Introduction to Safety in Chemical Process Industry

- Chemical Process, Chemical Engineering, Safety/Risk/Hazard/Loss -

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Middle East Technical University - NCC


H.S.E Policy
Health, Safety and Environment (HSE) Policy
2Q 2011 Financial Results
ABOUT TÜPRAŞ
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BOARD OF DIRECTORS
MESSAGE FROM GM
EXECUTIVES
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ANNUAL REPORTS
MATERIAL DISCLOSURES
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MEDIA RELATIONS
Press releases and corporate introduction documents can be followed from this page
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CSR REPORT
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TO CONTACT
HUMAN RESOURCES
Tupras implements an evaluation system based on content-based job assessment that is independent of title and function
HR VISON
HR POLICIES
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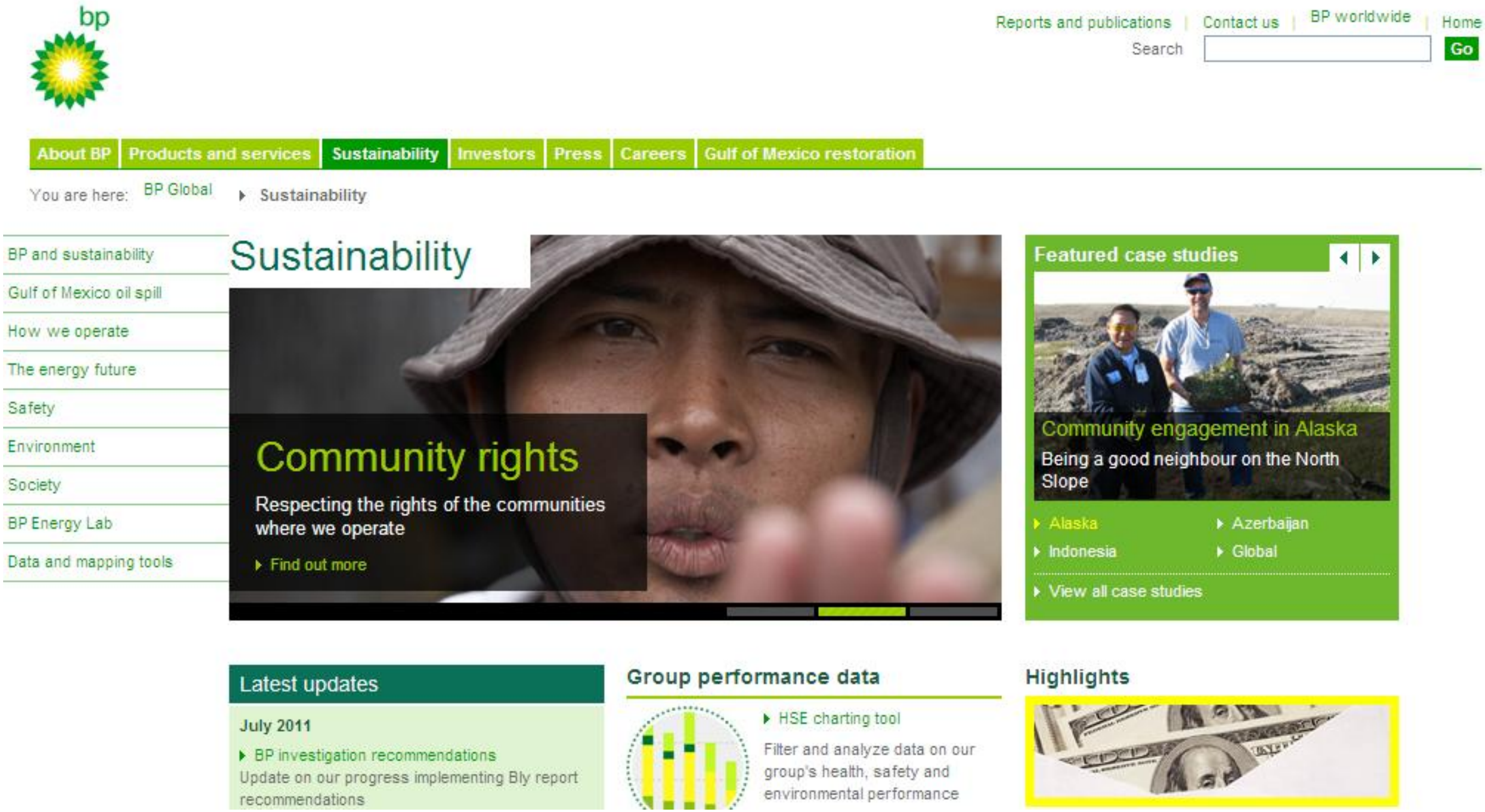
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The energy we supply helps to support economic growth and development. At our operations we aim to address social concerns and work to benefit local communities, protecting our reputation as we do business.
Environment
Through partnerships with environmental experts and by using new
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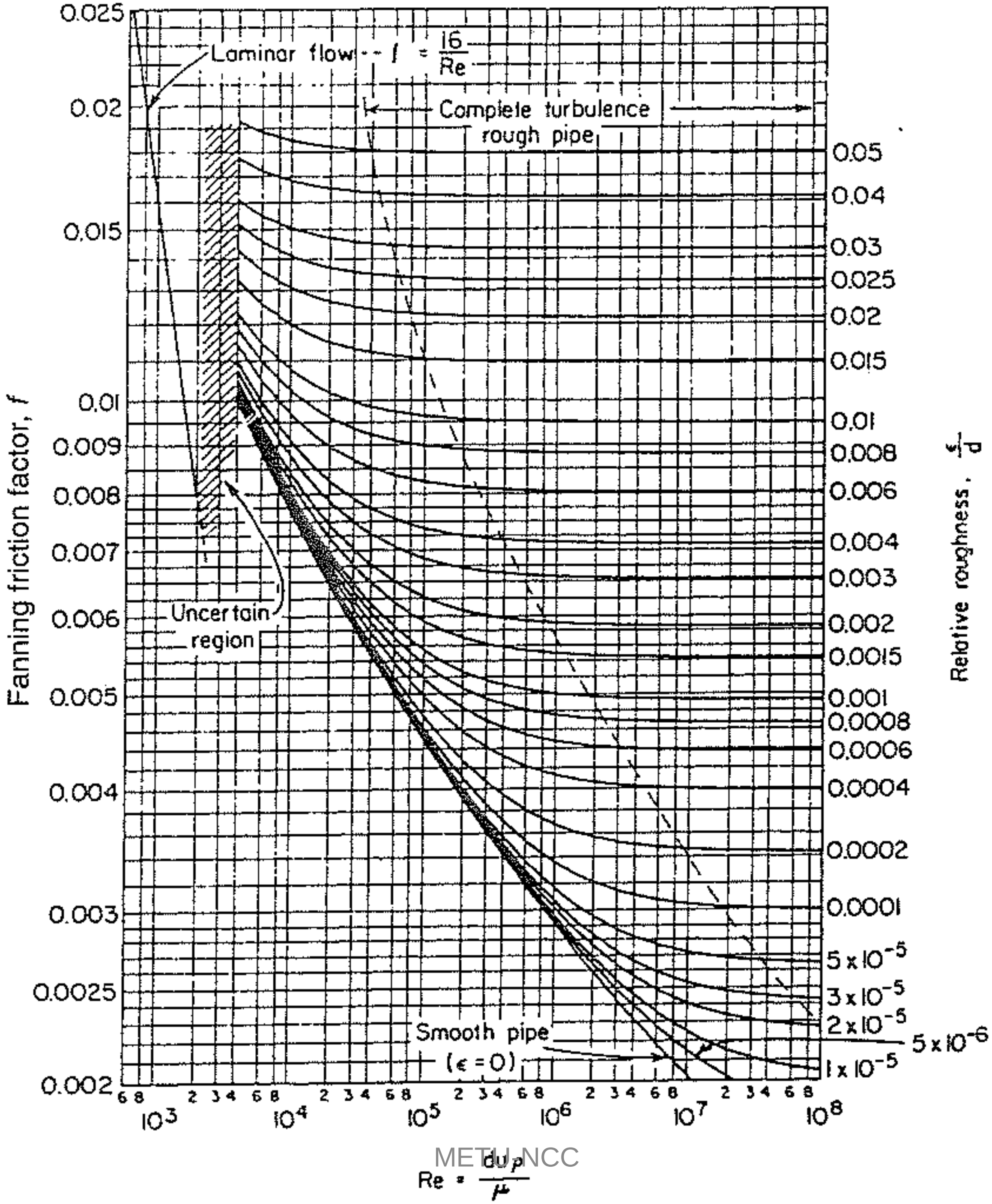


