Chemical
SAFETY AND SECURITY TRAINING

Process Safety Overview

Bangkok, Thailand

1 March 2011

SAND No. 2011-0548P

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

Sandia National Laboratories

Key acronyms

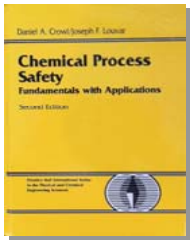
PSM = *process safety management*

SDS = *safety data sheet*

RAGAGEPS = *recognized and generally accepted good engineering practices*

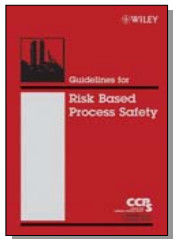
Process safety resources

D.A. Crowl and J.F. Louvar 2001. ***Chemical Process Safety: Fundamentals with Applications, 2nd Ed.,*** **Upper Saddle River, NJ: Prentice Hall.**



Process safety resources

CCPS 2007a. **Center for Chemical Process Safety,** ***Guidelines for Risk Based Process Safety*****, NY: American Institute of Chemical Engineers.**



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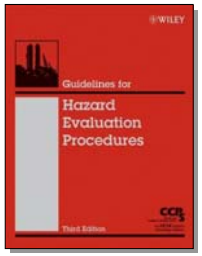
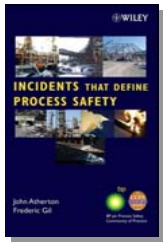


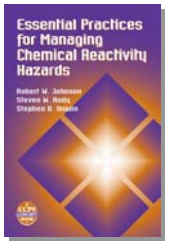
Process safety resources

CCPS 2008b. Center for Chemical Process Safety, ***Incidents that Define Process Safety***, NY: American Institute of Chemical Engineers.



Process safety resources

Johnson et al. 2003. ***Essential Practices for Managing Chemical Reactivity Hazards,*** NY: American Institute of Chemical Engineers, accessible free after registration on www.knovel.com.



Process safety resources

CCPS 2001. Center for Chemical Process Safety, **"Reactive Material Hazards: What You Need To Know," NY: American Institute of Chem. Engineers,** www.aiche.org/uploadedFiles/CCPS/Resources/SafetyAlerts/reactmat.pdf**.**

Process Safety Overview

1. What is "Process Safety"?
2. Opposite of process safety: Major incidents
3. The basic anatomy of process safety incidents
4. Overview of process safety strategies
5. Taking advantage of past experience
6. Defense in depth / layers of protection
7. Elements of process safety management

Process Safety Overview

1. What is "Process Safety"?

"Process Safety"

= the absence of loss and harm resulting from fires, explosions and hazardous material releases at process facilities.

(Event-focused definition)

"Process Safety"

= the absence of loss and harm at process facilities by
(a) identifying process hazards,
(b) containing and controlling them,
(c) countering abnormal situations with effective safeguards.

(Activity-focused definition)

Process Safety Overview

1. What is "Process Safety"?
2. **Opposite of process safety: Major incidents**

Some major process incidents

- **Flixborough, UK (June 1974)**
  - Partial oxidation of cyclohexane
  - Catastrophic failure of temporary piping
  - 30 tonnes of hot cyclohexane released in 30 s
  - Vapor cloud explosion
  - 28 fatalities, 53 injuries; 1800+ houses damaged; plant destroyed
  - 18 of those fatally injured were in control room
  - Hastened passage of UK "Health and Safety at Work Act"

Some major process incidents

- **Seveso, Italy (July 1976)**
  - Runaway reaction
  - 2 kg of dioxin release from relief system
  - Over 17 km^2 affected
  - Locally grown food banned for several months
  - Several inches of topsoil removed, incinerated
  - 80,000 animals died or slaughtered
  - Plant shut down and destroyed
  - EU "Seveso Directive" prompted

See CCPS 2008b for details of these incidents

Some major process incidents

- **Mexico City, Mexico (November 1984)**
  - Large LPG / fuels storage facility
  - Fires, vessel ruptures, boiling-liquid-expanding-vapor explosions (BLEVEs)
  - Initiating cause unknown
  - 600 fatalities, 7000 injuries
  - Horizontal tanks rocketed as far as 1200 m away
  - Fixed fire protection destroyed by blasts
  - Fuels terminal destroyed

Some major process incidents

- Bhopal, India (December 1984)
  - Pesticide production facility
  - Water introduced into methyl isocyanate storage
  - MIC toxic vapor release from vent system
  - 2000 to 3000 early fatalities; ~200,000 injuries
  - Plant shut down; Union Carbide eventually sold
  - Seveso II, EPA Risk Management Program prompted

Some major process incidents

- Toulouse, France (September 2001)
  - Ammonium nitrate storage at fertilizer plant
  - Explosive decomposition initiated; cause unknown
  - Equivalent blast energy 20-40 tons of TNT
  - 30 fatalities; 2500+ injuries; US$ 2 billion in losses

Some major process incidents

- Texas City, Texas (March 2005)
  - Refinery isomerization unit
  - One valve not opened during unit re-start
  - Release of hot flammable material from blowdown
  - Ignition and vapor cloud explosion
  - 15 fatalities, 170+ injuries; BP losses and impacts

