Tolerable Risk— The Missing Link Between Risk Assessment and SIL Assignment

Mike Schmidt, SIS Consultant

Learn • Lead • UNLEASH 2006

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Presenter

- Mike Schmidt

EMERSON PROCESS MANAGEMENT

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Introduction

- Understand what SIL ratings are
- Understand “tolerable risk”
- Getting a sense of tolerable risk
- Establishing a risk matrix for SIL assignment

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

What are SILs?

- "SIL" stands for Safety Integrity Level
- SILs represent the difference between the process risk without a Safety Instrumented Function (SIF) and the tolerable risk
- SILs apply to each SIF, not to the SIS as a whole
- SILs establish the required reliability of an SIF
- SILs are calculated to demonstrate that a SIF, as designed and operated, has the required reliability to maintain the tolerable risk

What are SILs?

- Safety Integrity Levels

Safety Integrity Level	Probability of Failure on Demand (PFD_{AVG})	Risk Reduction Factor (RRF)
SIL 4	**$10^{-4} > PFD > 10^{-5}$**	**$10000 < RRF < 100000$**
SIL 3	**$10^{-3} > PFD > 10^{-4}$**	**$1000 < RRF < 10000$**
SIL 2	**$10^{-2} > PFD > 10^{-3}$**	**$100 < RRF < 1000$**
SIL 1	**$10^{-1} > PFD > 10^{-2}$**	**$10 < RRF < 100$**

- SIFs can also be N/R (not rated) for a SIL

Recommended approach: Risk Matrix

Likelihood						
	f > High	N/R	SIL 1	SIL 2	SIL 3	SIL 4
	High > *f* > 0.1 High	N/R	N/R	SIL 1	SIL 2	SIL 3
	f < 0.1 High (Low)	N/R	N/R	N/R	SIL 1	SIL 2
		< 0.01 x Serious	> 0.01 x Serious	> 0.1 x Serious	> 1 x Serious	> 10 x Serious
		Consequence				

- The challenge is to define “x”, the serious consequence, and “High”, the high frequency
- After that, the categories themselves are separated by orders of magnitude

Learn • Lead • UNLEASH 2006

Many companies already have something similar for PHAs

Likelihood						
	1	5	4	3	2	1
	2	8	7	6	4	2
	3	9	8	7	6	3
	4	10	9	8	7	4
	5	10	10	9	8	5
		5	4	3	2	1
		Severity (Consequence)				

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Some typical likelihood categories

- Categories—
  1. Frequent
  2. Occasional
  3. Seldom
  4. Remote
  5. Unlikely
- But what do they mean?

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

The categories are usually unevenly distributed

- Typical definition of Likelihood Categories—
  1. Event occurs once a year
  2. Event occurs once every 10 years (~1 order of magnitude)
  3. Event occurs once every 50 years (~ ½ order of magnitude)
  4. Event occurs once every 150 years (~ ½ order of magnitude)
  5. Not likely to occur (??? orders of magnitude)

Emerson Global Users Exchange

Learn • Lead • UNLEASH 2006

Consequence categories are worse

- Severity (e.g. Consequence) –
  1. Loss of life; damage over $1 million
  2. Lost time injury; damage over $500k
  3. Medical treatment; damage less than $500k
  4. Minor injury; near miss; poor quality
  5. No injury, impact on process

Learn • Lead • UNLEASH 2006

Converting an existing matrix

- Adjust likelihood categories so they are one order of magnitude apart
- Adjust consequence categories so they are one order of magnitude apart
- Assign SILs to each box

Learn • Lead • UNLEASH 2006

Building the Risk Matrix

Likelihood						
	1. Frequent					
	1 event / year					
	2. Occasional					
	1 event / 10 years					
	3. Seldom					
	1 event / 50 years					
	4. Remote					
	1 event / 150 years					
	5. Unlikely					
		5.	4.	3.	2.	1.
		Consequence				

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Adjust and consolidate

Likelihood						
	1. Frequent					
	1 event / 1.5 years					
	2. Occasional					
	1 event / 15 years					
	3/4. Seldom/Remote					
	1 event / 150 years					
	5. Unlikely					
		5.	4.	3.	2.	1.
		Consequence				