Laminar flow $f = \frac{16}{Re}$
Complete turbulence rough pipe
Uncertain region
Smooth pipe ($\epsilon = 0$)
Fanning friction factor, f
Relative roughness, $\frac{\epsilon}{d}$
$Re = \frac{du\rho}{\mu}$
0.025
0.02
0.015
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.0025
0.002
0.05
0.04
0.03
0.025
0.02
0.015
0.01
0.008
0.006
0.004
0.003
0.002
0.0015
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
5×10^{-5}
3×10^{-5}
2×10^{-5}
5×10^{-6}
1×10^{-5}
10^3
10^4
10^5
10^6
10^7
10^8

Rev. Processes Involving Ideal Gas

- **Summary**

Process	Isometric ($V = \text{const.}$)	Isobaric ($P = \text{const.}$)	Isothermal ($T = \text{const.}$)	Adiabatic ($P\widetilde{V}^{\gamma} = \text{const.}$)
P-$\widetilde{V}$-T Relation	$\frac{P_1}{P_2} = \frac{T_1}{T_2}$	$\frac{\widetilde{V}_1}{\widetilde{V}_2} = \frac{T_1}{T_2}$	$\frac{P_1}{P_2} = \frac{\widetilde{V}_2}{\widetilde{V}_1}$	$\frac{T_2}{T_1} = \left(\frac{\widetilde{V}_1}{\widetilde{V}_2}\right)^{\gamma-1}$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$
$\widetilde{W}$	0	$-R\,\Delta T$ $-P\,\Delta\widetilde{V}$	$-RT\ln\left(\frac{\widetilde{V}_2}{\widetilde{V}_1}\right)$ $-RT\ln\left(\frac{P_1}{P_2}\right)$	$\frac{R\,\Delta T}{\gamma - 1}$ $\frac{\Delta(P\widetilde{V})}{\gamma - 1}$
$\widetilde{Q}$	$\widetilde{C}_V^*\,\Delta T$	$\widetilde{C}_P^*\,\Delta T$	$RT\ln\left(\frac{\widetilde{V}_2}{\widetilde{V}_1}\right)$ $RT\ln\left(\frac{P_1}{P_2}\right)$	0
$\Delta\widetilde{U}$	$\widetilde{C}_V^*\,\Delta T$	$\widetilde{C}_V^*\,\Delta T$	0	$\widetilde{C}_V^*\,\Delta T$
$\Delta\widetilde{H}$	$\widetilde{C}_P^*\,\Delta T$	$\widetilde{C}_P^*\,\Delta T$	0	$\widetilde{C}_P^*\,\Delta T$

Isentropic Expansion

Incorporate friction term:

$$\int \frac{dP}{\rho} + F = C_1^2 \left(\int \frac{dP}{\rho} \right)$$

$$C_1^2 \int_{P_o}^{P} \frac{dP}{\rho} + \frac{\bar{u}^2}{2\alpha g_c} = 0$$

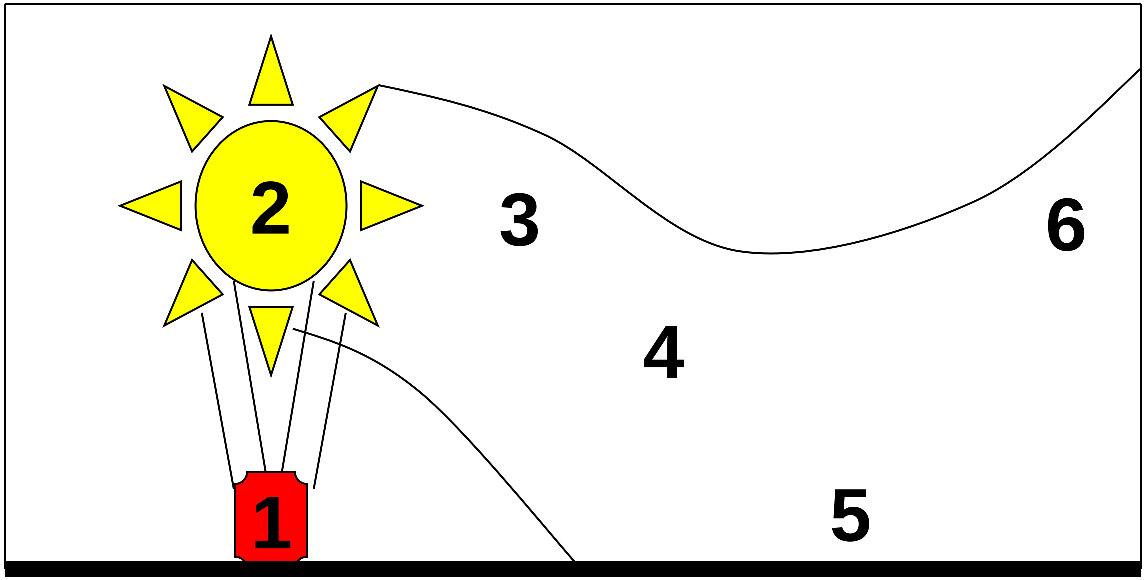
Ideal gas, isentropic expansion: $\frac{P}{\rho^\gamma}$ **= a,** $\gamma = C_p / C_v$

Integrate and solve for $\bar{u}$ **Mass flow rate:**

$$Q_m = C_o A P_o \sqrt{\frac{2 g_c M}{R_g T_o} \frac{\gamma}{\gamma - 1} \left[\left(\frac{P}{P_o} \right)^{2/\gamma} - \left(\frac{P}{P_o} \right)^{(\gamma+1)/\gamma} \right]}$$

Exposure to Release

Predict effects of exposure near the surface.