Photo credit: U.S. Chemical Safety & Hazard Investigation Board

Some major process incidents

- **Buncefield, UK (December 2005)**
  - **Petrol (gasoline) tank farm**
  - **Storage tank overflow**
  - **Ignition, vapor cloud explosion and fires**
  - **40+ injuries; 20+ tanks destroyed**
  - **Consequences could have been much worse**

See www.buncefieldinvestigation.gov.uk/index.htm for details

Process Safety Overview

1. What is "Process Safety"?
2. Opposite of process safety: Major incidents
3. **The basic anatomy of process safety incidents**

Process Safety Incident Anatomy

Preface

This presentation is adapted from course materials and from presentations used for several years for process safety lectures at the University of Cincinnati and The Ohio State University, with updates to reflect terminology used in the Third Edition of *Guidelines for Hazard Evaluation Procedures* (CCPS 2008a).

Incident - Definition

Incident:

An unplanned event or sequence of events that either resulted in, or had the potential to result in, adverse impacts.

Major Process Industry Incidents

- Fires
- Explosions
- Toxic Releases

→

- Fatalities
- Injuries
- Environ. Damage
- Property Damage
- Evacuations
- Business Losses
- Plant Closings
- Fines, Lawsuits

Loss Events

→

- Fatalities
- Injuries
- Environ. Damage
- Property Damage
- Evacuations
- Business Losses
- Plant Closings
- Fines, Lawsuits

Loss Events → Impacts

Key Definition

Loss Event:

Point of time in an abnormal situation when an irreversible physical event occurs that has the potential for loss and harm impacts.

– CCPS 2008a Glossary

Key Definition

Loss Event:

***Point of time** in an abnormal situation when an **irreversible physical event** occurs that has the potential for loss and harm impacts.*

– CCPS 2008a Glossary

Examples:

- Hazardous material release
- Flammable vapor or dust cloud ignition
- Tank or vessel overpressurization rupture

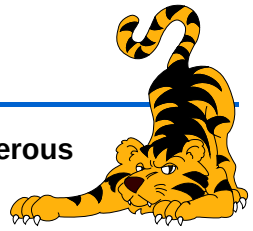
Key Questions

- **Why** do Loss Events happen?
- **How** do Loss Events happen?
- **What** must be done to avoid them?

WHY do Loss Events happen?

- We choose to handle dangerous process materials and energies
  - To make a living
  - To provide society with desirable products
- As long as we choose to handle them, a potential for loss events exists

Analogy



- We choose to handle dangerous animals at the Zoo
  - To make a living
  - To provide society with desirable experiences
- As long as we choose to handle them, a potential for loss events exists
  - Things can be done to reduce their likelihood and severity to negligible or tolerable levels

"Process Safety"

The absence of loss and harm at process facilities by

(a) identifying process hazards,

(b) containing and controlling them,

(c) countering abnormal situations with effective safeguards.

Process Hazard - Definition

Presence *of a*
stored or connected
material or energy *with*
inherent characteristics
having the ***potential*** *for*
causing loss or harm.

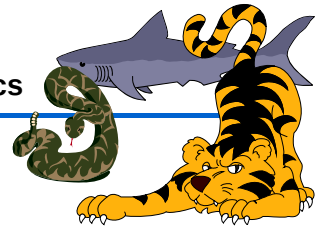
Three Types of Process Hazards

- Material hazards
- Energy hazards
- Chemical interaction hazards

Three Types of Process Hazards

- **Material hazard:** A contained or connected process material with one or more hazardous characteristics
- Energy hazard
- Chemical interaction hazard

Inherent Characteristics



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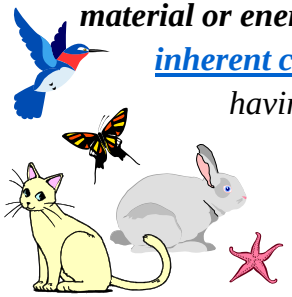


Material Hazards

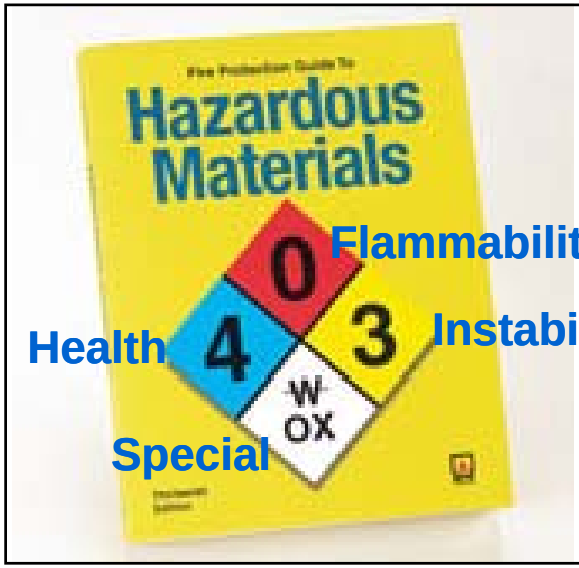
Inherently hazardous characteristics:

- Flammability
- Instability
- Toxicity
- Corrosivity

E.g., Flammable/Combustible Materials

Inherent Characteristics:

- **Flash point (volatility)**
- **Heat of combustion**
- **Ease of ignition**
  - **Flammability limits**
  - **Minimum ignition energy**
  - **Autoignition temperature**



NFPA 704
Summary of Material Hazards for Emergency Response

SDSs

Safety Data Sheets

- More complete summary of hazards
- Required to be accessible in workplace
- All hazardous materials on-site
- Available from suppliers, internet sources
- Give only basic chemical reactivity info
- Often inconsistent from source to source

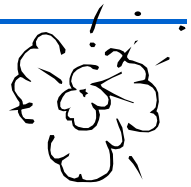
Hazard Identification

- **NFPA 704 diamonds and SDSs only give properties of individual hazardous materials**
  - **Hazardous energies not identified**
  - **Hazardous chemical interactions not identified**
  - **Connected hazards may not be identified**

Three Types of Process Hazards

- Material hazard
- **Energy hazard: Some form of physical energy contained within or connected to the process with the potential for loss or harm**
- Chemical interaction hazard

Process Hazard



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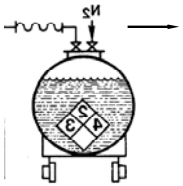

Form of Energy with Injury Potential (examples)

- Electrical (voltage, capacitance)
- Mechanical (spring, machine parts)
- Kinetic (moving or rotating mass)
- Positional (elevated part or equipment)
- Hydraulic (liquid under pressure)
- Pneumatic (gas/vapor under pressure)
- Chemical–Health Hazard (NFPA 2 to 4)
- Chemical–Flammables (NFPA 3 or 4)
- Chemical–Combustibles (NFPA 2)
- Chemical–Reactive (NFPA 2 to 4)
- Thermal–Hot Material (steam, hot oil)
- Thermal–Cryogenic Fluid (liquid N_2)

LOCKOUT/TAGOUT ENERGY CONTROL PROCEDURE

Page 1 of 1

Drawing No. X-100-101
Equipment Name Methanol Flowmeter
Location Bldg 1, Inside dike wall

Form of Energy with Injury Potential (examples)	Connected Energy Source and Magnitude	Residual and/or Stored Energy?
Electrical (voltage, capacitance)		
Mechanical (spring, machine parts)		
Kinetic (moving or rotating mass)		
Positional (elevated part or equipment)		
Hydraulic (liquid under pressure)	MeOH pump discharge, 3 bar g	
Pneumatic (gas/vapor under pressure)		
Chemical–Health Hazard (NFPA 2 to 4)	MeOH, up to 10,000 liters	Yes
Chemical–Flammables (NFPA 3 or 4)	MeOH, up to 10,000 liters	Yes
Chemical–Combustibles (NFPA 2)		
Chemical–Reactive (NFPA 2 to 4)		
Thermal–Hot Material (steam, hot oil)		
Thermal–Cryogenic Fluid (liquid N_2)		

...

ISOLATE CONNECTED ENERGY SOURCES
Energy Isolating Device #1 Ball Valve
Location Between MeOH transfer pump and flowmeter
Use of Device Close valve
LOTO Lockout and tagout **Initials**_____

LOCKOUT/TAGOUT ENERGY CONTROL PROCEDURE

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ISOLATE CONNECTED ENERGY SOURCES
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Location Between MeOH transfer pump and flowmeter
Use of Device Close valve
LOTO Lockout and tagout **Initials**_____

...

BLEED OFF RESIDUAL OR STORED ENERGIES

Bleed-Off Procedure:
Drain residual flammable liquid into grounded catch pan.
Initials_____

VERIFY ISOLATION AND DEENERGIZATION

Verification Procedure:
Visually check for pockets of flammable liquid while disassembling.
Initials_____

Three Types of Process Hazards

- Material hazard
- Energy hazard
- **Chemical interaction hazard:**
  Presence of materials with the potential for loss or harm upon their interaction in an unintentional or uncontrolled manner

Reactive Interactions

Example Compatibility Chart for an Acetic Anhydride Handling Facility

Will These Two Materials React?	Acetic Acid	Acetic Anhydride	Cooling Water	Sulfuric Acid	50% Caustic	Lube Oil	Cleaning Solution
Acetic Acid							
Acetic Anhydride	*Reactive*						
Cooling Water	*Not reactive*	*Reactive*					
Concentrated Sulfuric Acid	*Reactive*	*Reactive*	*Reactive*				
50% Caustic	*Reactive*	*Reactive*	*Reactive*	*Reactive*			
Lube Oil	*Not reactive*	*Not reactive*	*Not reactive*	*Reactive*	*Reactive*		
Cleaning Solution	*Find out what the cleaning solution contains, then determine reactions*						

From CCPS 2001

Process Hazard

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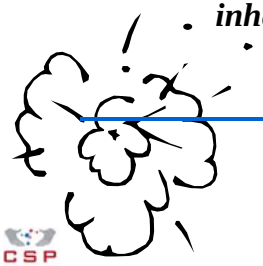
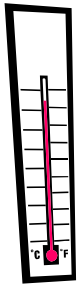