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Or reconsider entirely

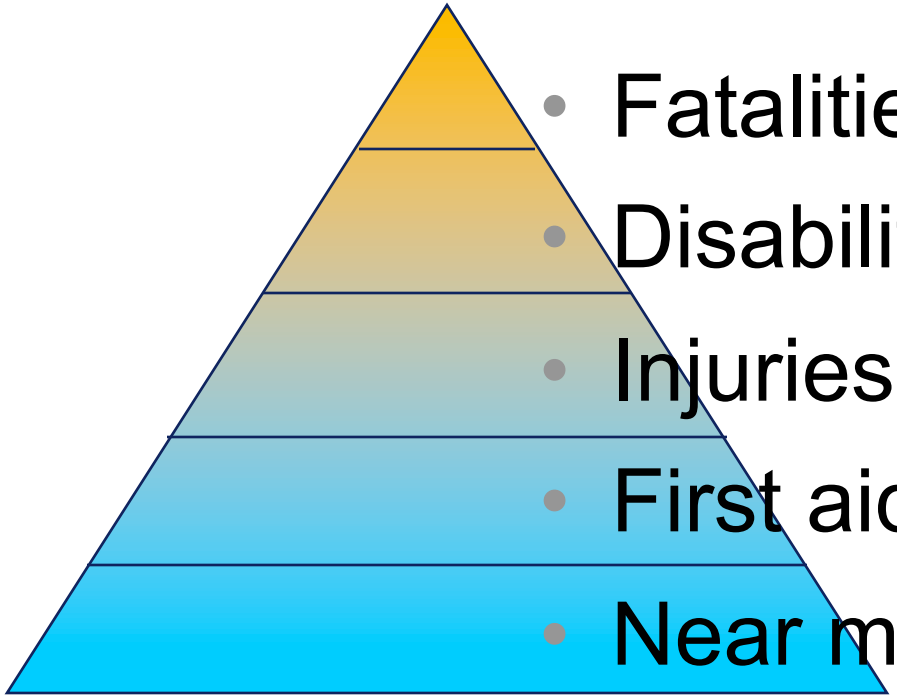
Likelihood						
	1. Frequent					
	1 event / 5 years					
	2. Occasional					
	1 event / 50 years					
	3. Seldom/Remote					
	1 event / 500 years					
	4. Unlikely					
		5.	4.	3.	2.	1.
		Consequence				

EMERSON GLOBAL USERS EXCHANGE

SIS and consequences

- Personnel consequences – The primary purpose of an SIS
- Community consequences – Can be another important purpose of an SIS
- Environmental consequences – Sometimes part of the purpose of an SIS
- Site and operability – Usually not appropriate to include in an SIS

The Accident Triangle



- Fatalities
- Disabilities
- Injuries
- First aids
- Near misses

Learn • Lead • UNLEASH 2006

H.W. Heinrich's theory

- For 300 near misses, 29 first aids
- For 29 first aids, 1 serious injury or fatality

- Basis of the safety pyramid.

- Something like orders of magnitude

Heinrich, H.W., *Industrial Accident Prevention: A Scientific Approach*, 4th Edition, McGraw-Hill (New York), 1959.

Learn • Lead • UNLEASH 2006

Cost of Occupational Injuries

• First aid	$292	
• Temporary injury	$2782	(9.5x)
• Permanent partial	$15,342	(5.5x)
• Permanent total	$113,372	(7.4x)
• Fatality	$612,150	(5.4x)

Leigh, J.Paul, Steven Markowitz, Marianne Fahs, Philip Landrigan, *Cost of Occupational Injuries and Illnesses*, University of Michigan Press, 2000.

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Cost of Accidents

- Reportable without lost work day $7,000
- Reportable with lost work day $28,000 (4x)
- Fatality $910,000 (32.5x)

Mine Safety and Health Administration, “Cost of Accidents”, http://www.msha.gov/s&hinfo/costgenerator/costgenerator.htm, 2006

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

From the literature

• Fatalities	~$1,000,000
• Serious injuries	~$100,000
• Injuries (reportables)	~$10,000
• First aids (non-reportables)	~$1,000

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Relative cost of consequences

- Fatalities 1.0*x*
- Serious injuries 0.1*x*
- Injuries (reportables) 0.01*x*
- First aids (non-reportables) 0.001*x*

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Aligns with some of the consequence categories

- Severity (e.g. Consequence) –
  1. Loss of life; damage over $1 million ←
  2. Lost time injury; damage over $500k
  3. Medical treatment; damage less than $500k
  4. Minor injury; near miss; poor quality ←
  5. No injury, impact on process ←

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

The Risk Matrix

Likelihood						
	1. Frequent	5	4	3	2	1
	1 event / 1.5 years					
	2. Occasional	8	7	6	4	2
	1 event / 15 years					
	3/4. Seldom/Remote	9/10	8/9	7/8	6/7	3/4
	1 event / 150 years					
	5. Unlikely	10	10	9	8	5
		5. < 0.1 injuries < 1 first aid < 1 near miss	4. ≥ 0.1 injuries ≥ 1 first aid ≥ 1 near miss	3. ≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	2. ≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	1. ≥ 1 fatality ≥ 10 disabilities
		Consequence (per event)				

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

What SIL goes in each box?

