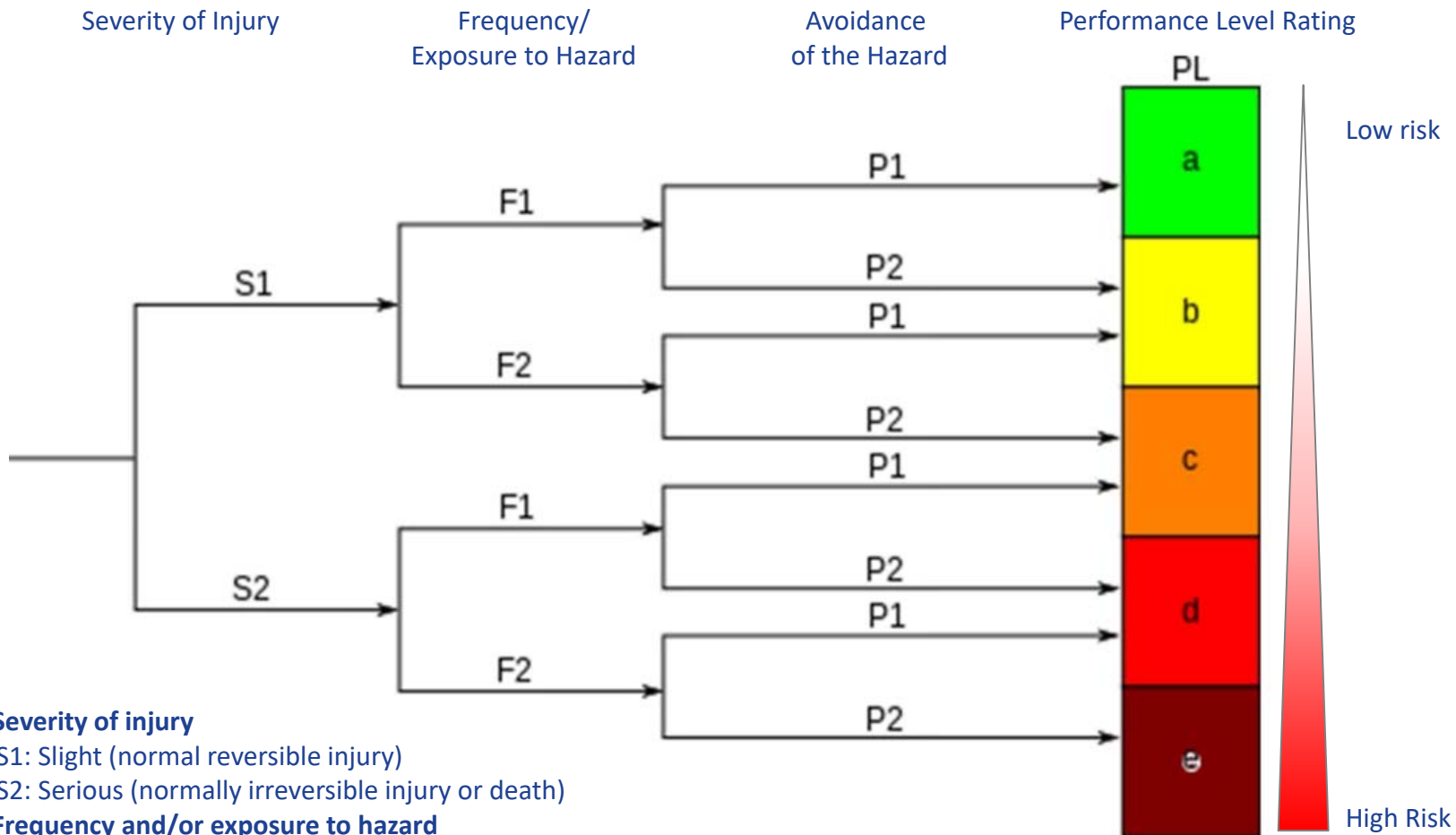
Source: Matt Epperson, Compliance Safety and Health Officer, OSHA

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

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.

