SKF 4163 : Safety in Process Plant Design

Introduction to Chemical Process Safety

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When you gamble with safety,

you bet your life……….

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Introduction to Chemical Process Safety

Modern chemical plants use advanced and complex technology.

Chemical plants are the safest of all manufacturing facilities.

…….BUT …….

it has the potential for accident of CATASTROPIC proportions.

…….since we utilize advanced safety technology/tools for the complex chemical processes……..

We need engineers with,

Sound technical knowledge (fundamental and application) of process safety as well as

experiences in order to effectively apply the technology.

What is Safety?

- "Safety" used to mean:

  Strategy of accident prevention through the use of safety helmet, safety shoes and a variety of rules and regulation

  – the emphasis was on workers safety.

- Nowadays, “safety” is used synonymously with “loss prevention”:

The prevention of accidents through the use of appropriate technologies to identify the hazards of a chemical plant and eliminate them before an accident occurs….i.e. proactive….

- Safety also means freedom from unacceptable risk of harm [see ISO/IEC Guide]

Term	Definition
Accident	Undesired event giving rise to death, ill health, injury, damage or other loss
Incident	Event that gave rise to an accident or had potential to lead to an accident (not all incidents propagate into accidents) (An incident where no ill health, injury, damage, or other loss occurs is referred to as ‘near-miss’)

Term	Definition
Hazard	Source or situation (chemical or physical) with a potential to cause harm, injury or damage to either human, property or the environment or some combination of these. Mechanical hazards e.g. wet floor could cause tripping, moving equipment that could cause collision etc. Chemical hazards e.g. fuel leakage could cause fire, explosion, toxic fumes form hazardous chemical etc.

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Term	Definition
Risk	Combination of the likelihood (probability) of a specified hazardous event occurring and its consequences
Risk Assessment	Overall process of estimating the magnitude of risk and deciding whether or not the risk is tolerable

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What about process safety?

- To ensure safe design, installation, commission, and operation throughout the life of a plant.
- Need to identify all potential hazards or incident scenarios and to minimize all risks using loss prevention techniques such as:
  - inherent safety concept in design
  - hazard identification methods
  - technological advances using better design/ control
  - proper maintenance etc.

Notes

Any potential hazards need to be identified as early as possible so that action can be taken to correct or mitigate the situation.

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Safety Program

A successful safety program needs,

- System e.g. OSHMS, SHC, SHO, Policy, Regulation (Act) etc.
- Attitude or awareness
- Fundamentals (technical knowledge to design, construct, operate, maintain etc.)
- Experience (learn from past accident and experience of others)
- Time (to train, to set up system, to do hazard identification, risk assessment, documentation and review etc.)
- You….everyone should participate/contribute

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Engineering Professional Ethics

AICHE's Code of Professional Ethics

Fundamental principles

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

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Engineering Professional Ethics

AICHE's Code of Professional Ethics

Fundamental canons (for engineers)

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

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Accident and Loss Statistics

- Accident and loss statistics are used to measure the effectiveness of safety programs.

- Among statistical methods used to characterize accident and loss performance :
  1. **OSHA Incidence Rate**
  2. **Fatal Accident Rate** (FAR)
  3. **Fatality rate** or deaths per person per year

- These methods report number of accidents and/or fatalities for fixed number of workers during specified period.

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Here OSHA refers to,

Occupational Safety and Health Administration, USA

....i.e. similar to Department of Occupational Safety and Health (DOSH) in Malaysia

In Malaysia, the term OSHA stands for Occupational Health and Safety Act.

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Some glossary of terms used by OSHA (USA)

- **Occupational injury**- Any injury such as cut, fracture, sprain, amputation etc as a result from work accident or from exposure involving single incident in the work environment.
- **Occupational illness**- Any abnormal condition, caused by exposure to environment factors associated with employment. It includes acute and chronic illnesses or diseases that may be caused by inhalation, absorption, ingestion, or direct contact.
- **Lost workdays-** Days which employee normally work but could not because of occupational injury or illness. This day does not include the day of injury.

See Table 1-2 for more definitions

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More definitions...