Likelihood						
	1. Frequent					
	1 event / 1.5 years					
	2. Occasional					
	1 event / 15 years					
	3/4. Seldom/Remote					
	1 event / 150 years					
	5. Unlikely					
		5. < 0.1 injuries < 1 first aid < 1 near miss	4. ≥ 0.1 injuries ≥ 1 first aid ≥ 1 near miss	3. ≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	2. ≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	1. ≥ 1 fatality ≥ 10 disabilities
		Consequence (per event)				

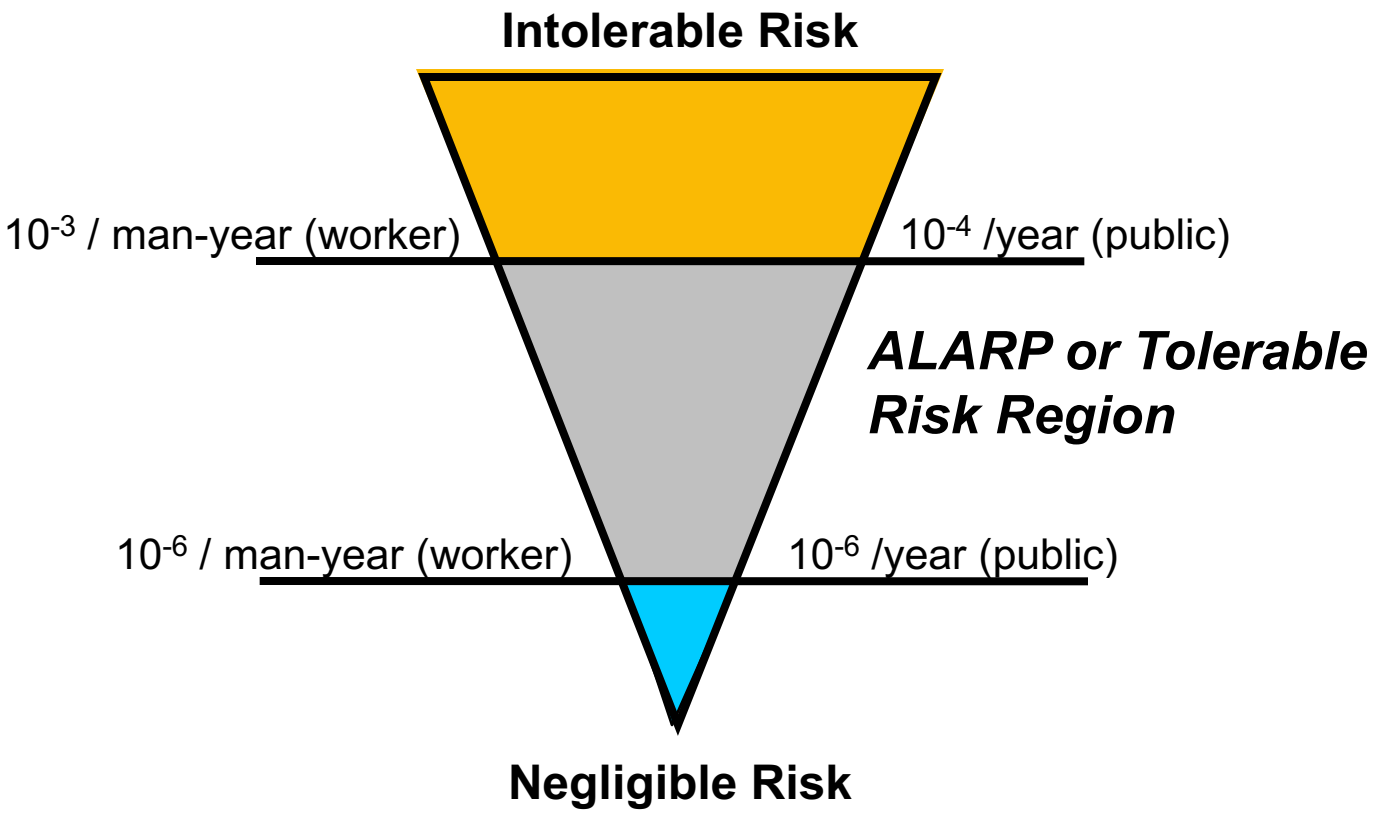
EMERSON GLOBAL USERS EXCHANGE

This depends on tolerable risk

- As an individual, what do you believe the tolerable risk should be for the facility?