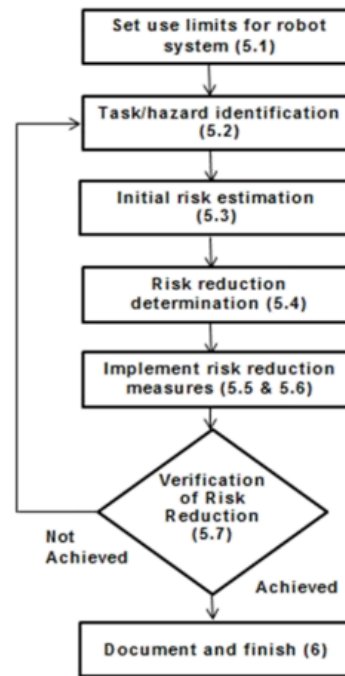
Floor Space Optimization

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

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

Severity	Probability		
	A	B	C
4			
3			
2			
1			

ISO 12100/ANSI B11.0



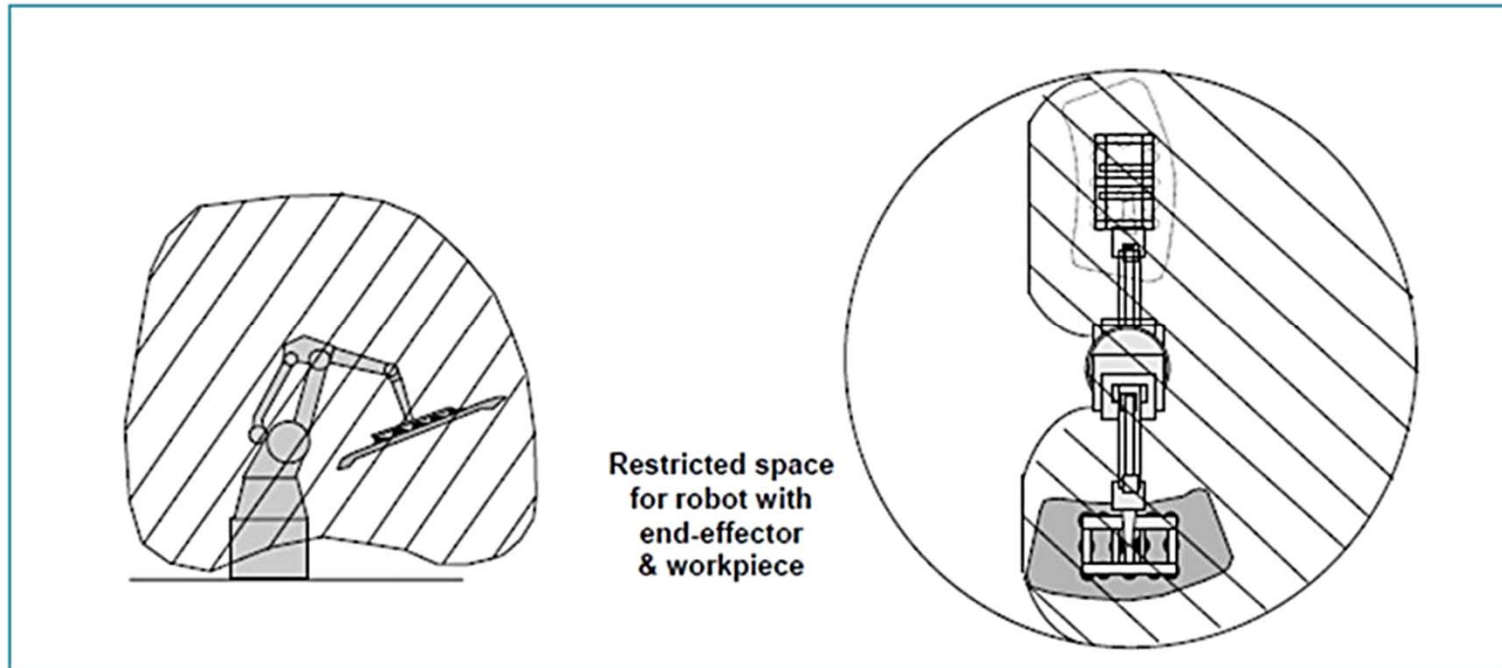
Typical flow chart

Severity of Injury	Exposure to the Hazard	Avoidance of the Hazard	Risk Level
S1 - Minor	E1 - Low	A1 - Likely	NEGLIGIBLE
		A2 - Not Likely	LOW
		A3 - Not Possible	
S2 - Moderate	E2 - High	A1 - Likely	MEDIUM
		A2 - Not Likely	HIGH
		A3 - Not Possible	
S3 - Serious	E1 - Low	A1 - Likely	HIGH
		A2 - Not Likely	
		A3 - Not Possible	VERY HIGH

