Chapter 1. Introduction

Introduction

- In 1987, Robert M. Solow, an economist at the Massachusetts Institute of Technology,
- Nobel Prize in economics for his work in determining the sources of economic growth
- Economy’s growth is the result of technological advances
- more complex processes: higher pressure, more reactive chemicals, and exotic chemistry

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more complex safety technology

- As chemical engineers will need a more detailed and fundamental understanding of safety.
- safety is equal in importance to production and has developed into a scientific discipline

highly technical and complex theories and practices.

- Examples of the technology of safety include
  - Hydrodynamic models representing two-phase flow
  - Dispersion models representing the spread of toxic vapor
  - Mathematical techniques to determine the various ways that processes can fail and the probability of failure

- **Chemical plant safety emphasize**:

use of appropriate technological tools to provide information for making safety decisions with respect to plant design and operation.

- **safety**: Accident prevention (older strategy) worker safety through the use of hard hats, safety shoes, and a variety of rules and regulations

  Loss prevention includes hazard identification, technical evaluation, and the design of new engineering features to prevent loss.

Safety, Hazard, and Risk

- Frequently used terms in chemical process safety
- ***Safety*** **or** ***loss prevention****:* Technologies to identify the hazards of a chemical plant and eliminate them before an accident occurs
- ***Hazard****:* a chemical or physical condition that has the potential to cause damage to people, property, or the environment.
- ***Risk:*** measure of human injury, environmental damage, or economic loss (incident likelihood, magnitude of the loss)

Chemical plants

Large variety of hazard

- **Mechanical hazards:** Worker injuries from tripping, falling, or moving equipment
- **Chemical hazards**: Fire and explosion hazards, reactivity hazards, and toxic hazards
- **Safety Programs: (**For participants)

A successful safety program ingredients are

System
Attitude
Fundamentals
Experience
Time
You

Safety Programs

- **System**

  (1) to record what needs to be done

  (2) to do what needs to be done

  (3) to record that the required tasks are done

- **Attitude**: Participants must have a positive attitude.

  willingness to do some of the thankless work that is required for success.

- **Fundamentals**: Must understand and use the fundamentals of chemical process safety.

Experience: Learn from the experience of history

(1) read and understand case histories of past accidents and

(2) ask people in their own and other organizations for their experience and advice

Time: Safety takes time.

This includes time to study

time to do the work

time to record results (for history)

time to share experiences

time to train or be trained.

You: everyone (you) should take the responsibility to contribute to the safety program.

Safety Programs

Distinction between a good and an outstanding safety program.

- ***Good* safety program**: identifies and eliminates existing safety hazards.
- **Outstanding safety program:** has management systems that prevent the existence of safety hazards.

prevents the existence of a hazard in the first place

include

Safety reviews,

Safety audits,

Hazard identification techniques,

Checklists,

Proper application of technical knowledge

Engineering Ethics

- Engineers are responsible for minimizing losses and providing a safe and secure environment for the company's employees

- Responsibility to themselves, fellow workers

- Family, community, and the engineering profession.

- Part of this responsibility is described
  - by the American Institute of Chemical Engineers

American Institute of Chemical Engineers Code of Professional Ethics

Fundamental principles
Engineers shall uphold and advance the integrity, honor, and dignity of the engineering profession by
1. using their knowledge and skill for the enhancement of human welfare;
2. being honest and impartial and serving with fidelity the public, their employers, and clients;
3. striving to increase the competence and prestige of the engineering profession.

American Institute of Chemical Engineers Code of Professional Ethics

Fundamental canons
1. Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties.
2. Engineers shall perform services only in areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputations on the merits of their services.
6. Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the engineering profession.
7. Engineers shall continue their professional development throughout their careers and shall provide opportunities for the professional development of those engineers under their supervision.

Accident and Loss Statistics

- Accident and loss statistics are important measures of the effectiveness of safety programs
  - process is safe or safety procedure is working effectively
- No single method is capable of measuring all required aspects
- Many statistical methods are available
- Three systems considered here are
  - OSHA incidence rate,
  - Fatal accident rate (FAR)
  - Fatality rate, or deaths per person per year

All three methods report the number of accidents and/or fatalities for a fixed number of workers during a specified period.

OSHA

- Occupational Safety and Health Administration of the United States government.
- OSHA is responsible for ensuring that workers are provided with a safe working environment

OSHA definitions applicable to accident statistics references

Injury Facts, 1999 ed. (Chicago: National Safety Council, 1999), p. 151. OSHA regulations, 29 CFR 1904.12.