- **Occupational safety – the protection of people/workers from physical injury**

- **Occupational health – the protection of the bodies and minds of people/ workers from illness**

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1. OSHA Incidence Rate (OSHA IR)

- Based on cases per 100 worker years.

$$1 \text{ worker year} = \frac{50 \text{ work weeks}}{\text{yr}} \frac{40 \text{ hrs}}{\text{week}} = 2000 \text{ hrs}$$

100 worker years = 100x2000 = 200,000 hrs worker exposure to hazard

- Two types of calculation

OSHA IR(1) : Based on injuries and illness (including fatalities)

OSHA IR(2) : Based on lost workdays

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OSHA Incidence Rate (OSHA IR)

$$\text{OSHA IR(1)} = \frac{\text{Number of injuries/illness/fatalities x 200000}}{\text{Total hrs work by all employees during period covered}}$$

$$\text{OSHA IR(2)} = \frac{\text{Number of lost workdays x 200000}}{\text{Total hrs work by all employees during period covered}}$$

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Examples,

1) A company with 100 workers recorded 10 injuries in one year.

$$\text{OSHA IR(1)} = \frac{10x200000}{100x2000} = 10$$

We could say OSHA IR as a number of injury per 200000 working hours or exposed hours

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Cont. Examples,

2) A company with 50 workers recorded 10 injuries in one year.

$$\text{OSHA IR(1)} = \frac{10x200000}{50x2000} = 20$$

3) A company with 10 workers recorded 10 injuries in one year.

$$\text{OSHA IR(1)} = \frac{10x200000}{10x2000} = 100$$

4) A company with 50 workers recorded 10 injuries in 6 months .

$$\text{OSHA IR(1)} = \frac{10x200000}{50x1000} = 40$$

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2. Fatal Accident Rates (FAR)

- FAR is used by British chemical industries. FAR data is widely available in open literature.
- Based on 1000 employees working for 50 years during their lifetime.

so, $1000 \times 50 \times 2000 = 10^8$ working hrs or exposed hrs

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

We could say FAR as no of deaths per 10^8 working hrs or exposed hrs.

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If a FAR for a construction industry is 5 for year 1990.

This means that if 1000 workers begin employment in the industry, 5 of the workers will die as a result of their employment throughout all of their working lifetimes (i.e. 50 years).

Check:

or

$$\text{FAR} = \frac{5x10^8}{1000x50x2000} = \frac{5x10^8}{10^8} = 5$$

We could say that for every 50000 workers in the construction industry in year 1990, 5 of them died in work related accident.

$$\text{FAR} = 5 = \frac{Yx10^8}{50000x2000}$$

$$Y = 5\ fatalities$$

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For example:

A rock climbing club has 1000 members working in chemical industry, on average each member spend 3 hrs/day driving and 2 hrs/month climbing. In 10 years how many member will die due to rock climbing, road accident and occupational accident.

$$\text{FAR} = \frac{\text{Number of fatalities x } 10^8}{\text{Total working hrs by all employees during period covered}}$$

in this case,

$$\text{FAR} = \frac{\text{Number of fatalities x } 10^8}{\text{Total exposed hrs by all members during 10 year period}}$$

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Answer:

ROCK CLIMBING

$$\text{Number of fatalities} = \frac{\text{FAR}}{10^8} \text{x(Total hrs climbing by all member in 10 years)}$$

$$\text{Number of fatalities} = \frac{4000}{10^8} \text{x}(1000\text{x}2\text{x}12\text{x}10) = 9.6 \text{ deaths}$$

ROAD ACCIDENT

$$\text{Number of fatalities} = \frac{\text{FAR}}{10^8} \text{x(Total hrs on the road by all member in 10 years)}$$

$$\text{Number of fatalities} = \frac{57}{10^8} \text{x}(1000\text{x}3\text{x}365\text{x}10) = 6.2 \text{ deaths}$$

ACCUPATIONAL ACCIDENT

$$\text{Number of fatalities} = \frac{\text{FAR}}{10^8} \text{x(Total hrs working by all member in 10 years)}$$

$$\text{Number of fatalities} = \frac{1.2}{10^8} \text{x}(1000\text{x}2000\text{x}10) = 0.24 \text{ deaths}$$

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3. FATALITY RATE

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

Unit for Fatality Rate is deaths/person.year

Easy to use if the number of working hrs or exposed hours is poorly defined.

FAR can be converted to Fatality Rate (or vice versa) if number of exposed hours is known. See next example.

