Hazards, Accidents, Process Safety Management & Process Hazard Analysis

"As if there were safety in stupidity alone." – Thoreau

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Lecture Topics

- Hazards and Accidents
- Process Safety Management (PSM)
- Process Hazard Analysis (PHA)

Learning Objectives

- Describe the hazard and accident-driven stimulus for, and main components of OSHA's *Process Safety Management* standard
- Define *Process Hazard Analysis* and related terminology
- Describe major hazard analysis methods
- Assess applicability (via pros and cons) of major hazard analysis methods

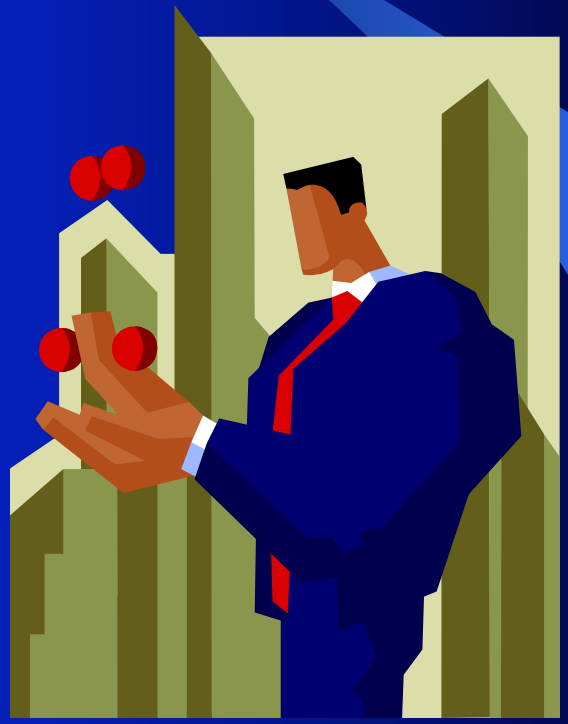
Hazards

- An inherent physical or chemical characteristic that has the potential for causing harm to people, the environment, or property[1]
- Hazards are intrinsic to a material, or its conditions of use
- Examples
  - Hydrogen sulfide – toxic by inhalation
  - Gasoline – flammable
  - Moving machinery – kinetic energy, pinch points

[1] *AICHE Center for Chemical Process Safety*

Hazard Management: The World as It Was Before

- Good people
- … doing good things



The Rising Case for Change

- 1984 – Bhopal, India – Toxic Material Released
  - 2,500 immediate fatalities; 20,000+ total
  - Many other offsite injuries

The Rising Case for Change

- 1984 – Mexico City, Mexico –Explosion
  - 300 fatalities (mostly offsite)
  - $20M damages

The Rising Case for Change

- 1988 – Norco, LA – Explosion
  - 7 onsite fatalities, 42 injured
  - $400M+ damage

The Rising Case for Change

- 1989 – Pasadena, TX – Explosion and Fire
  - 23 fatalities, 130 injured; damage $800M+

Enter … Process Safety Management

- Integral part of OSHA Occupational Safety and Health Standards since 1992
- Known formally as: *Process Safety Management of Highly Hazardous Chemicals* (29 CFR 1910.119)
- ***PSM*** applies to most industrial processes containing 10,000+ pounds of hazardous material

In a Few Words, What is PSM?

- The ***proactive*** and ***systematic*** identification, evaluation, and mitigation or prevention of chemical releases that could occur as a result of failures in process, procedures, or equipment.

What's Covered by PSM?

- Process Safety Information
- Employee Involvement
- Process Hazard Analysis
- Operating Procedures
- Training
- Contractors
- Pre-Startup Safety Review
- Mechanical Integrity
- Hot Work
- Management of Change
- Incident Investigation
- Emergency Planning and Response
- Compliance Audits
- Trade Secrets

Process Hazard Analysis

Simply, PHA allows the employer to:

- Determine locations of potential safety problems
- Identify corrective measures to improve safety
- Preplan emergency actions to be taken if safety controls fail

PHA Requirements

- Use one or more established methodologies appropriate to the complexity of the process
- Performed by a team with expertise in engineering and process operations
- Includes personnel with experience and knowledge specific to the process being evaluated and the hazard analysis methodology being used

PHA Must Address …

- The hazards of the process
- Identification of previous incidents with likely potential for catastrophic consequences
- Engineering and administrative controls applicable to the hazards and their interrelationships

PHA Must Address … (cont'd)

