Risk Assessment for High Power Lasers

(in manufacturing)

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Risk Assessment for High Powered Lasers

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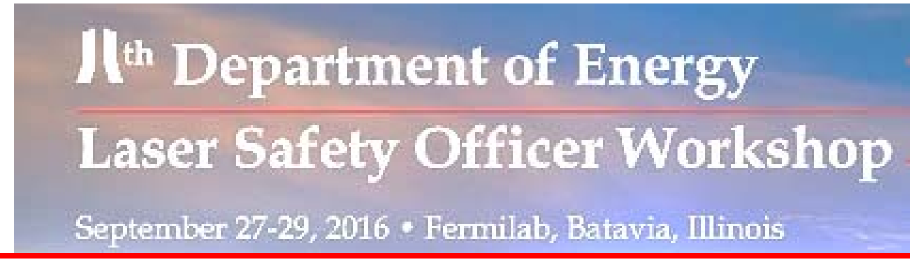
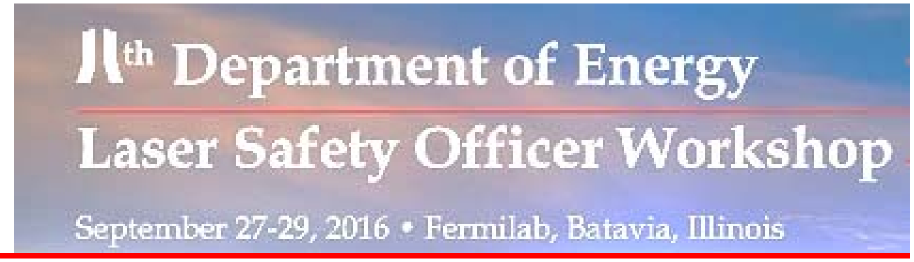
- Update on a work in progress, for submission to Z136 TSC-2 on risk assessment guidance for high power (Class 4+) laser systems.

- Disclaimer: Material is author’s own opinion and not sanctioned, endorsed, sponsored or otherwise commercialized, licensed or marketed by or for Z136, or any other third party entity.

Risk Assessment for High Powered Lasers



- Introduction
- Background
- Safety Challenge
- Risk Assessment Principles
- Risk Assessment Methods (Guides)
- Example Scoring Matrices
- Reference Probabilities
- Summary of Key Standards
- Conclusion



Introduction

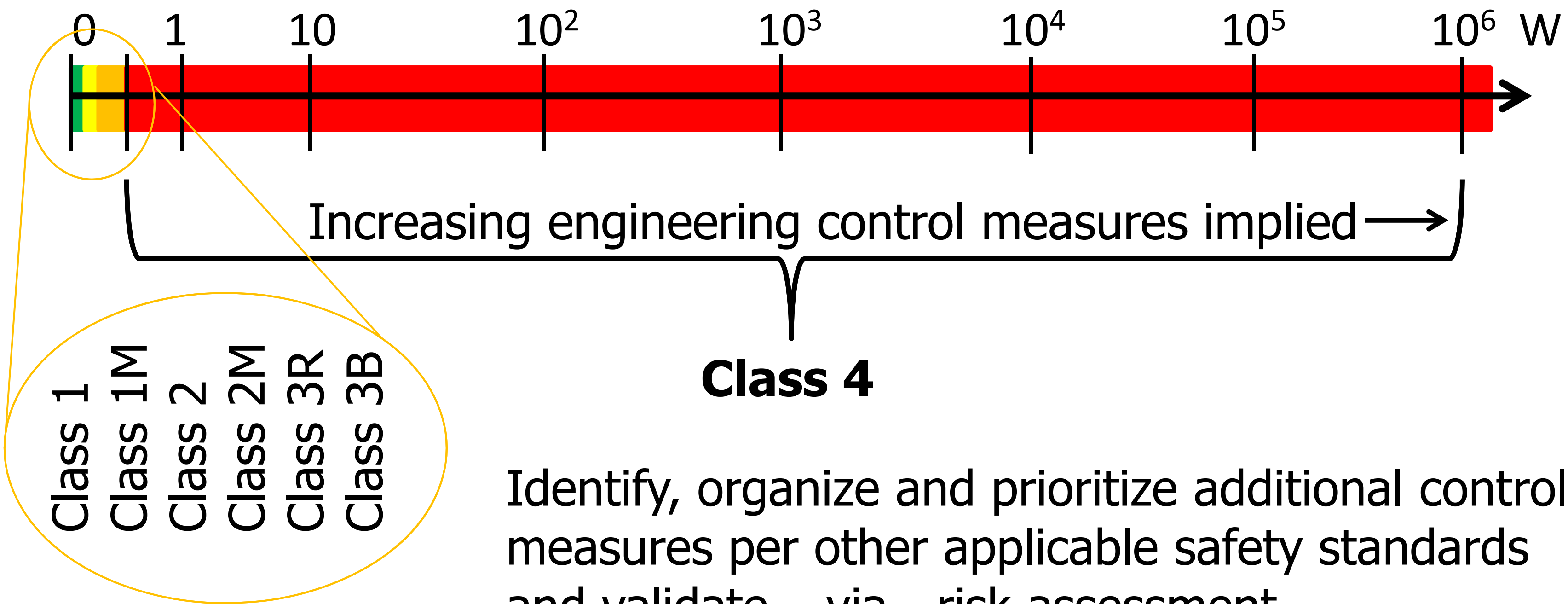
Scope of this topic is with regards to high power industrial laser applications and the applicability of risk assessments for them.

- Build/product safety performance standards for lasers includes, but are not limited to:
  - US 21CFR1040.10/.11
  - IEC 60825-1

- User safety standards for lasers and equipment using lasers includes, but are not limited to:
  - ANSI Z136.1/.2/.3/.5/.6/.8/.9
  - IEC 60825-14

Introduction

- Current Hazard Classes (CW)



Identify, organize and prioritize additional control measures per other applicable safety standards and validate – via - risk assessment.

Introduction

Table 10a. Control Measures for the Seven Laser Classes

Engineering Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Protective Housing (4.4.2.1)	X	X	X	X	X	X	X
Without Protective Housing (4.4.2.1.1)	LSO shall establish Alternative Controls						
Interlocks on Removable Protective Housings (4.4.2.1.3)	∇	∇	∇	∇	∇	X	X
Service Access Panel (4.4.2.1.4)	∇	∇	∇	∇	∇	X	X
Key Control (4.4.2.2)	—	—	—	—	—	•	•
Viewing Windows, Display Screens and Diffuse Display Screens (4.4.2.3)	Assure viewing limited < MPE						
Collecting Optics (4.4.2.6)	X	X	X	X	X	X	X
Fully Open Beam Path (4.4.2.7.1)	—	—	—	—	—	X NHZ	X NHZ
Limited Open Beam Path (4.4.2.7.2)	—	—	—	—	—	X NHZ	X NHZ
Enclosed Beam Path (4.4.2.7.3)	None is required if 4.4.2.1 and 4.4.4.1.3 are fulfilled						
Remote Interlock Connector (4.4.2.7.4)	—	—	—	—	—	•	X
Beam Stop or Attenuator (4.4.2.7.5)	—	—	—	—	—	•	X
Area Warning Device (4.4.2.8)	—	—	—	—	—	•	X
Class 4 Laser Controlled Area (4.4.2.9 and 4.4.3.5)	—	—	—	—	—	—	X
Protective Barriers and Curtains (4.4.2.5)	—	—	—	—	—	•	•

LEGEND:
- X Shall
- • Should
- — No requirement
- ∇ Shall if enclosed Class 3B or Class 4
- MPE Shall if MPE is exceeded
- NHZ Nominal Hazard Zone analysis required
- • May apply with use of optical aids

Table 10b. Control Measures for the Seven Laser Classes (cont.)