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Ex:

An industry has a reported FAR of 57. If an employee works 8 hr shift 300 days per year, compute the deaths per person per year (or Fatality Rate).

$$
\begin{aligned}
\text{Fatality Rate} &= \text{(Exposed hrs per person per year)xFAR} \\
&= (8\text{hr/day})(300\text{day/yr})\ 57\text{deaths}/10^8\text{hr} \\
&= 1.368\text{x}10^{-3}\ \text{deaths/person.year}
\end{aligned}
$$

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Risk Acceptance and ALARP Concept

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Tolerable Risk

- Risk cannot be eliminated entirely.
- Every chemical process has a certain amount of risk associated with it.
- At some point in the design stage someone needs to decide if the risks are "tolerable".
- One tolerability criteria in the UK is **"As Low As Reasonably Practicable" (ALARP)** concept formalized in 1974 by United Kingdom Health and Safety at Work Act.
- **Tolerable risk** is also defined as the risk that has been reduced to a level that can be endured by the organization having regards to its legal obligations and its own OHS policy

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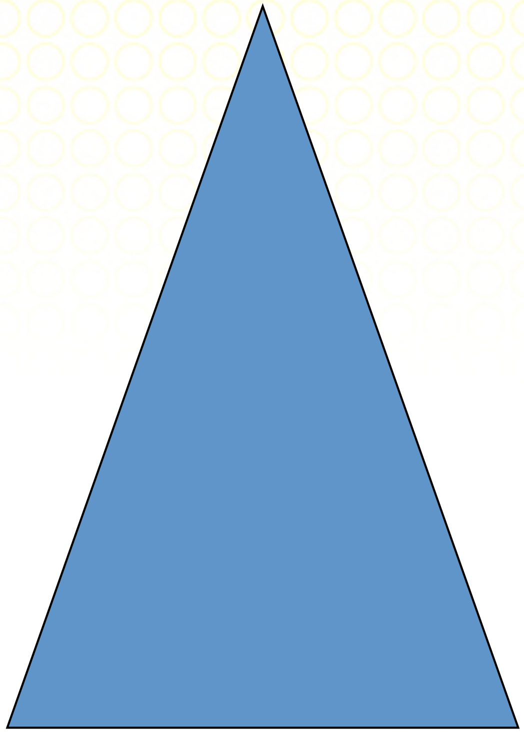
The Accident Pyramid

1	Death/Disabling injury
100	Minor Injury
500	Property Damage
10000	No Damage (near misses)



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Risk Category

- **Individual risk (IR)** is the frequency at which a given individual may be expected to sustain a given level of harm from specified hazard.

- **Occupational risk** is a risk that may happen at the work place. Usually given in term of FAR. It has been suggested that IR ~ 2.2×10^{-5} xFAR.

- **Societal risk** is frequencies with which specified numbers of people in a given population sustain a specified level of harm from specified hazards.

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Tolerability Criteria

This framework is represented as a three-tier system as shown in figure. It consists of several elements :

(1) **Intolerable level**: Beyond the upper-bound on individual (and possibly, societal) risk levels

(2) **Tolerable (ALARP)** region between (1) and (3), risk is undertaken only if benefit is desired after considering the cost on individual and societal risk reductions.

(3) **Negligible risk** (acceptable region): below the lower-bound on individual (and possibly, societal) risk levels. This level not to warrant regulatory concern.