- Consequences of failure of engineering and administrative controls, especially those affecting employees
- Facility siting; human factors
- The need to promptly resolve PHA findings and recommendations

Hazard Analysis Methodologies

- What-If
- Checklist
- What-If/Checklist
- Hazard and Operability Study (HAZOP)
- Failure Mode and Effects Analysis (FMEA)
- Fault Tree Analysis
- An appropriate equivalent methodology

What-If

- Experienced personnel brainstorming a series of questions that begin, "What if…?”
- Each question represents a potential failure in the facility or misoperation of the facility

What-If

- The response of the process and/or operators is evaluated to determine if a potential hazard can occur
- If so, the adequacy of existing safeguards is weighed against the probability and severity of the scenario to determine whether modifications to the system should be recommended

What-If – Steps

1. Divide the system up into smaller, logical subsystems
2. Identify a list of questions for a subsystem
3. Select a question
4. Identify hazards, consequences, severity, likelihood, and recommendations
5. Repeat Step 2 through 4 until complete

What-If Question Areas

- Equipment failures
  - What if … a valve leaks?
- Human error
  - What if … operator fails to restart pump?
- External events
  - What if … a very hard freeze persists?

What-If – Summary

- Perhaps the most commonly used method
- One of the least structured methods
  - Can be used in a wide range of circumstances
  - Success highly dependent on experience of the analysts
- Useful at any stage in the facility life cycle
- Useful when focusing on change review

Checklist

- Consists of using a detailed list of prepared questions about the design and operation of the facility
- Questions are usually answered “Yes” or “No”
- Used to identify common hazards through compliance with established practices and standards

Checklist Question Categories

- Causes of accidents
  - Process equipment
  - Human error
  - External events
- Facility Functions
  - Alarms, construction materials, control systems, documentation and training, instrumentation, piping, pumps, vessels, etc.

Checklist Questions

- Causes of accidents
  - Is process equipment properly supported?
  - Is equipment identified properly?
  - Are the procedures complete?
  - Is the system designed to withstand hurricane winds?
- Facility Functions
  - Is is possible to distinguish between different alarms?
  - Is pressure relief provided?
  - Is the vessel free from external corrosion?
  - Are sources of ignition controlled?

Checklist – Summary

- The simplest of hazard analyses
- Easy-to-use; level of detail is adjustable
- Provides quick results; communicates information well
- Effective way to account for ‘lessons learned’
- **NOT** helpful in identifying new or unrecognized hazards
- Limited to the expertise of its author(s)

Checklist – Summary (cont'd)

- Should be prepared by experienced engineers
- Its application requires knowledge of the system/facility and its standard operating procedures
- Should be audited and updated regularly

What-If/Checklist

- A hybrid of the What-If and Checklist methodologies
- Combines the *brainstorming* of What-If method with the *structured features* of Checklist method

What-If/Checklist – Steps

- Begin by answering a series of previously-prepared ‘What-if’ questions
- During the exercise, brainstorming produces additional questions to complete the analysis of the process under study

What-If/Checklist – Summary

- Encourages creative thinking (What-If) while providing structure (Checklist)
- In theory, weaknesses of stand-alone methods are eliminated and strengths preserved – not easy to do in practice
- E.g.: when presented with a checklist, it is typical human behavior to suspend creative thinking

HAZOP

***Haz**ard and **Op**erability Analysis*

- Identify hazards (safety, health, environmental), and
- Problems which prevent efficient operation