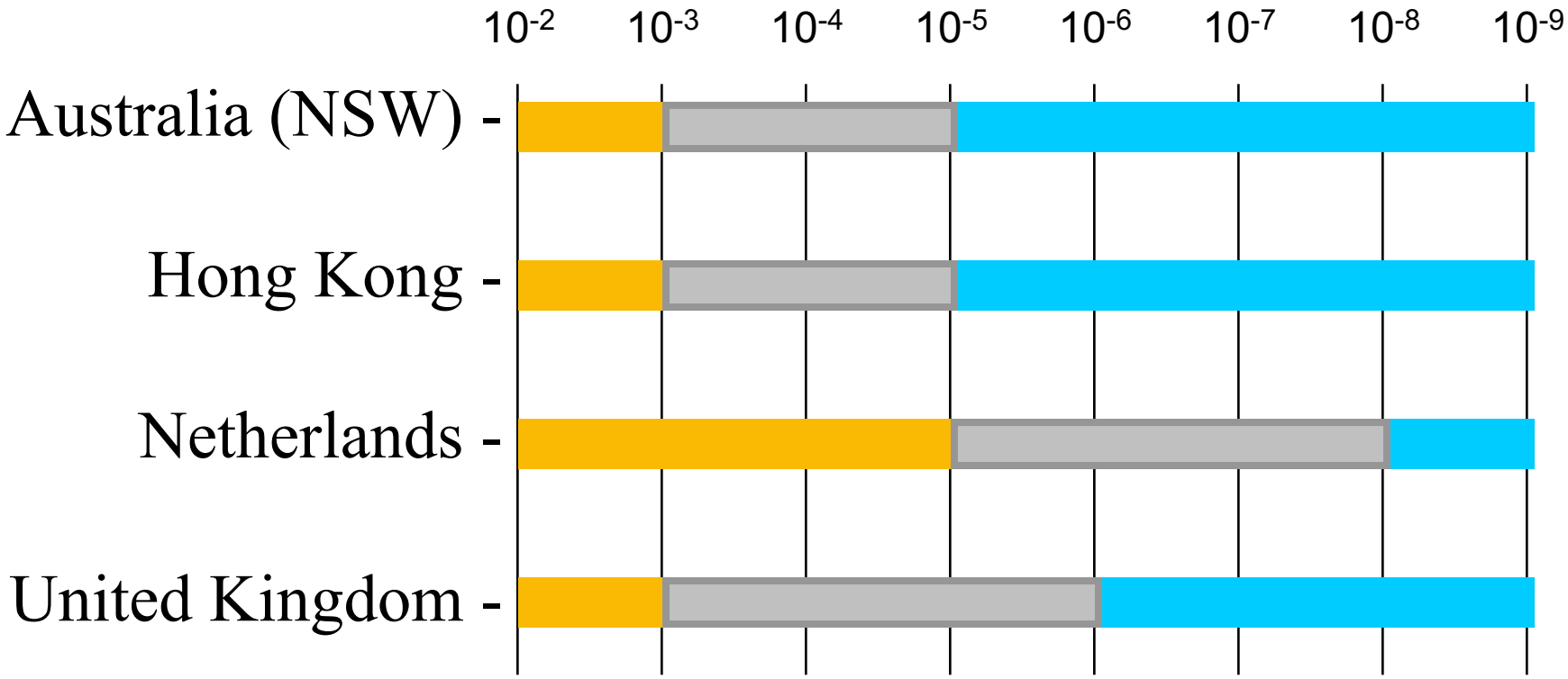
- Take a moment to consider the mean time between fatalities that would be low enough to consider your facility **safe**.