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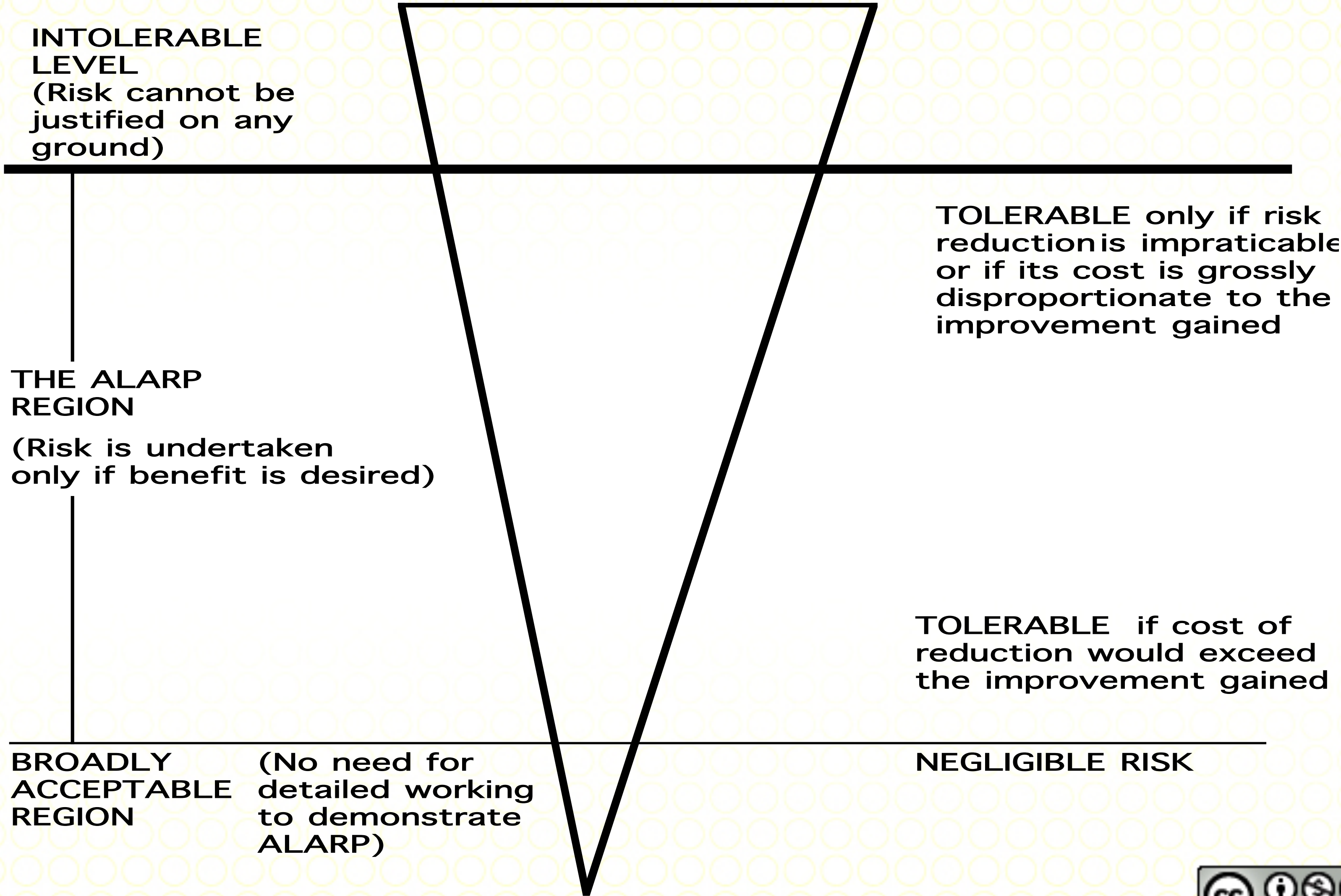
ALARP Criteria



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Public Perceptions

- From one survey, 28% say chemicals do more good than harm, 29% say more harm than good, 38% say same amount of good and harm.
- Some naturalists suggest eliminating chemical plant hazards by "returning to nature" e.g. to eliminate synthetic fibers production and use natural fibers such as cotton….. but FAR for agriculture is actually higher than for chemical industry.

See table 1-3

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Cause of Accident

Accidents have direct, indirect and root causes:

- Direct cause – attribute to equipment failure or unsafe operating conditions
- Indirect cause – not as readily apparent and can generally be tied to some human failure
- **Root cause** – result of poor management safety policies, procedures or decisions

Note:

This causes do not include natural hazards such as flood and windstorm etc.

Three Type of Chemical Plant Accidents

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 (equipment) Other such as cleanup, legal etc can be high