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

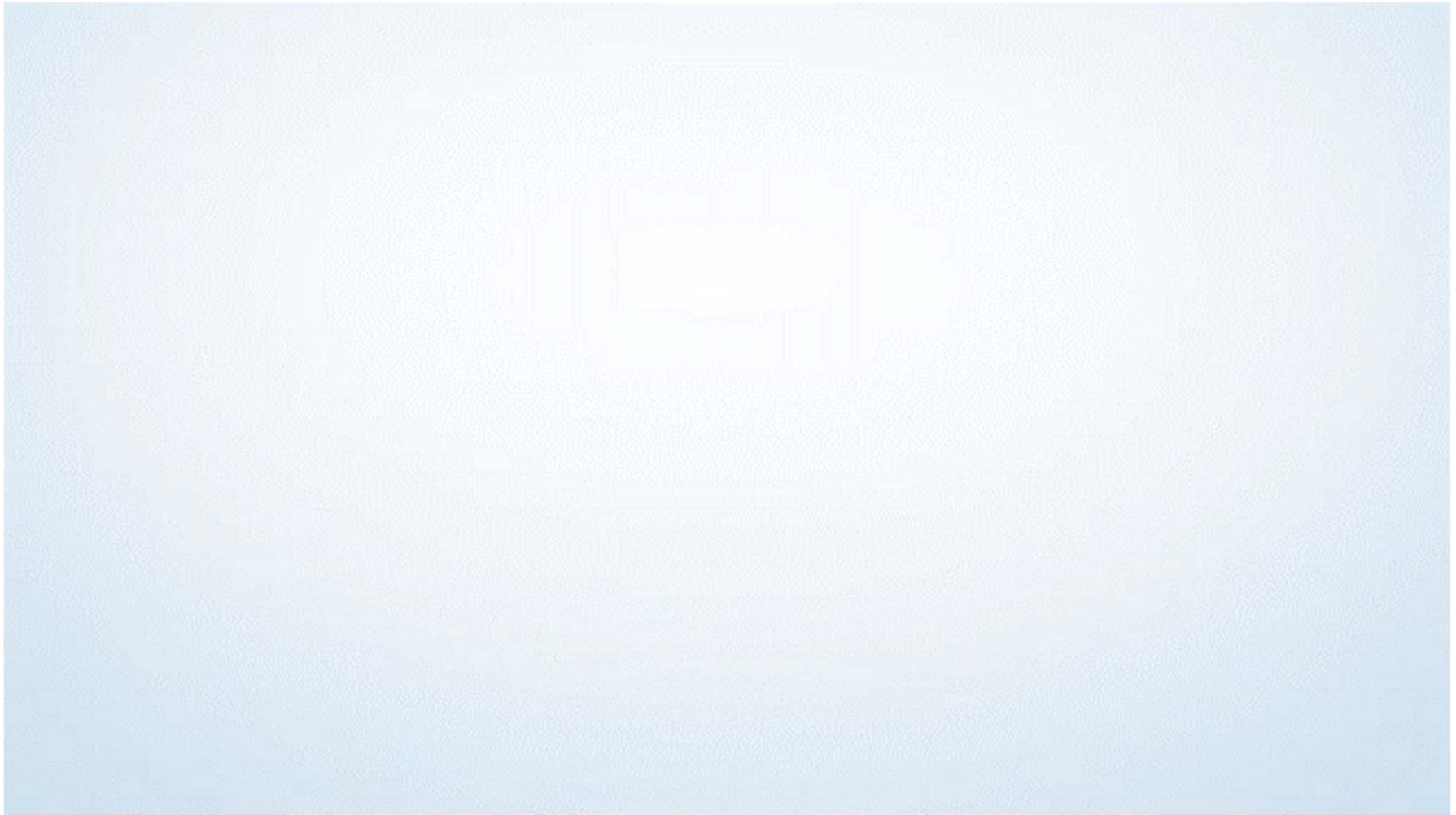
3. Apply **safeguarding**, providing **operator clearance** only where tasks inside the safeguarded space occur
 - No Task → no need for clearance
 - 2012: 20 inch clearance required for high speed manual
 - 1999: 18 inch clearance form the operating space was required.