Administrative (and Procedural) Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Standard Operating Procedures (4.4.3.1)	—	—	—	—	—	•	X
Output Emission Limitations (4.4.3.2)	—	—	—	—	—	LSO Determination	
Education and Training (4.4.3.3)	—	•	•	•	•	X	X
Authorized Personnel (4.4.3.4)	—	—	—	—	—	X	X
Indoor Laser Controlled Area (4.4.3.5)	—	•	—	•	—	X NHZ	X NHZ
Class 4 Laser Controlled Area (4.4.2.9 and 4.4.3.5)	—	—	—	—	—	—	X
Temporary Laser Controlled Area (4.4.3.10)	∇ MPE	∇ MPE	∇ MPE	∇ MPE	∇ MPE	—	—
Controlled Operation (4.4.3.5.2.1)	—	—	—	—	—	—	•
Outdoor Control Measures (4.4.3.6)	X	• NHZ	X NHZ	• NHZ	X NHZ	X NHZ	X NHZ
Laser in Navigable Airspace (4.4.3.6.2)	•	•	•	•	•	•	•
Spectators (4.4.3.7)	—	•	—	•	—	•	X
Alignment Procedures (4.4.3.8)	∇	X	X	X	X	X	X
Service Personnel (4.4.3.9)	LSO Determination						

LEGEND:
- X Shall
- • Should
- — No requirement
- ∇ Shall if enclosed Class 3B or Class 4
- MPE Shall if MPE is exceeded
- NHZ Nominal Hazard Zone analysis required
- • May apply with use of optical aids

Background

- Are the laser safety regulations and standards sufficient?
  - Well… not really when evaluated on their own.
- Can we do better?
  - Yes.
- What is missing?
  - A life cycle perspective and means for the LSO to participate in a broader spectrum of safety disciplines.
- What safety control measures are taken for granted? – LOTO, TNA, ERP, SILs, etc. – Addressed via RA

Background

New generation of lasing technology providing greater beam power/energy with increased beam quality at reduced cost of ownership to industry.

Increased utilization of lasers for manufacturing (and elsewhere).

Increased laser capabilities also engender increased scale of Class 4 hazards and their potential, and for new hazards not previously realized except for R&D lasers.

- Plasma radiation (> ~10^{12} W·cm^{-2})
- Ionizing radiation (> ~10^{16} W·cm^{-2})

Safety Challenge

Higher power/energy lasers are operating within the retinal hazard region in the near infrared spectrum. (1030 – 1070 nm)

For the builder and user entering the new process regimes being enabled, one can justifiably also ask if the control measures identified in laser build standards such as FLPPS or IEC 60825-1 are sufficient?

- What additional considerations need to be given, addressed and documented?

~ 1 watt @ ~532 nm

Same Hazard Class 4. Same Safety Control Measures?

~ 30,000 watt @ ~1030 nm

Safety Challenge

A frame of reference for NIR lasers:

- ca. 2000: Nd:YAG, CW, arc lamp pumped
  - 1,000 W @ 300 um fiber (a common NIR laser for cutting sheet metal)
  - 1,500 W @ 400 um fiber
  - 4,000 W @ 600 um fiber (the max NIR laser for welding sheet metal)
- 2009: Yb:fiber, CW, diode pumped
  - 10,000 W @ ~20 um fiber (near diffraction limited)
- 2013: Yb:fiber, CW, diode pumped
  - 100,000 W @ 300 um fiber (commercially available)
- *Is the laser safety community keeping pace with technology?*

Safety Challenge

Occupational Safety and Health Act of 1970

29 U.S.C. § 654, 5(a)1: 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."

29 U.S.C. § 654, 5(a)2: Each employer shall comply with occupational safety and health standards promulgated under this act.

29 U.S.C. § 654, 5(b): Each employee shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to this Act which are applicable to his own actions and conduct.

Safety Challenge

OSHA Interpretations:

- “The machines which are not covered by specific OSHA standards are required under the Occupational Safety and Health Act (OSHA Act) and Section 29 CFR 1910.303(b)(1) to be free of recognized hazards which may cause death or serious injuries.”
- “ These machines must be designed and maintained to meet or exceed the requirements of the applicable industry consensus standards. In such situations OSHA may apply standards published by the American National Standards Institute (ANSI), such as standards contained in ANSI/NFPA 79, Electrical Standard for Industrial Machinery, to cover hazards that are not covered by specific OSHA standards.”

Safety Challenge

- There is a prevalent "escape clause" employed in various standards and regulations to ensure that the excuse of:

  "…I didn't know…"

  or

  "…but the standard didn't specify…"

That "escape clause":

> "…a risk assessment shall be…to ensure that…residual risk is acceptable…and… as low as reasonably practicable"

Safety Challenge

"Due diligence"

- Have the appropriate applicable regulations and standards been fulfilled?
- Have all reasonably foreseeable hazards and machine conditions been identified with the corresponding risks reduced to acceptable levels?
- Risk assessment can be employed when there are no prescriptive standard(s)/regulation(s) for a hazard safeguard measure, to ensure that those safety control measure(s) developed and applied are sufficient.

Safety Challenge

Q: What is a risk assessment?

A: A structured approach to assessing and ensuring that hazards and their potential to cause harm are reduced to generally acceptable levels.

Q: Are we talking numerical evaluations?

A: No.

Safety Challenge

RA for (Industrial) Laser Safety:

- Where we are at: Mostly there. Solutions exist and are implemented in various forms, by virtue of the project execution and the multiple disciplines involved.
- When there are accidents, the deficiencies (weak points in safety) are all too familiar.

Safety Challenge

OSHA 2014 Top 10 Citations Workplace Safety

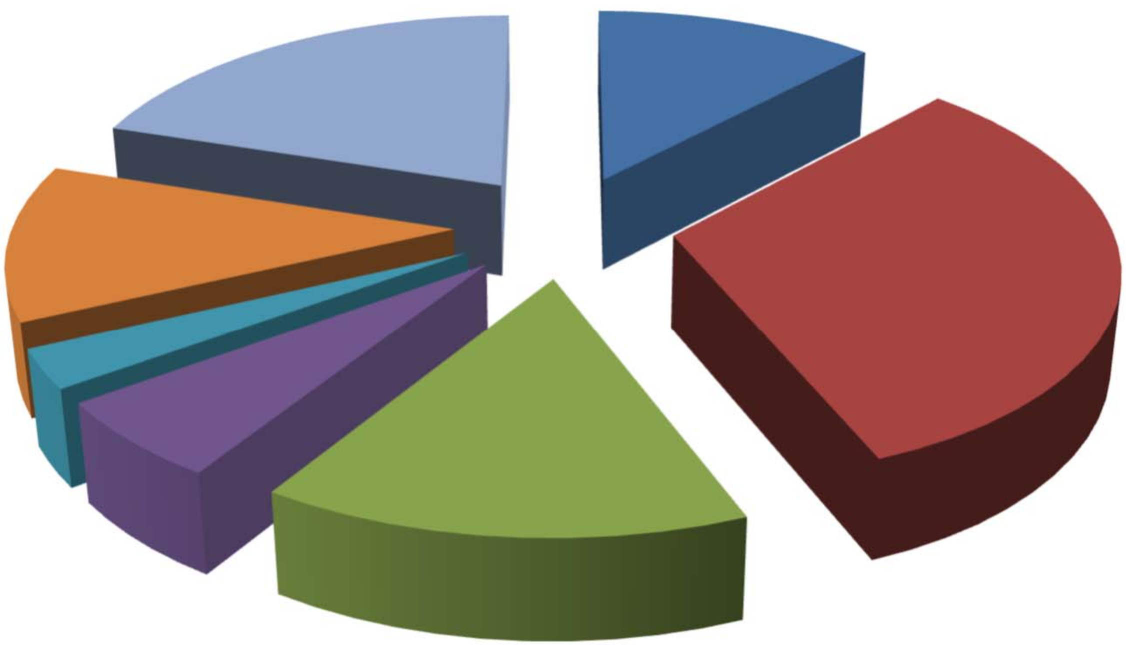
#	Number of Citations	Description
1	7,516	Fall Protection
2	6,148	Hazard Communication
3	4,968	Scaffolding
4	3,843	Respiratory Protection
5	3,147	Powered Industrial Trucks
6	3,117	Lockout/Tagout
7	2,967	Ladders (in construction)
8	2,907	Electrical Wiring
9	2,520	Machine Guarding
10	2,427	Electrical Systems