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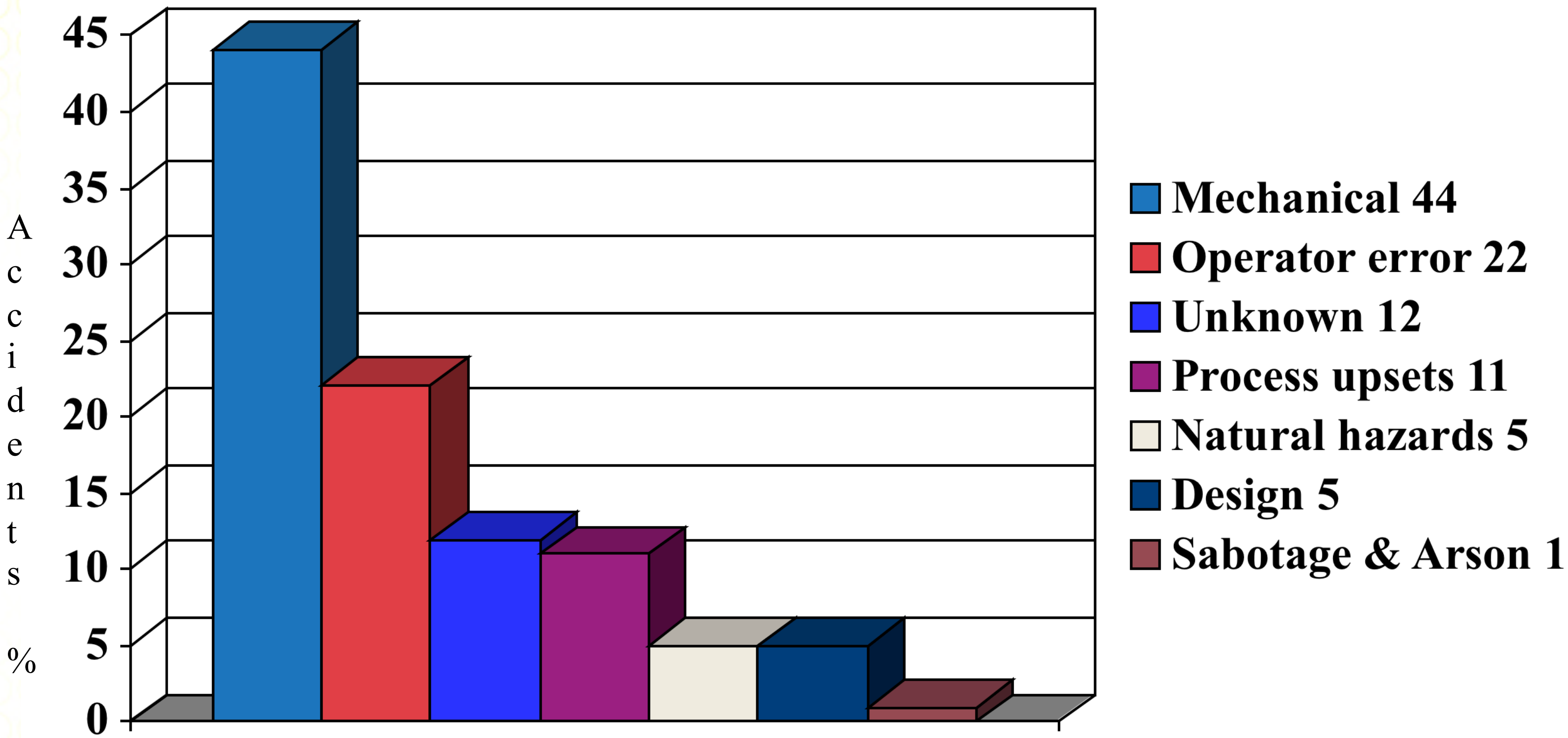
Causes of Losses (accidents) associated with 100 of the largest property damage losses in hydrocarbon-chemical industry: A thirty-year review



Note: Except for natural hazards, all of these causes can be traced back to human error.

Losses here mean accidents.

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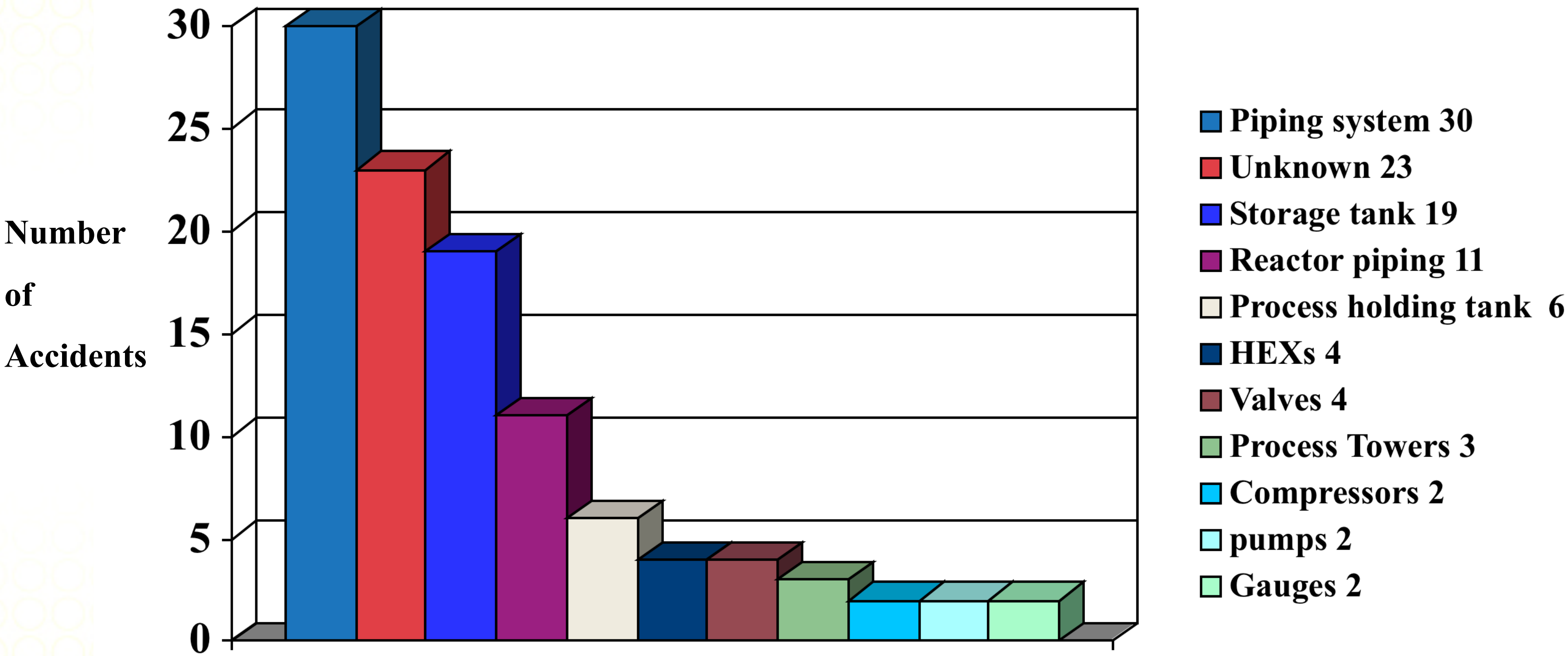
Hardware associated with 100 of the largest property damage losses in hydrocarbon-chemical industry: A thirty-year review