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?



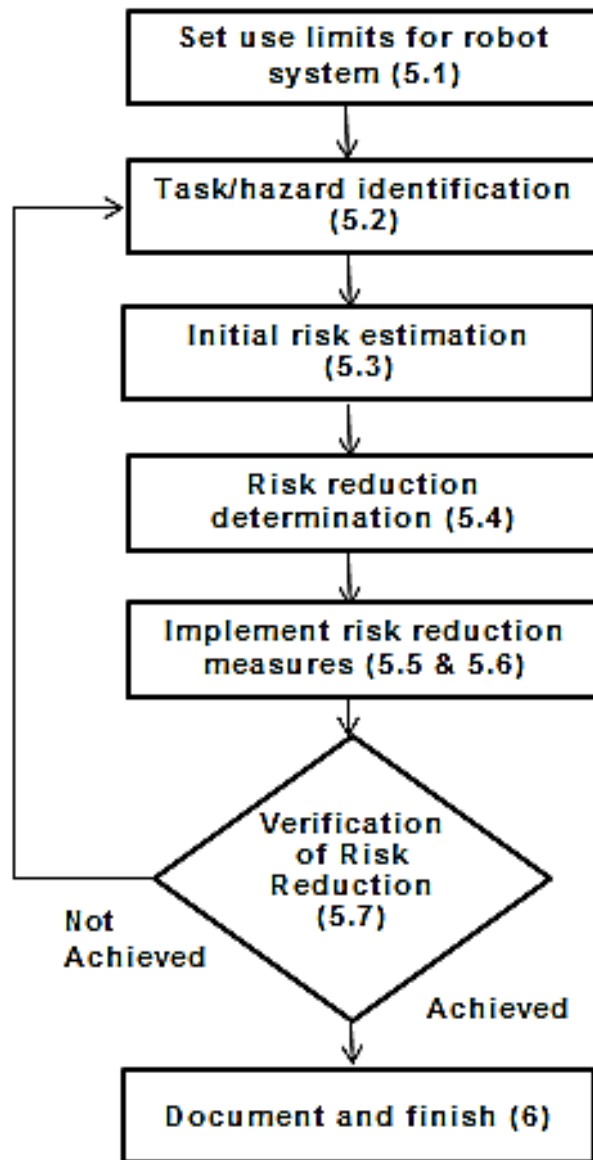
FREQUENCY

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

Severity of Injury	Exposure to the Hazard	Avoidance of the Hazard	Risk Level
S1 - Minor	E1 - Low	A1 - Likely	NEGLIGIBLE
		A2 - Not Likely	
		A3 - Not Possible	
S2 - Moderate	E2 - High	A1 - Likely	LOW
		A2 - Not Likely	
		A3 - Not Possible	
S3 - Serious	E1 - Low	A1 - Likely	MEDIUM
		A2 - Not Likely	
		A3 - Not Possible	
S3 - Serious	E2 - High	A1 - Likely	HIGH
		A2 - Not Likely	
		A3 - Not Possible	
			VERY HIGH