Safety Challenge

Activities	Hazards
Electrician receives fatal electric shock	1 Fatal
Electrician fall from ladder due to startle reaction from electric shock	30 Lost Time Injuries
Electrician receives minor burn from electric shock	300 Recordable Injuries
Electrician receives minor electric shock while connecting light fixture	30,000 Near Miss / First Aid
Electrician connects light fixture with circuit energized	300,000 Hazards / Unsafe Acts / At-Risk Behaviours

Safety Challenge

Control system root cause failures over equipment lifespan (inadequacies)



Ref.: Out Of Control, Health and Safety Executive, U.K., (2003).

Safety Challenge

Ref. “Out of Control”, HSE Study

- Analysis of incidents/accidents:
  - Majority could have been anticipated if a systematic risk-based approach had been used
  - Safety principles are independent of the technology
  - Situations often missed through lack of systematic approach

Safety Challenge

Ref. “Out of Control”, HSE Study

- Design problems:
  - Need to verify that the specifications have been met
  - Over dependence on single channel safety
  - Failure to verify software
  - Poor consideration of human factors

Safety Challenge

Ref. "Out of Control", HSE Study

- Operational problems:
  - Training of staff
  - Safety analysis
  - Management control of procedures
- Conclusion:
  - Being systematic ensures safety, minimizes chances of error, facilitates continuity of hazard communication, achieves regulatory compliance

Safety Challenge

Laser Safety and RA:

- RA is not necessary for many laser systems as the methodology and control measures identified with noted laser safety standards have served industry well.
- RA principles and terms should be understood by the person(s) responsible for laser safety to be an effective and productive team member in a project involving lasers.

RA Essentials

Essential elements:

- Terms
- What is acceptable and how does this relate to functional safety
- A holistic approach: the laser system life cycle
- The LSO is not alone, but an integral part of the team
- RA processes can vary in forms and styles (JHA, JSA, RM, HAZOP, etc.)

RA Terms

- **Harm** is physical injury or damage to the health of people either directly, or indirectly as a result of damage to property or to the environment
- **Hazardous event:** a hazardous situation which results in harm
- **Hazardous situation:** a circumstance in which a person is exposed to hazard(s)
- **Risk:** [the/a] combination of the probability of occurrence of harm and the severity of that harm
- **Tolerable risk:** risk which is acceptable in a given context, based on the current values of society

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- **Safety:** freedom from unacceptable risk

RA Approaches

Approaches to RA:

- Scope:
  - High level: organizational
  - Discipline: e.g. controls, process, financial
  - Project: equipment life cycle
- Style:
  - Qualitative: subjective, principles
  - Semi-(qualitative, quantitative): banding
  - Quantitative: numerical and detailed

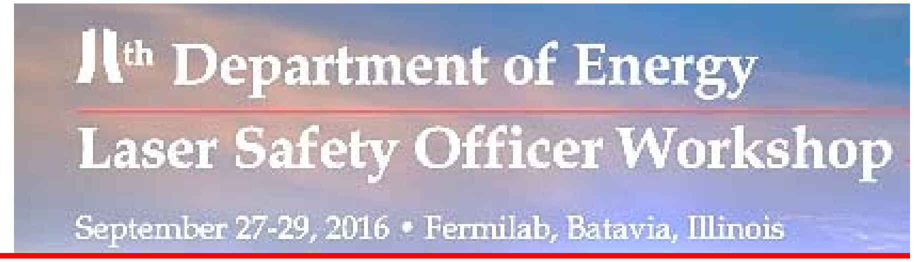
RA Principles

- **Risk Assessment:**

  The process by which the intended use (and reasonably foreseeable misuse) of the machine, the tasks and hazards, and the level of risk are determined
- *Risk assessment generates an informed hazard evaluation to effect (if necessary) risk reduction measures*
- **Risk Reduction:**

  The application of protective measures to reduce the risk to a tolerable level (where the residual risk is as low as reasonably practicable or acceptable)

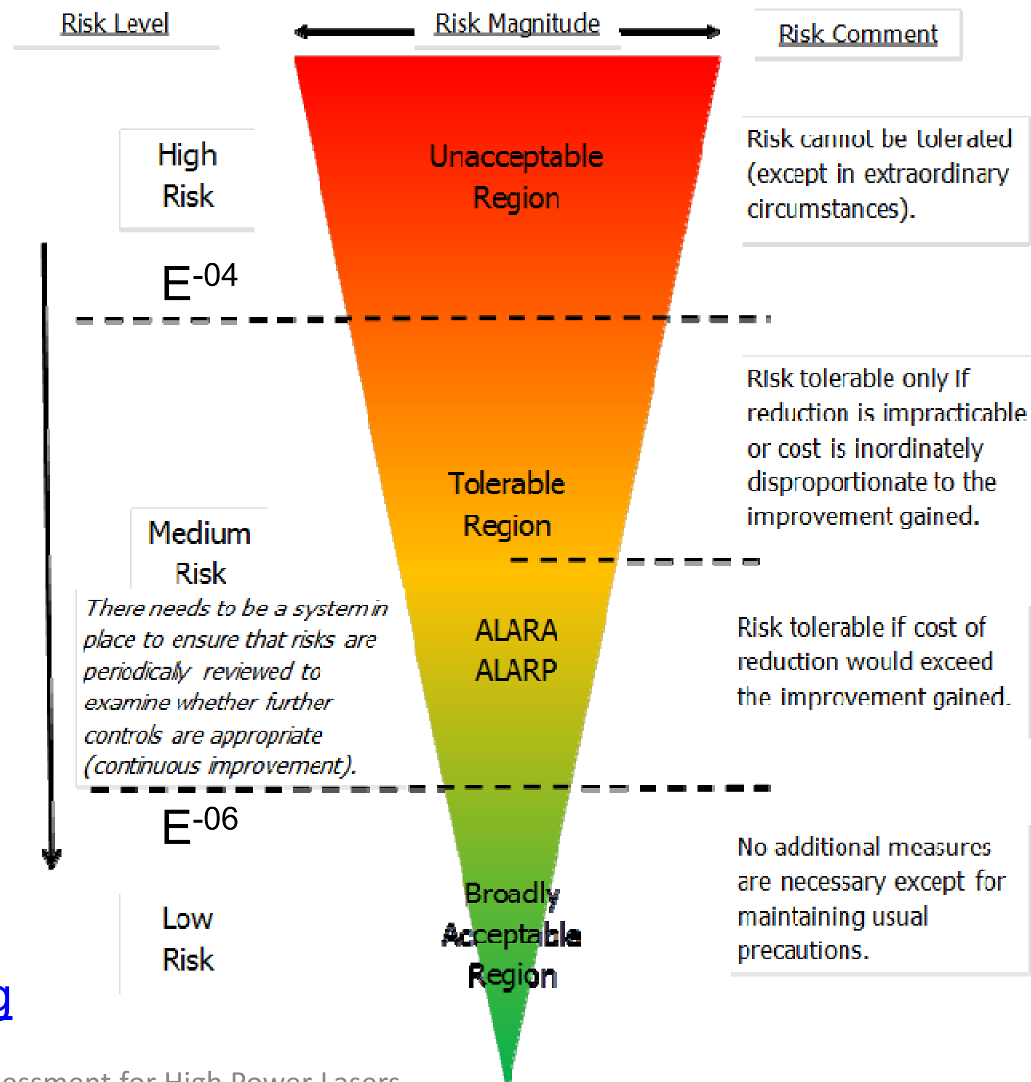
RA Principles



To reduce risk to:
As Low as Reasonably Acceptable (ALARA)

a.k.a.

