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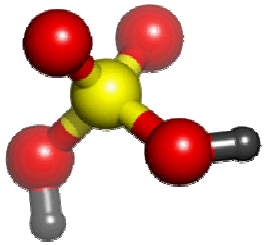
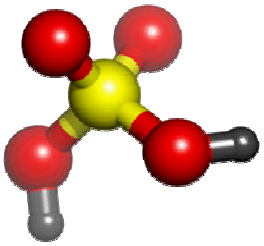


An Introduction to Process Safety Management

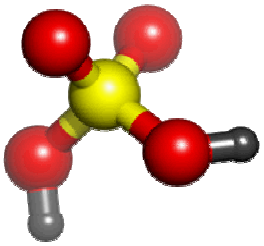
CSP CHEMICAL SECURITY ENGAGEMENT PROGRAM

Sandia National Laboratories



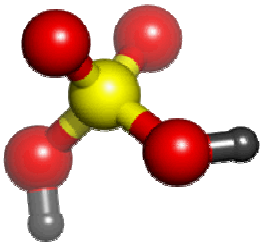
Key Terms

- **Process** – a series of operations or treatments to manufacture, transform, transport, or store a product or bulk material (i.e., pressurized gases and potentially hazardous liquids)
- **Chemical Process Industry** – an industry whose products result from either chemical changes, physical operations such as separation or purification, or the preparation of specifically formulated mixtures of materials



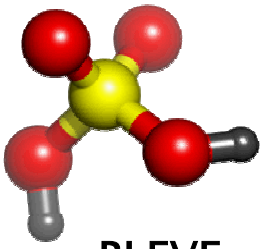
Key Terms

- **Hazard** – a chemical or physical condition that has the potential for causing damage to people, property, or the environment
- **Incident** – the loss of containment of material or energy
- **Consequence** – a measure of the expected effects of an incident
- **Likelihood** – a measure of the expected probability or frequency of occurrence of an event (e.g., events/year, probability of occurrence, conditional probability)



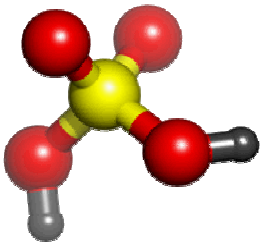
Key Terms

- **Risk** – a measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and magnitude of the loss or injury
- **Risk analysis** – the development of a quantitative estimate of risk based engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies
- **Risk assessment** – the process by which the results of a risk analysis are used to make decisions, either through a relative ranking of risk reduction strategies or through comparison with risk targets



Acronyms Used Throughout Course

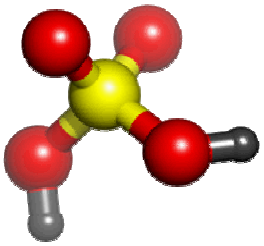
- **BLEVE** – Boiling Liquid Expanding Vapor Explosion
- **CAAA** – Clean Air Act Amendments
- **FMEA** – Failure Mode and Effects Analysis
- **HAZOP** – Hazard and Operability Study
- **MSDS** – Material Safety Data Sheet
- **OSHA** – Occupational Safety and Health Administration
- **NFPA** – National Fire Protection Association
- **PEPCON** – Pacific Engineering Production Company of Nevada
- **PHA** – Process Hazard Analysis
- **PSM** – Process Safety Management
- **RAGAGEP** – Recognized And Generally Accepted Good Engineering Practices
- **TCDD** – 2,3,7,8–tetrachlorodibenzoparadioxin



Process safety

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

(Event-focused definition)



Process safety

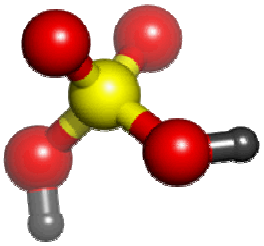
= the absence of loss and harm at process facilities by

(a) identifying process hazards,

(b) containing and controlling them,

(c) countering abnormal situations with effective safeguards.

(Activity-focused definition)



Process safety

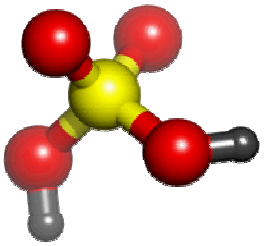
Loss event:

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

– CCPS 2008a Glossary

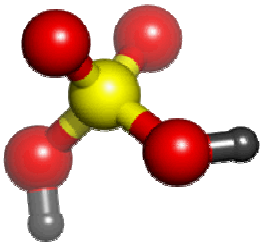
Examples:

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



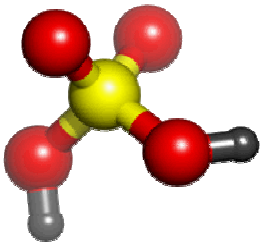
Key questions

- Why do loss events happen?
- How do loss events happen?
- What must be done to avoid them?



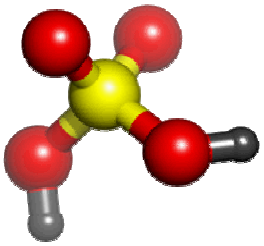
3 types of process hazards

- Material hazards
- Energy hazards
- Chemical interaction hazards



3 types of process hazards

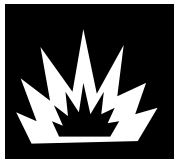
- Material hazard: A contained or connected process material with one or more hazardous characteristics
- Energy hazard
- Chemical interaction hazard



Material hazards

Inherently hazardous characteristics:

Flammability

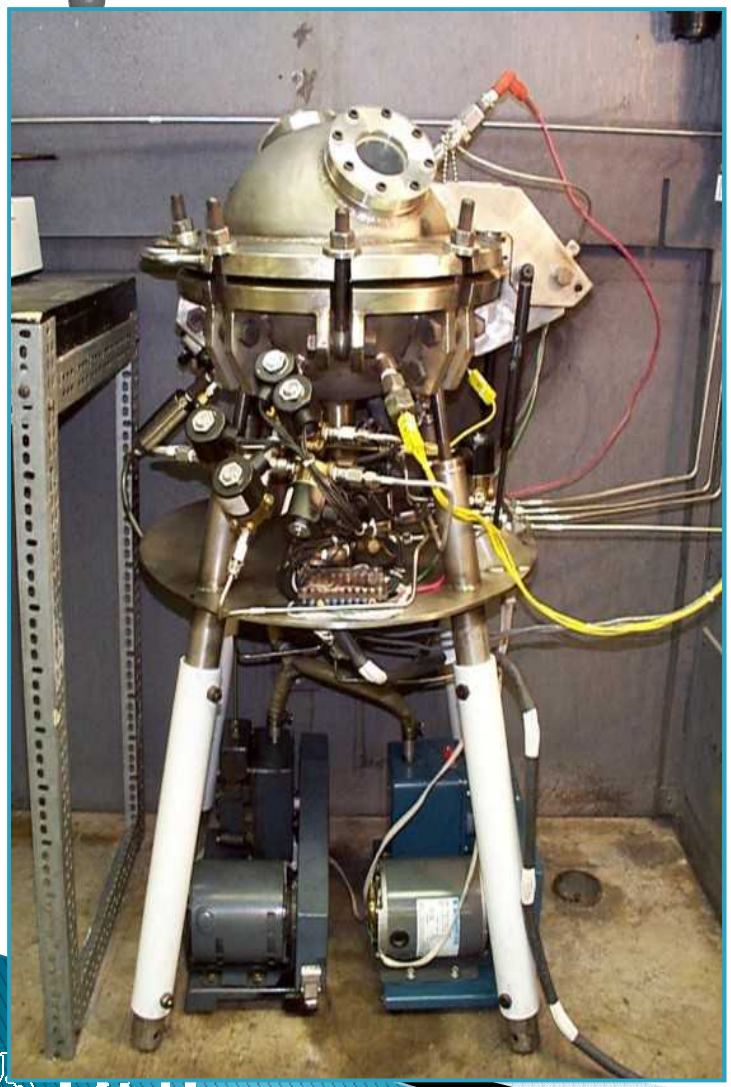


Instability

Toxicity

Corrosivity

Example: Flammable 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

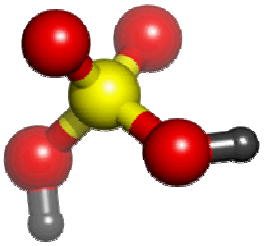
Flammability

Instability

Health

Special

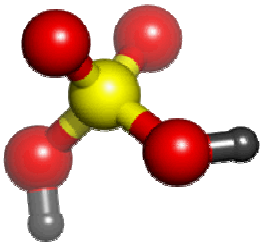
Chemical
SAFETY AND SECURITY TRAINING



Material Safety Data Sheets

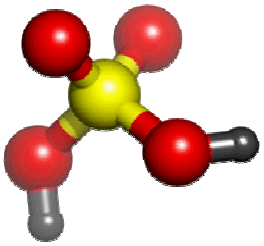
MSDS

- 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



Limitations

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



3 types of process hazards

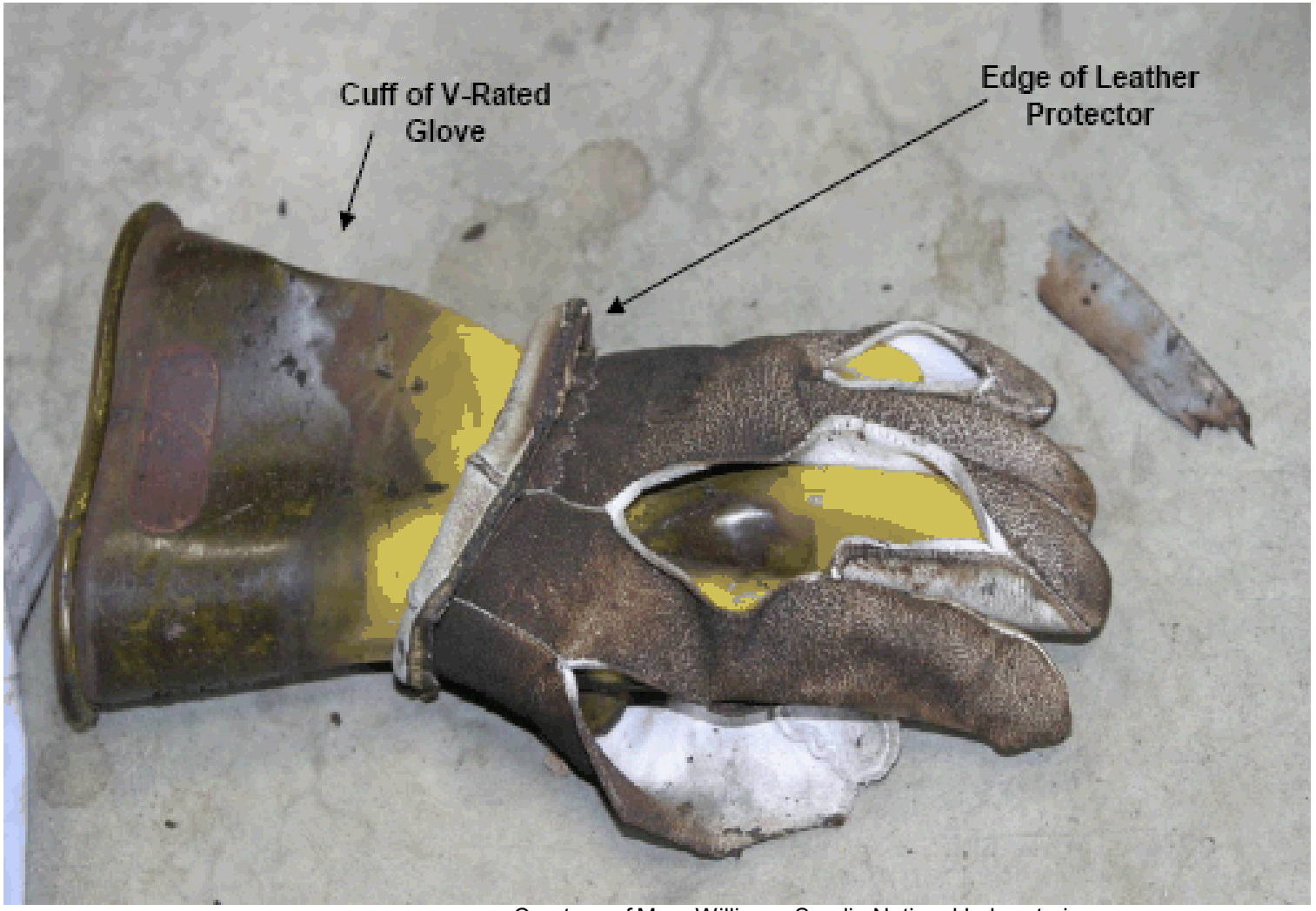
- Material hazard
- Energy hazard: Some form of physical energy contained within or connected to the process with the potential for loss or harm
- Chemical interaction hazard