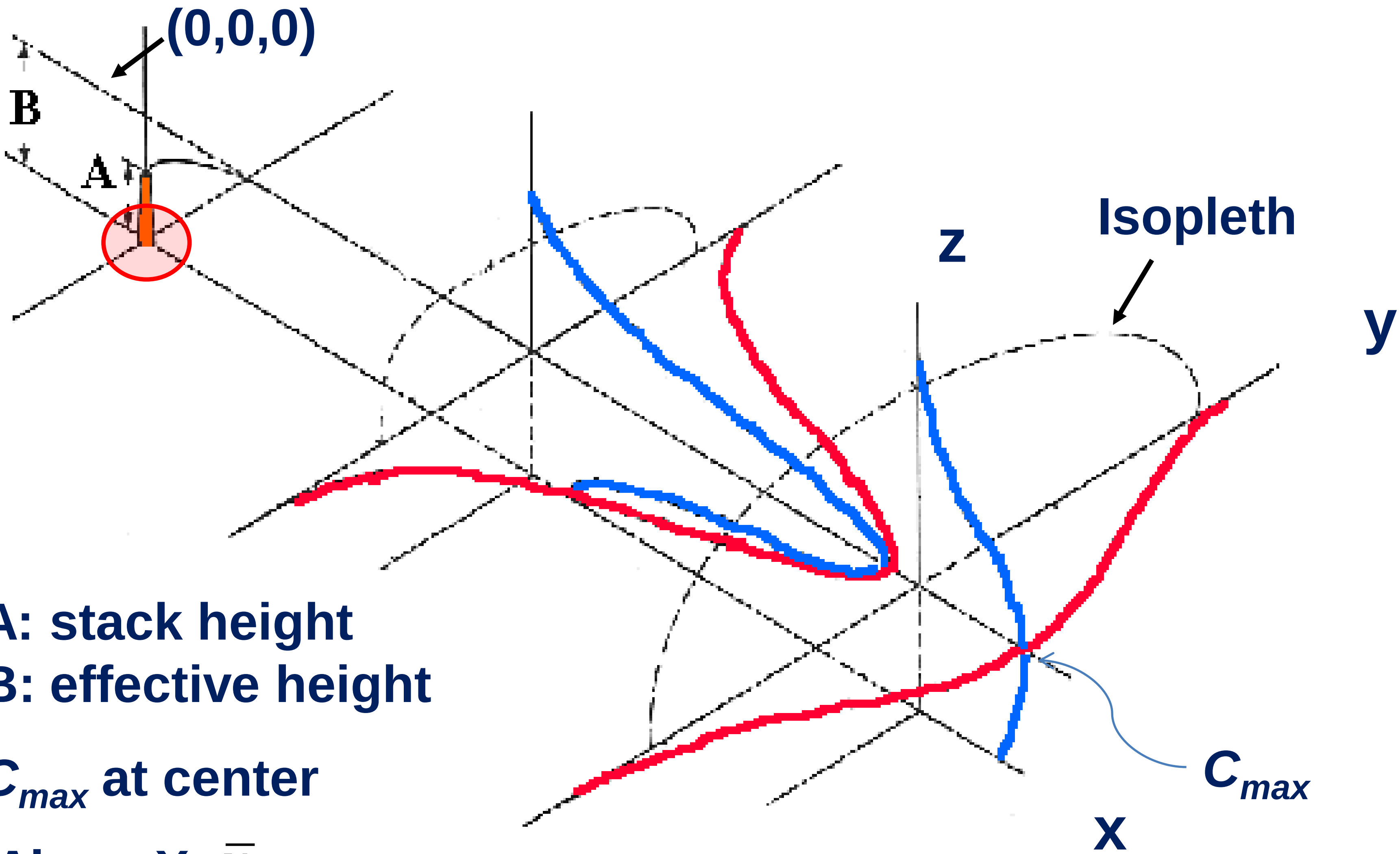


Stages

1. Source
2. Acceleration, Diffusion
3. Gravity
4. Transition
5. Surface
6. Turbulence

Predict % affected by the exposure.