Degree of Hazard

- **More hazardous material**
  ➡ ***greater degree of hazard***
- **Farther from zero energy state**
  ➡ ***greater degree of hazard***



Form of Energy with Injury Potential (examples)	Zero Energy State
Electrical (voltage, capacitance)	0 volts
Mechanical (spring, machine parts)	Sprung
Kinetic (moving or rotating mass)	At rest
Positional (elevated part or equipment)	Ground level
Hydraulic (liquid under pressure)	0 bar gage
Pneumatic (gas/vapor under pressure)	0 barg, 0 m^3
Chemical–Health Hazard (NFPA 2 to 4)	Nontoxic
Chemical–Flammables (NFPA 3 or 4)	Non-flammable
Chemical–Combustibles (NFPA 2)	Non-flammable
Chemical–Reactive (NFPA 2 to 4)	Nonreactive
Thermal–Hot Material (steam, hot oil)	Ambient
Thermal–Cryogenic Fluid (liquid N_2)	Ambient

Key Questions

- **Why** do Loss Events happen?
- **How** do Loss Events happen?
- **What** must be done to avoid them?

HOW Do Loss Events Happen?

- **Anatomy of an Incident**
- **Unsafe act & condition precursors**

Incident Sequence: *Initiating Cause*

- *(Hazard)*
- ***Cause***
- *Deviation*
- *Loss Event*
- *Impacts*

Process Hazard

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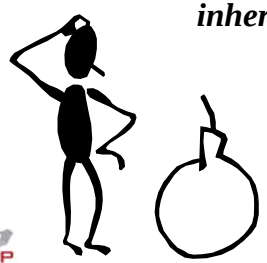


Normal Operation

During **normal operation**, all hazards are contained and controlled…

Normal Operation

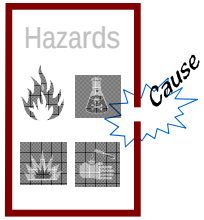
During normal operation, all hazards are contained and controlled, ***but they are still present.***

Incident Sequence: *Initiating Cause*

- *(Hazard)*
- ***Cause***
- *Deviation*
- *Loss Event*
- *Impacts*

Initiating Cause

Every incident starts with an ***initiating cause*** *(also called an* ***initiating event*** *or just a "****cause****".*

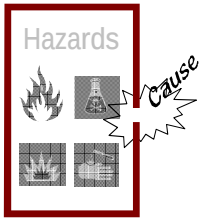


Example initiating causes:

– Feed pump fails off
– Procedural step omitted
– Truck runs into process piping
– Wrong raw material is received
– Extreme low ambient temperature

Initiating Cause

Once an ***initiating cause*** occurs, normal operation cannot continue without a process or operational response.

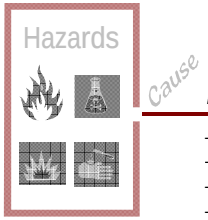


Incident Sequence: *Deviation*

- *(Hazard)*
- *Cause*
- ***Deviation***
- *Loss Event*
- *Impacts*

Deviation

The immediate result of an initiating cause is a ***deviation.***



Deviation

- **No Flow**
- **Low Temperature**
- **High Pressure**
- **Less Material Added**
- **Excess Impurities**
- **Transfer to Wrong Tank**
- **Loss of Containment**
- **etc.**

Abnormal Situations

- Most engineering focuses on designing a process to ***work***:

  (**normal situation**)

- We must also consider how a process can ***fail***, starting with an

  "**abnormal situation**"

Deviation

A ***deviation*** is an abnormal situation, outside defined design or operational parameters.

Cause

Deviation

- No Flow
- Low Temperature
- **High Pressure** *(exceed upper limit of normal range)*
- Less Material Added
- Excess Impurities
- Transfer to Wrong Tank
- Loss of Containment
- etc.

Incident Sequence: *Loss Event*

- *(Hazard)*
- *Cause*
- *Deviation*
- ***Loss Event***
- *Impacts*

Loss Event

A ***loss event*** will result if a deviation continues uncorrected and the process is not shut down.

Cause → Deviation → ***Loss Event***

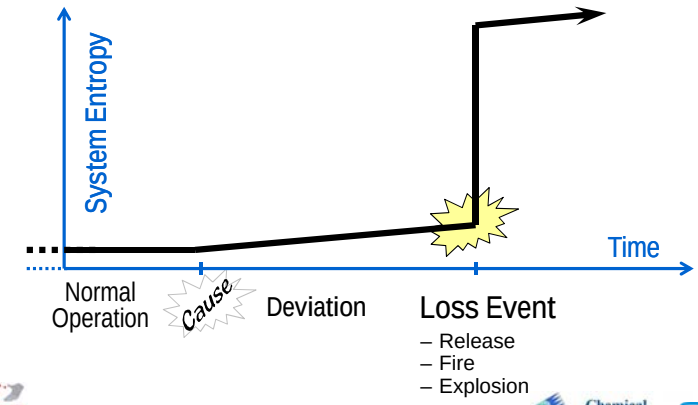
Loss Event

Loss events are generally irreversible process material/energy releases.