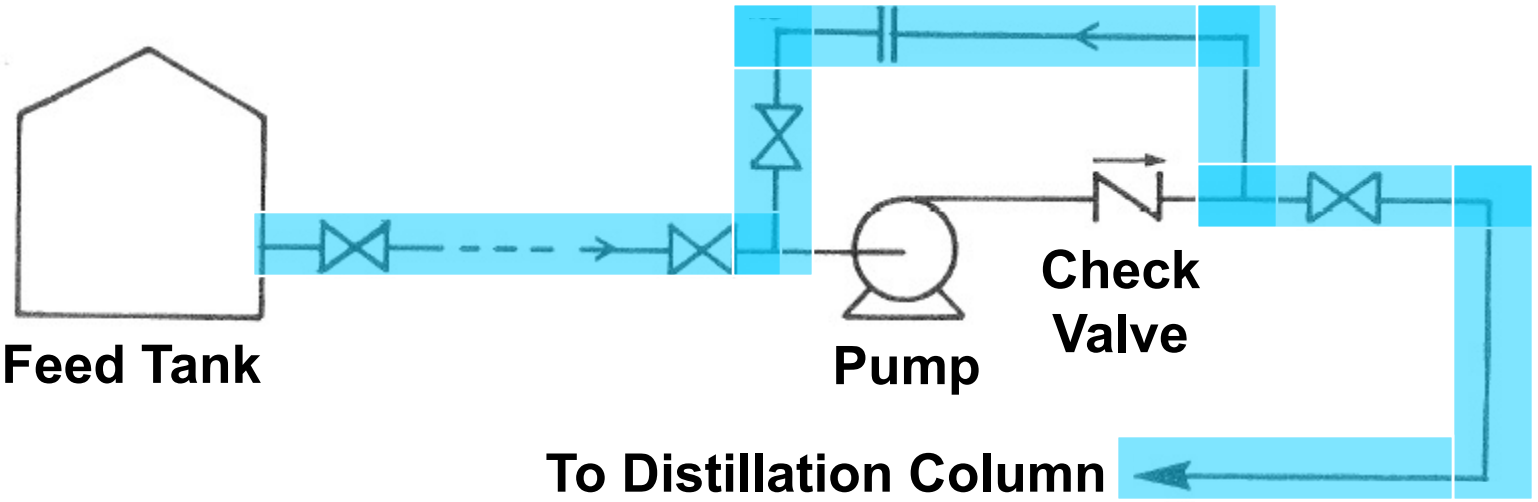
HAZOP

1. Choose a vessel and describe intention
2. Choose and describe a flow path
3. Apply ***guideword*** to ***deviation***
   - Guidewords include **NONE, MORE OF, LESS OF, PART OF, MORE THAN, OTHER THAN, REVERSE**
   - Deviations are expansions, such as **NO FLOW, MORE PRESSURE, LESS TEMPERATURE, MORE PHASES THAN** (there should be),