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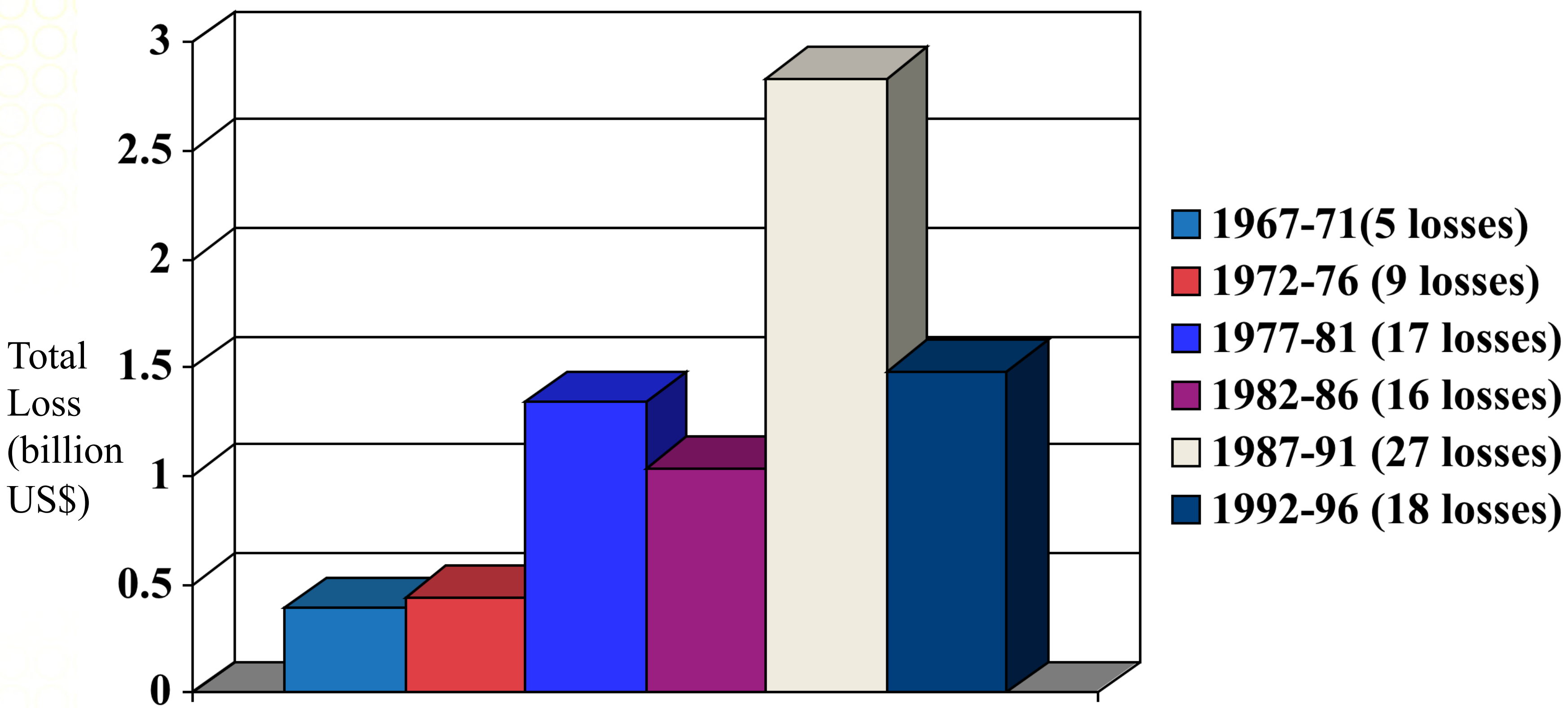
Loss distribution for onshore accidents for 5-year intervals over 30-year period