Term	Definition
First aid	Any one-time treatment and any follow-up visits for the purpose of observation of minor scratches, cuts, burns, splinters, and so forth that do not ordinarily require medical care. Such one-time treatment and follow-up visits for the purpose of observation are considered first aid even though provided by a physician or registered professional personnel.
Incident rate	Number of occupational injuries and/or illnesses or lost workdays per 100 full-time employees.

Accident and Loss Statistics

Term	Definition
Lost workdays	Number of days (consecutive or not) after but not including the day of injury or illness during which the employee would have worked but could not do so, that is, during which the employee could not perform all or any part of his or her normal assignment during all or any part of the workday or shift because of the occupational injury or illness.
Medical treatment	Treatment administered by a physician or by registered professional personnel under the standing orders of a physician. Medical treatment does not include first aid treatment even though provided by a physician or registered professional personnel.
Occupational injury	Any injury such as a cut, sprain, or burn that results from a work accident or from a single instantaneous exposure in the work environment.
Occupational illness	Any abnormal condition or disorder, other than one resulting from an occupational injury, caused by exposure to environmental factors associated with employment. It includes acute and chronic illnesses or diseases that may be caused by inhalation, absorption, ingestion, or direct contact.

Accident and Loss Statistics

Term	Definition
Recordable cases	Cases involving an occupational injury or occupational illness, including deaths.
Recordable fatality cases	Injuries that result in death, regardless of the time between the injury and death or the length of the illness.
Recordable nonfatal cases without lost workdays	Cases of occupational injury or illness that do not involve fatalities or lost workdays but do result in (1) transfer to another job or termination of employment or (2) medical treatment other than first aid or (3) diagnosis of occupational illness or (4) loss of consciousness or (5) restriction of work or motion.
Recordable lost workday cases due to restricted duty	Injuries that result in the injured person not being able to perform their regular duties but being able to perform duties consistent with their normal work.
Recordable cases with days away from work	Injuries that result in the injured person not being able to return to work on their next regular workday.
Recordable medical cases	Injuries that require treatment that must be administered by a physician or under the standing orders of a physician. The injured person is able to return to work and perform his or her regular duties. Medical injuries include cuts requiring stitches, second-degree burns (burns with blisters), broken bones, injury requiring prescription medication, and injury with loss of consciousness.

OSHA incidence rate

- Based on cases per 100 worker/years.
- A worker 2000 hours

  (50 work weeks/year × 40 hours/week)
- The OSHA incidence rate is therefore based on 20,0000 hours of worker exposure to a hazard.
- Provides information on all types of work-related injuries and illnesses, including fatalities
- Better representation of worker accidents than systems based on fatalities alone
- For instance, a plant might experience many small accidents with resulting injuries but no fatalities

OSHA incidence rate:

Number of occupational injuries and illnesses and the total number of employee hours worked during the applicable period

$$\text{OSHA incidence rate (based on injuries and illness)} = \frac{\text{Number of injuries and illnesses} \times 200{,}000}{\text{Total hours worked by all employees during period covered.}}$$

An incidence rate can also be based on lost workdays instead of injuries and illnesses

$$\text{OSHA incidence rate (based on lost workdays)} = \frac{\text{Number of lost workdays} \times 200{,}000}{\text{Total hours worked by all employees during period covered.}}$$

FAR

- Mostly used by the British chemical industry
- Reports the number of fatalities based on 1000 employees working their entire lifetime
- Employees are assumed to work a total of 50 years

Based on 10^8 working hours

$$FAR = \frac{\text{Number of fatalities} \times 10^8}{\text{Total hours worked by all employees during period covered.}}$$

Fatality rate

- or deaths per person per year
- Independent of the number of hours actually worked
- Report only the number of fatalities expected per person per year
- Useful for performing calculations on the general population where number of exposed hours is poorly defined

Fatality rate

$$\text{Fatality rate} = \frac{\text{Number of fatalities per year}}{\text{Total number of people in applicable population.}}$$

- Both the OSHA incidence rate and the FAR depend on the number of exposed hours
- An employee working a ten-hour shift is at greater total risk than one working an eight-hour shift

- FAR can be converted to a fatality rate (or vice versa) if the number of exposed hours is known
- OSHA incidence rate cannot be readily converted to a FAR or fatality rate

Example

- A process has a reported FAR of 2. If an employee works a standard 8-hr shift 300 days per year, compute the deaths per person per year.