Cause → Deviation → ***Loss Event***

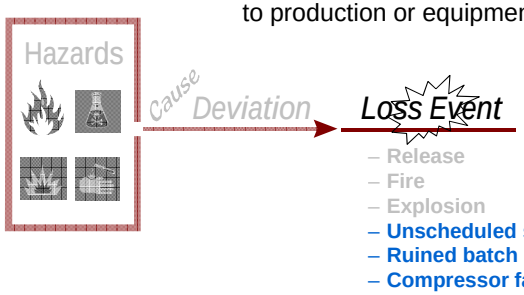
- Release
- Fire
- Explosion

Loss Event: Step Change in System Entropy



Loss Event

Loss events may also be related to production or equipment failures.

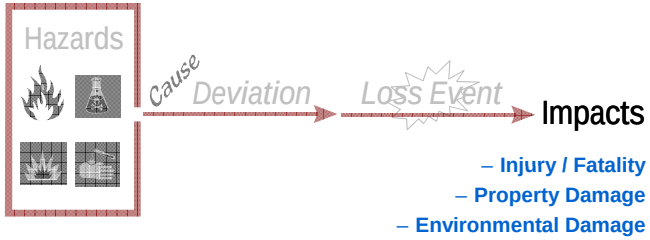


Incident Sequence: *Impacts*

- *(Hazard)*
- *Cause*
- *Deviation*
- *Loss Event*
- ***Impacts***

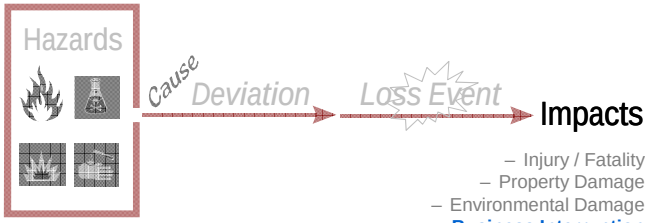
Impacts

Impacts are the losses and injuries that can result from a loss event.



Impacts

There are often other,
less tangible impacts as well.



- Injury / Fatality
- Property Damage
- Environmental Damage
- **Business Interruption**
  - **Market Share Loss**
  - **Reputation Damage**

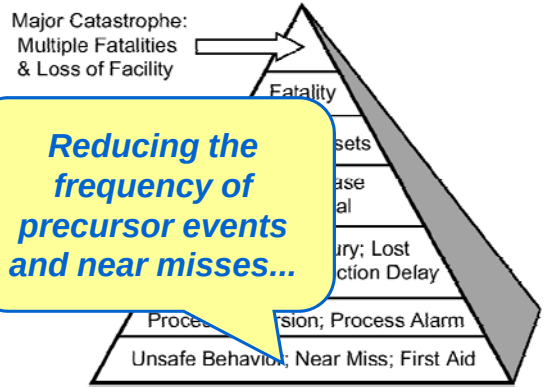
Incident Sequence Without Safeguards

HOW Do Loss Events Occur?

- Anatomy of an Incident
- **Unsafe act & condition precursors**

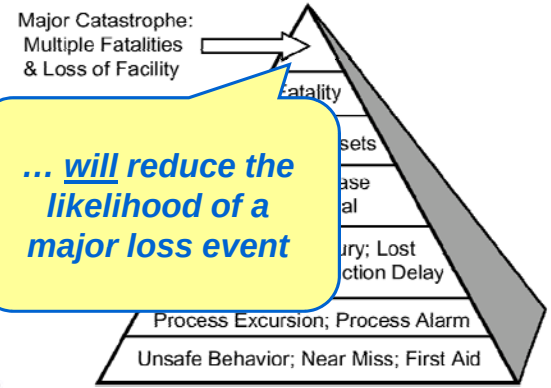
Unsafe Act & Condition Precursors

Pyramid Principle of Process Safety



Reducing the frequency of precursor events and near misses...

Pyramid Principle of Process Safety



... will reduce the likelihood of a major loss event

Key Questions

- **Why** do Loss Events happen?
- **How** do Loss Events happen?
- **What** must be done to avoid Loss Events?

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1. What is "Process Safety"?
2. Opposite of process safety: Major incidents
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What must be done

Process Safety Overview

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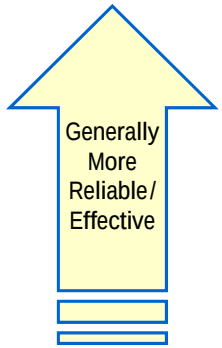
Overview of Process Safety Strategies

- **Inherent** - Hazard reduction
- **Passive** - Process or equipment design features that reduce risk without active functioning of any device
- **Active** - Engineering controls
- **Procedural** - Administrative controls



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3. The basic anatomy of process safety incidents
4. Overview of process safety strategies
5. **Taking advantage of past experience**

Taking Advantage of Past Experience

"Those who cannot remember the past are condemned to repeat it." - George Santayana

- **Learnings from past** (usually bad) **experiences have been embodied in various forms:**
  - **Regulations**
  - **Codes**
  - **Industry standards**
  - **Company standards**
  - **"Best practices"**
  - **Handbooks**
  - **Guidelines**
  - **Procedures**
  - **Checklists**
  - **Supplier Recommendations**

Taking Advantage of Past Experience

- **One term commonly used for non-regulatory codes and standards is "RAGAGEPS"**
- **From U.S. OSHA's Process Safety Management Standard (Process Safety Information element):**

  29 CFR 1910.119(d)(3)(ii) The employer shall document that equipment complies with **recognized and generally accepted good engineering practices**.