Example: Electrical Hazards

- Fifth highest cause of industrial fatalities
- Electrical energy which may cause shock, breaker explosion, or arc flashing to personnel
- May be alternating current (ac) or direct current (dc) sources
  - Exposures may occur from plugs, cabling, wiring, circuit breakers
  - Stored electrical sources such as capacitors and batteries must also be considered

http://static.emedco.com/media/catalog/product/cache/1/image/9df78eab33525d08d6e5fb8d27136e95/ANSI-Warning-Labels-QS3622-ba.jpg

Example: Electrical Hazards

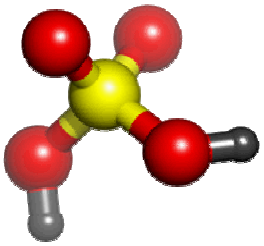


Courtesy of Marc Williams, Sandia National Laboratories

Example: Mechanical Hazards

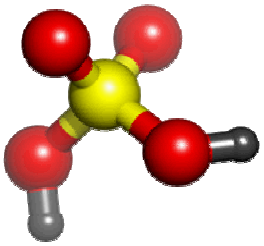
- Thermal: extreme colds (cryogenics), extreme heat (steam)
- Kinetic: moving or rotational forces
- Hydraulic: liquid under pressure
- Pneumatic: gas/vapor under pressure
- Physical: pinch points, sharp or pointed objects or edges
- Gravitational: elevated component or equipment
- Tension/Compressive: springs

http://www.mysafetysign.com/img/lg/S/Caution-Mechanical-Crushing-Hazard-Sign-S-8291.gif



3 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

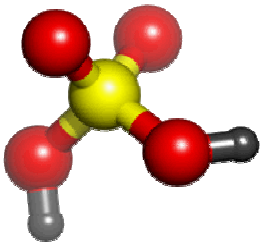


Reactive interactions

Example Compatibility Chart for an Acetic Anhydride Handling Facility

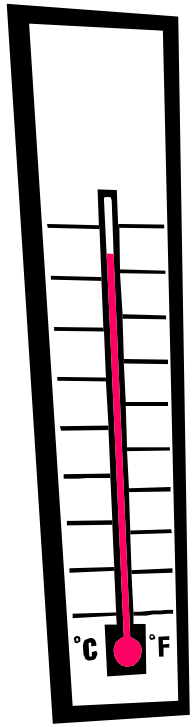
Will These Two Materials React?	Acetic Acid	Acetic Anhydride	Cooling Water	Sulfuric Acid	50% Caustic	Lube Oil	Cleaning Solution
Acetic Acid							
Acetic Anhydride	***Reactive***						
Cooling Water	***Not reactive***	***Reactive***					
Concentrated Sulfuric Acid	***Reactive***	***Reactive***	***Reactive***				
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*						

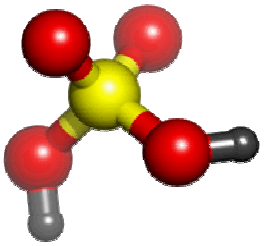
From CCPS 2001



Degree of hazard

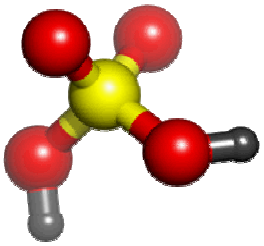
- More hazardous material
  → *greater degree of hazard*
- Farther from zero energy state
  → *greater degree of hazard*





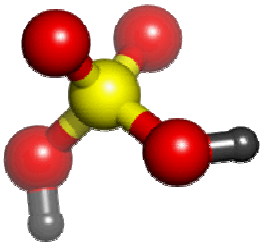
Key questions

- Why do loss events happen?
- How do loss events happen?
- What must be done to avoid them?



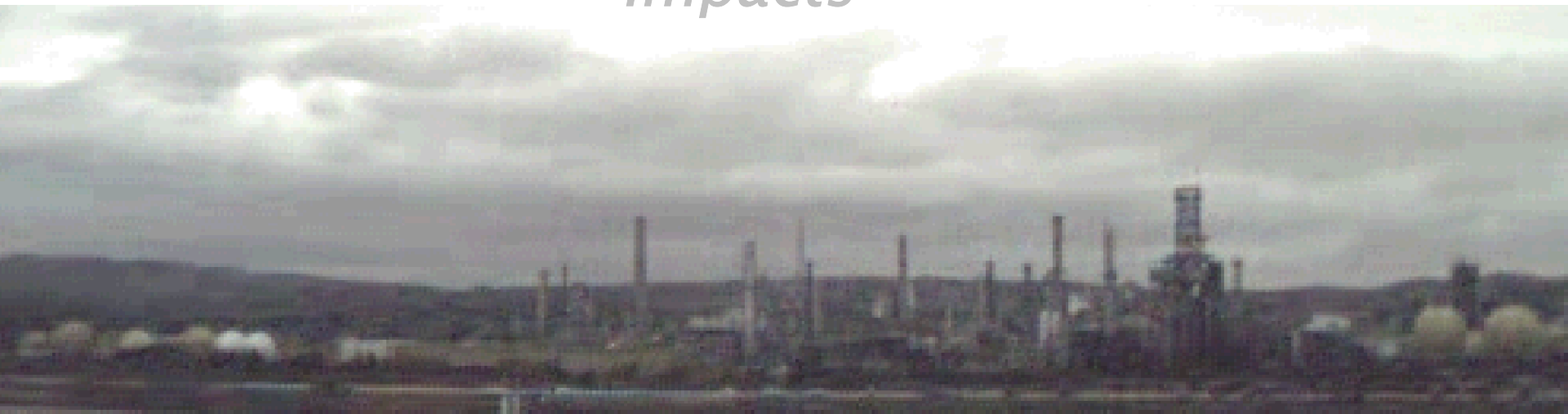
HOW do loss events happen?

- Anatomy of an incident
- Unsafe act & condition precursors



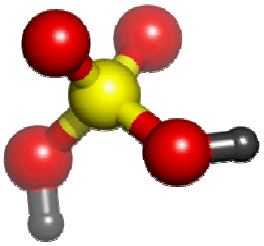
Incident sequence: Hazard

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



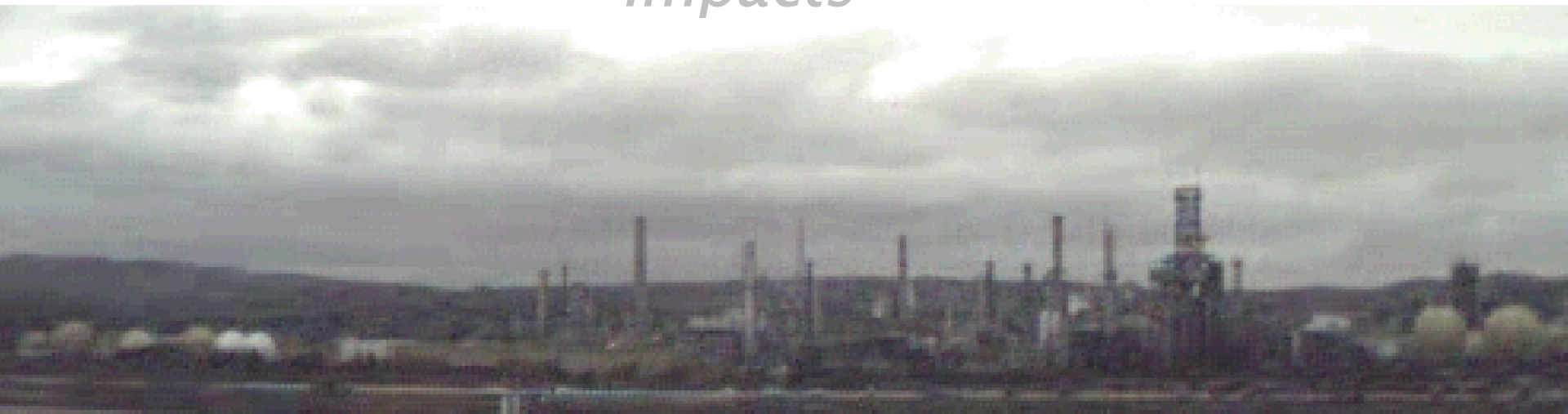
Normal operation

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



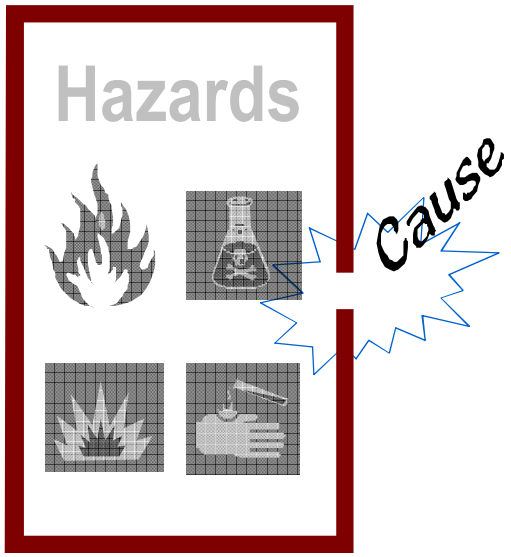
Incident sequence: Cause

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



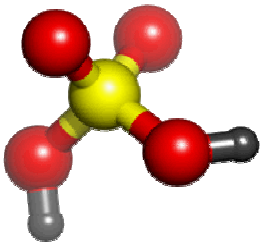
Initiating cause

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



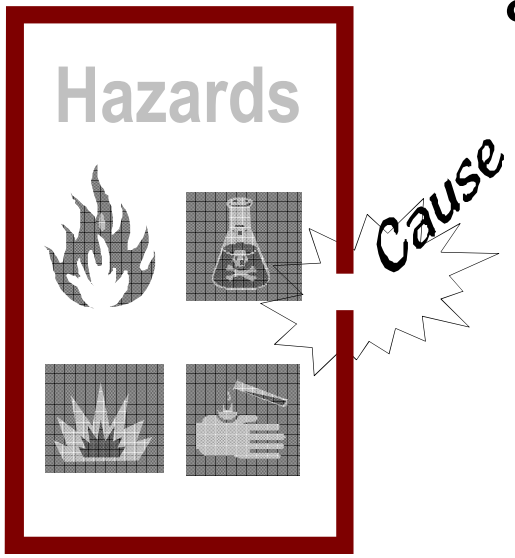
Example initiating causes:

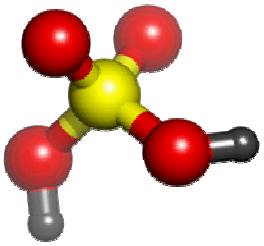
- Feed pump fails off
- Procedural step omitted
- Truck runs into process piping
- Wrong raw material is received
- Extreme low ambient temperature



Initiating cause

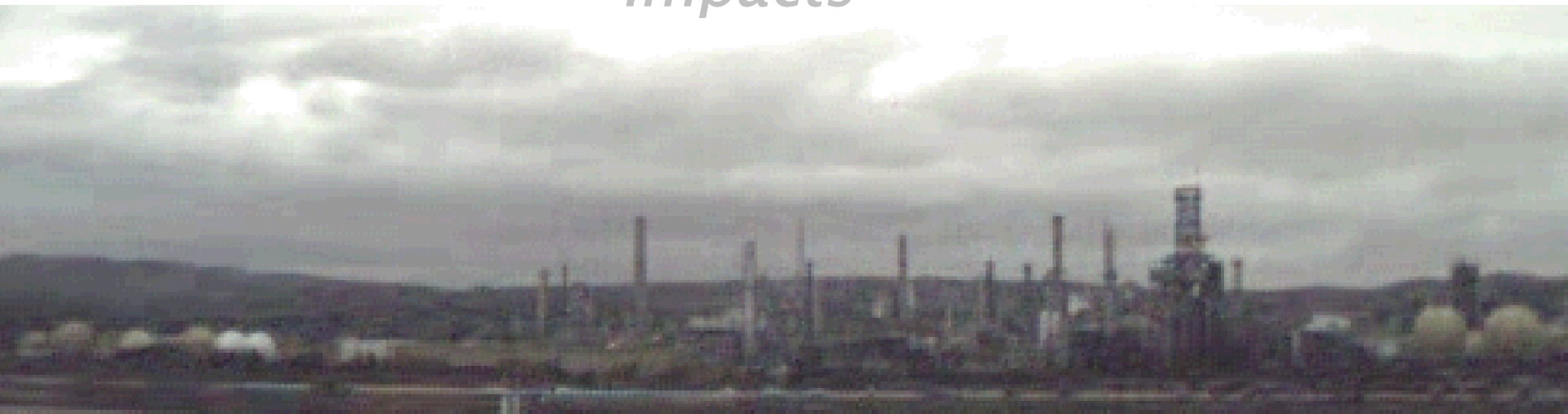
Once an *initiating cause* occurs, normal operation cannot continue without a process or operational response.