Solution

Deaths per person per year

= (8 hr/day) x (300 days/yr) x (2 deaths/10^8 hr)

= 4.8 x 10–5.

Fatality Statistics for Common Nonindustrial Activities

Activity	FAR (deaths/10^8 hours)	Fatality rate (deaths per person per year)
Voluntary activity		
Staying at home	3	
Traveling by		
Car	57	17×10^{-5}
Bicycle	96	
Air	240	
Motorcycle	660	
Canoeing	1000	
Rock climbing	4000	4×10^{-5}
Smoking (20 cigarettes/day)		500×10^{-5}
Involuntary activity		
Struck by meteorite		6×10^{-11}
Struck by lightning (U.K.)		1×10^{-7}
Fire (U.K.)		150×10^{-7}
Run over by vehicle		600×10^{-7}

Example 1-2.

- If twice as many people used motorcycles for the same average amount of time each, what will happen to (a) the OSHA incidence rate, (b) the FAR, (c) the fatality rate, and (d) the total number of fatalities?

Solution

- **a.** The OSHA incidence rate will remain the same. The number of injuries and deaths will double, but the total number of hours exposed will double as well.
- **b.** The FAR will remain unchanged for the same reason as in part a.
- **c.** The fatality rate, or deaths per person per year, will double. The fatality rate does not depend on exposed hours.
- **d.** The total number of fatalities will double.

Accident statistics

- Accident statistics do not include information on the total number of deaths from a single incident

Example

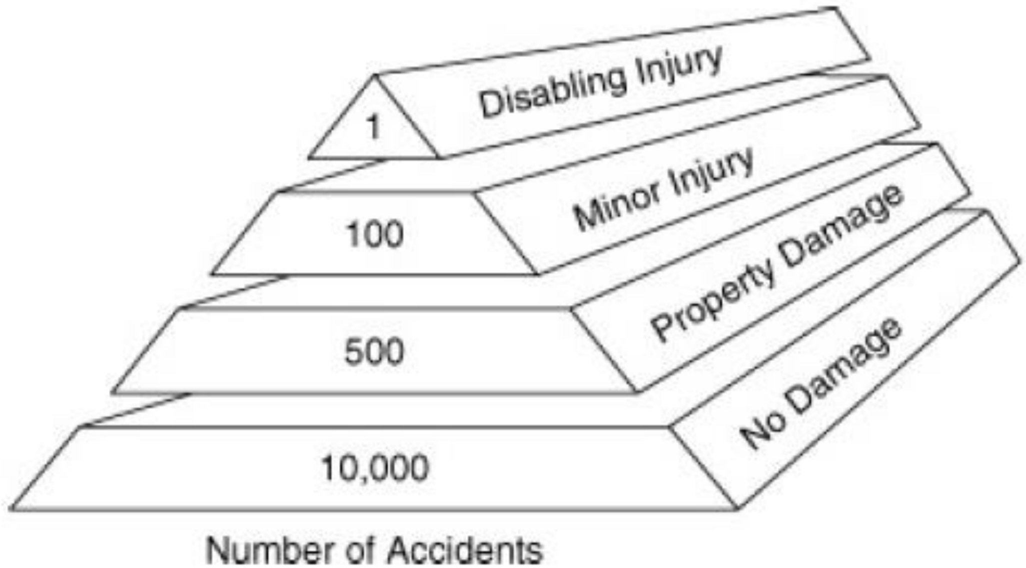
consider two separate chemical plants. Both plants have a probability of explosion and complete devastation once every 1000 years.

- The first plant employs a single operator. When the plant explodes, the operator is the sole fatality.
- The second plant employs 10 operators.

In both cases the FAR and OSHA incidence rate are the same.

correspondingly larger number of exposed hours.

Accident pyramid



- Property damage and loss of production must also be considered in loss prevention.
- These losses can be substantial. Accidents of this type are much more common than fatalities.
- “No Damage” accidents are called “near misses” provide a good opportunity for determine that a problem exists

Accident pyramid

- Each company needs to determine an appropriate level for safety expenditures.
- This is part of risk management
- Engineers need to also consider other alternatives when designing safety improvements otherwise may make the system unduly complex
- It is also important to recognize the causes of accidental deaths,
- Most company safety programs are directed toward preventing injuries to employees, the programs should include off-the-job safety
- Although the emphasis of chemical-related accidents
- include training to prevent injuries resulting from transportation, assaults, mechanical and chemical exposures, and fires and explosions.