Risk Reduction Measures

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
<ul style="list-style-type: none"> • Process design • Redesign or • Modification 	<ul style="list-style-type: none"> • Less hazardous materials • Intrinsically safe • Reduced energy levels • Reduced volumes 	<ul style="list-style-type: none"> • Eliminate or reduce human interaction • Automate tasks 	<ul style="list-style-type: none"> • Guards • Interlocks • SPE • Two-hand controls devices • Safety controls and logic • Safety-related functions and safety parameters • Integration of protective devices 	<ul style="list-style-type: none"> • Emergency Stop Devices and functions • Platforms and guard railing & Safe Access • Measures for escape & Rescue, isolation & energy control, handling heavy parts 	Lights Beacons and strobes Audible alarms Signs, labels or markings	<ul style="list-style-type: none"> • Training and safe job procedures • Safety equipment inspections • Job rotation • Changing work schedule • LOTO • HazCom Confined Space Entry 	<ul style="list-style-type: none"> • Clothing & Footwear for specific safety purposes

Risk Assessments

Collaborative Robot Application Information

EHS Tool No. G2011_T1
Tool Revision No. 2.1
Tool Date: 9/4/2015

Collaborative Robot Risk Assessment Identification Information

Business: [] Date of assessment: []
 Location: [] Conducted by: []
 Robot or Cell Identification: []
 Robot manufacturer and Model number: []
 Date of manufacture: [] Review or revision date: []

Summary description of application:
[]

Collaborative Robot system limits associated with intended use

Use limits

1.1 Description of functions, intended use and foreseeable misuse

1.2 Description of the different user modes;

1.3 Analysis of process sequences including manual intervention;

1.4 Description of interfaces, tooling and equipment

1.5 Utility connections

1.6 Information supplied by the manufacturer, including applied measures

1.7 Required power supply and their appliances;

1.8 Required or anticipated user skills (competency);

Space limits

Collaborative Robot Risk Assessment Data Input Form

EHS Tool No. G2011_T1
Revision No. 2.1
Date: 9/4/2015

Task ID: 1 Activity: [] Task Description: []

Hazards: [] Potential Consequences: [] Body Parts Exposure: []

Risk Scoring: Severity/Exposure/Incidence [] Risk Level []

Primary Risk Reduction Measures [] Additional Risk Reduction Measures [] Risk Reduction Measures Summary []

Minimum Requirements for SRP/CS Measures: PLR [] Structure Category [] With Safeguards []

ACTIVITY DEFINITIONS

- 1 Installation
- 2 Assembling of robot components, related systems and hardware and verifying functionality
- 3 Teach
- 4 Actions to program the robot
- 5 Servo & Start
- 6 Connecting end effectors, setting up inventory and tools, selecting program and starting the operation
- 7 Collaborative Operation
- 8 State in which purposely designed robots work in direct cooperation with a human within a defined workspace
- 9 Autonomous Operation
- 10 State in which robots work automatically in defined workspaces without planned human cooperation or intervention
- 11 Maintenance & Housekeeping
- 12 Troubleshooting, routine service, repair
- 13 Sweeping, cleaning, removing scraps & debris

Examples of Significant Hazards for Robot and Robot Systems

From Annex A ANDRIA R15.00-2012 Standard for Industrial Robots and Robot Systems - Safety Requirements

Mechanical hazards

- movements of any part of the robot arm (including tools, end-effector or mobile parts of robot)
- movement of external part (including end-effector tool at serving position)
- movement or rotations of sharp tool on end-effector or on external tool
- movement or rotations of part being handled and associated equipment
- rotational motion of any robot arm
- materials and products falling or being ejected
- end-effector failure (separation)
- loose clothing, long hair
- between robot arm and any fixed object
- injection and ejection and ...

Collaborative Robot Risk Assessment Data Table

Business: [] Assessment Date: 1/0/1900
 Location: [] Conducted by: []
 Robot or Cell: []

ID	Activity	Task Description	Insequences	Body Parts Exposure	Severity/Exposure/Avoidance	Risk Level	Risk prior to safeguard selection	Primary Risk Reduction Measures	Additional Risk Reduction Measures	Risk Reduction Measures <small>* indicates collaborative operation safety feature required by Section 5.2.4 of ANDRIA R15.00-2012 "Safety Requirements for Industrial Robots and Robot Systems"</small>	Project-specific details on Risk Reduction Measures		Minimum Requirements for SRP/CS		Risk	
											PLR	Structure Category	Severity/Exposure/Incidence	Risk Level		

Help!



imagination at work

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

ria Robotic Industries Association

ROBOTICS ONLINE

Search Robotics Online BROWSE BY

RIA & YOU | ROBOTIC RESOURCES | **UPCOMING EVENTS** | **SAFETY** | INTEGRATOR CERTIFICATION | BECOME A MEMBER

Parallel and Angular Grippers, Tool Changers, Linear Rails, Compliance Devices, & more...