Taking Advantage of Past Experience

- **One term commonly used for non-regulatory codes and standards is "RAGAGEPS"**
- **Example:** International consensus standard **IEC 61511** [ANSI/ISA-84.00.01 (IEC 61511 Mod)], "Functional Safety: Safety Instrumented Systems for the Process Industry Sector"

RAGAGEPS

Recognized and Generally Accepted Good Engineering Practices

- **Take advantage of wealth of experience**
- **Pass on accumulated knowledge**
- **Reduce recurrence of past incidents**
- **Enable uniformity of expectations**
- **Reduce liabilities when followed**

Example 2: Anhydrous Ammonia

- **Regulatory Requirements:**

  E.g., U.S. OSHA Standard 29 CFR 1910.111, "Storage and Handling of Anhydrous Ammonia"

- **Industry Standards**
  - CGA G-2, "Anhydrous Ammonia"
  - ANSI/CGA K61.1, "American National Standard Safety Requirements for the Storage and Handling of Anhydrous Ammonia"

- **Other standards apply to specific applications, e.g., ammonia refrigeration**

RAGAGEPS Alphabet Soup

- US OSHA
- US EPA
- IEC
- NFPA
- ASME
- ISA
- UL
- FM
- CGA
- ASHRAE
- IIAR
- ASTM
- API
- AIChE/CCPS
- IRI
- Chlorine Institute
- SOCMA
- etc.

Process Safety Overview

1. What is "Process Safety"?
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6. **Defense in depth / layers of protection**

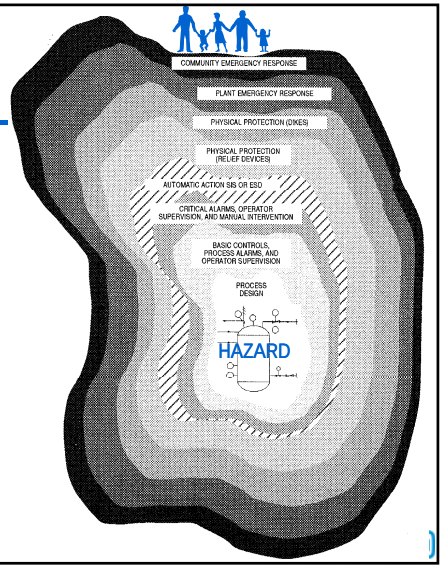
Defense in Depth / Layers of Protection

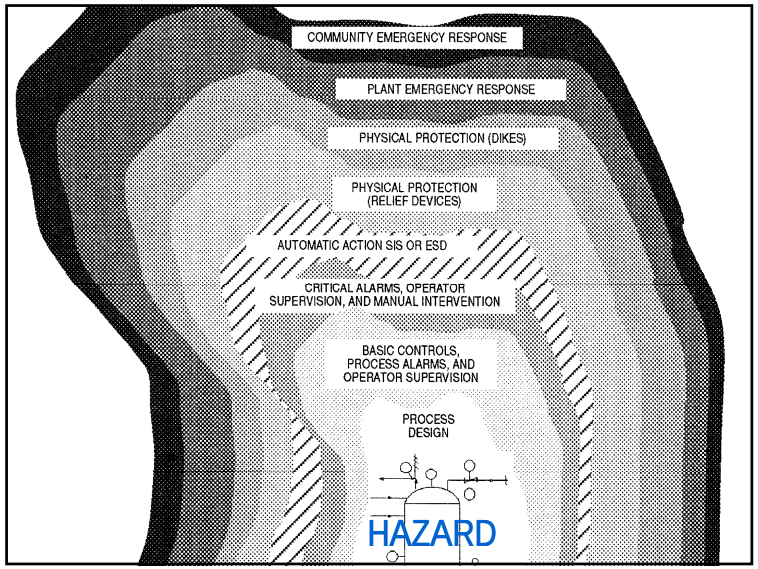
- Also called "Safety Layers"
- Multiple layers may be needed, since no protection is 100% reliable
- Each layer must be <u>designed</u> to be effective
- Each layer must be <u>maintained</u> to be effective
- Some layers of protection are *contain and control measures*
- Other layers of protection are *safeguards*

"Layers of Protection" between hazards and receptors

=

"Defense In Depth"





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- Each layer must be maintained to be effective
- **Some layers of protection are *contain and control measures***
- **Other layers of protection are *safeguards***