Gaussian Dispersion Pattern



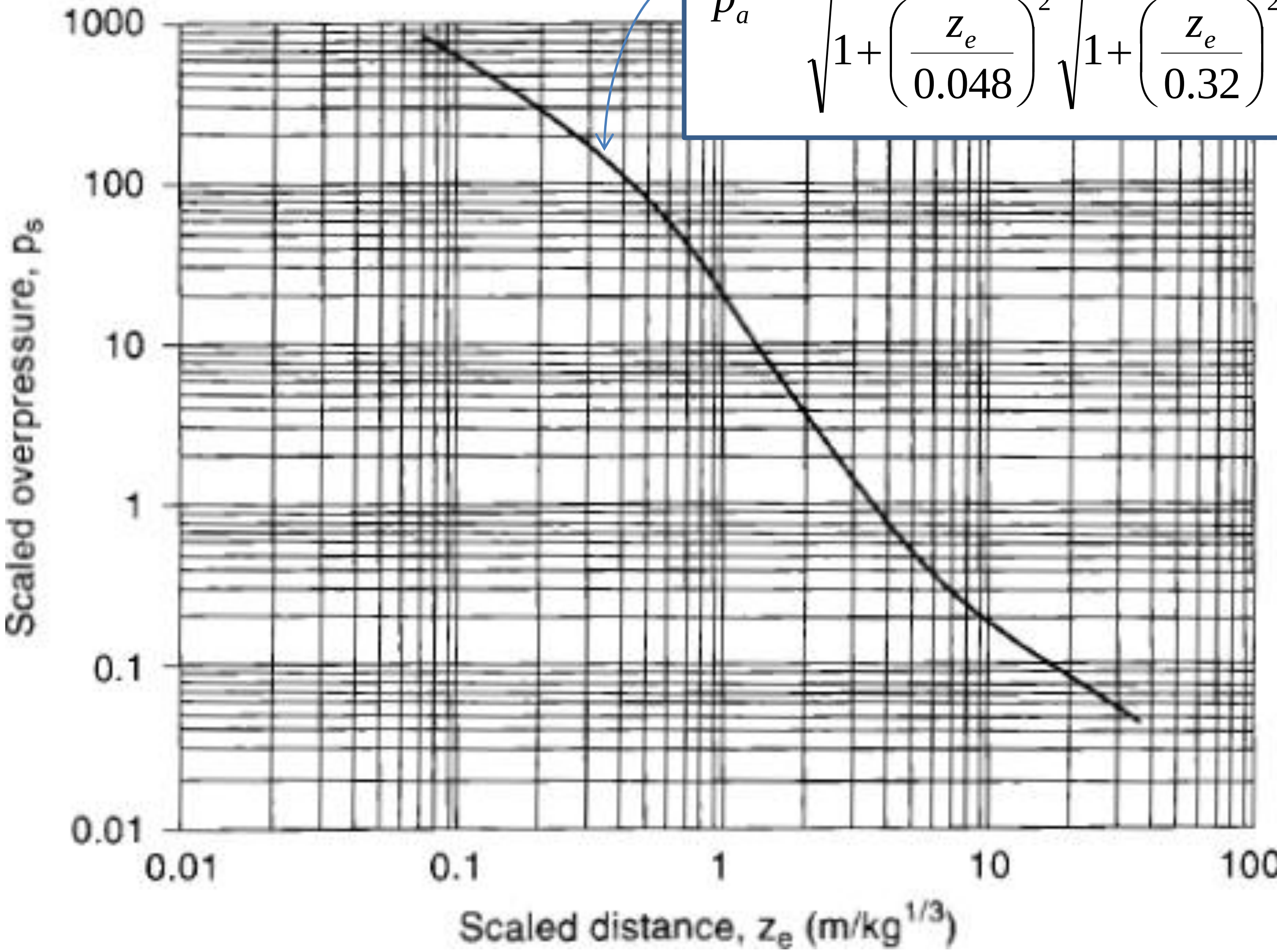
A: stack height

B: effective height

C_{max} at center

Along X $\bar{u}$

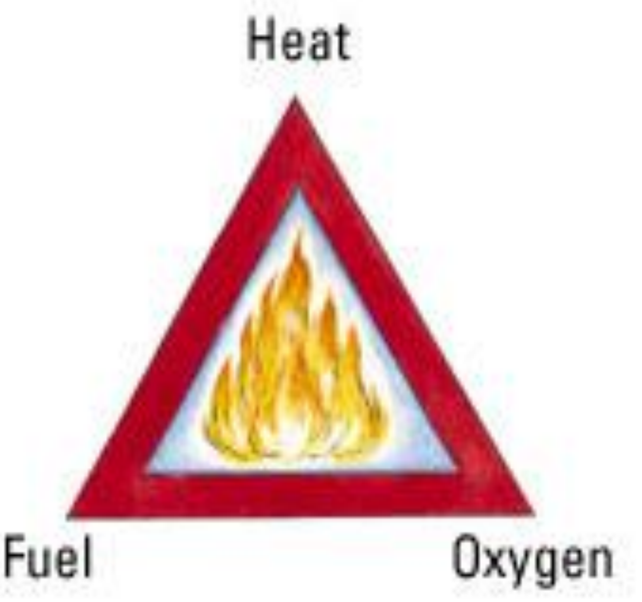
$$\frac{p_o}{p_a} = \frac{1616\left[1+\left(\frac{z_e}{4.5}\right)^2\right]}{\sqrt{1+\left(\frac{z_e}{0.048}\right)^2}\sqrt{1+\left(\frac{z_e}{0.32}\right)^2}\sqrt{1+\left(\frac{z_e}{1.35}\right)^2}}$$