As Low As Reasonably Practicable (ALARP)



Source: www.risk-assessments.org

RA Principles

To help frame this qualitatively, a risk is acceptable when one or more of the following is met:

- it falls below an arbitrary defined probability
- it falls below some level that is already tolerated in a similar field
- the costs of reducing the risk would exceed the costs saved (hard costs)
- the costs of reducing the risk would exceed the costs saved when the costs of suffering are also factored in (hard and soft costs considered)
- health and safety professionals agree it is acceptable
- the general public (majority thereof) agree it is acceptable (or more accurately, the general public does not say it is not acceptable)

RA Principles

- There is also a need to distinguish between individual voluntary risk, such as in driving a car, versus public perception of involuntary risk (such as with nuclear plants), which can vary by a factor of 1000
- For laser safety, and industrial safety (non-nuclear), societal values are employed for determining what is acceptable risk in a workplace

Ref: Chauncey Starr, “Social Benefits versus Technological Risks" in *Science* Vol. 165, No. 3899. (Sep. 19, 1969), pp. 1232–1238

RA Principles

As a frame of reference, in the United Kingdom, the Health and Safety Executive adopted the following levels of risk, in terms of the probability of an individual dying in any one year:

- 1 in 1,000 as just about tolerable risk for any substantial category of workers for any large part of a working life
- 1 in 10,000 as the maximum tolerable risk for members of the public from any single non-nuclear plant
- 1 in 100,000 as the maximum tolerable risk for members of the public from any new nuclear power station
- 1 in 1,000,000 as the level of acceptable risk at which no further improvements in safety need to be made (at ~ background risk level)

It is interesting to note that similar probabilities are referenced in the United States, but on a lifetime basis.

RA Process

- Risk assessment can take the form of high level, such as equipment life cycle; to single elements, such as a beam mirror.
- Risk definition:

Likelihood/probability of occurrence of a harm

X

Severity of harm that can result from a hazard

Risk
of identified hazard

=

Severity, Se
of damage, injury

and

Frequency, Fr
of failure and duration

Probability, Pr
of hazardous event

Avoidance, Av
of hazardous event

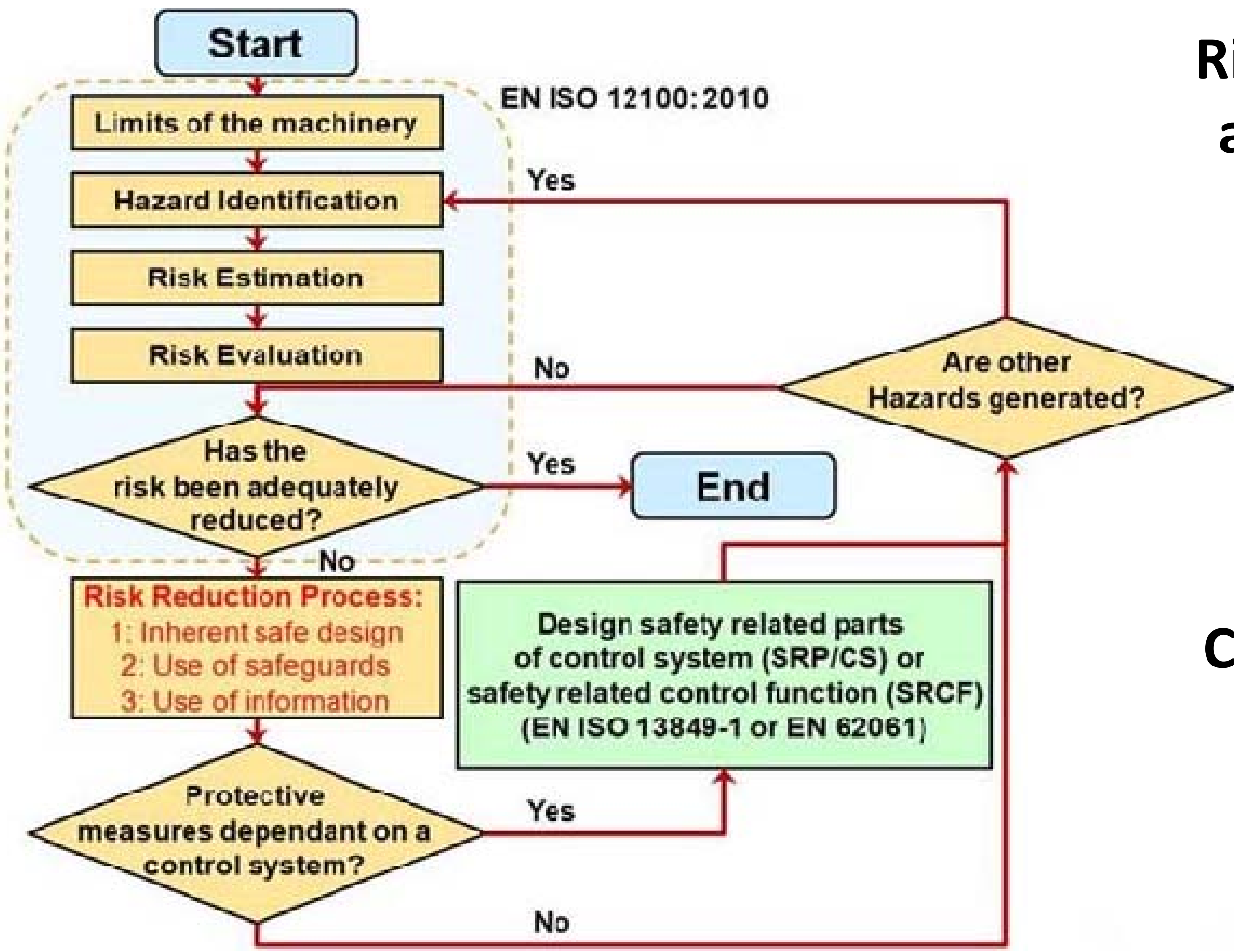
RA Process

The Risk Assessment Process:

- General preparations:
  - Assessor should do preliminary work to provide the structure and framework for the assessment
- Set the scope:
  - identify the hazard (safety problem) to be resolved
- Form a team:
  - 4-8 persons, respective of operations
- Gather the appropriate information
- Conduct the assessment (see prior summary process flow)
- Monitor and assess as determined from the process

Ref.: ANSI B11.0: 2010, Annex A Guidance for the Risk Assessment Process

RA Process



Risk reduction can be an iterative process to achieve safety.