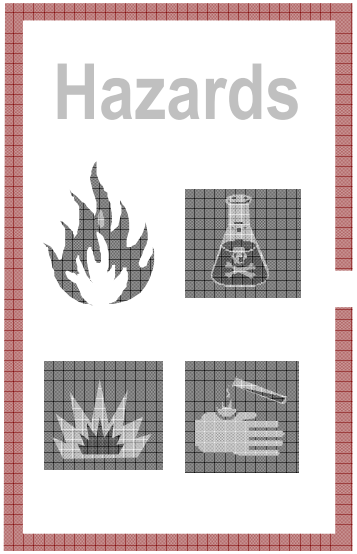
Incident sequence: Deviation

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



Deviation

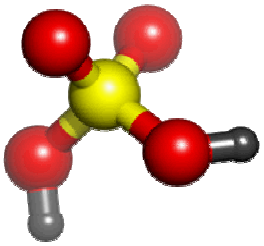
The immediate result of an initiating cause is a *deviation.*



Cause

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:*

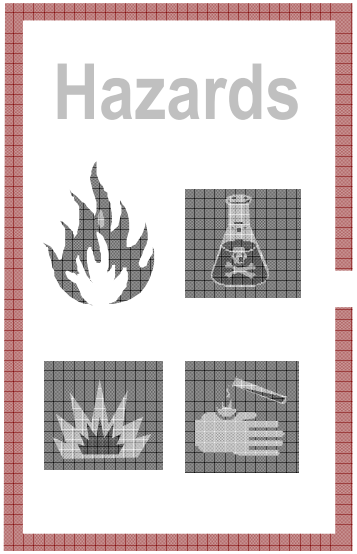
  (normal situation)

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

  "abnormal situation"

Deviation

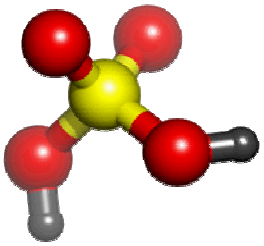
A *deviation* is an abnormal situation, outside defined design or operational parameters.



Cause

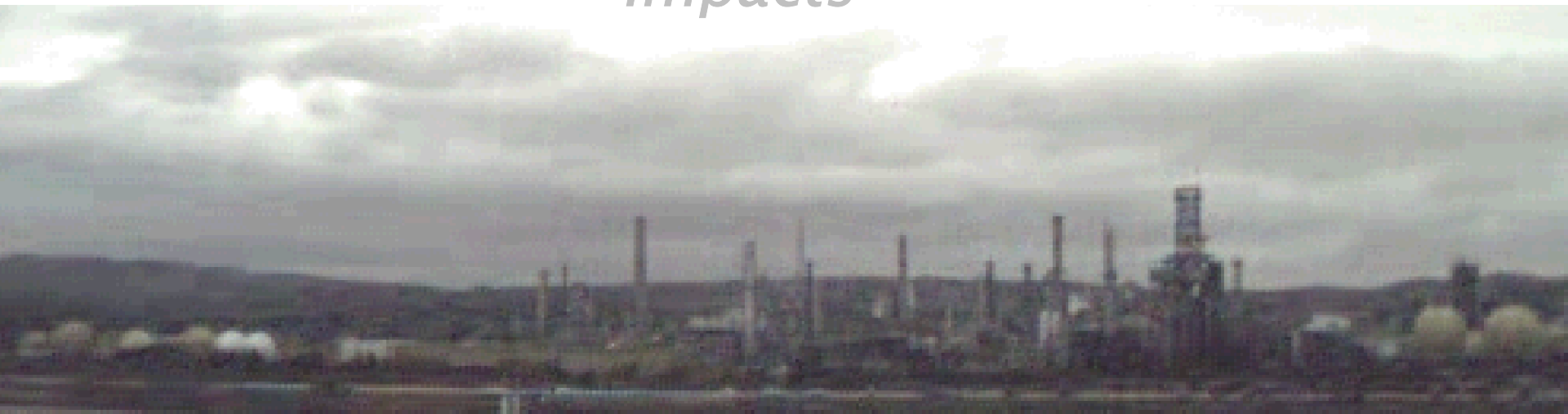
Deviation

- 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.



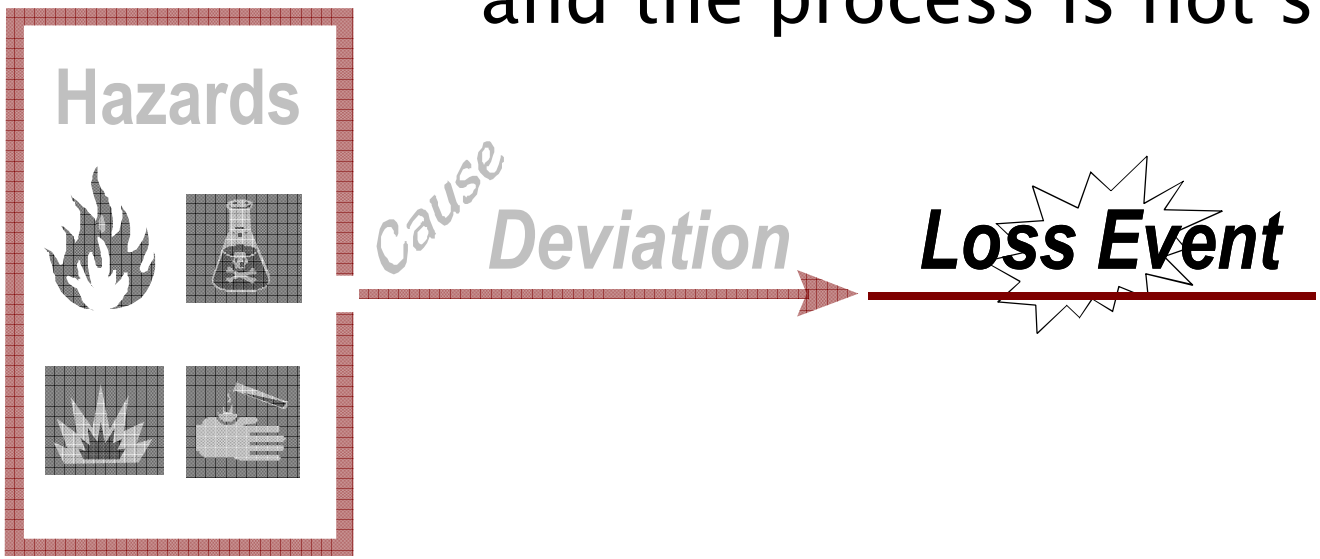
Incident sequence: Loss event

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



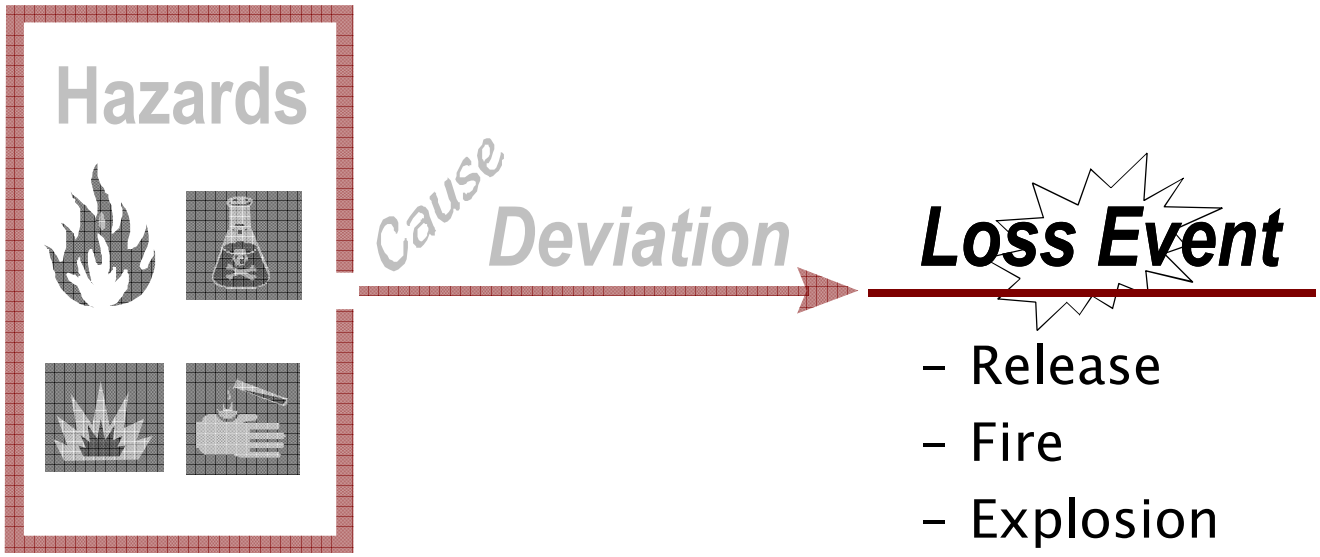
Loss event

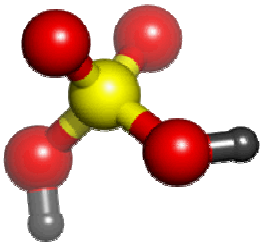
A *loss event* will result if a deviation continues uncorrected and the process is not shut down.



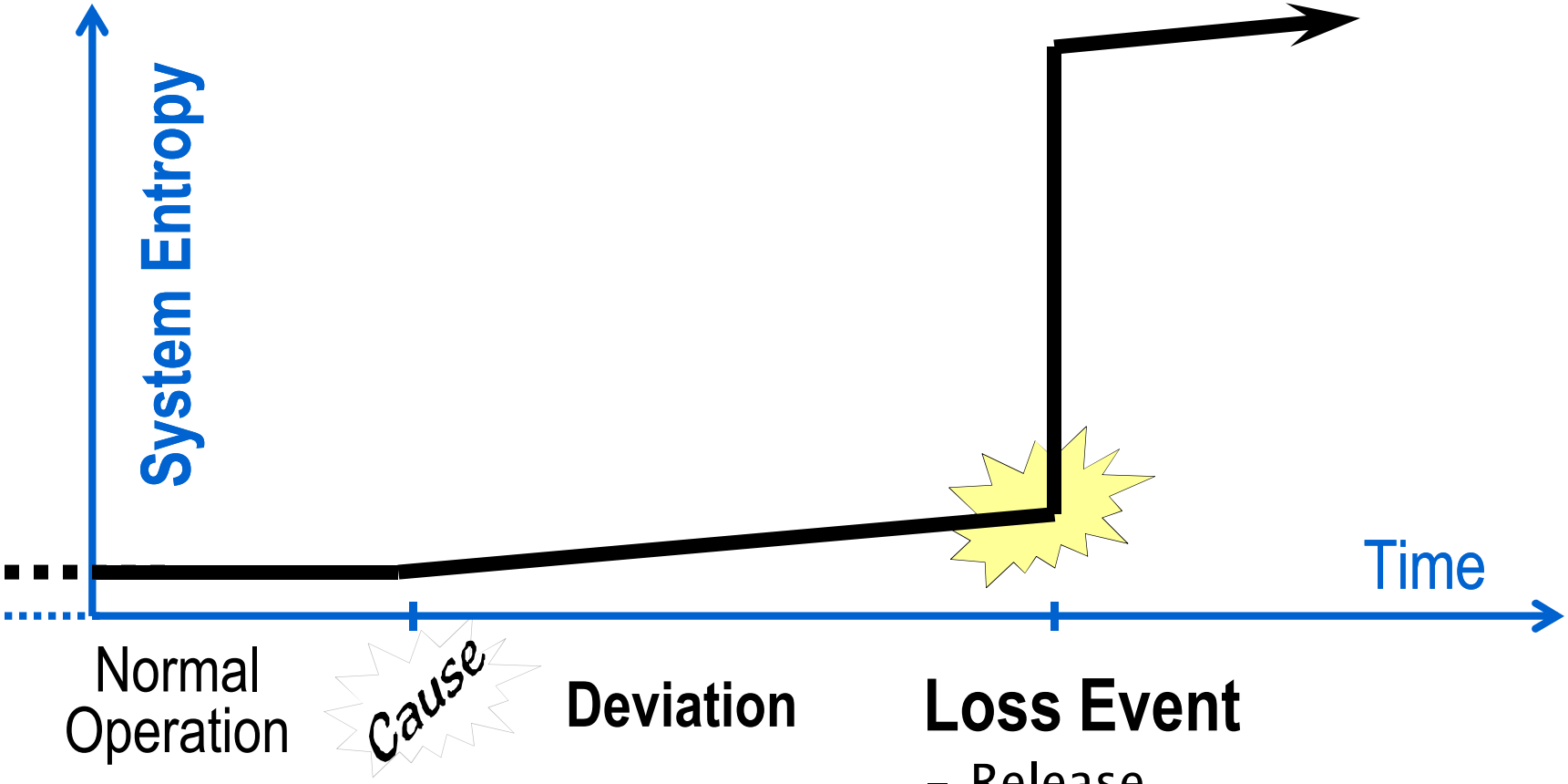
Loss event

Loss events are generally <u>irreversible process material/energy releases</u>.