ALARP – Levels Set per UK HSE



Learn • Lead • UNLEASH 2006

Government mandates

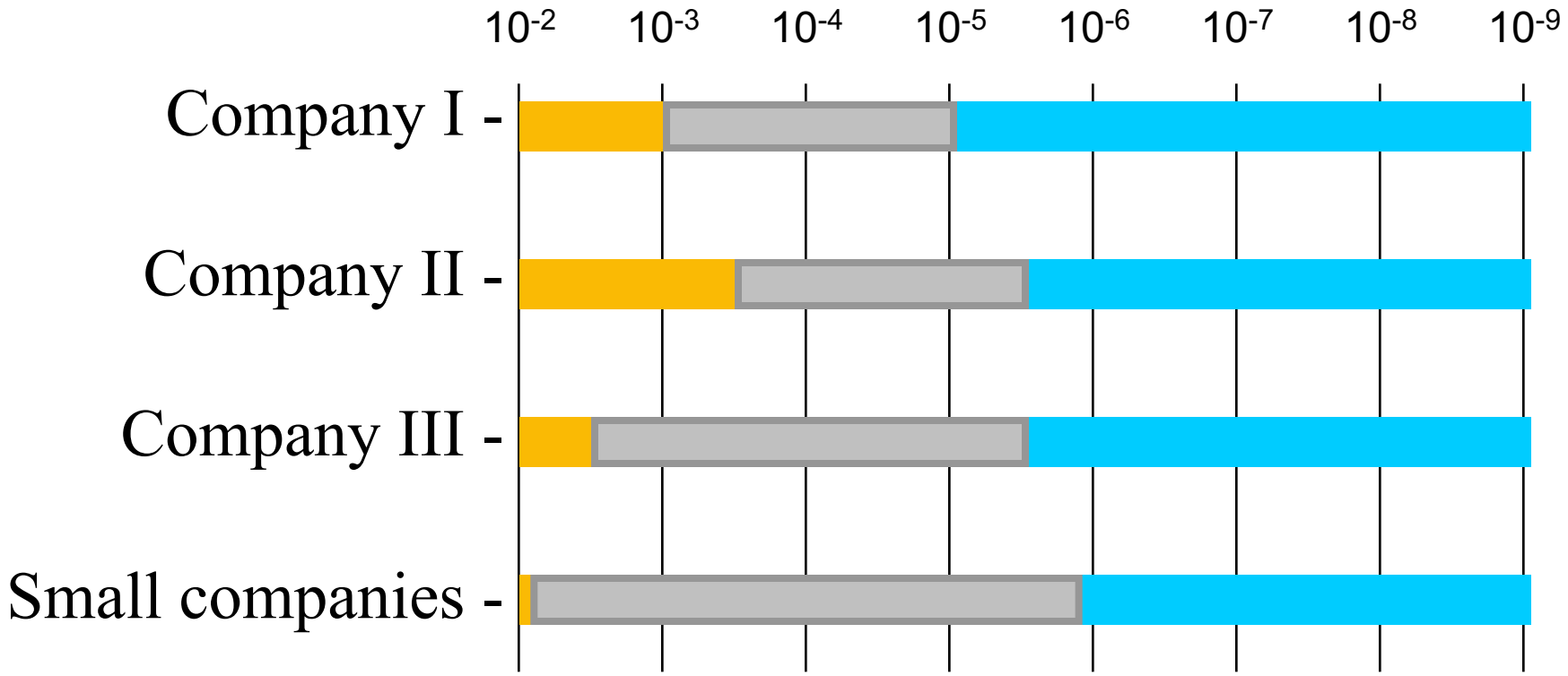


- The United States does not set tolerable risk levels, or offer guidelines.

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Chemical industry benchmarks



- Large, multinational chemical companies tend to set levels consistent with international mandates
- Smaller companies tend to operate in wider ranges and implicitly, at higher levels of risk

Emerson Global Users Exchange

Learn • Lead • UNLEASH 2006

Voluntary and "natural" risks—a comparison of fatality rates

- Smoking a pack a day—
  - 5.0×10^{-3}/year or 5000 fatalities per year per million smokers
- Automobile accident—
  - 1.5×10^{-4}/year or 150 fatalities per year per million people
- Lightning strike—
  - 1.0×10^{-7}/year or 1 fatality per 10 years per million people