Generic Example of Common Safety Hazard Analysis and Risk Assessment

RA Process

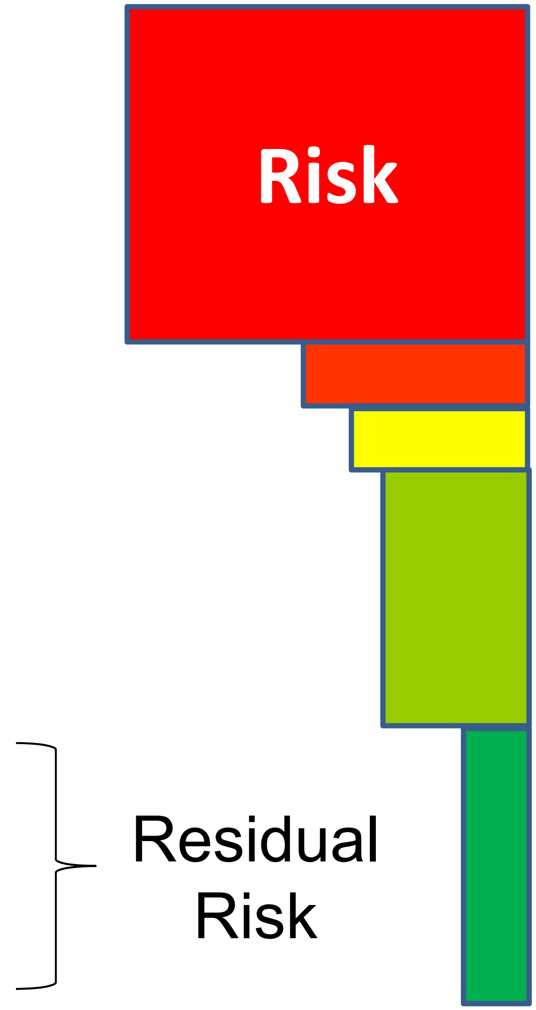
Integrated Risk Reduction with Hierarchy of Control Measures

↓

Protective measures taken by builder
- **design**
- **safeguards**
- **other protective measures**

↓

Protective measures taken by user
- **additional safeguards**
- **organization**
- **training**
- **personal protective equipment**



RA Process

Don't forget:

- A risk assessment is not about creating huge amounts of paperwork.
- The objective is to determine the threat potential (risk) of a hazard which can cause injury (severity) being realized (a function of the probability of occurrence).
- It is to identify/document sensible measures to control the risk(s) in your workplace.

RA (Guides)

Prevailing or dominant Risk Assessment and Scoring Matrices for reference, includes but is not limited to:

- ANSI B11.0-2010 (B11.TR3) *"Safety of Machinery – General Requirements and Risk Assessment"* [4x4]
- IEC 61508 series *"Functional Safety of E/E/PE"* [4x6]
- ANSI/RIA R15.06-2012 *"American National Standard for Industrial Robots and Robot Systems- Safety Requirements"*
- MIL STD 882E *"System Safety"* [4x5]
- Plus, reference ISO 12100:2010
  "Safety of machinery -- General principles for design -- Risk assessment and risk reduction" , a Four-Factor risk scoring, using: Likelihood of Occurrence (LO), Frequency of Exposure (FE), Degree of Possible Harm (DPH) and Number of Persons at risk (NP)

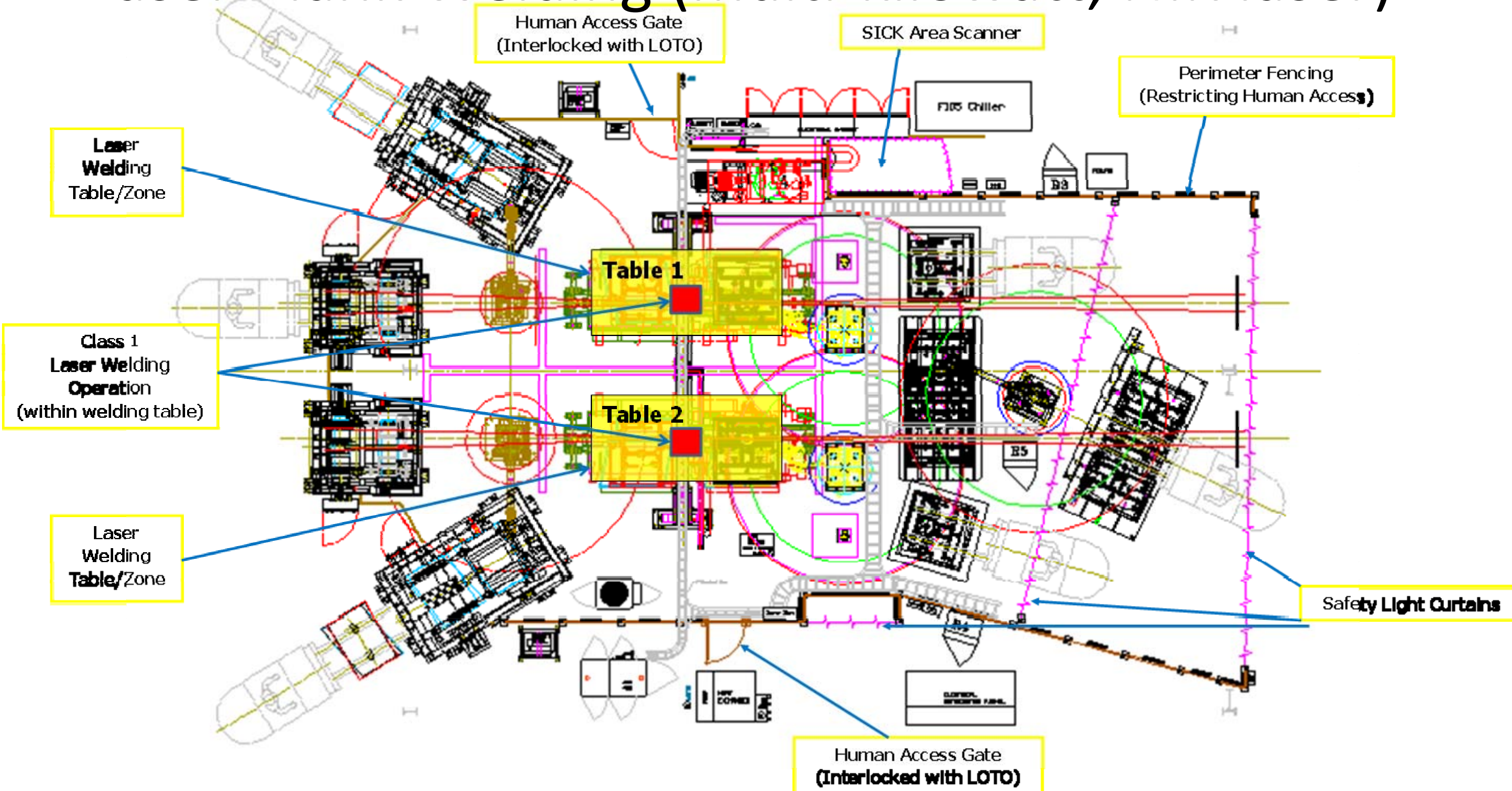
Example

Industrial laser blank welding:

- 5 kW NIR laser power
- Production operations
- RA applied as part of project execution and plan, following the life cycle of the equipment
- Qualitative RA conducted on critical process/hazard, used to establish appropriate safety circuit performance/integrity level

Example

Laser Blank Welding (multi-kilowatt, NIR laser)



Example

RA applied through life cycle (phases) of project:

- Concept: TNA, standards & regulations
- Design development: Establish functional safety targets, SFFP applied, emergency preparedness plan
- Manufacture/Build:
- Integrate: Modular safety checks
- Commission: Full up safety checks/regimen
- Customer acceptance: Follow through on operation, maintenance and service, sign-off, auth. personnel

Example

Laser Blank Welding (multi-kilowatt, NIR laser)

- Enclosure about weld process zone, local containment.
- Rated for intended use, direct, specular, scattered radiation and thermal loads.
- There are operators and support personnel in the area and plant.
- Requirement under single fault analysis, is that enclosure endure that single fault condition for 30,000 sec, before inspection. (If not monitored)

RA Scoring Matrices

- Solutions:
  - Either design and build the containment housing (laser barrier) to endure for the nominal time.
  - Install active panels (for integrity monitoring) to enable a shorter duration period of intended use and reduce the thickness of the “bunker walls” for the containment housing (assess response time and thresholds)
  - Enable beam on-time monitoring, in a reliable manner to provide a practical containment housing construct. What is the integrity level required?