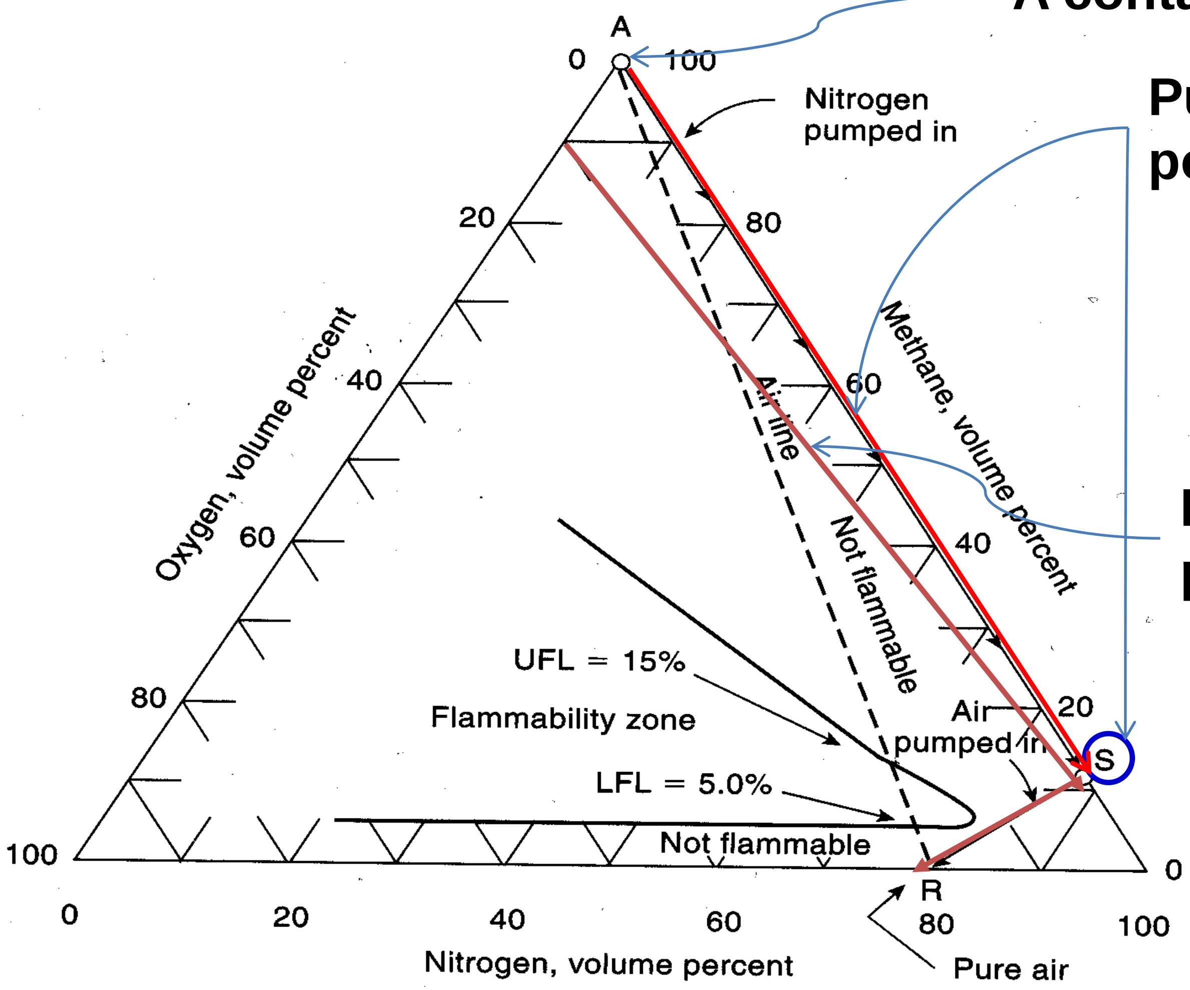
Objective

Prevent the initiation of the fire or explosion and minimize the damage produced after it.