Hear Industry Experts From Around the World **September 30, 2014**
Speak on the Hottest Topic in Robotics

INTERNATIONAL COLLABORATIVE ROBOTS WORKSHOP

San Jose Convention Center
San Jose, California USA

Robotics Online | Free Webinar Series | Collaborative Robots | Automate Show 2015

FEATURED PRODUCT (5 of 7)

ATI EDUCATOR SPONSOR

Multi-Axis Force/Torque Sensors

Our Sensors give robots a tactile sense of touch by sending force & torque feedback to control the robot's positioning.

[Learn More](#)

WELCOME TO THE NEW RIA!

RIA Launches Redesigned Website and New Logo

The Robotic Industries Association (RIA) is excited to introduce our new look! Robotics Online, your online resource for industrial robotics, has been completely overhauled. And along with our new website, we are introducing RIA's new logo! [READ MORE](#)

ria Robotic Industries Association

RIA In-House Safety Training

RIA will visit your company and teach your employees essential robot safety guidelines.

[Learn More](#)

Cobotsguide.com

MyGE

CobotsGuide | Making Sense of C

https://cobotsguide.com

Apps Online Video Downl Imported From IE EVENTS | Pipe to Pipe MyGE

Cobotsguide Home The Cobots Accessories In Use News Library Contact

Twitter Facebook YouTube

Guide to Making Sense of Collaborative Robots

Watch Video: History of Cobots

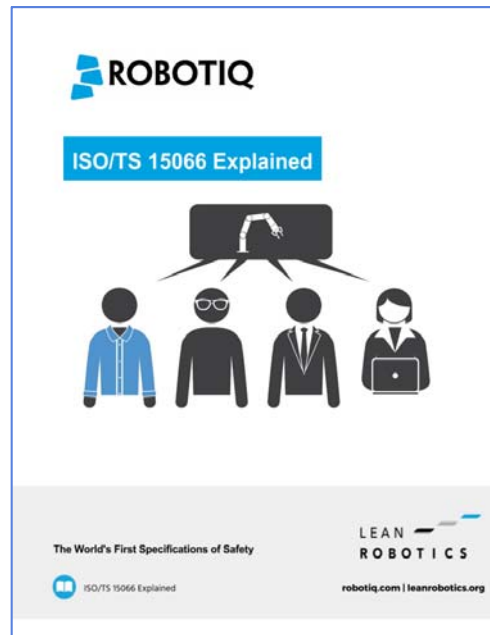
COBOT COMPARISON CHART
Over 20 Cobots compared by payload, reach, weight & accuracy!

MEET THE COBOTS
Discover the Collaborative Robotic Manufacturers and their Products

COBOTS AT WORK
Learn the best Applications for Collaborative Robots

collaborative robots

Robotiq.com



1. DOCUMENT IDENTIFICATION

Document Identification			
Project Name	UR-ROBOTIQ-MACHINETENDING-002	Project No.	UR-RD-MCH-002
Version	0	Date	04/11/2016
Lead Author			
Name	Salvador Gomez	Signature	X
Date			04/11/2016
Reviewed by			
Name	John Butler	Signature	X
Date			04/11/2016
Revision			
Revision	2	Description	Initial Draft
Changed by		S. Gomez	
Date			04/11/2016

2.1 PROJECT INFORMATION

MACHINE INFORMATION	
Machine Name:	URS DEMO CELL
Manufacturer:	UNIVERSAL ROBOTS
Machine Type:	Industrial Robot
Serial Number:	XXXXXXXXXX
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:	Robotiq Gripper
Serial Number:	XXXXXXXXXX
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:	Aul. 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 P12® documentation format to conduct a formal risk assessment on their URS 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