HAZOP

1. Vessel

2. FLOW PATH

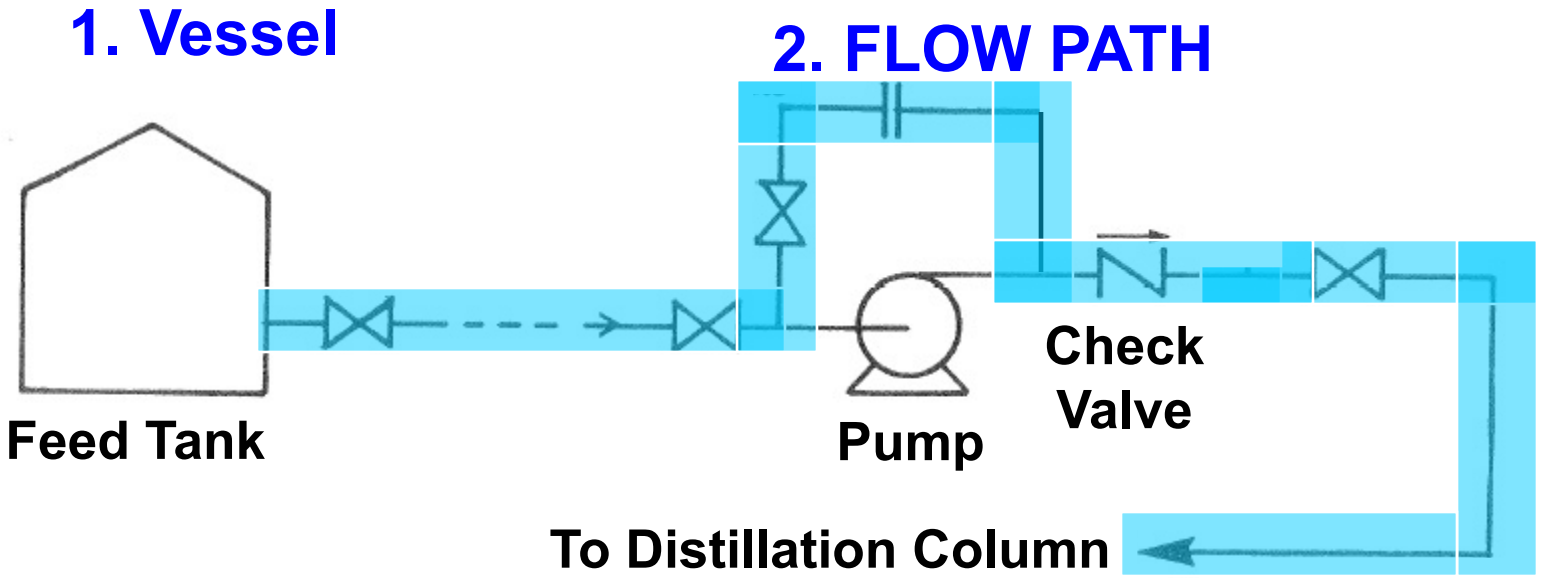


3. REVERSAL OF FLOW

HAZOP

4. Can deviation initiate a hazard of consequence?
5. Can failures causing deviation be identified?
6. Investigate detection and mitigation systems
7. Identify recommendations
8. Document
9. Repeat 3-to-8, 2-to-8, and 1-to-8 until complete

HAZOP



3. REVERSAL OF FLOW
4. Distillation materials returning via pumparound
5. Pump failure could lead to REVERSAL OF FLOW
6. Check valve located properly prevents deviation
7. Move check valve downstream of pumparound

Loss of Containment Deviations

- Pressure too high
- Pressure too low (vacuum)
- Temperature too high
- Temperature too low
- Deterioration of equipment

HAZOP's Inherent Assumptions

- Hazards are detectable by careful review
- Plants designed, built and run to appropriate standards will not suffer catastrophic *loss of containment* if ops stay within design parameters
- Hazards are controllable by a combination of equipment, procedures which are *Safety Critical*
- HAZOP conducted with openness and good faith by competent parties

HAZOP – Pros and Cons

- Creative, open-ended
- Completeness – identifies all process hazards
- Rigorous, structured, yet versatile
- Identifies safety ***and*** operability issues

- Can be time-consuming (e.g., includes operability)
- Relies on having right people in the room
- Does not distinguish between low probability, high consequence events (and vice versa)

FMEA – Failure Modes, Effects Analysis

- **Manual analysis** to determine the consequences of component, module or subsystem failures
- Bottom-up analysis
- Consists of a spreadsheet where each failure mode, possible causes, probability of occurrence, consequences, and proposed safeguards are noted.

FMEA – Failure Mode Keywords

- Rupture
- Crack
- Leak
- Plugged
- Failure to open
- Failure to close
- Failure to stop
- Failure to start
- Failure to continue
- Spurious stop
- Spurious start
- Loss of function
- High pressure
- Low pressure
- High temperature
- Low temperature
- Overfilling
- Hose bypass
- Instrument bypassed

FMEA on a Heat Exchanger

Failure Mode	Causes of Failure	Symptoms	Predicted Frequency	Impact
Tube rupture	Corrosion from fluids (shell side)	H/C at higher pressure than cooling water	Frequent – has happened 2x in 10 yrs	Critical – could cause a major fire

- Rank items by risk (frequency x impact)
- Identify safeguards for high risk items

FMEA – Failure Modes, Effects Analysis

- FMEA is a very structured and reliable method for evaluating hardware and systems.
- Easy to learn and apply and approach makes evaluating even complex systems easy to do.
- Can be very time-consuming (and expensive) and does not readily identify areas of multiple fault that could occur.
- Not easily lent to procedural review as it may not identify areas of human error in the process.

Fault Tree Analysis

- **Graphical method** that starts with a hazardous event and works backwards to identify the causes of the ***top event***
- Top-down analysis
- Intermediate events related to the top event are combined by using logical operations such as AND and OR.