Accident pyramid

Type of death	1998 deaths	2007 deaths
Motor-vehicle		
Public nonwork	38,900	40,955
Work	2,100	1,945
Home	200	200
Subtotal	41,200 (43.5%)	43,100 (35.4%)
Work		
Non-motor-vehicle	3,000	2,744
Motor-vehicle	2,100	1,945
Subtotal	5,100 (5.4%)	4,689 (3.9%)
Home		
Non-motor-vehicle	28,200	43,300
Motor-vehicle	200	200
Subtotal	28,400 (30.0%)	43,500 (35.7%)
Public	20,000 (21.1%)	30,500 (25%)
All classes	94,700	121,789

Organizations focus on the root causes of worker injuries

Acceptable Risk

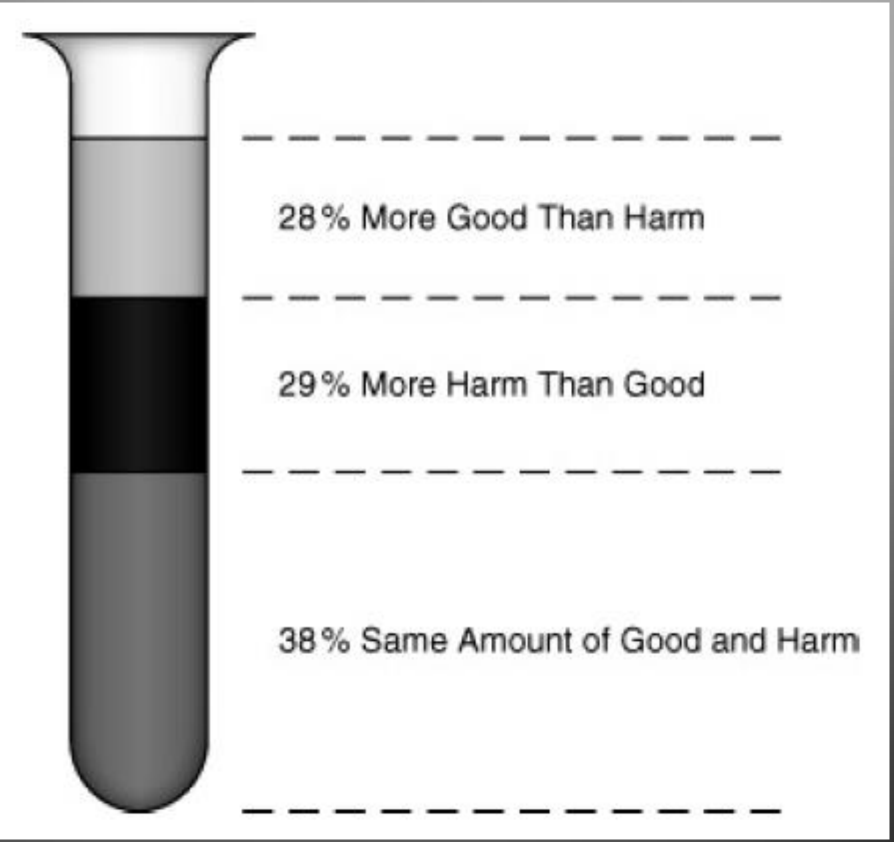
- Every chemical process has a certain amount of risk associated with it
- Engineers must make every effort to minimize risks within the economic constraints of the process.
- No engineer should ever design a process that he or she knows will result in certain human loss or injury

Public Perceptions

- Acceptable risk are assuming that these risks are satisfactory to the civilians living near the plant
- The results of a public opinion survey on the hazards of chemicals

Results from a public opinion survey

- The results show an almost even three-way split,
- with a small margin who considered the good and harm to be equal.