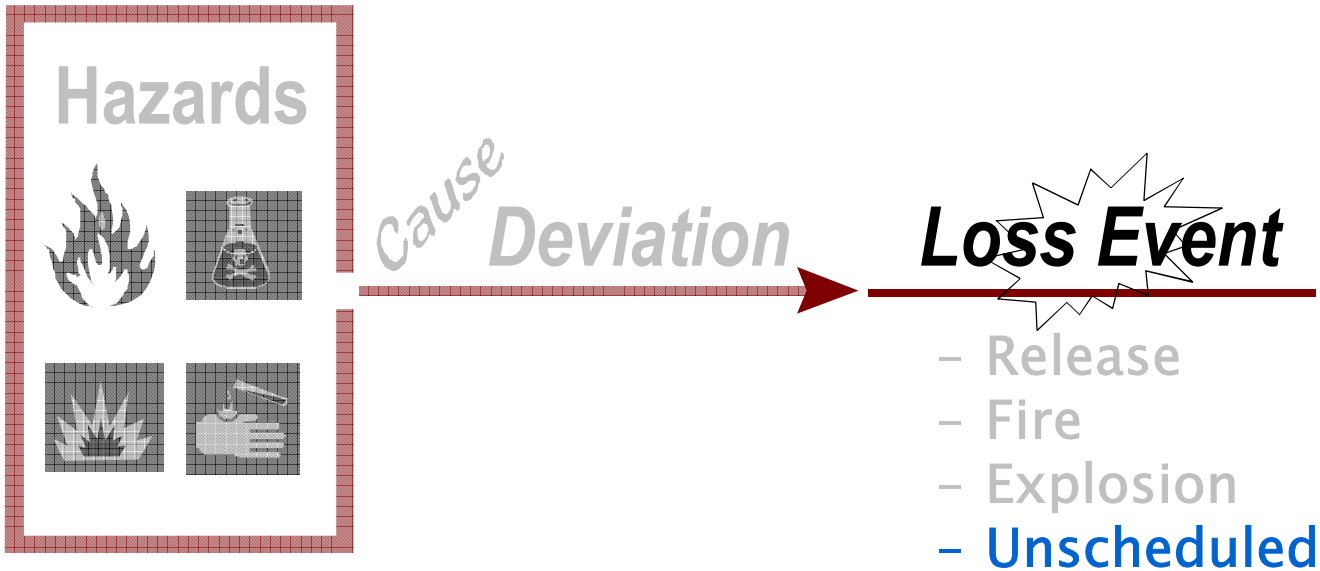


Loss event: Step change in system entropy

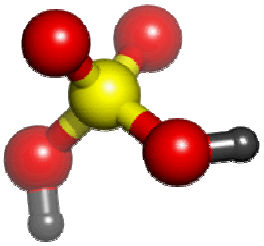


Loss event

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

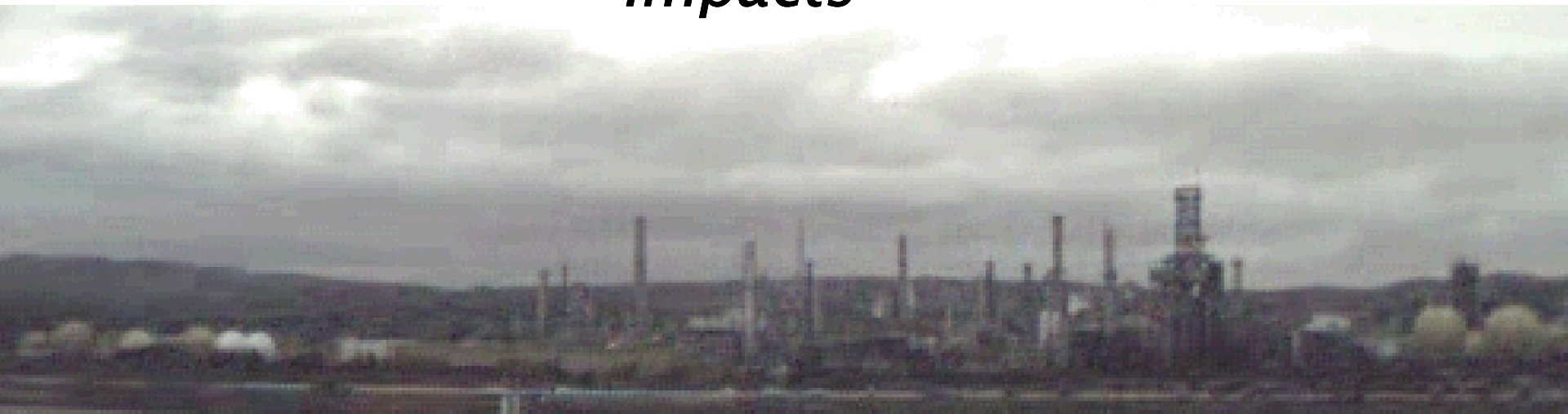


- Release
- Fire
- Explosion
- Unscheduled shutdown
- Ruined batch
- Compressor failure



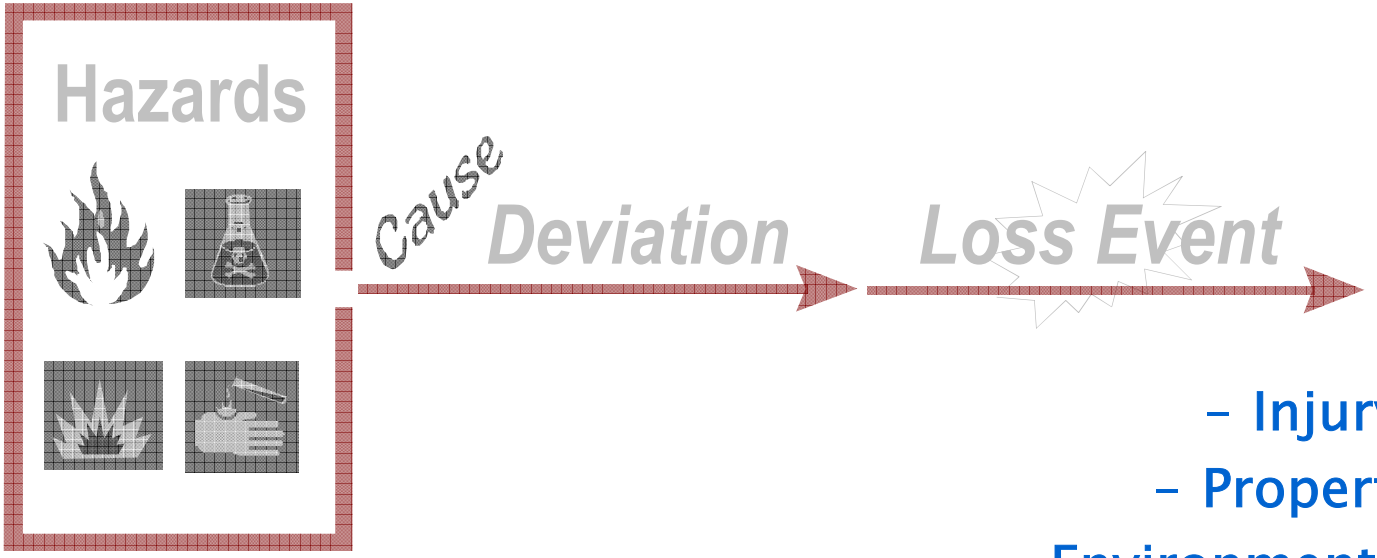
Incident sequence: Impacts

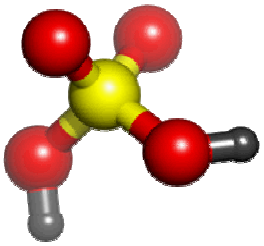
- *(Hazard)*
  - *Cause*
    - *Deviation*
      - *Loss event*
        - *Impacts*



Impacts

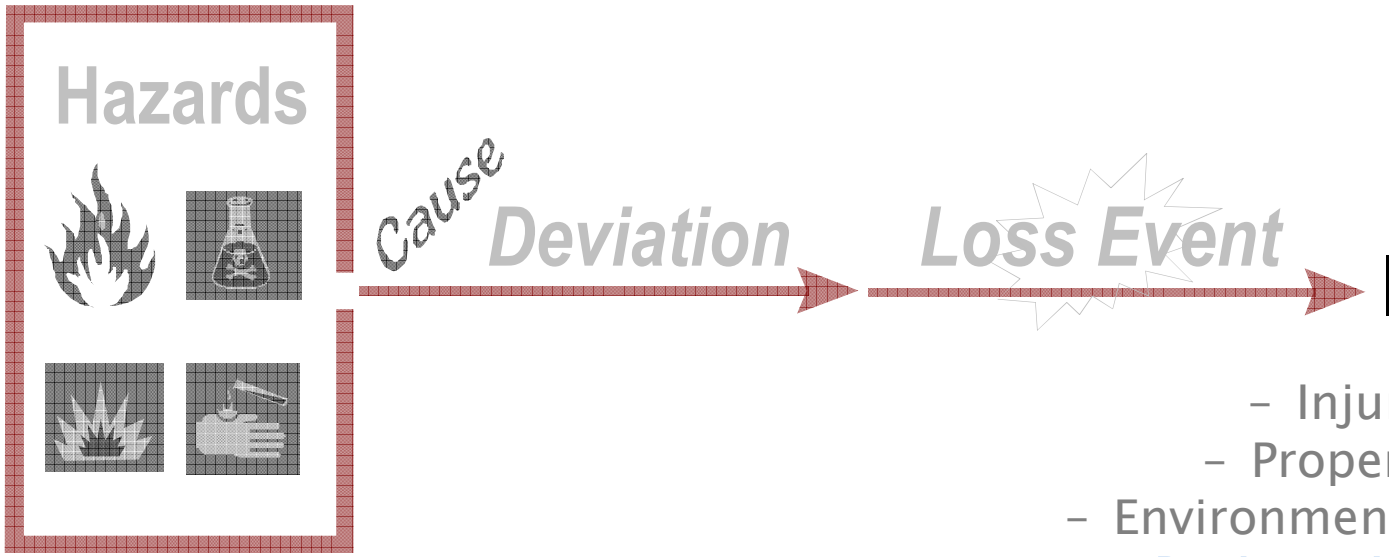
Impacts are the losses and injuries that can result from a loss event.





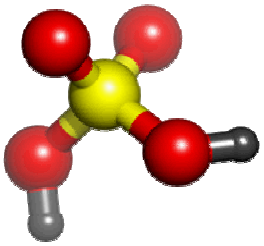
Impacts

There are often other, less tangible impacts as well.