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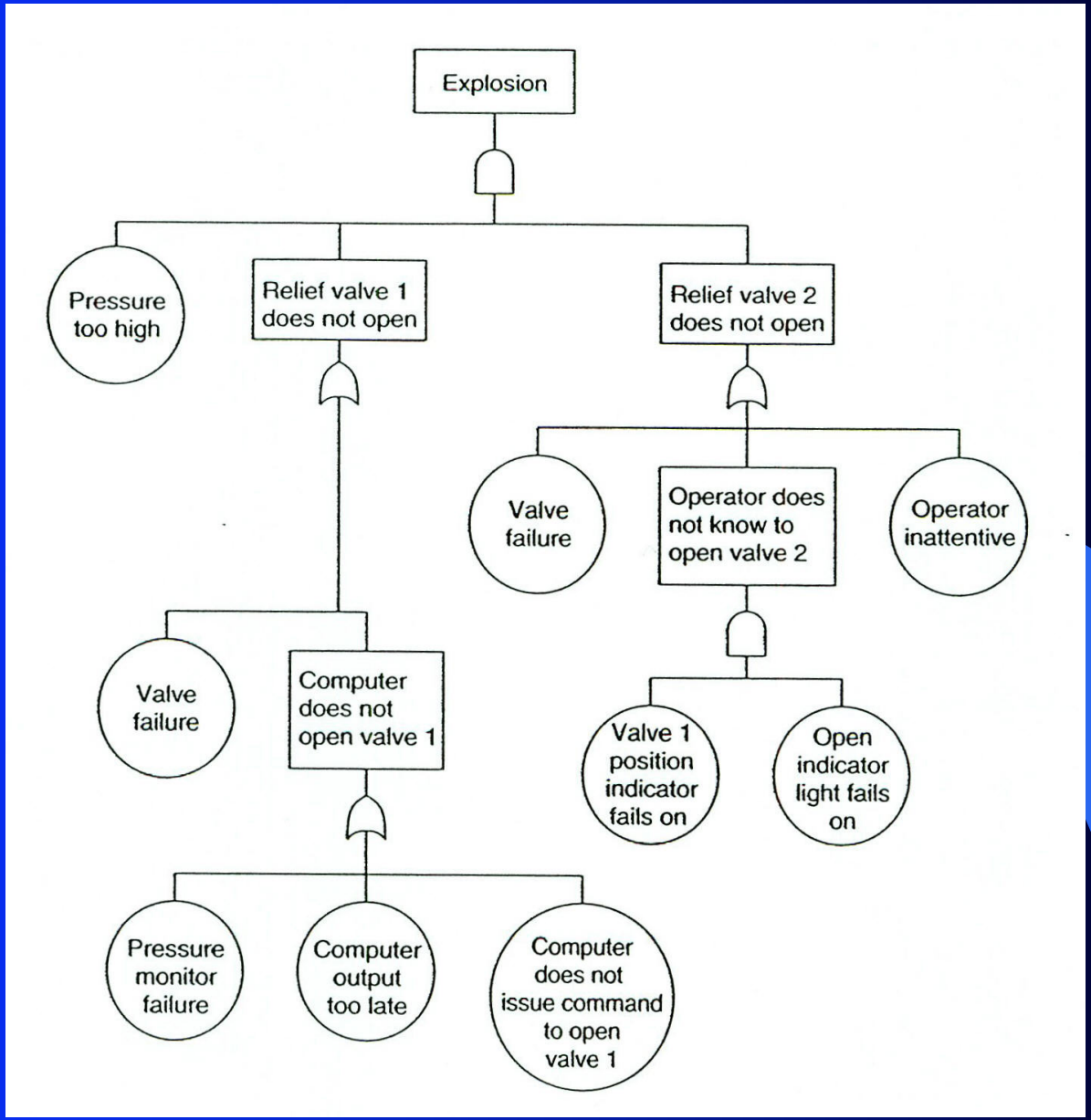
Explosion
Pressure too high
Relief valve 1 does not open
Relief valve 2 does not open
Valve failure
Operator does not know to open valve 2
Operator inattentive
Valve failure
Computer does not open valve 1
Valve 1 position indicator fails on
Open indicator light fails on
Pressure monitor failure
Computer output too late
Computer does not issue command to open valve 1

Fault Tree Analysis

- Provides a traceable, logical, quantitative representation of causes, consequences and event combinations
- Amenable to – but for comprehensive systems, requiring – use of software
- Not intuitive, requires training
- Not particularly useful when temporal aspects are important

Accident Scenarios May Be Missed by PHA

- No PHA method can identify all accidents that could occur in a process
- A scenario may be excluded from the scope of the analysis
- The team may be unaware of a scenario
- The team consider the scenario but judge it not credible or significant
- The team may overlook the scenario

Summary

Despite the aforementioned issues with PHA:

- Companies that rigorously exercise PHA are seeing a continuing reduction is frequency and severity of industrial accidents
- ***Process Hazard Analysis*** will continue to play an integral role in the design and continued examination of industrial processes

Using What You Learn

- The ideas and techniques of Process Hazard Analysis will be immediately useful in upcoming recitation exercise on **Hazard Evaluation**

- Expect to be part of a Process Hazard Analysis Team early on in your professional career

Where to Get More Information

- Chemical Safety and Hazard Investigation Board's web site: *www.csb.gov*
- MPRI web site: *www. Mpri.lsu.edu/main/*
- Crowl and Louvar – *Chemical Process Safety: Fundamentals with Applications*
- Kletz – *HAZOP & HAZAN: Notes on the Identification and Assessment of Hazards*