Contain & Control

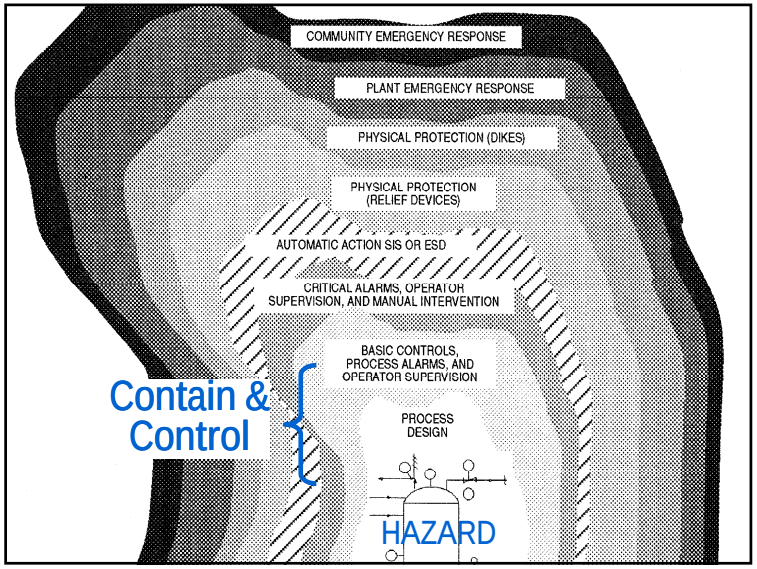
Contain & Control

Operational Mode: **Normal operation**

Objective: **Maintain normal operation; keep hazards contained and controlled**

Examples of *Contain & Control*:

- Basic process control system
- Inspections, tests, maintenance
- Operator training
  - How to conduct a procedure or operate a process correctly and consistently
  - How to keep process within established limits
- Guards, barriers against external forces
- Management of change



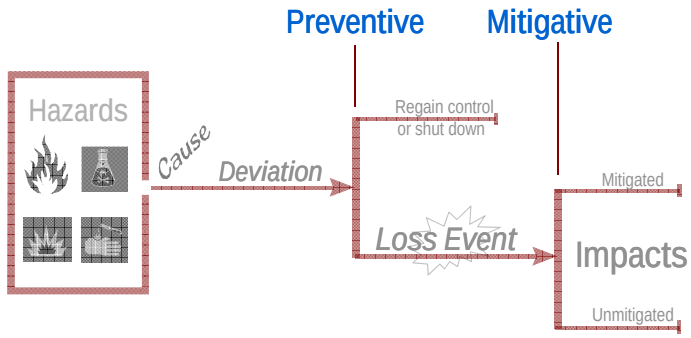
Key Definition

Safeguard:

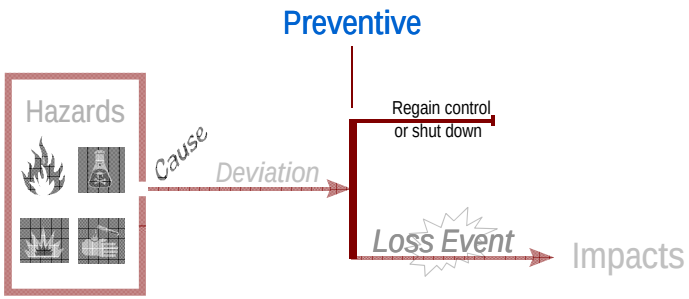
Any device, system, or action that would likely interrupt the chain of events following an initiating cause or that would mitigate loss event impacts.

– CCPS 2008a Glossary

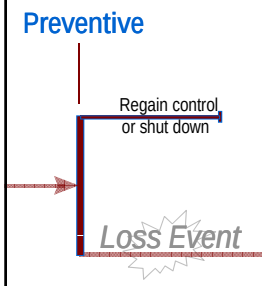
Two Types of Safeguards



Preventive Safeguards



Preventive Safeguards

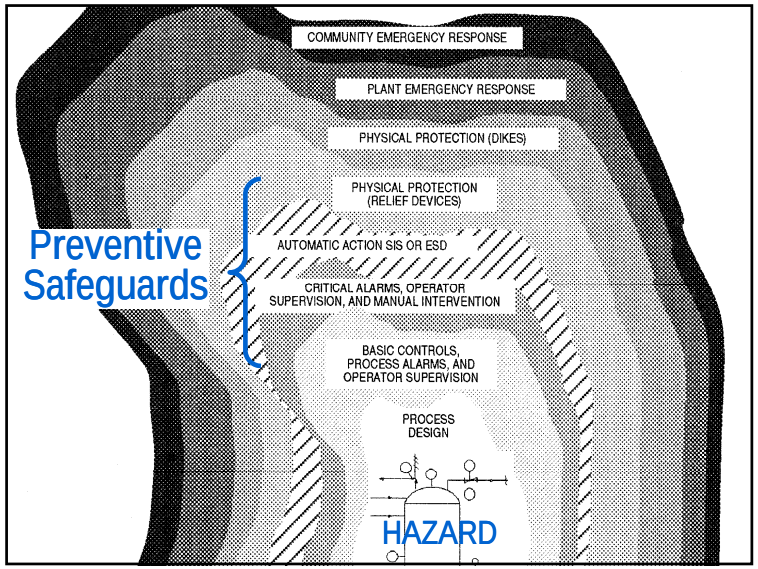


Operational Mode: **Abnormal operation**

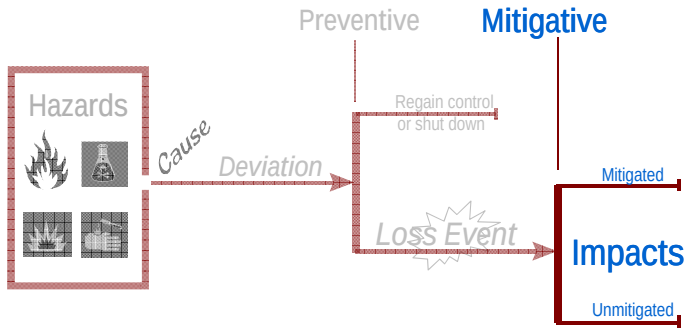
Objective: **Regain control or shut down; keep loss events from happening**