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

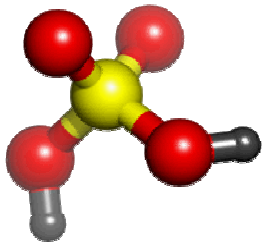
Incident sequence without safeguards

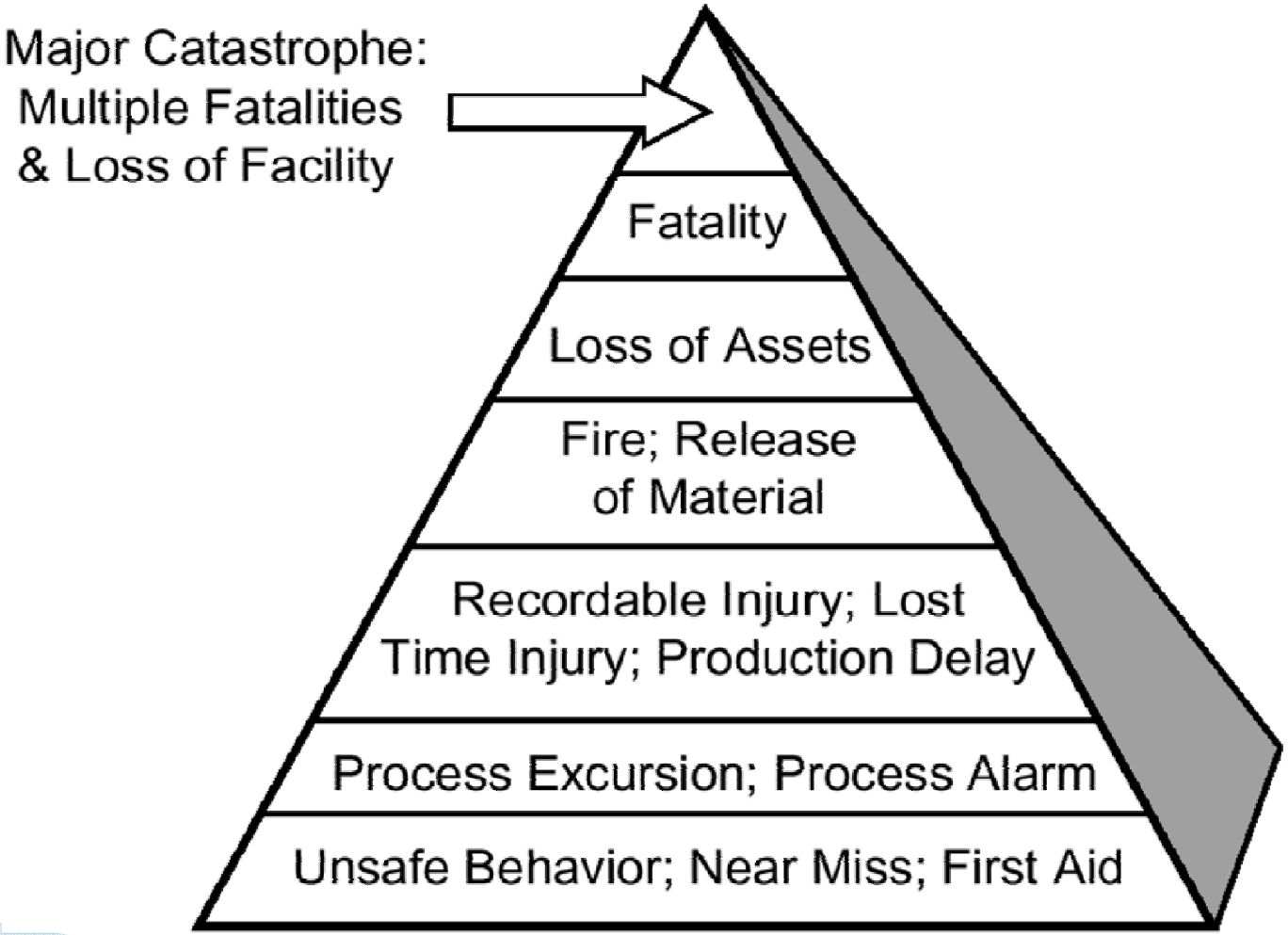


HOW do loss events occur?

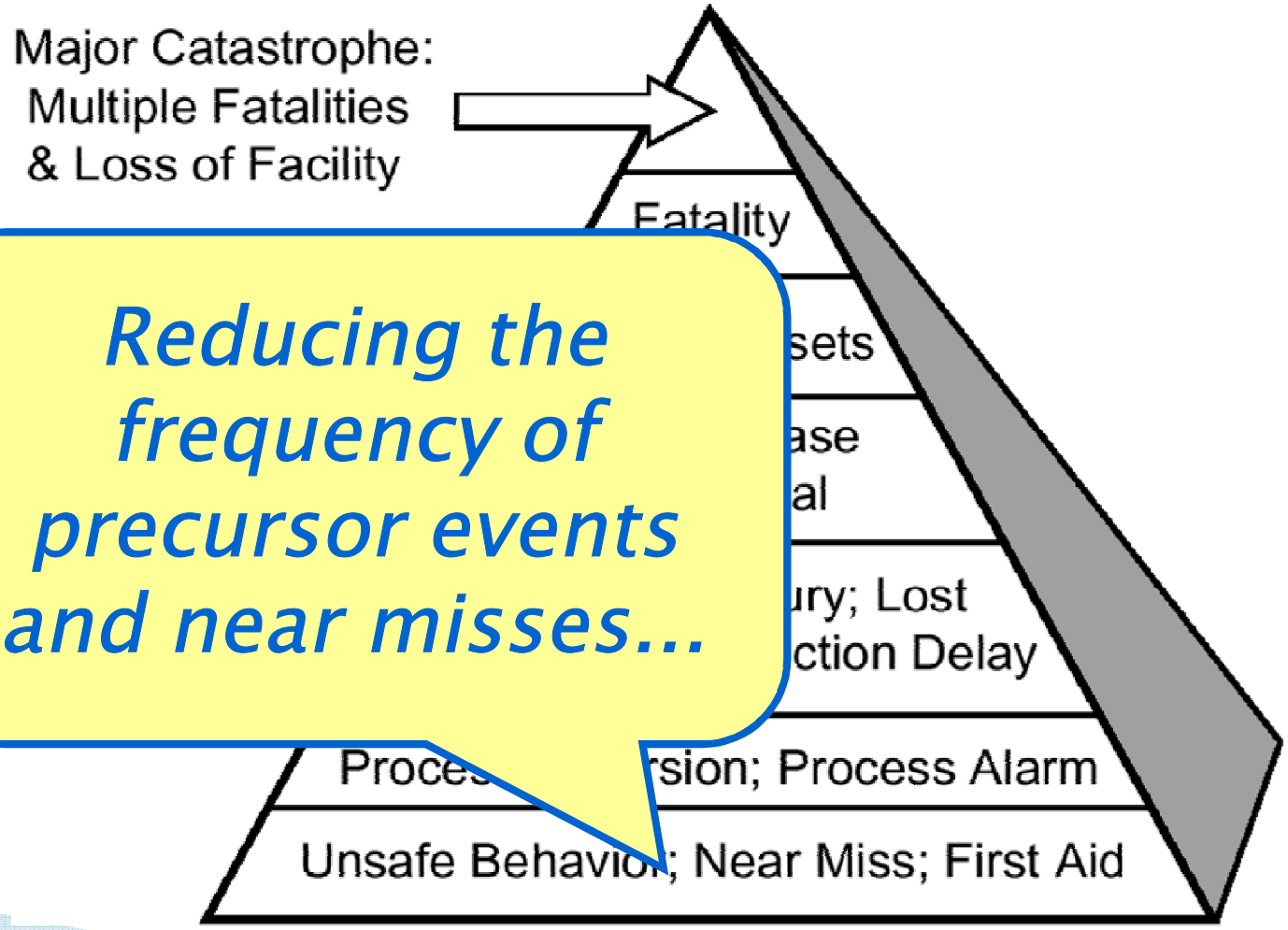
- Anatomy of an Incident
- Unsafe act & condition precursors

Unsafe act & condition precursors



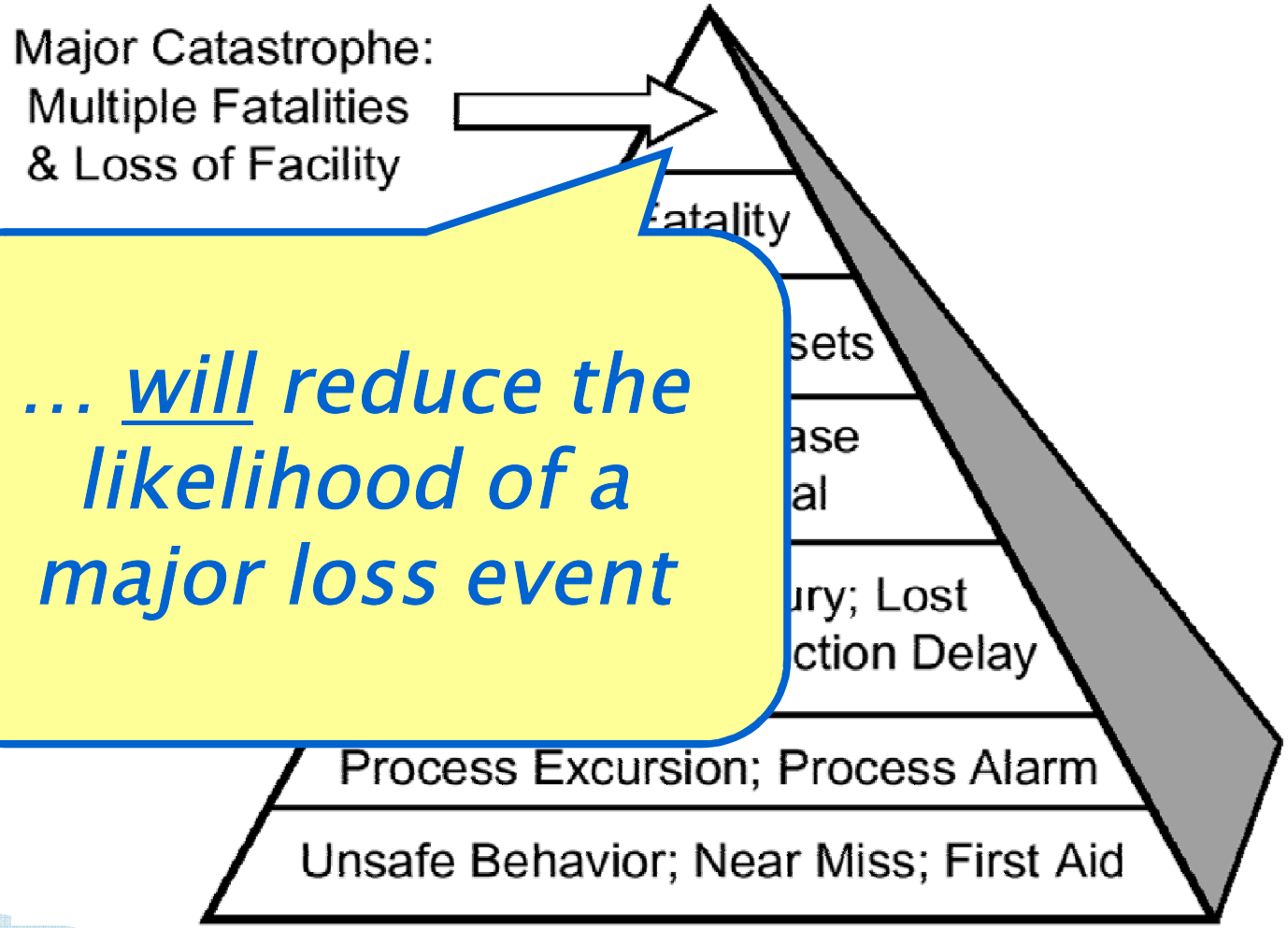


Pyramid principle of safety

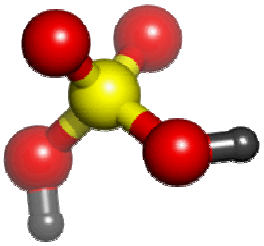


Reducing the frequency of precursor events and near misses…

Pyramid principle of safety

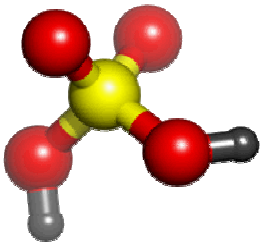


… will reduce the likelihood of a major loss event



Key questions

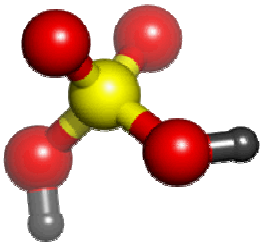
- Why do loss events happen?
- How do loss events happen?
- What must be done to avoid loss events?