RA Scoring Matrices

ANSI B11.0 (B11.TR3) *“Safety of Machinery – General Requirements and Risk Assessment”*

Two-Factor Risk Scoring System [4x4]

4 x 4 Risk Matrix		SEVERITY OF HARM			
PROBABILITY OF OCCURRENCE OF HARM		Catastrophic	Serious	Moderate	Minor
	Very Likely	High	High	High	Medium
	Likely	High	High	Medium	Low
	Unlikely	Medium	Medium	Low	Negligible
	Remote	Low	Low	Negligible	Negligible

RA Scoring Matrices

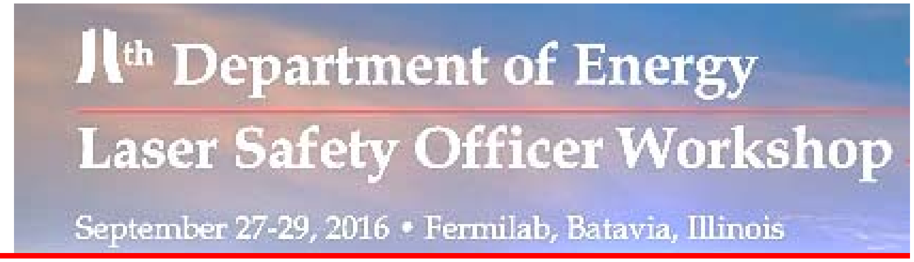
For the considered scenario:

Assess the severity of harm:

- *Catastrophic* – death or permanently disabling injury or illness (unable to return to work);
- *Serious* – severe debilitating injury or illness (able to return to work at some point);
- *Moderate* – significant injury or illness requiring more than first aid (able to return to same job);
- *Minor* – no injury or slight injury requiring no more than first aid (little or no lost work time).

Ref: ANSI B11.0-2010 (6.4.2.1)

RA Scoring Matrices



For the considered scenario:

Assess probability:

- *Very likely* – near certain to occur;
- *Likely* – may occur;
- *Unlikely* – not likely to occur;
- *Remote* – so unlikely as to be near zero.
- *Note: Predicting the probability of harm occurring is difficult. Unless quantitative data are available, the process of selecting the probability of harm occurring will be subjective (qualitative).*

Ref: ANSI B11.0-2010 (6.4.2.2)

RA Scoring Matrices

- Scoring for the noted example:

4 x 4 Risk Matrix		SEVERITY OF HARM			
PROBABILITY OF OCCURRENCE OF HARM		Catastrophic	Serious	Moderate	Minor
	Very Likely	High	High	High	Medium
	Likely	High	High	Medium	Low
	Unlikely	Medium	Medium	Low	Negligible
	Remote	Low	Low	Negligible	Negligible

RA Scoring Matrices

- There are other RA scoring methods that can help establish the safety performance requirements/specifications for the control measures.
- Ensure that the standard applied is respective of the control measure being applied.
- Following is for the noted example, but using IEC 62061 and ISO 13849

RA Scoring Matrices

Determining the required Safety Integrity Level (IEC 62061):

”Safety of machinery: Functional safety of electrical, electronic and programmable electronic control systems”

1. Determine the severity of the consequence of a hazardous event.
2. Determine the point value for the frequency and duration the person is exposed to harm.
3. Determine the point value for the probability of the hazardous event occurring when exposed to it.
4. Determine the point value for the possibility of preventing or limiting the scope of the harm.

RA Scoring Matrices

Probability of occurrence of harm					
Fr		**Pr**		**Av**	
Frequency, duration		Probability of hazardous event		Avoidance	
<= 1 hour	5	Very high	5		
>1 hour <= 1 day	5	Likely	4		
> 1 day <= 2 weeks	4	Possible	3	Impossible	5
> 2 weeks <= 1 year	3	Rarely	2	Possible	3
> 1 year	2	Negligible	1	Likely	1
				Total: 5+ 1 + 3 = 9	

Severity of harm		**SIL Class**				
Se		**Class CL**				
Consequences (severity)		3 – 4	5 - 7	8 - 10	11 - 13	14 - 15
Death, losing an eye or arm	4	SIL2	SIL2	SIL2	SIL3	SIL3
Permanent, losing fingers	3			SIL1	SIL2	SIL2
Reversible, medical attention	2				SIL1	SIL1
Reversible, first aid	1					SIL1

Note: Arguably, this is an upper bound SIL2, broaching SIL3 requirement.

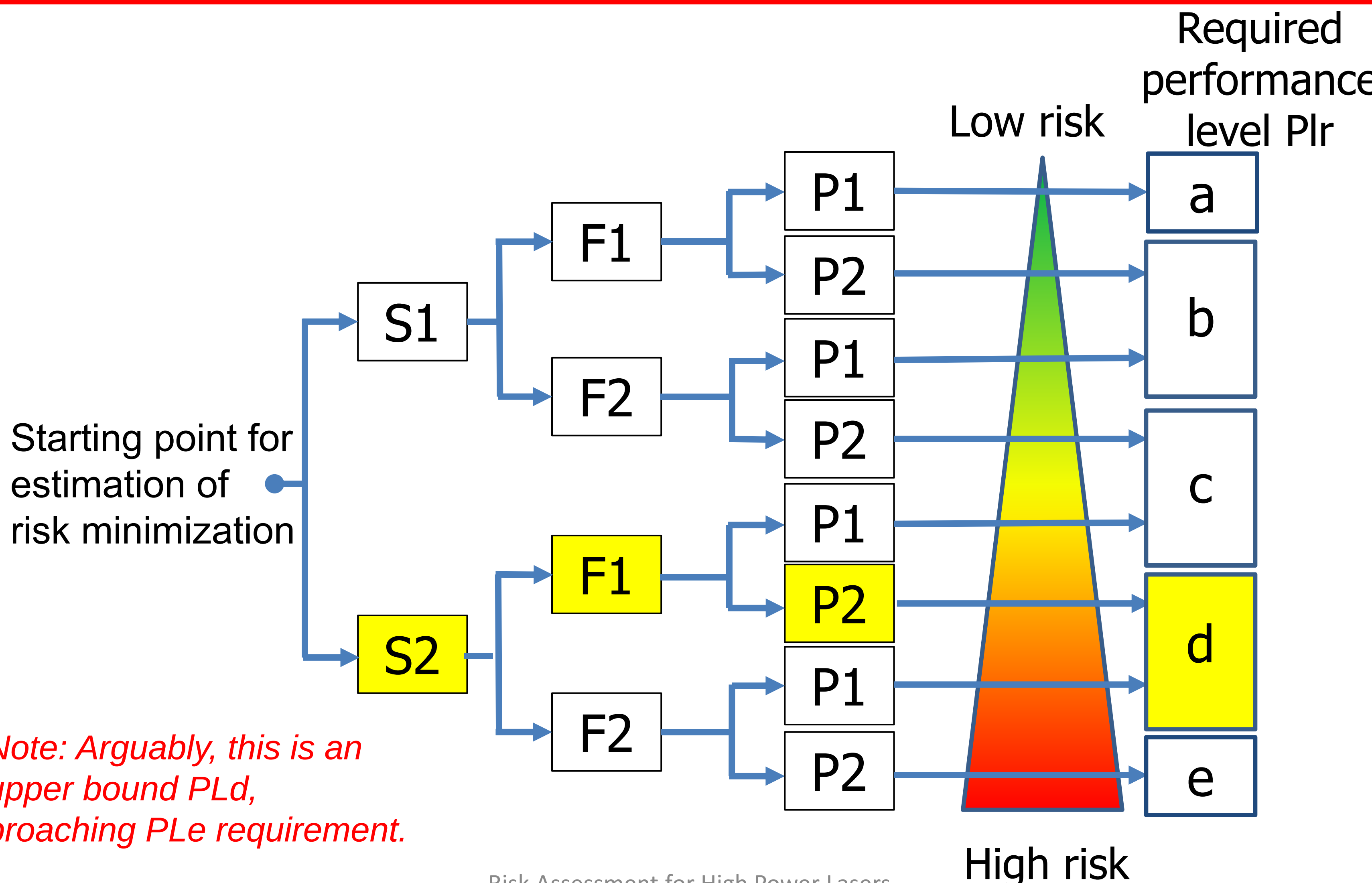
Ref: Beam on-time monitoring, reliability spec

RA Scoring Matrices

Determining the required safety Performance Level Pl (ISO 13849-1)

- Pl is an alternative parameter to SIL. To determine the required Pl, select one of the alternatives from the following categories and create a 'path' to the required Pl in the risk graph following, which lists the resulting performance level as a, b, c, d or e.
- Determine the severity of injury/damage:
  - S1 Slight, usually reversible injury
  - S2 Severe, usually irreversible injury, including death
- Determine the frequency and duration of exposure to the hazard:
  - F1 Rare to often and/or short exposure
  - F2 Frequently to continuous and/or long exposure
- Determine the possibility of preventing the hazard or limiting the damage caused by the hazard:
  - P1 Possible under certain conditions
  - P2 Hardly possible

RA Scoring Matrices



Note: Arguably, this is an upper bound PLd, broaching PLe requirement.