Note: OSHA legislation on Process Safety Mgmt of Highly Hazardous Chemicals was introduced (in USA) in the year 1992

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Defeating the Accident Process

Steps (Accident process or sequence of accident))	Desired effect	Procedure (to defeat the accident process)
Initiation (the event that starts the accident)	Diminish (eliminate this step if possible)	Grounding & bonding Inerting Explosion proof electrical Guardrails Maintenance procedure Hot work permits Human factor design Process design Awareness of dangerous properties of chemicals
Propagation (the events that maintain/expand the accident)	Diminish (stop propagation)	Emergency material transfer Reduce inventories of flammable materials Equipment spacing and layout Nonflammable construction materials Installation of check & emergency valves
Termination (the events that stop the accident)	Increase (to terminate as quickly as possible)	Firefighting equipment and procedures Relief systems Sprinkler systems Installation of check and emergency shutoff valves

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Introduction to Risk Ranking

Determination of Risk

Risk = Severity x Likelihood

- **Extent of Damage**
- **Probability of Fatality**

- Based on design and modeling equations

- **Likelihood of failure**
- **Historical data**

- Based on design and historical data

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Risk is expressed as Rating

- Rating is typically
  - simple to use and understand
  - Not require extensive knowledge to use
  - Have consistent likelihood ranges that cover the full spectrum of potential scenarios
- In applying risk assessment
  - Clear guidance on applicability is provided
  - Detailed descriptions of the consequences of concern for each consequence range should be described
  - Have clearly defined tolerable and intolerable risk levels
- Following risk assessment
  - Scenarios that are at an intolerable risk level can be mitigated to a tolerable risk level on the matrix
  - Clear guidance on what action is necessary to mitigate scenarios with intolerable risk levels are provided

Example of Multiple Consequences for a Consequence Range

Description	Category	Environmental, Safety, and Health Result Criteria
Catastrophic	I	Could result in death, permanent total disability, loss exceeding $1M, or irreversible severe environmental damage that violates law or regulation.
Critical	II	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding $200K but less than $1M, or reversible environmental damage causing a violation of law or regulation.
Marginal	III	Could result in injury or occupational illness resulting in one or more lost work days(s), loss exceeding $10K but less than $200K, or mitigatible environmental damage without violation of law or regulation where restoration activities can be accomplished.
Negligible	IV	Could result in injury or illness not resulting in a lost work day, loss exceeding $2K but less than $10K, or minimal environmental damage not violating law or regulation.

Example of Likelihood Ranges

Description*	Level	Specific Individual Item	Fleet or Inventory**
Frequent	A	Likely to occur than 10^{-1} in that life.	Continuously experi-enced.
Probable	B	Will occur several times in the life of an item, with a probability of occurrence less than 10^{-1} but greater than 10^{-2} in that life.	Will occur frequently.
Occasional	C	Likely to occur some time in the life of an item, with a probability of occurrence less than 10^{-2} but greater than 10^{-3} in that life.	Will occur several times.
Remote	D	Unlikely but possible to occur in the life of an item, with a probability of occurrence less than 10^{-3} but greater than 10^{-6} in that life.	Unlikely, but can rea-sonably be expected to occur.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced, with a probability of occurrence less than 10^{-6} in that life.	Unlikely to occur, but possible.