Process Safety Overview

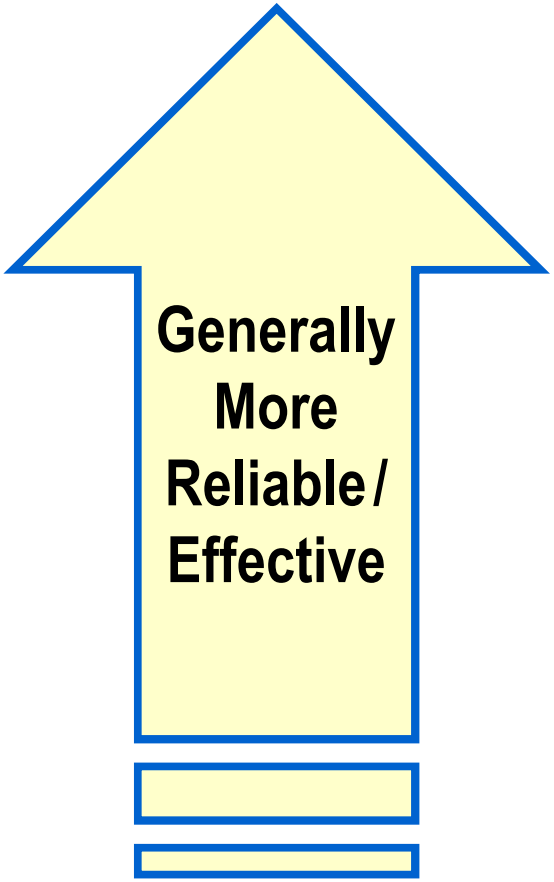
1. What is *process safety*?
2. Opposite of process safety: Major incidents
3. The anatomy of process safety incidents
4. Overview of process safety strategies
5. Taking advantage of past experience
6. Defense in depth / layers of protection
7. Elements of process safety management

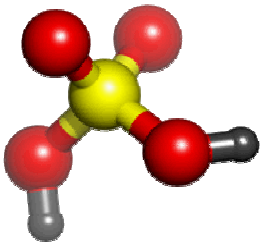
What must be done



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



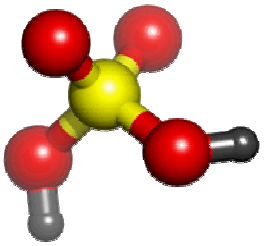


Using past experience

"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"

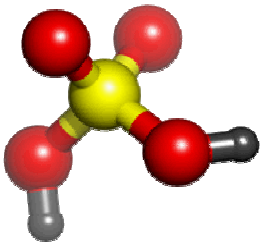
- Handbooks
- Guidelines
- Procedures
- Checklists
- Supplier Recommendations



Using 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):

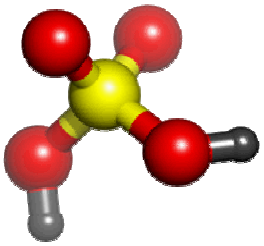
> 29 CFR 1910.119(d)(3)(ii) The employer shall document that equipment complies with recognized and generally accepted good engineering practices.



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



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*

Contain & control

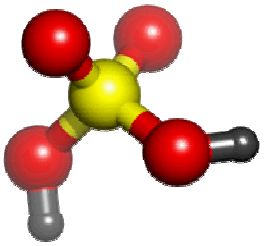
Contain & Control

Operational Mode: Normal operation

Objective: Maintain normal operation; keep hazards contained and controlled

Examples of ***contain & control*** measures:

- 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



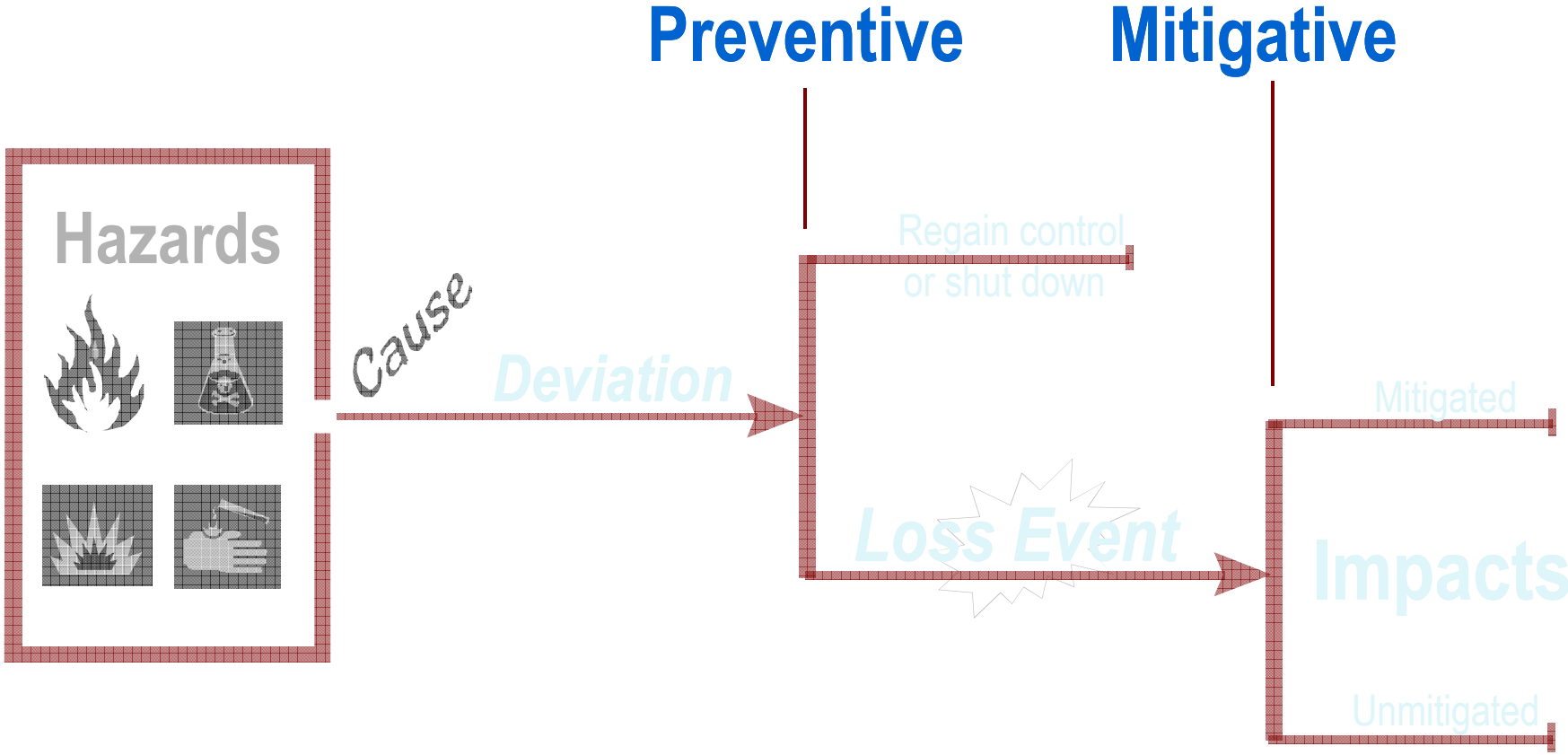
Key definition

Safeguard:

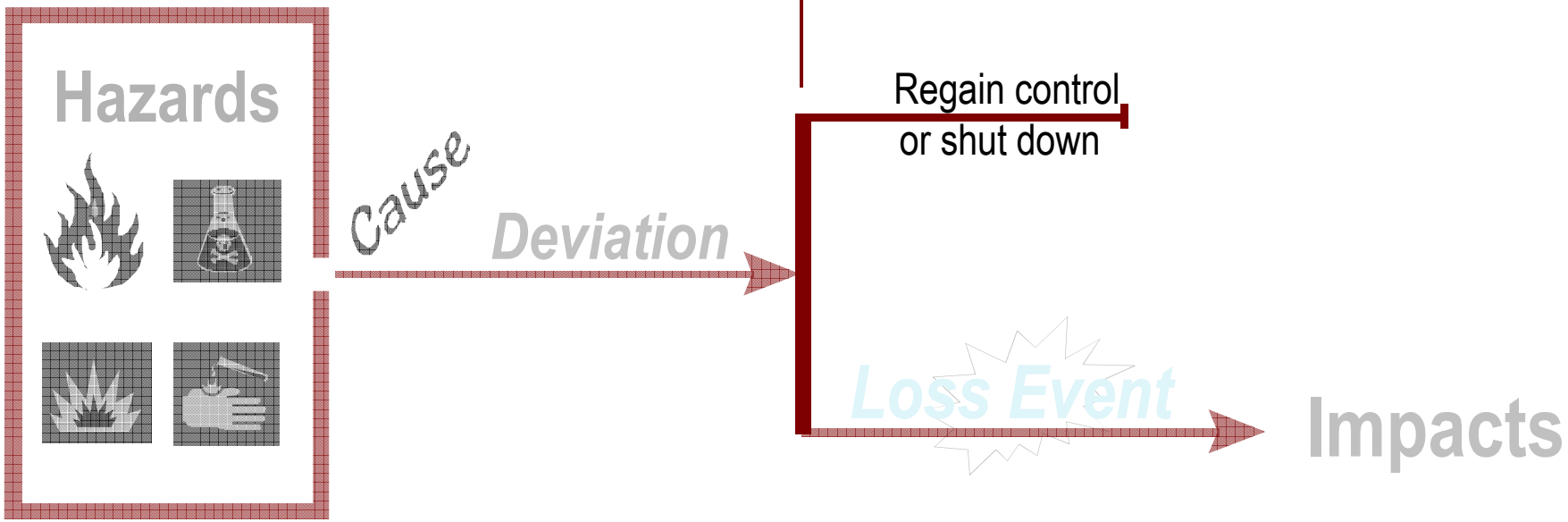
Any device, system, or action that would likely interrupt the chain of events following an initiating cause or that would mitigate loss event impacts.

– CCPS 2008a Glossary

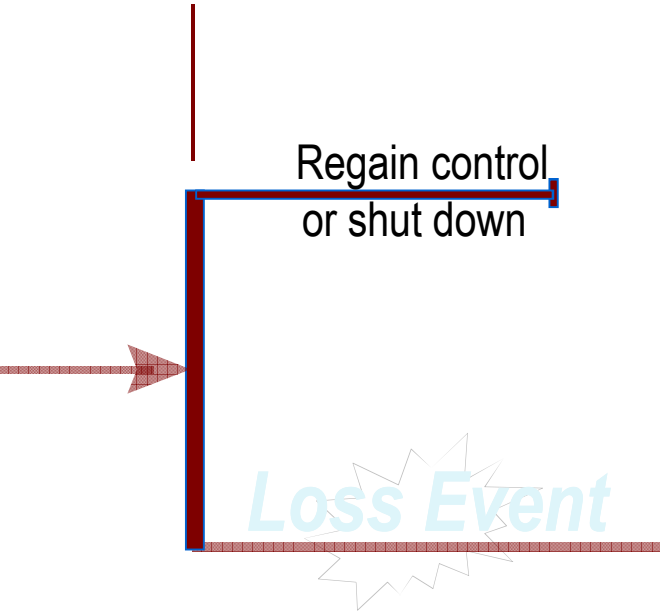
Two types of safeguards



Preventive safeguards



Preventive safeguards



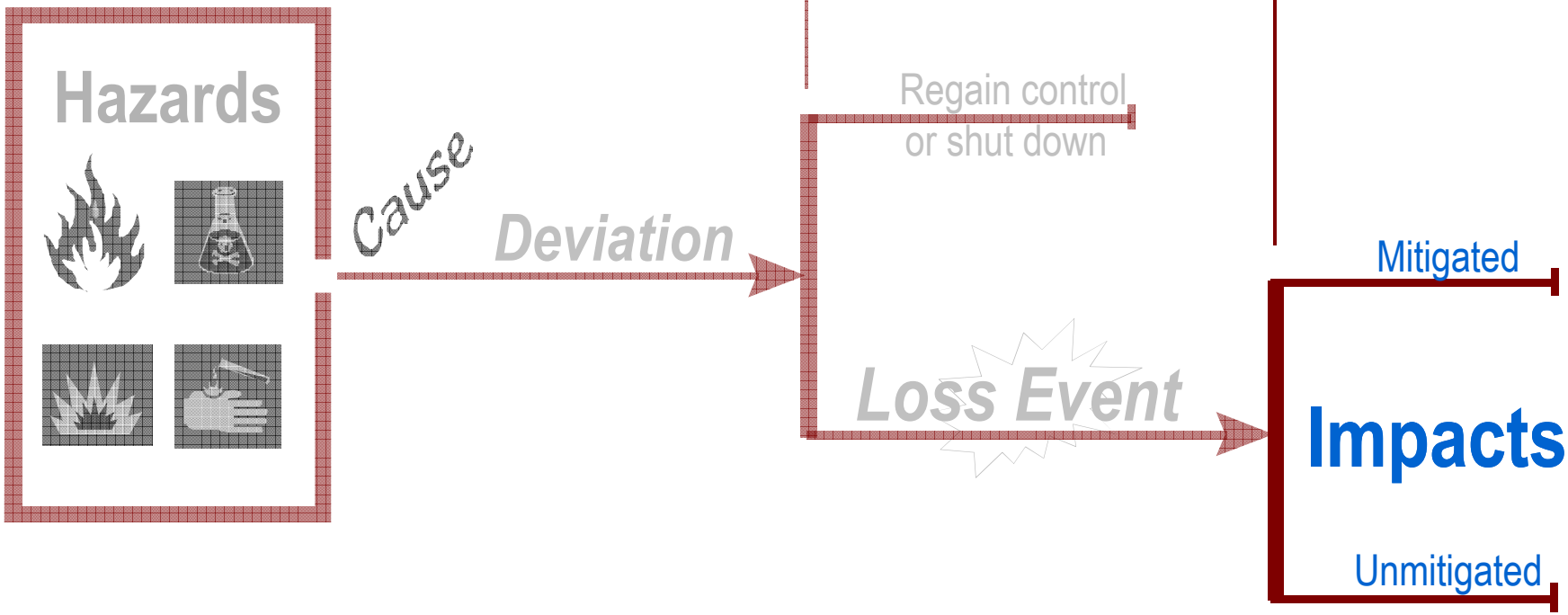
Operational Mode: Abnormal operation

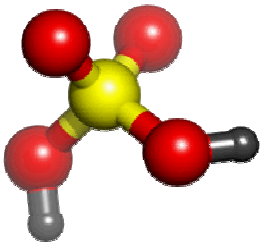
Objective: Regain control or shut down; keep loss events from happening