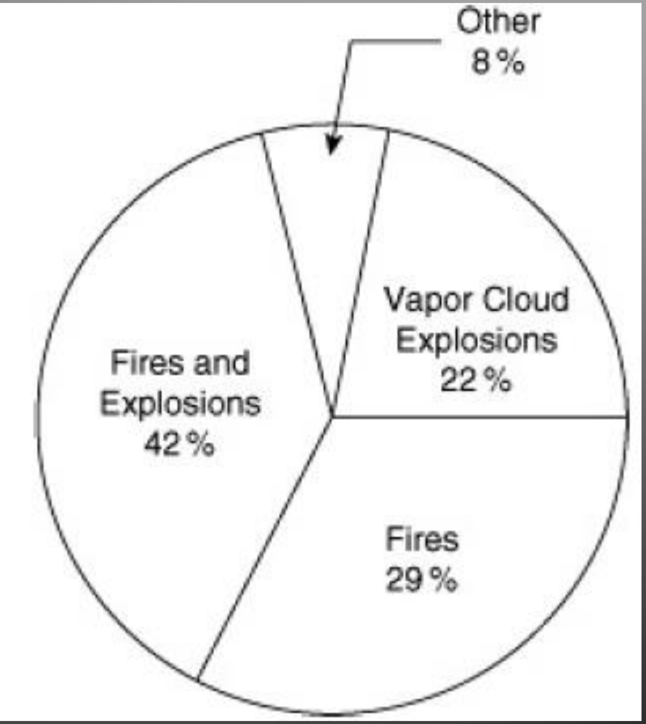


Nature of the Accident Process

Type of accident	Probability of occurrence	Potential for fatalities	Potential for economic loss
Fire	High	Low	Intermediate
Explosion	Intermediate	Intermediate	High
Toxic release	Low	High	Low

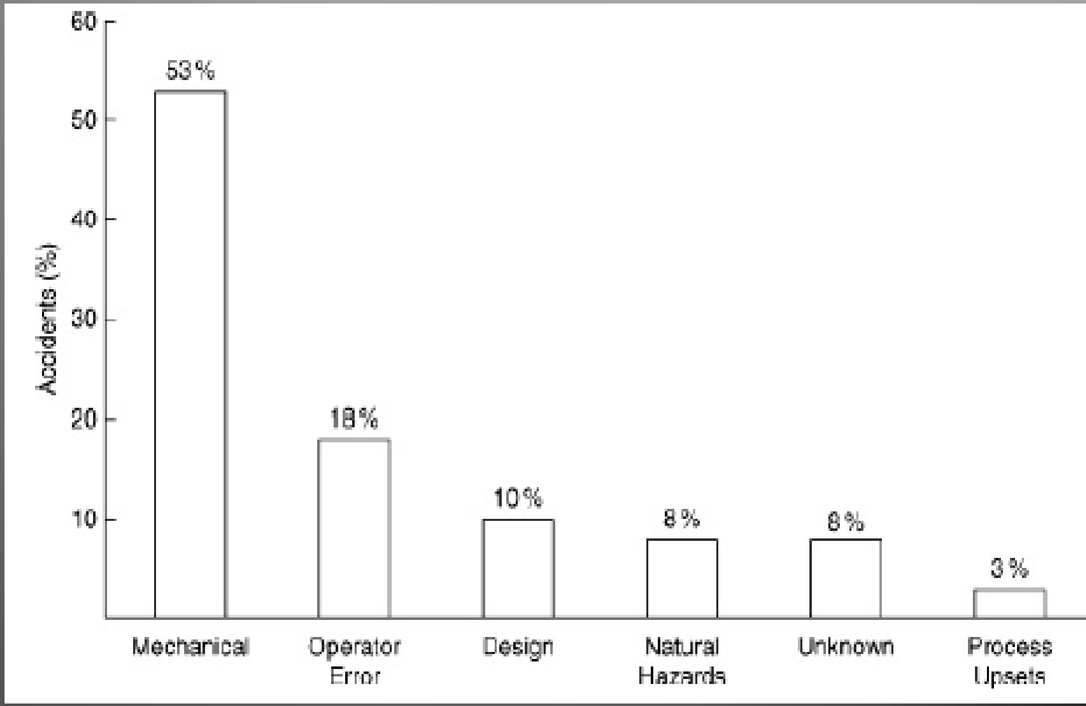
Three Types of Chemical Plant Accidents

- Economic loss consistently high explosions
- most damaging type of vapor cloud explosion



Causes of losses for largest hydrocarbon-chemical plant accidents

- By far the most mechanical failures, such as pipe failures due to corrosion, erosion, and high pressures, and seal/ gasket failures.
- Operator error example, valves are not opened or closed in the proper sequence or reactants are not charged to a reactor in the correct order



- OSHA published its final rule “Process Safety Management of Highly Hazardous Chemicals (PSM)
- Most accidents follow a three-step sequence:
  - Initiation (the event that starts the accident)
  - Propagation (the event or events that maintain or expand the accident), and
  - Termination (the event or events that stop the accident or diminish it in size)