Example Risk Ranking Categories

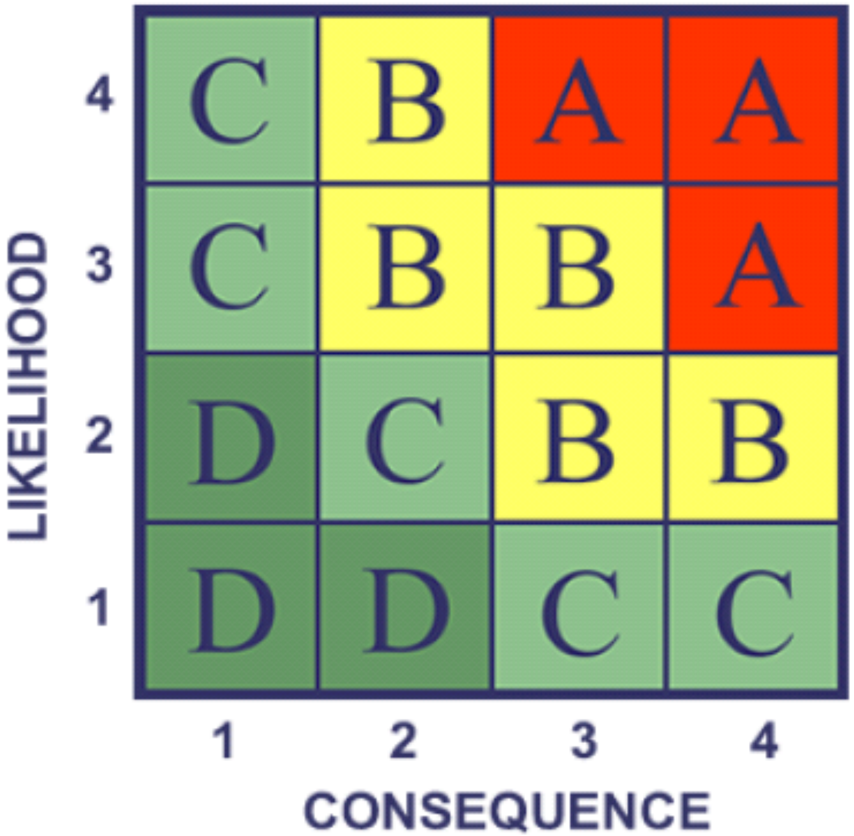
Risk Rank	Category	Description
I	Unacceptable	Should be mitigated with engineering and/or administrative controls to a risk ranking of III or less within a specified period such as six months
II	Undesirable	Should be mitigated with engineering and/or administrative controls to a risk ranking of III or less within a specified period such as 12 months
III	Acceptable with controls	Should be verified that procedures or controls are in place
IV	Acceptable as is	No mitigation required

Typical Consequence Range Criteria

Consequence Range	Qualitative Safety Consequence Criteria
Level 4	Onsite or offsite: Potential for multiple life-threatening injuries or fatalities. Environment: Uncontained release with potential for major environmental impact Property: Plant damage value in excess of $100 million
Level 3	Onsite or offsite: Potential for a single life-threatening injury or fatality. Environment: Uncontained release with potential for moderate environmental impact Property: Plant damage value in the range of $10-100 million
Level 2	Onsite or offsite: Potential for an injury requiring a physician's care. Environmental: Uncontained release with potential for minor environmental impact Property: Plant damage value in the range of $1-10 million
Level 1	Onsite: Potential restricted to injuries requiring no more than first aid. Offsite: Odor or noise complaint Environment: Contained release with local impact Property: Plant damage value in the range of $0.1 to 1 million

Risk Matrix

Risk = Probability of occurrence x Consequence of occurrence



In Chemical Health Risk Assessment (CHRA):

Risk Rating (RR) is calculated as,

$$RR = \sqrt{(HR \times ER)}$$

HR: Hazard Rating

ER: Exposure Rating

To be covered later……..

Example of Major Disasters

Major Disaster

- **Flixborough, England 1974**

Failure of temporary bypass pipe connecting reactor 4 to reactor 6 (this occurred while the reactor 5 was undergoing repair)

Resulting in the release of 30 tons of liquid cyclohexane

Forming vapor clouds that exploded, killing 28 people, injured 36. It was on saturday.

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Major Disaster

Bhopal, India 1984

Contaminated methyl isocynate (MIC) caused runaway reaction, temperature rise….. as well as pressure.

Vapor released through pressure relief system but the scrubber and flare systems failed to function. 25 tons of MIC vapor released.

Toxic cloud spread nearby town poisoning/killing 2500 civilian, injured more than 20,000. No plant workers were injured or killed.

No plant equipment was damaged. The owner was Union Carbide.

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Major Disaster

- **Seveso, Italy 1976**

  Reactor out of control, produced excessive side product of extremely toxic TCDD (dioxin).

  2 kg of vapor TCDD released to atmosphere through relief system and heavy rain washed into soil.

  250 people suffered from chloracne (skin disease).

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The Way Forward

- Safety comes first !!!
- Two Important Elements
  - Human Factor
    We Need Good Safety Management Practice
  - Safe Design
    Need to Incorporate Inherently Safe Design
- This class will look at both issues and more!

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Reference

- Crowl, Daniels A. and Louvar, Joseph F., Chemical Process Safety: Fundamentals with Applications, Prentice Hall, 1990, New Jersey, USA.