Examples of Preventive Safeguards:

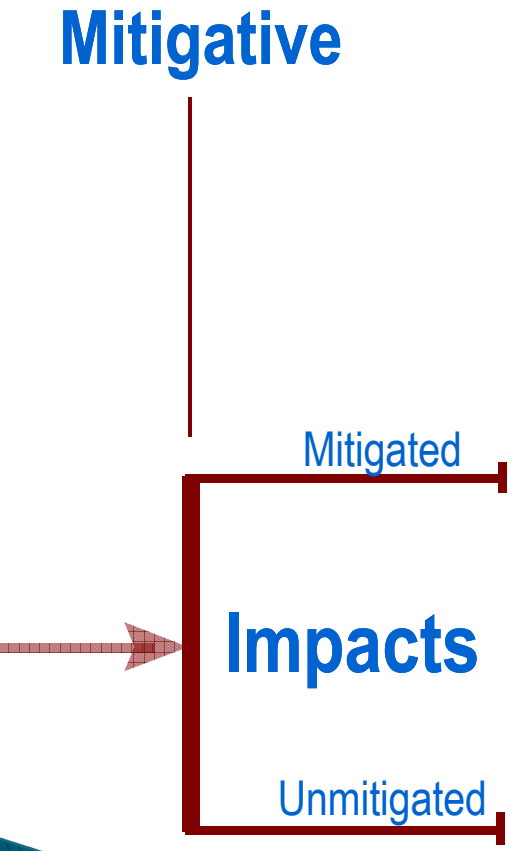
- Operator response to alarm
- Safety Instrumented System
- Hardwired interlock
- Last-resort dump, quench, blowdown
- Emergency relief system

Mitigative safeguards





Mitigative safeguards



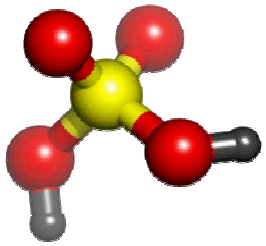
Operational Mode: Emergency

Objective: Minimize impacts

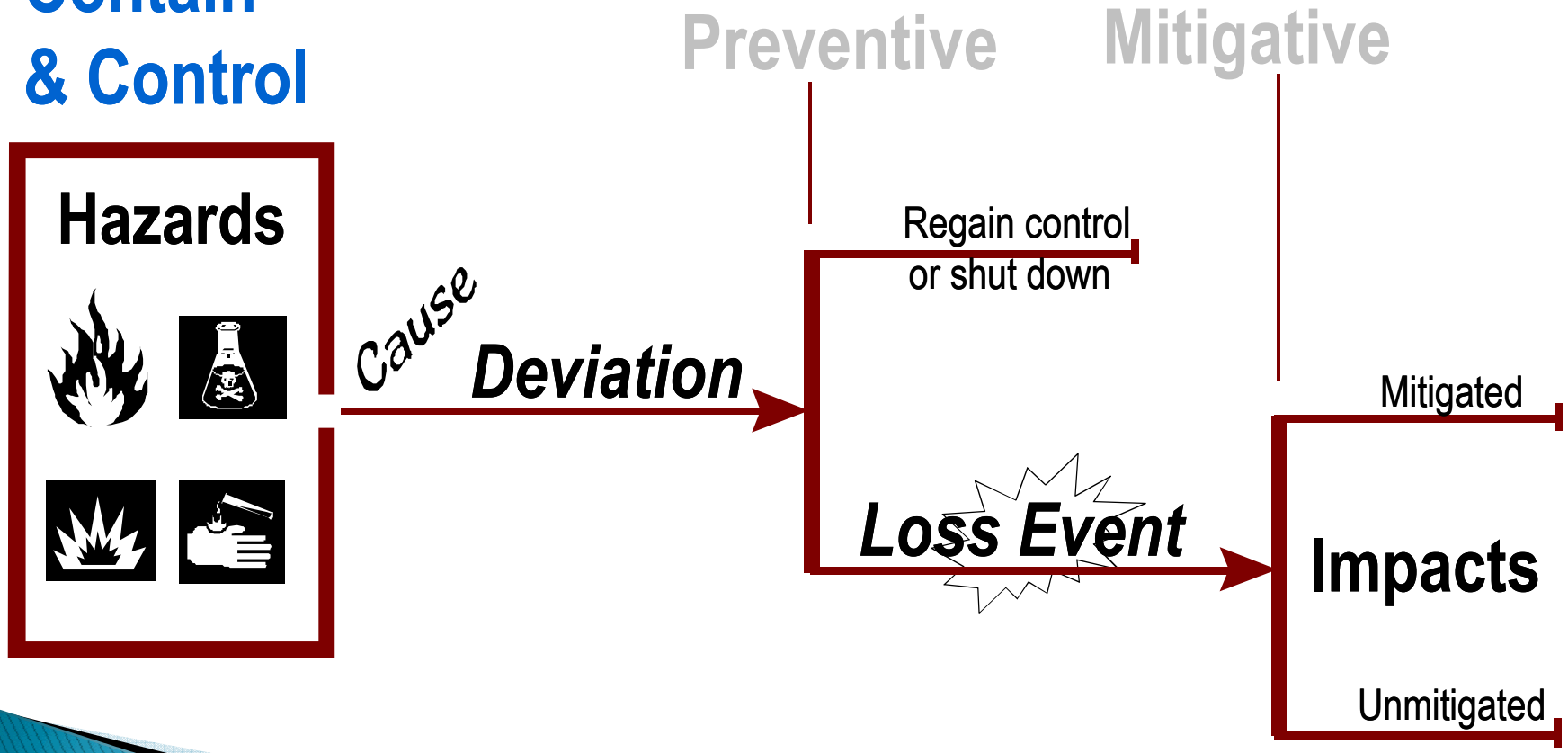
Examples of Mitigative Safeguards:

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

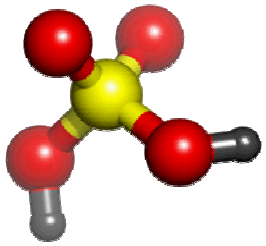
Contain & control: Before initiating cause

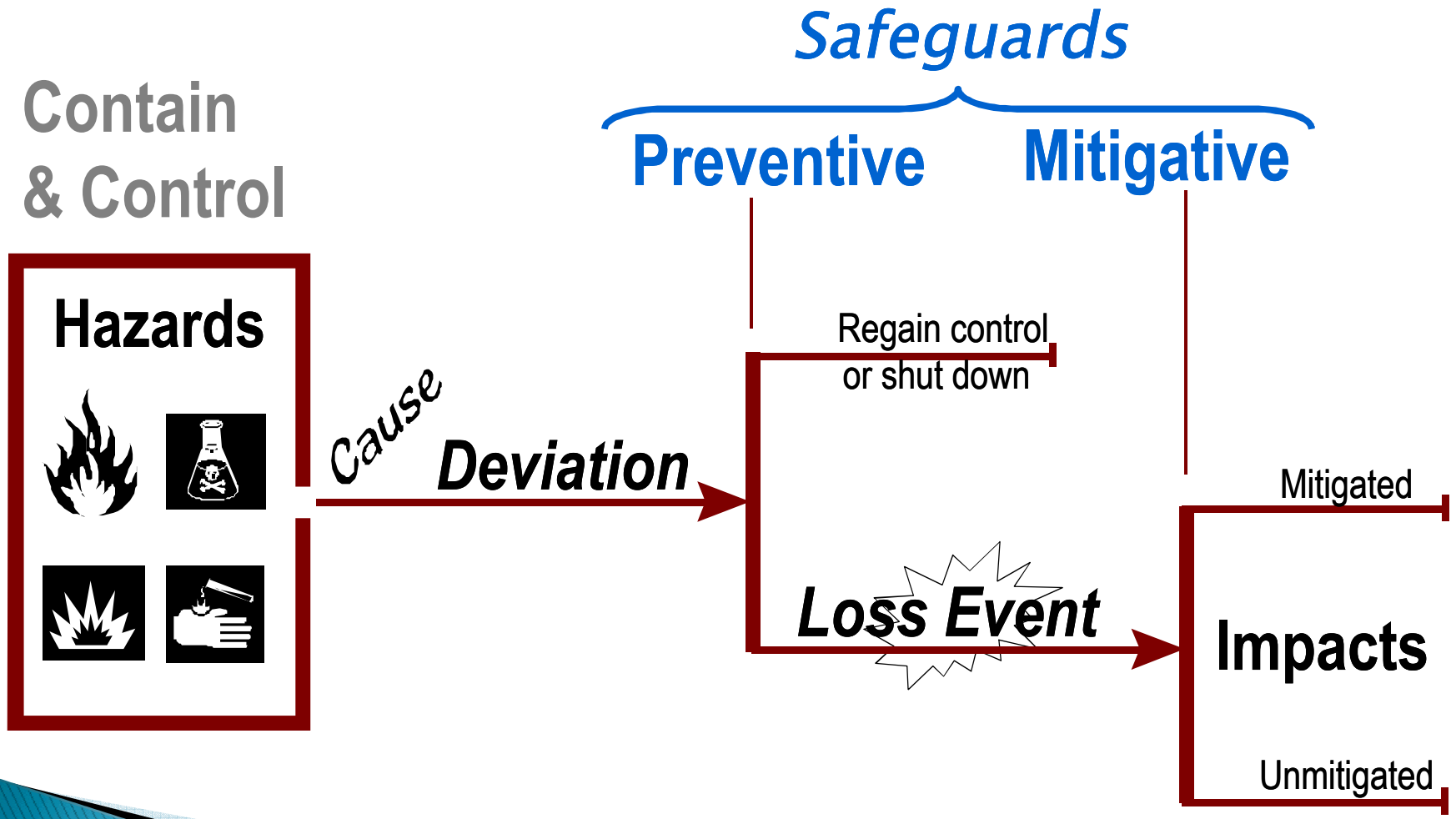


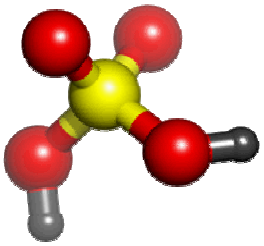
Contain & Control



Safeguards: After cause

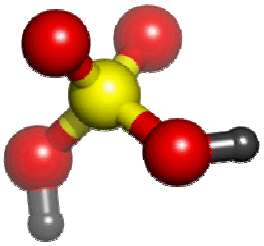






Comprehensive PSM program elements

- 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



What's the driving force behind PSM?