Defeating the Accident Process

Step	Desired effect	Procedure
Initiation	Diminish	Grounding and bonding Inerting Explosion proof electrical Guardrails and guards Maintenance procedures Hot work permits Human factors design Process design Awareness of dangerous properties of chemicals
Propagation	Diminish	Emergency material transfer Reduce inventories of flammable materials Equipment spacing and layout Nonflammable construction materials Installation of check and emergency shutoff valves
Termination	Increase	Fire-fighting equipment and procedures Relief systems Sprinkler systems Installation of check and emergency shutoff valves

Definitions for Case Histories by
Center for Chemical Process Safety (CCPS), *Guidelines for Consequence Analysis*

Term	Definition
Accident	The occurrence of a sequence of events that produce unintended injury, death, or property damage. "Accident" refers to the event, not the result of the event.
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; not all events propagate into incidents; not all incidents propagate into accidents.
Consequence	A measure of the expected effects of the results of an incident.
Likelihood	A measure of the expected probability or frequency of occurrence of an event. This may be expressed as a frequency, a probability of occurrence during some time interval, or a conditional probability.

Definitions for Case Histories by
Center for Chemical Process Safety (CCPS),
Guidelines for Consequence Analysis

Risk	A measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury.
Risk analysis	The development of a quantitative estimate of risk based on an 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.
Scenario	A description of the events that result in an accident or incident. The description should contain information relevant to defining the root causes.

Inherent Safety

- A process that does not require complex safety interlocks and elaborate procedures is simpler, easier to operate, and more reliable.
- Smaller equipment, operated at less severe temperatures and pressures, has lower capital and operating costs.
- Safety of a process relies on multiple layers of protection. The first layer of protection
  - process design features.
  - Subsequent layers include control systems, interlocks, safety shutdown systems, protective systems, alarms, and emergency response plans.
- Inherent safety is a part of all layers of protection
- best approach to prevent accidents
  - Add process design features to prevent hazardous situations.
  - An inherently safer plant is more tolerant of operator errors and abnormal conditions.

Inherent Safety

- At these early stages process engineers and chemists have the maximum degree of freedom in the plant and process specifications
- Free to consider basic process alternatives, such as changes to the fundamental chemistry and technology
- The following four words are recommended to describe inherent safety:
    - Minimize (intensification)
    - Substitute (substitution)
    - Moderate (attenuation and limitation of effects)
    - Simplify (simplification and error tolerance)

Inherent Safety Techniques

Type	Typical techniques
Minimize (intensification)	Change from large batch reactor to a smaller continuous reactor Reduce storage inventory of raw materials Improve control to reduce inventory of hazardous intermediate chemicals Reduce process hold-up
Substitute (substitution)	Use mechanical pump seals vs. packing Use welded pipe vs. flanged Use solvents that are less toxic Use mechanical gauges vs. mercury Use chemicals with higher flash points, boiling points, and other less hazardous properties Use water as a heat transfer fluid instead of hot oil
Moderate (attenuation and limitation of effects)	Use vacuum to reduce boiling point Reduce process temperatures and pressures Refrigerate storage vessels Dissolve hazardous material in safe solvent Operate at conditions where reactor runaway is not possible Place control rooms away from operations Separate pump rooms from other rooms Acoustically insulate noisy lines and equipment Barricade control rooms and tanks
Simplify (simplification and error tolerance)	Keep piping systems neat and visually easy to follow Design control panels that are easy to comprehend Design plants for easy and safe maintenance Pick equipment that requires less maintenance Pick equipment with low failure rates Add fire- and explosion-resistant barricades Separate systems and controls into blocks that are easy to comprehend and understand Label pipes for easy "walking the line" Label vessels and controls to enhance understanding

Inherent Safety

- Minimizing entails reducing the hazards by using smaller quantities of hazardous substances in the reactors, distillation columns, storage vessels, and pipelines.

- Possible, hazardous materials should be produced and consumed in situ.
- Minimizes the storage and transportation of hazardous raw materials and intermediates.
- Toxic materials will not accumulate around leaking tanks. Smaller tanks also reduce the hazards of a release.

Inherent Safety

- Substitutions should also be considered as an alternative, safer materials should be used in place of hazardous ones.
- Using a hazardous material under less hazardous conditions
- Reduce the release concentration
- Refrigerating to lower the vapor pressure
- Handling larger particle size solids to minimize dust
- Processing under less severe temperature or pressure conditions

Seven Significant Disasters

Seven most cited accidents

- Flixborough, England;
- Bhopal, India;
- Seveso, Italy;
- Pasadena, Texas;
- Texas City, Texas;
- Jacksonville, Florida;
- Port Wentworth, Georgia

Flixborough accident is perhaps the most documented chemical plant disaster