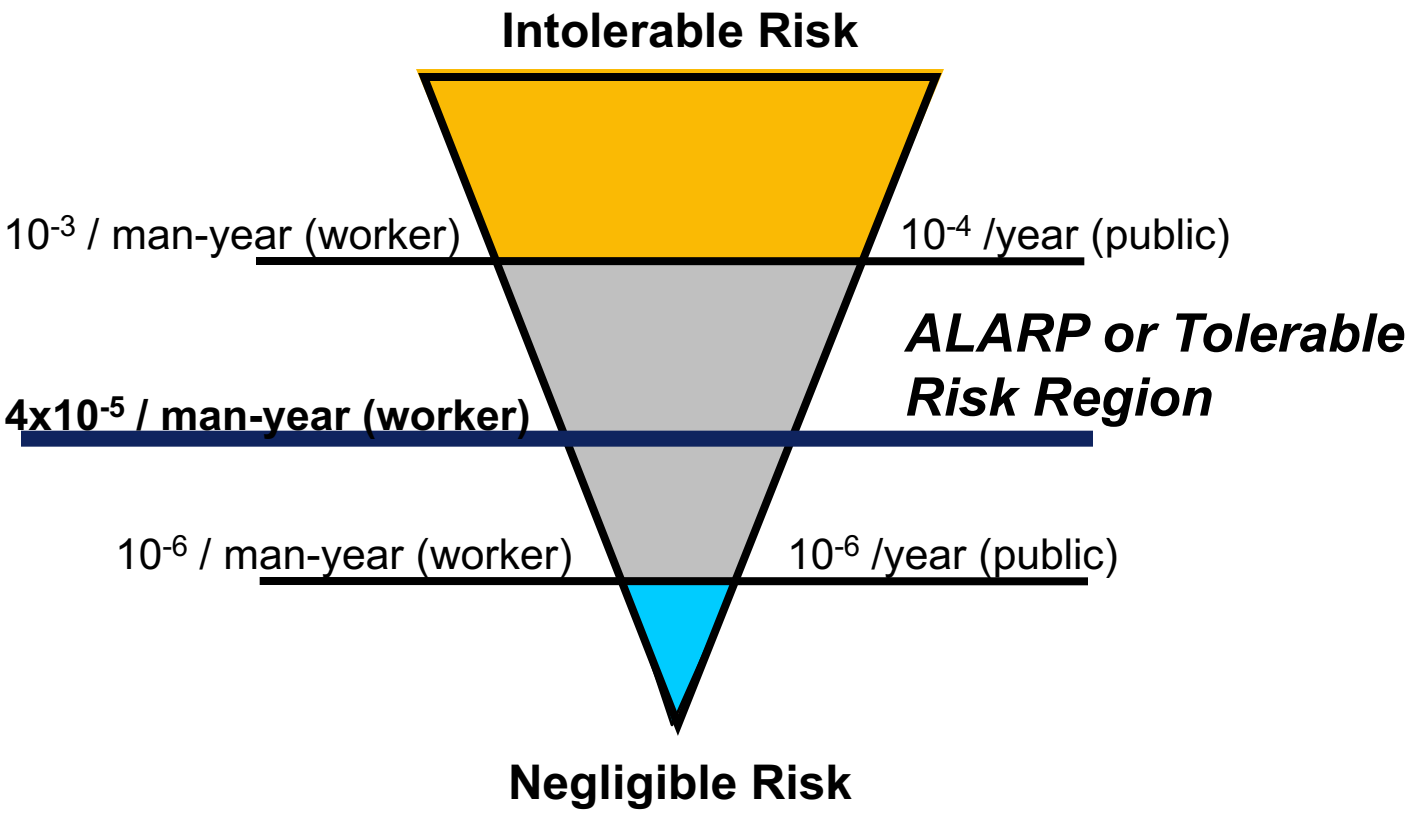
Emerson Global Users Exchange

Plant A – 1 fatality/100 years

- Assume that 1 fatality per 100 years is “safe”
- Exposed workforce ~ 250 workers
- (1 year / 250 man-years) x (1 fatality/100 years) = 1 fatality/25000 man-years

  = 4 x 10^{-5} fatalities/man-year = total tolerable risk

ALARP – Levels Set per UK HSE



Process safety is only part of risk

Process safety is only part of the total tolerable risk

- Total tolerable risk = 4×10^{-5} fatalities/man-year
- Assume process safety risk is half = 2×10^{-5} fatalities/man-year

Tolerable risk per safety function

Process safety risk should not be allocated all to a single hazard

- Process safety risk = 2×10^{-5} fatalities/man-year
- Assume workers are each exposed to about 5 potentially fatal hazards
  - N/R ≤ 4×10^{-6} fatalities/man-year
  - SIL 1 ≤ 4×10^{-5} fatalities/man-year
  - SIL 2 ≤ 4×10^{-4} fatalities/man-year
  - SIL 3 ≤ 4×10^{-3} fatalities/man-year
  - SIL 4 or re-design > 4×10^{-3} fatalities/man-year

Learn • Lead • UNLEASH 2006

Putting a stake in the ground

Likelihood						
	1. Frequent					
	1 event / 1.5 years					
	2. Occasional					
	1 event / 15 years					
	3/4. Seldom/Remote					
	1 event / 150 years					
	5. Unlikely					
		5. < 0.1 injuries < 1 first aid < 1 near miss	4. ≥ 0.1 injuries ≥ 1 first aid ≥ 1 near miss	3. ≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	2. ≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	1. ≥ 1 fatality ≥ 10 disabilities
		Consequence (per event)				

EMERSON GLOBAL USERS EXCHANGE

The middle of the box

- 4.7 years is the log mean of the box
- 0.32 fatalities per event is the log mean of the box
- (1 event/4.7 year) x (0.32 fatalities per event) x (1 yr/250 man-year)
- = 2.7×10^{-4} fatalities/man-year
- SIL rating = SIL 2

Learn • Lead • UNLEASH 2006

The implied Risk Matrix

Likelihood						
	1. Frequent	N/R	SIL 1	SIL 2	SIL 3	re-design
	1 event / 1.5 years					
	2. Occasional	N/R	N/R	SIL 1	SIL 2	SIL 3
	1 event / 15 years					
	3/4. Seldom/Remote	N/R	N/R	N/R	SIL 1	SIL 2
	1 event / 150 years					
	5. Unlikely	N/R	N/R	N/R	N/R	SIL 1
		5. < 0.1 injuries < 1 first aid < 1 near miss	4. ≥ 0.1 injuries ≥ 1 first aid ≥ 1 near miss	3. ≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	2. ≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	1. ≥ 1 fatality ≥ 10 disabilities
		Consequence (per event)				