Ref: Beam on-time monitoring, reliability spec

RA Scoring Matrices

Following the trail: starting with facility services to operate the laser, through beam generation, delivery path, process target and to residual effects can generate the elements to be risk assessed against failure.

Applied control measures are evaluated against risk mitigation results achieved

Documentation is important to evaluate, track and relay critical safety information

RA Scoring Matrices

An example of a risk assessment worksheet

Sequence Task No.	Description	Hazard	Prior to Safeguard Selection				Solution	After Safeguard Selection			
			Severity	Exposure	Avoidance	Risk Index/Score		Severity	Exposure	Avoidance	Risk Index/Score
			S1 or S2	E1 or E2	A1 or A2			S1 or S2	E1 or E2	A1 or A2	

Safety Performance

ISO 13849 Performance Level (Pl)	IEC 62061 Safety Integrity Level (SIL)	IEC 61508 Safety Integrity Level (SIL)	PFH_D (Probability of Dangerous Failure per Hour)
a	None	None	$\geq 10^{-5}$ to $< 10^{-4}$
b	1	1	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$
c	1	1	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$
d	2	2	$\geq 10^{-7}$ to $< 10^{-6}$
e	3	3	$\geq 10^{-8}$ to $< 10^{-7}$
-	-	4	$\geq 10^{-8}$ to $< 10^{-8}$

- The above is for general reference only and does NOT provide for conversion of ratings. Each standard has its own scope and applicability, though there are some cross-over.
- Specify components, design and build of controls architecture

Safety Performance

A frame of reference:

- Typically, in a well designed system, a figure of 10^{-1} is assumed for the probability of an operator failing to take correct action on demand.
- Where exceptional care has been taken in design of human factors such as alarm management, instructions and training, and where such arrangements are monitored and reviewed, then a probability of failure on demand of not better than 10^{-2} may be achievable.

Ref: Control Systems, Health and Safety Executive, UK
http://www.hse.gov.uk/comah/sragtech/techmeascontsyst.htm

Safety Performance

Probability of failure on demand (when a safety function is required to perform, what are the odds it will fail to perform correctly)

System	Claimed failure rate or probability of failure on demand
Operator action	10^{-1}/demand (typical)
	10^{-2}/demand (best)
Non-safety related system (e.g. PLC)	Not better than 10^{-5}/hr
High integrity protective system (e.g. Safety PLC)	Not better than 10^{-9}/hr

Safety Performance

11th Department of Energy
Laser Safety Officer Workshop
September 27-29, 2016 • Fermilab, Batavia, Illinois

	Safety PLC (New)	Weld Head Housing Access Panel Interlock	Weld Head Housing Over-Travel Interlock	Weld Head Assembly (New)	Weld Shuttle and Beam Dump (New)	Access Light Curtains (Existing)	Area Safety Scanner
Manufacturer	PILZ	Allen Bradley	Schmerzal	IFM Efector	IFM Efector	STI	SICK
Model	Multi PNOZ M1P	Guard Master TLS-2 GD2	TESZ1102/35	GF711S	GF711S	MS4800S	S30A-4011BA, P/N: 1028934
Quantity	1	2	2	2	4	3 (pairs)	1
Safety Performance							
Category:	PL e (CPU)	PL d/e	PL d/e	PL d	PL d	PL e	PL d
Safety Integrity Level:	SIL CL 3 (CPU)	SIL CL 2/3	SIL CL 2/3	SIL CL 2	SIL CL 2	SIL CL 3	SIL CL 2
Functional Safety Data							
Mission Time TM (y):	20	20	20	20	20	20	20
PFH_d (1/h):	4.90E-09 (CPU)	3.0E-07	8.30E-07	1.07E-07	1.07E-07	3.50E-08	7.67E-08
Data Sheet	*PNOZ m1p datasheet.pdf*	*440G-T27,(TLS-GD2).pdf*	*Datasheet_TESZ1102-35.pdf*	*GF711S Datasheet.pdf*	*GF711S Datasheet.pdf*	*MS4800_datasheet.pdf*	*S30A-4011BA Datasheet.pdf*
User Manual	*PNOZmulti (Under Manual).pdf*	*440g-in006_-mu-d.pdf*	*mrl_tesz_en.pdf*	*IFM Efector GF711S Operation Manual.pdf*	*IFM Efector GF711S Operation Manual.pdf*	*MS4800_datasheet.pdf*	*S30A-4011BA (User Manual).pdf*
Standard(s)	EN 61131-2:09.2007, EN 62061:07.2005, EN 60204-1:06.2006, DIN EN ISO 13849-1:2007, DIN EN 12622:2007	EN954-1, ISO13849-1, IEC/EN60204-1, NFPA79, EN1088, ISO14119, IEC/EN60947-5-1, ANSI B11.19, AS4024.1	IEC 60947-5-3; ISO 13849-1; ISO 14119; BG-GS-ET-14	EN ISO 13849-1, IEC 61508, IEC 62061	EN ISO 13849-1, IEC 61508, IEC 62061	Category 4 / PL e (EN ISO 13849-1), SIL3 / SIL3 CL3 (IEC 61508 / EN 62061)	RL 2004/108/EG, RL 2006/42/EC, EN 61000-6-2/4, EN 61496-1, EN ISO 13849-1, EN ISO 13849-1/AC, EN 62061, EN 61496-1/A1, IEC 61508, IEC 61496-3
Conformance Certificate(s)	*PNOZ_m1p_Decl_Conf_1001196-2EN-02.pdf*	*SCB-0014-F-EN (Certificate of Conformity).pdf*	*z_tesp05 (DGUV Test Certificate).pdf*	*IFM Efector GF711S EC Declaration of Conformity.pdf*	*IFM Efector GF711S EC Declaration of Conformity.pdf*	*Prod Certs - MS, MSF4800 - Rev C.pdf*	*S30A-4011BA__2014-12-06__10-34-06 (Declaration of Conformity).pdf*

Standards Summary

Basic safety standards

Type A Standards

Design principles and basic concepts for machines

Safety group standards (generic standards)

Type B Standards

B1 Standards General safety aspects

B2 Standards Reference to special protective devices

Process or product safety standards

Type C Standards

Safety requirements for specific machines or machine types

ANSI American National Standards Institute

ISO

IEC

CENELEC

cen

OSHA

Standards Summary

Standards Addressing General Requirements ("A" Level Standards)	
U.S.	**International/European**
OSHA 29CFR1910 (applicable provisions – see **www.osha.gov** for further information)	**ISO 12100-1&2 (EN292)** Safety of Machinery: Basic Concepts, General Principles for Design
OSHA 29CFR1910.212 General Requirements for (Guarding of) All Machines	**ISO 14121 (EN1050)** Safety of Machinery: Risk Assessment

Note well: Not a complete listing, for reference purposes only.