- Provide historical perspective
- Discuss the elements of process safety management
- Detail incidents which shaped the way PSM is performed

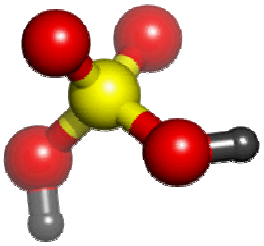
Historical Perspective of PSM

- Unexpected releases of toxic, reactive, flammable gases and liquids were reported throughout the world
  - Environmental impacts
    - 1976: Seveso Disaster
  - Fatalities and injury
    - 1984: Bhopal disaster
  - Large property loss
    - 1988: PEPCON disaster

http://www.srai.org

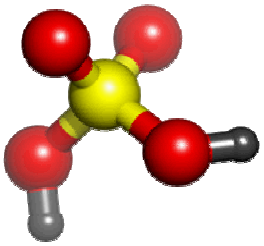
http://safetymatters.aonfpe.com

http://www.h2it.org



Historical Perspective of PSM

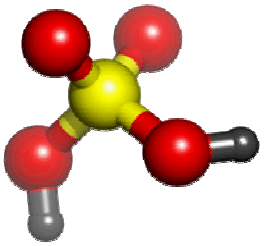
- OSHA proposed "Process Safety Management of Highly Hazardous Chemicals" in 1990
  - Emphasized the management of hazards associated with highly hazardous chemicals
  - Established a management program that integrated technologies, procedures, and management practices
- Clean Air Act Amendments were enacted into law which defined 14 minimum elements of the OSHA standard



Historical Perspective of PSM

Summary of CAAA main points (1 – 5)

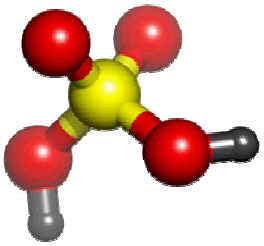
1. Develop and maintain written safety information
2. Perform workplace hazard assessment
3. Consult with employees on the development and conduct of hazard assessments and accident prevention plans
4. Establish a system to respond to hazard assessment findings
5. Review periodically the hazard assessment and response system



Historical Perspective of PSM

Summary of CAAA main points (6 – 10)

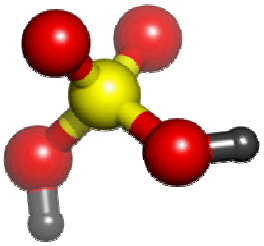
6. Develop and maintain written operating procedures for chemical processes
7. Provide written safety and operating information for employees
8. Ensure contractors are provided with appropriate information and training
9. Train and educate employees in emergency response procedures
10. Establish a quality assurance program to ensure process-related equipment, maintenance materials, spare parts are consistent with design specifications



Historical Perspective of PSM

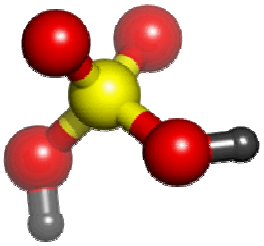
Summary of CAAA main points (11 – 14)

11. Establish maintenance systems for critical process-related equipment
12. Conduct pre-startup safety reviews of all newly installed or modified equipment
13. Establish and implement written procedures managing change to process chemicals, technology, and equipment facilities
14. Investigate every incident that results in or could have resulted in a major workplace accident



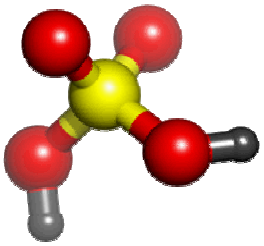
Elements of PSM

- Information on hazardous chemicals
  - Toxicity
  - Permissible exposure limits
  - Physical data
  - Reactivity data
  - Corrosivity data
  - Thermal and chemical stability data



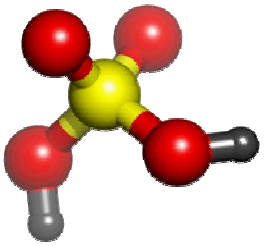
Elements of PSM

- Information on processes
  - Block flow diagram or simplified process flow diagram
  - Process chemistry
  - Maximum intended inventory
  - Safe upper and lower limits (temperature, pressure, flows)
  - Evaluation of consequences of deviations



Elements of PSM

- Information on equipment in the process
  - Materials of construction
  - Piping and instrument diagrams
  - Electrical classification
  - Relief system design and design basis
  - Ventilation system design
  - Design codes and standards (if any)
  - Safety systems (e.g., interlocks, detection, suppression systems)



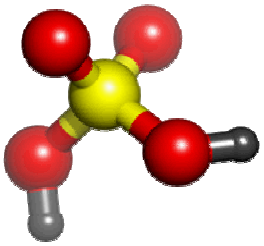
Elements of PSM

- Hazard of the process
- Identification of any previous incident that had the potential for catastrophic consequences
- Engineering and administrative controls
- Consequences of failure of engineering and administrative controls
- Facility siting
- Human factors
- Qualitative evaluation of a range of possible safety and health effects is there is a failure of controls

Perspectives of PSM

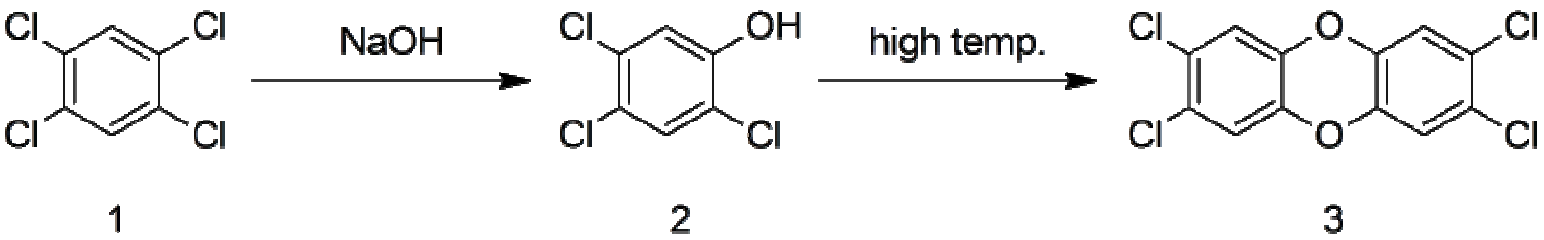
- Seveso, Italy (1976)
  - Population of 17,000
  - 15 km north of Milan
  - Manufactured bactericide (hexachlorophene) with trichlorophenol as intermediate
  - Tetrachlorodibenzoparadioxin (TCDD) was normally produced
  - TCDD is perhaps the most potent toxin known to humans
    - Carcinogenic
    - Endocrine disruptor
    - Birth defects

http://www.yourchildlearns.com



Perspectives of PSM

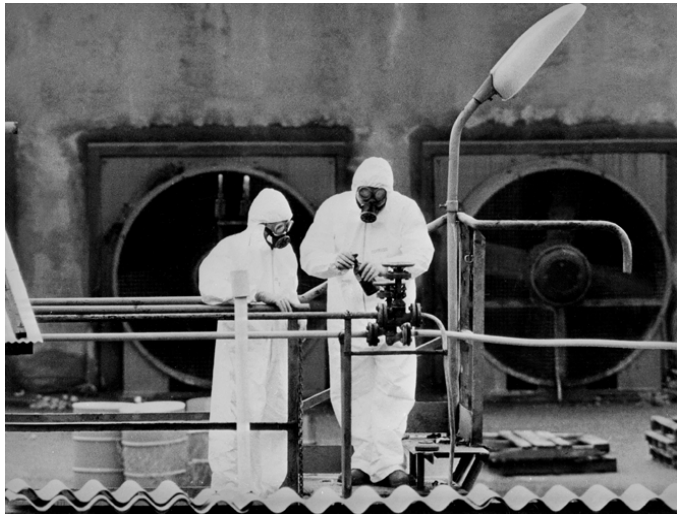
- Seveso, Italy (1976)
  - Trichlorophenol reactor went out of control producing higher than normal temperatures and an increase of TCDD
  - 2 kg of dioxin release from relief system
  - Heavy rain then washed the dioxin cloud into soil
    - TCDD is water insoluble
  - Over 17 km^2 affected



Perspectives of PSM

- Seveso, Italy (1976)
  - 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
  - 30 years later, children found to be nearly 7 times more likely to have reduced thyroid function
  - Areas **still** quarantined from public

http://ehp03.niehs.nih.gov/



http://www.fmglobalreason.com

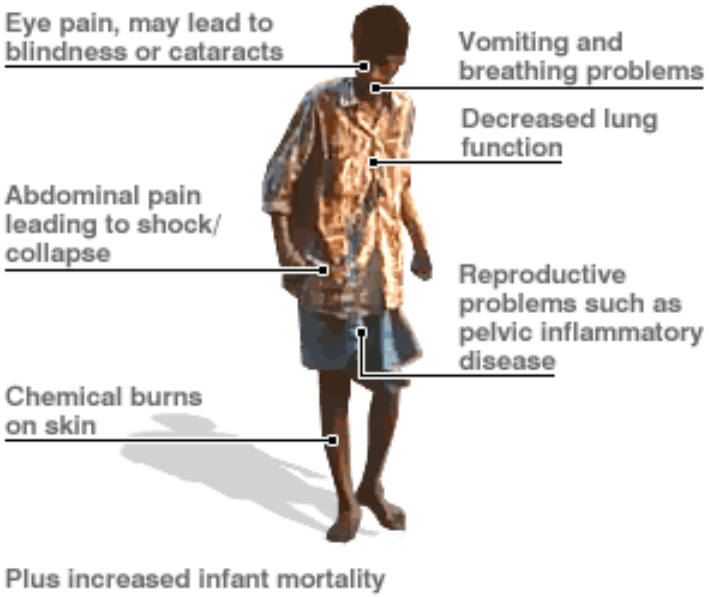
Perspectives of PSM

- Bhopal, India (1984)
  - Dense population area
  - Pesticide manufacturing facility
  - Union Carbide Company
  - Storage of 42 tons of methyl isocyanate (MIC)
  - Poor maintenance of system
    - Clogs in pipes
    - Faulty gauges
    - Leaking valves
  - Cost cutting activities
    - Lack of skilled operators
    - Reduction of safety management
    - Insufficient maintenance
    - Inadequate emergency action plans

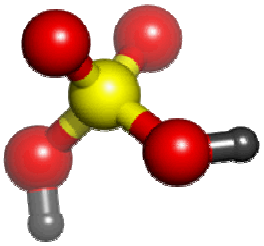
http://www.yourchildlearns.com

Perspectives of PSM

- Bhopal, India (1984)
  - Water introduced into MIC storage causing exothermic reaction
  - ~30 metric tons of MIC released over 45 – 60 minute period
  - 3000 early fatalities; ~560,000 injuries reported
  - Two theories
    - Malicious (insider threat)
    - Maintenance related
  - Plant shut down; Union Carbide eventually sold



http://www.epa.gov



Perspectives of PSM

Bhopal Disaster Video (1984), 3 minutes, 10 seconds

Perspectives of PSM

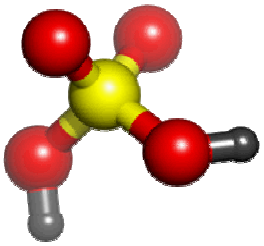
- Henderson, Nevada, USA (1988)
  - Located just outside Las Vegas
  - Pacific Engineering Production Company of Nevada (PEPCON)
  - One of two companies in the US to produce ammonium perchlorate, an oxidizer used in solid rocket fuel
  - 4000 tons of finished product stored on-site in 55-gallon, high-density polyethylene drums

http://www.destination360.com

Perspectives of PSM

- Henderson, Nevada, USA (1988)
  - Windstorm damaged fiberglass structure
  - Repair consisted of hotwork and welding activities
  - Hotwork ignited fiberglass structure and ammonium perchlorate residue
  - 2 fatalities, $100M US in damages

http://safetymatters.aonfpe.com



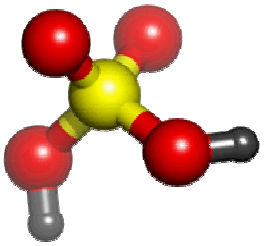
Perspectives of PSM

PEPCON Disaster Video (1988), 3 minutes, 30 seconds

Perspectives of PSM

- Sandoz Basel Disaster (1986)
- Textile and agrochemical manufacturing facility
- Original building used for machinery storage, converted over to flammable liquids storage
- No automatic sprinklers or smoke detectors
- Chemicals stored in plastic bags, plastic and steel drums
- Materials stacked to maximum height of 8m

http://www.yourchildlearns.com



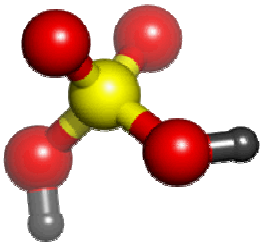
Perspectives of PSM

- Incident occurred on October 31, 1986
- Key points to the incident
  - Palletized chemicals were plastic shrink wrapped and then finished by using a blow torch
  - Plastic wrap could ignite if exposed for sufficient duration
  - Chemicals in the warehouse (e.g., Prussian Blue dye) could burn flamelessly, smokelessly, and slowly thus eluding early detection by workers
  - No automatic suppression or smoke detection

Perspectives of PSM

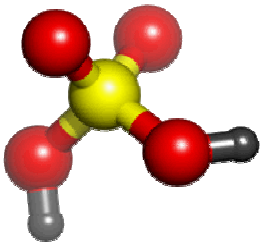
- Extensive environmental impacts
  - Most fish were killed by mercury poisoning in a 250km section of the Rhine downstream of Basel
  - Subsoil water levels had to be pumped away to preserve the municipal underground water supply
  - Wind carried the smoke produced by the fire over residential communities causing eye and respiratory issues
- Extensive financial impacts
  - $60M US in settle charges
  - Figure does NOT include environmental clean-up and restoration efforts

http://www.novaquatis.eawag.ch/media/2006/20061101/index_EN



Perspectives of PSM

Sandoz Basel Disaster (1987), 3 minutes, 15 seconds



Primary Section Goals

- Recognize key terms and acronyms
- Define process safety
  - the absence of loss and harm resulting from fires, explosions and hazardous material releases at process facilities.
  - 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.
- Identify elements of the process safety management process
- Learn from catastrophic events impacting people, facilities, and the environment prompted more formalized assessment methodologies

Questions