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Reverting to the PHA matrix

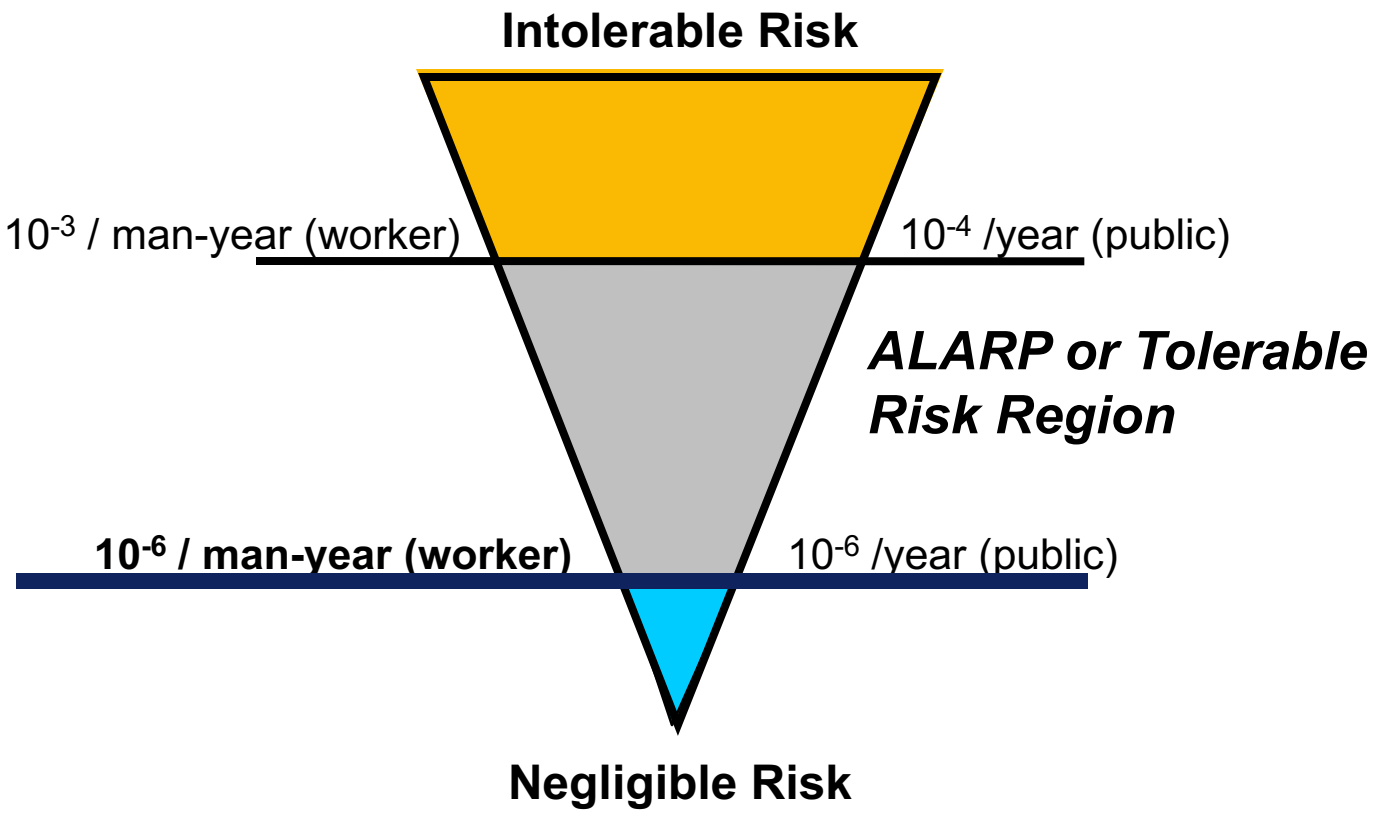
Likelihood						
	1. Frequent	5	4	3	2	1
	1 event / 1.5 years					
	2. Occasional	8	7	6	4	2
	1 event / 15 years					
	3/4. Seldom/Remote	9/10	8/9	7/8	6/7	3/4
	1 event / 150 years					
	5. Unlikely	10	10	9	8	5
		5. < 0.1 injuries < 1 first aid < 1 near miss	4. ≥ 0.1 injuries ≥ 1 first aid ≥ 1 near miss	3. ≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	2. ≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	1. ≥ 1 fatality ≥ 10 disabilities
		Consequence (per event)				

1 = re-design
2 = SIL 3
3 – 4 = SIL 2?
5 – 7 = SIL 1?
8 – 10 = N/R

or, recognize that the PHA priority matrix will not convert directly

Emerson Global Users Exchange

Plant B – 1 x 10^{-6} fatality/man-year



Plant B – 1 x 10^{-6} fatality/man-yr

- Total tolerable risk = 1 x 10^{-6} fatality/man-year
- Process safety risk = 5 x 10^{-7} fatality/man-year
- Workers exposed to 5 potentially fatal hazards
  - N/R ≤ 1 x 10^{-7} fatalities/man-year
  - SIL 1 ≤ 1 x 10^{-6} fatalities/man-year
  - SIL 2 ≤ 1 x 10^{-5} fatalities/man-year
  - SIL 3 ≤ 1 x 10^{-4} fatalities/man-year
  - SIL 4 or re-design > 1 x 10^{-4} fatalities/man-year

The middle of the same box

- (1 event/4.7 year) x (0.32 fatalities per event) x (1 yr/250 man-year)
- = 2.7 x 10^{-4} fatalities/man-year
- SIL rating = SIL 4 or re-design