UB
University at Buffalo
The State University of New York

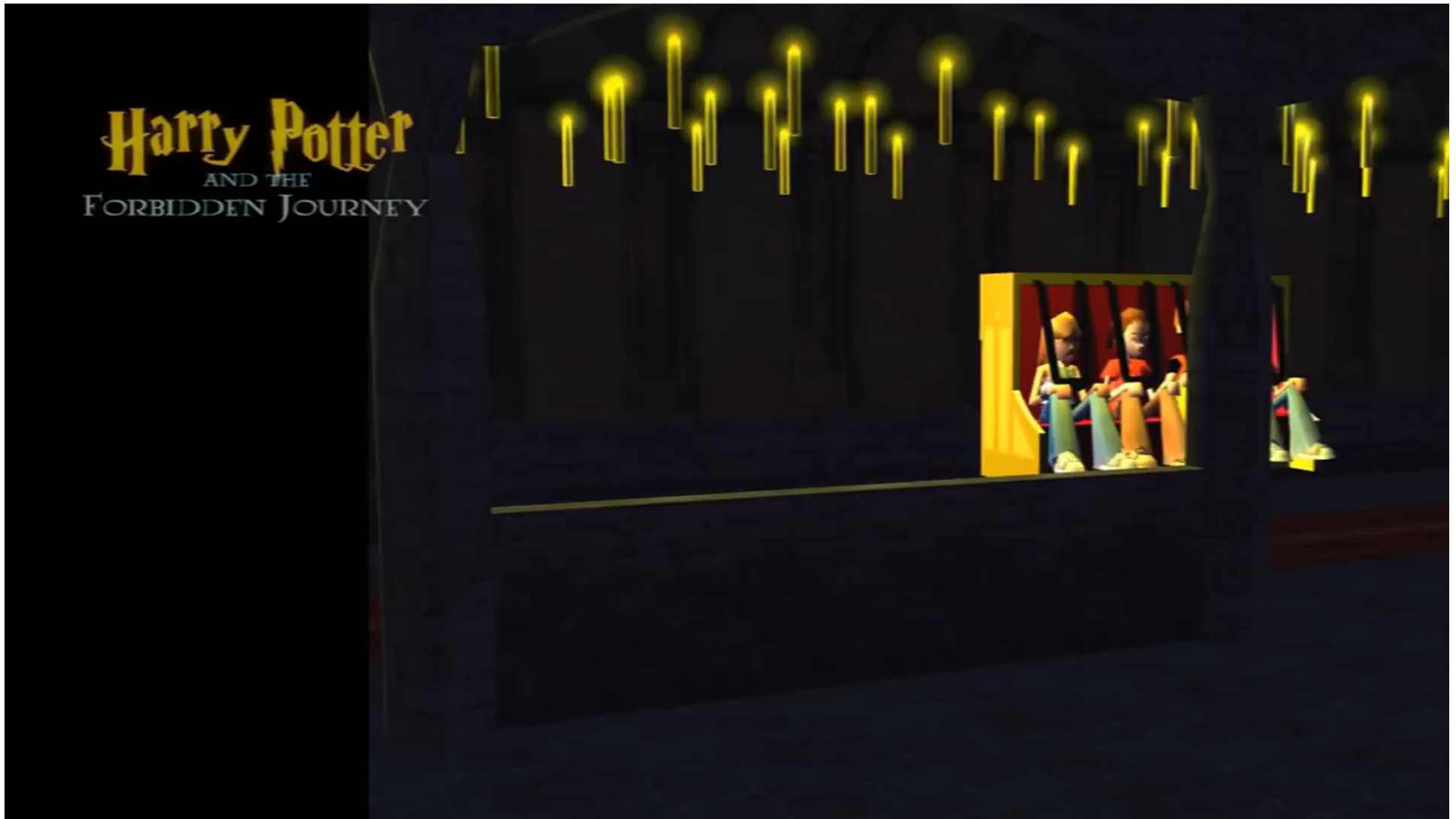




Ride the Movies ... on a Robot



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>





Jim Biaglow
GE Global Research
Niskayuna, NY

biaglow@ge.com
518-387-7561