Examples of Preventive Safeguards:

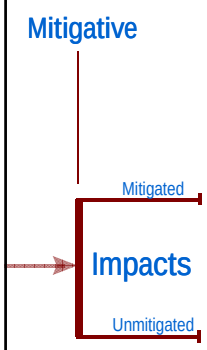
- Operator response to alarm
- Safety Instrumented System
- Hardwired interlock
- Last-resort dump, quench, blowdown
- Emergency relief system



Mitigative Safeguards



Mitigative Safeguards

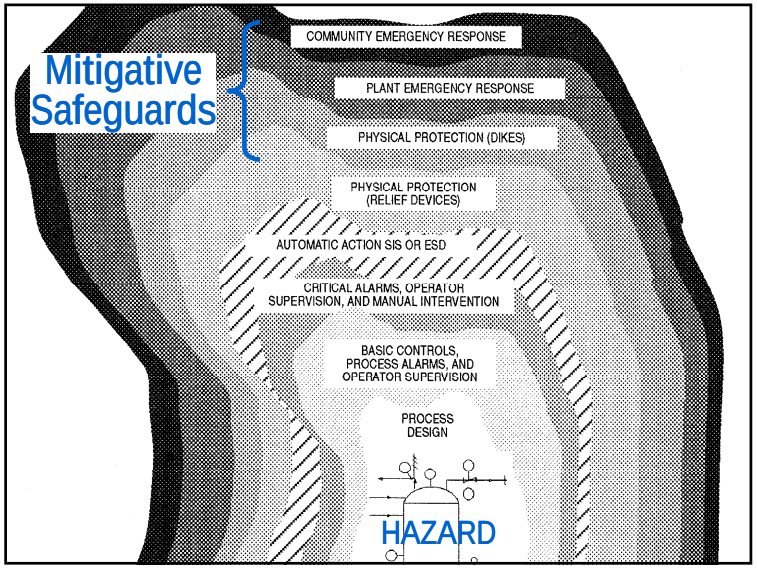


Operational Mode: **Emergency**

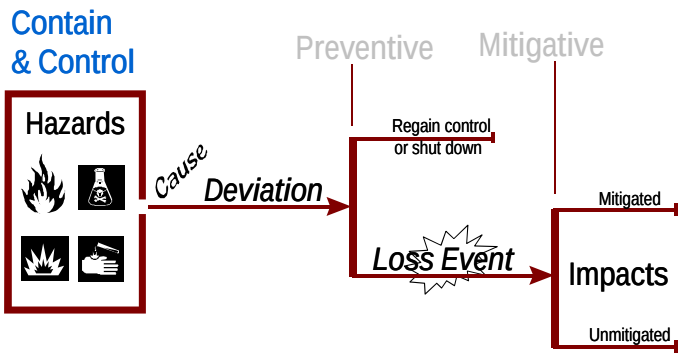
Objective: **Minimize impacts**

Examples of Mitigative Safeguards:

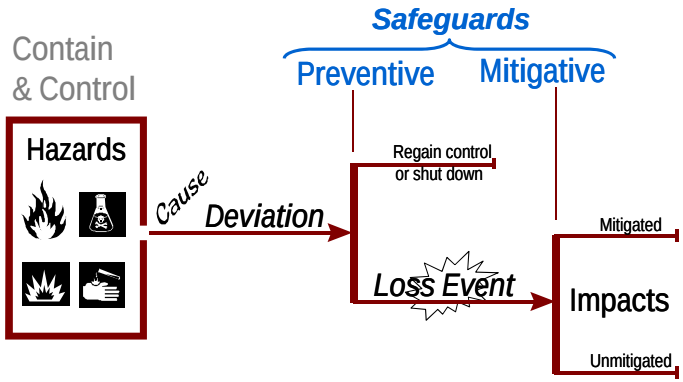
- Sprinklers, monitors, deluge
- Emergency warning systems
- Emergency response
- Secondary containment; diking/curbing
- Discharge scrubbing, flaring, treatment
- Shielding, building reinforcement, haven
- Escape respirator, PPE



Contain & Control: Before Initiating Cause



Safeguards: After Initiating Cause



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7. **Elements of process safety management**

Elements of a comprehensive PSM program

- Management systems
- Employee participation
- Process safety information
- Process hazard analysis
- Operating procedures
- Training
- Contractor safety
- Pre-startup safety reviews
- Mechanical integrity
- Safe work practices
- Management of change
- Emergency planning and response
- Incident investigation
- Compliance audits

PSM elements addressed in this course

- Management systems
- Employee participation
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