Standards Summary

Standards Addressing Safety, Safeguarding, and Methodologies (“B” Level Standards) – U.S.	
ANSI/NFPA70 The National Electrical Code	**OSHA 29CFR1910.147** The Control of Hazardous Energy (Lockout/Tagout)
ANSI/NFPA70E Electrical Safety Requirements for Employee Workplaces	**ANSI Z244.1** Lockout/Tagout of Energy Sources
ANSI/NFPA79 Electrical Standard for Industrial Machinery (Aligned with IEC60204-1)	**ANSI Z535** Presentation of Safety and Accident Prevention Information
OSHA 29CFR1910.333 Selection and Use of Work Practices (Electrical Safety)	**ANSI Z136.1** Safe Use of Lasers
ANSI B11.21 Machine Tools Using Lasers – Safety	**ANSI B11.0** Safety of Machinery; General Requirements and Risk Assessment
ANSI B11.19 Safeguarding (Machine Tools)	**OSHA 3071** Job Hazard Analysis
U.S. 21CFR1040.10/.11 Performance Standards for Light Emitting Products	

Note well: Not a complete listing, for reference purposes only.

Standards Summary

Standards Addressing Safety, Safeguarding, and Methodologies ("B" Level Standards) – International/European	
IEC 60204-1 Electrical Equipment of Machines (Aligned with NFPA79)	**ISO 14120 (EN953)** Guards – General Requirements for the Design and Construction
ISO 14118 (EN1037) Prevention of Unexpected Start Up	**ISO 14119 (EN1088)** Interlocking Devices With and Without Guard Locking
ISO 13849 Safety Related Parts of Control Systems	**IEC 61496** Electro Sensitive Protective Equipment
IEC 62061 Functional Safety of Electrical/Electronic/ Programmable Control Systems	**ISO 13850 (EN418)** Emergency Stop Devices, Functional Aspects – Principles for Design
IEC 61508 Functional Safety of Electrical /Electronic/ Programmable Electronic Safety Related Systems (Software/Firmware)	**IEC 1131** Programmable Controllers
ISO 11553 Safety of machinery — Laser processing machines	**IEC 60825-1** Safety of laser products – Part 1: Equipment classification and requirements

Note well: Not a complete listing, for reference purposes only.

Standards Summary

Standards Addressing Specific Machine Applications ("C" Level Standards) – U.S., International/European	
ANSI B11.20 Manufacturing Systems / Cells	**ISO 11161** Industrial Automation / Safety of Integrated Manufacturing Systems
ANSI/RIA R15.06 Industrial Robots and Robot Systems	**ISO 10218** Manipulating Industrial Robots – Safety
ANSI Z136.7 Testing and Labeling of Laser Protective Equipment	**IEC 60824-4** Safety of laser products – Part 4: Laser guards

Note well: Not a complete listing, for reference purposes only.

Considerations

Unique laser system components to be assessed (additional to those identified in machine safety standards):

- Secondary, radiation and plasma effects of laser target material interaction (incoherent, coherent, x-rays, temperature, oxygen depletion, LGACs, etc.)
- Identification of mission critical elements within laser system (power source, delivery, process and beyond)
- Engineering design review of mission critical elements (to assist with FMEA, FMMEA, FTA studies)
- FMEA of mission critical elements
- E/E/PE code reliability (fault tolerance & stress testing)
- Controlled emergency shut-down procedures (automatic and operator initiated)

Considerations

Measures to mitigate risk on very high power Class 4 laser systems (power source, equipment and process):

- Beam on-time monitoring (can determine time budget for shut-down response prior to mission critical element failure)
- Control of hazardous energy (LOTO)
- Monitoring of mission critical elements (safe, out of tolerance, failure, drift & deviations)
- Pre-commission radiometric audit
- Competency testing, on-the-job-training, re-certification program for personnel, training needs assessment
- Maintenance and service re-commission checklist to validate safety functionality before putting into operation

Considerations

Consider all foreseeable hazard scenarios (which off-the-shelf components may not have been designed to handle):

- Failure of power supplies and various control circuits
- Power surges and brown-outs, unanticipated E-stops
- Errors in software code (control logic and safety circuit)
- Effects (source or receiver) of EMC/EMI
- Environmental effects (temperature, humidity, dust, etc.)
- Operator "mode confusion", will (how) the equipment resist incorrect operator inputs of control system
- Emergency preparedness plan

Considerations

The level of documentation or record keeping will depend on:

- level of risk involved,
- legislated requirements, and/or
- facility or corporate requirements

Documentation should show that:

- conducted a sufficient hazard review,
- determined the risks of those hazards,
- implemented control measures suitable for the risk,
- reviewed and monitored all hazards in the workplace

Conclusion

YES	NO	
√		Have all foreseeable operating conditions and safety control measures been taken into account?
√		Has the method of the hierarchy of control been applied?
√		Have the hazards been eliminated, or their risks reduced to lowest practical and acceptable levels?
√		Do the safety measures NOT create new hazards?
√		Operator working conditions are NOT jeopardized by new safety measures?
√		Are the users sufficiently informed and aware of the residual risks?
√		Protective measures taken do NOT adversely affect the performance of the machine?

Conclusion

When to implement a laser risk assessment?

- The risk assessment scope should be commensurate with the high value or high power/energy laser system and/or the unknowns.
- Risk assessments are increasingly recognized to ensure safety, success and capability of projects. It is an appropriate tool for ensuring due diligence for:
  - **L**ight
  - **A**pplied
  - **S**afely
  - **E**fficiently &
  - **R**eliably

Thank You!

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References

Can draw upon national and international consensus standards, including, but not limited to the following:

- **ANSI/ASSE Z690.X-2011** *"Risk Management & Assessment"* (national adaption of ISO 31000:2009)
- **ANSI B11.0-2010** *"Safety of Machinery – General Requirements and Risk Assessment"*
- **ANSI/ASSE Z244.1-2003 (R2008)** *"Control of Hazardous Energy – Lockout/Tagout and Alternative Methods"*
- **MIL-STD-882E-2012** *"Standard Practice for System Safety"*
- **SEMI S10-0307E (2006)** *"Safety Guideline for Risk Assessment and Risk Evaluation Process"*
- **ANSI/RIA R15.06-(2012)** "For Industrial Robots and Robot Systems – Safety Requirements" (Incorporates **ISO 10218 (2011)**)
- **NFPA 79-2012** *"Electrical Standard for Industrial Machinery"*
- **ANSI B11.19** *"Machine Tools Performance Criteria for Safety"*
- **ANSI B11.21** *"Machine Tools-Safety Requirements for Machine Tools Using Lasers for Processing Materials"*

References

Can draw upon national and international consensus standards, including, but not limited to the following:

- **ISO/IEC Guide 51:2014** *“Safety aspects -- Guidelines for their inclusion in standards”*
- **ISO/IEC 31010:2009** *“Risk management - Risk assessment techniques”*
- **ISO 12100:2010** *“Safety of machinery – General principles for design – Risk assessment and risk reduction”*
- **IEC 61508:2010**, *“Functional safety of electrical/electronic/programmable electronic safety-related systems “*
- **IEC/EN 62061:2005** *“Safety of machinery”* Machinery specific implementation of IEC 61508.
- **ISO 13849-1: (R2010)** *“Safety of machinery – Safety-related parts of control systems – Part 1: General principles of design”* (supersedes EN 954-1)

- **Ontario Pre-Start Health and Safety Review**

Odds & Ends

- Safety and Compliance Plan: A Master Checklist
- Design objectives, tolerances and deviations, applicable regulations, codes, consensus standards and guidance documents
- N.B. The above standards are in general, not the product of hazard and failure prevention fore-planning, but from failure and catastrophe analysis. *"Need not make the same mistake again."*
- Training needs analysis: Personnel (pre-requisites & continuing education)
- Start-up & commissioning plan, to include critical control measures performance/integrity testing.