Learn • Lead • UNLEASH 2006

The implied Risk Matrix

Likelihood	5.	4.	3.	2.	1.
	< 0.1 injuries < 1 first aid < 1 near miss	≥ 0.1 injuries ≥ 1 first aid ≥ 1 near miss	≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	≥ 1 fatality ≥ 10 disabilities
1. Frequent 1 event / 1.5 years	SIL 2	SIL 3	re-design	re-design	re-design
2. Occasional 1 event / 15 years	SIL 1	SIL 2	SIL 3	re-design	re-design
3/4. Seldom/Remote 1 event / 150 years	N/R	SIL 1	SIL 2	SIL 3	re-design
5. Unlikely	N/R	N/R	SIL 1	SIL 2	SIL 3
	Consequence (per event)				

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Variations to consider, depending on risk philosophy

Define SIL based on upper right corner, rather than the middle of the box. Most conservative approach, this increases SIL by one.

Likelihood	5.	4.	3.	2.	1.
1. Frequent					
1 event / 1.5 years					
2. Occasional					
1 event / 15 years					
3/4. Seldom/Remote					
1 event / 150 years					
5. Unlikely					
	< 0.1 injuries < 1 first aid < 1 near miss	≥ 0.1 injuries ≥ 1 first aid ≥ 1 near miss	≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	≥ 1 fatality ≥ 10 disabilities
	Consequence (per event)				

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Fewer categories

A 5x5 matrix is probably the largest workable matrix. A 3x3 matrix is probably smallest workable matrix.

Likelihood					
	1. Likely	N/R	SIL 1	SIL 2	SIL 3
	1 event / 15 years				
	2. Possible	N/R	N/R	SIL 1	SIL 2
	1 event / 150 years				
	3. Unlikely	N/R	N/R	N/R	SIL 1
		4. < 0.1 disability < 1 injuries < 10 first aids	3. ≥ 0.1 disability ≥ 1 injuries ≥ 10 first aids	2. ≥ 0.1 fatality ≥ 1 disability ≥ 10 injuries	1. ≥ 1 fatality ≥ 10 disabilities
		Consequence (per event)			

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Adjust categories

While categories should be separated by orders of magnitude, the significant figure can be whatever is consistent with an organization's philosophy of risk.

Likelihood					
	1. Likely	SIL 1	SIL 2	SIL 3	re-design
	1 event / 25 years				
	2. Possible	N/R	SIL 1	SIL 2	SIL 3
	1 event / 250 years				
	3. Unlikely	N/R	N/R	SIL 1	SIL 2
		4. < 0.3 disability < 3 injuries < 30 first aids	3. ≥ 0.3 disability ≥ 3 injuries ≥ 30 first aids	2. ≥ 0.3 fatality ≥ 3 disability ≥ 30 injuries	1. ≥ 3 fatality ≥ 30 disabilities
		Consequence (per event)			

EMERSON GLOBAL USERS EXCHANGE

Business Results Achieved

- A Risk Matrix for SIL assignment never explicitly states the tolerable risk.
- Likelihood and consequence only need order-of-magnitude estimates, reducing the extent of calculations required or the number of conflicting opinions that must be resolved, resulting in less cost to assign SILs.
- The Risk Matrix can be broadly applied and results in consistent treatment of hazards and risks, with much less under- or over-specification, resulting in lower total cost of safety instrumented system.

Summary

- SIL assignment is based on orders of magnitude
- A familiar risk matrix can be used to assign SILs, preferably with the likelihood and consequence categories are adjusted to orders of magnitude
- Tolerable risk is specific to an organization, and depends on its size and circumstances, government mandates, and industry standards
- Identical plants with identical risks will assign different SILs if their tolerable risk differs. There is no “Standard Risk Matrix”.

Learn • Lead • UNLEASH
2006

Questions?

EMERSON GLOBAL USERS EXCHANGE

Learn • Lead • UNLEASH 2006

Where To Get More Information

- Heinrich, H.W., *Industrial Accident Prevention: A Scientific Approach*, 4th Edition, McGraw-Hill (New York), 1959.
- Leigh, J.Paul, Steven Markowitz, Marianne Fahs, Philip Landrigan, *Cost of Occupational Injuries and Illnesses*, University of Michigan Press, 2000.
- Mine Safety and Health Administration, "Cost of Accidents", http://www.msha.gov/s&hinfo/costgenerator/costgenerator.htm, 2006
- Health & Safety Executive, *Reducing risks, protecting people—HSE's decision-making process*, HSE Books, 2001.
- Jones, David W., chairman, *Guidelines for Developing Quantitative Risk Criteria*, CCPS Guidelines Books, AIChE, due to be published in 2007.
- Emerson Process Management, SIS Consulting

Emerson Global Users Exchange