- **How can it be prevented?**
  - **Inerting**
  - **Control static electricity**
  - **Ventilation**
  - **Explosion–proof equipment**



Flammability Diagram - OSFC



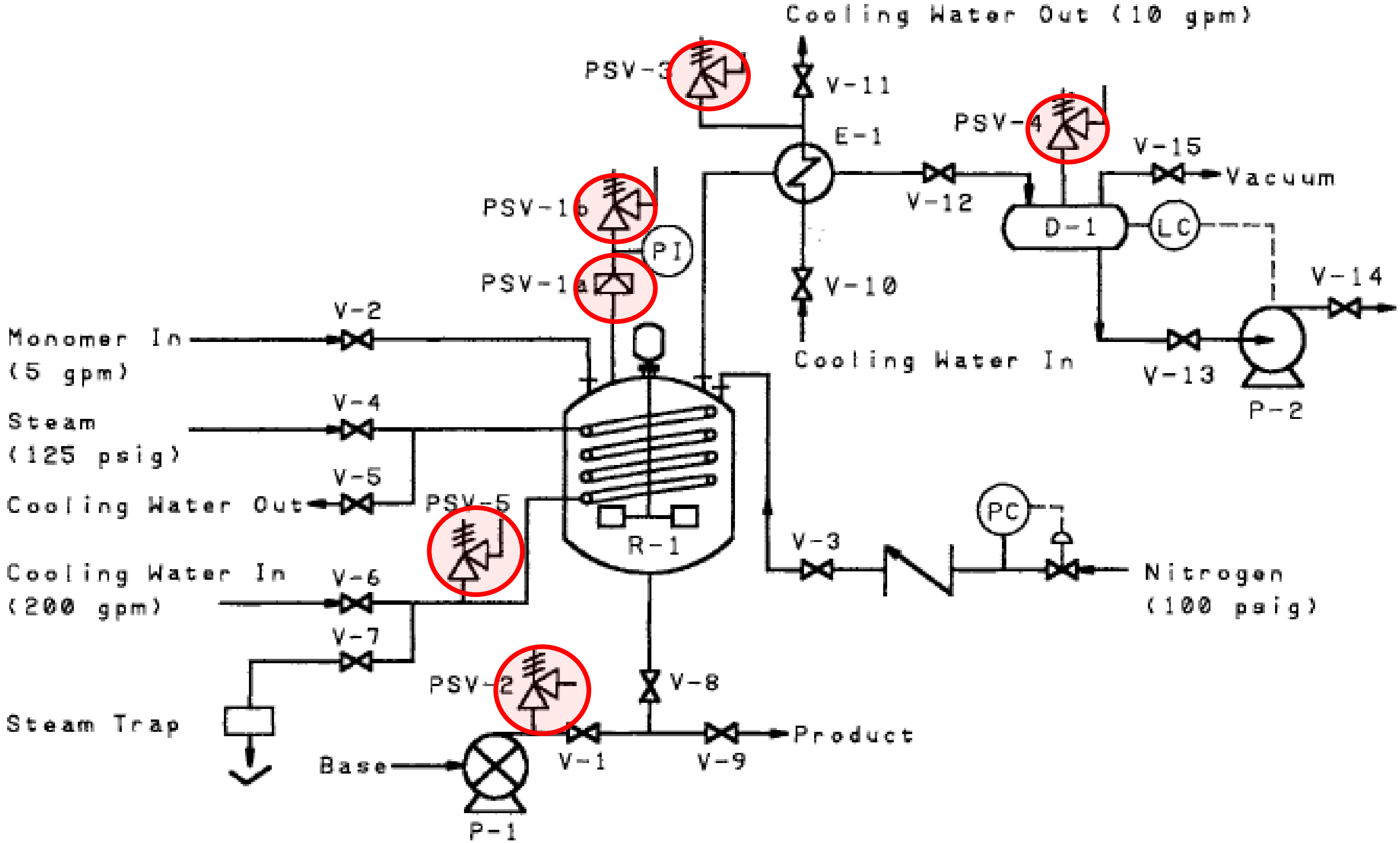
A contains pure fuel

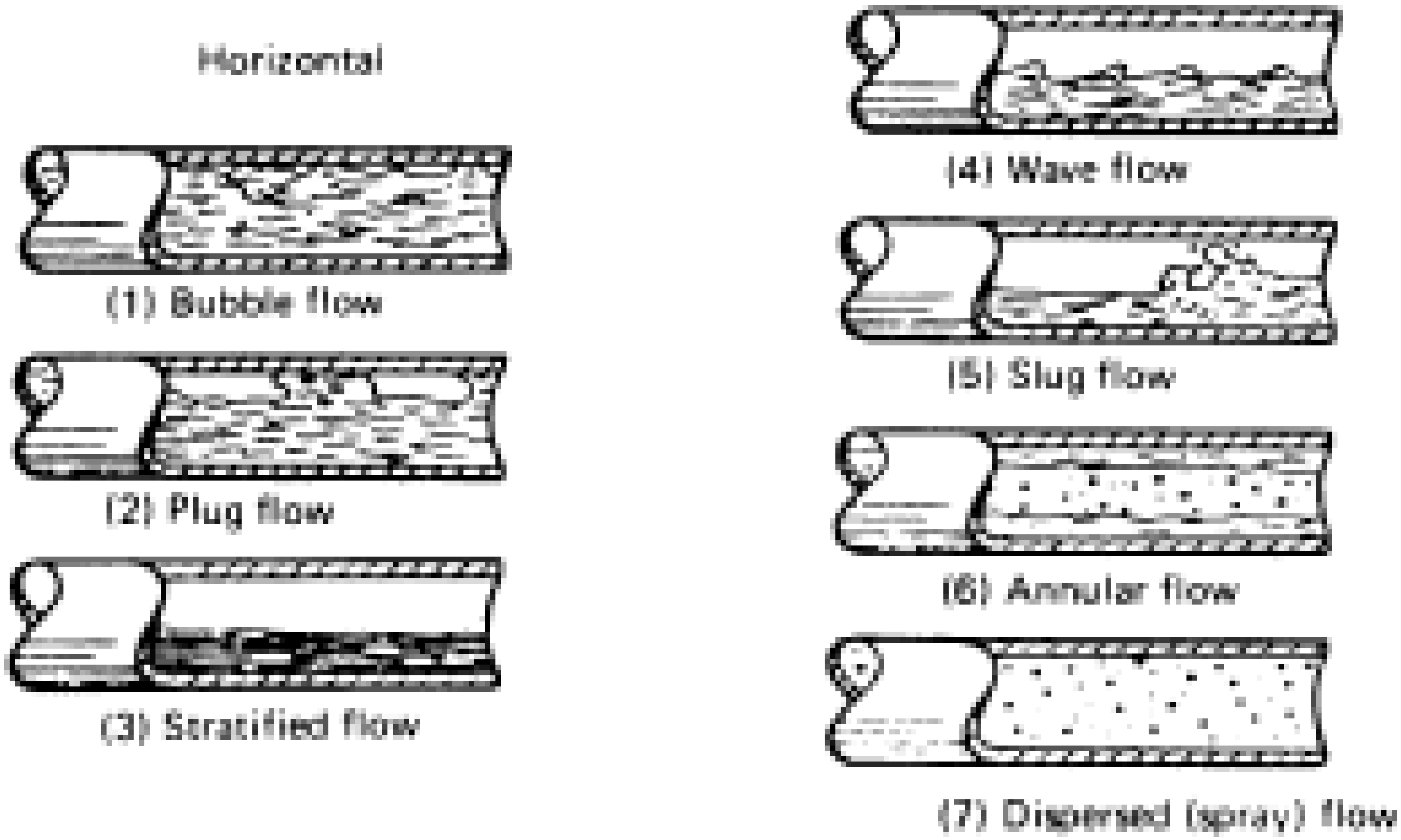
Pure N_2 added till point S, OSFC

Requires a large amount of nitrogen ⇒ costly

Pure N_2 added till point S, OSFC

the air forms a flammable mixture at the entry point


Cooling Water Out (10 gpm)
PSV-3
V-11
E-1
PSV-4
V-15
Vacuum
PSV-1b
V-12
D-1
LC
PI
PSV-1a
V-10
V-14
V-2
Monomer In
(5 gpm)
Cooling Water In
V-13
P-2
V-4
Steam
(125 psig)
V-5
Cooling Water Out
PSV-5
PC
R-1
V-3
Nitrogen
(100 psig)
Cooling Water In
(200 gpm)
V-6
V-7
PSV-2
V-8
Steam Trap
Product
Base
V-1
V-9
P-1



Patterns of two phase flow

Chemical Process &
Chemical Process Industry

Chemical Industry: Products

- **Polyurethane mattress, polyester sheets**
- **Plastic clock, nylon carpet, phenolic switch**
- **Polyvinyl chloride insulated conductors**
- **Sanitized water, soap, refrigerants**
- **Fertilizers, printing inks, paper**
- **Electrical components in TV, radio**

Adapted: R.E. Sanders, *Chemical Process Safety*, Butterworth-Heinemann (1999)

Chemical Product Groups

- Food, shelter, health
- Electronics, computing, communications
- Biotechnology, pharmaceuticals
- Automobiles, appliances, furniture
- Paper, textiles, paint
- Agriculture, construction

Chemical Industry: History I

Early to 5,000 BC

- **First industrial chemical process: fire**
- **Burning wood for heat, cooking food**
- **Firing pottery, bricks**

History adapted from: R.E. Sanders,
***Chemical Process Safety*,**
Butterworth-Heinemann (1999)

Chemical Industry: History II

3,000 - 4,000 BC

- **Chemical: soda ash (sodium carbonate)**
- **Arabic name for soda: *al kali***
- **Process: burning seaweeds & seashore vegetation including kali**
- **Hot water extraction to form brown lye**
- **Products: beads,**

  glass ornaments, soap

Chemical Industry: History III

Prior to 3,000 BC

- Alcoholic fermentation
- Ale, wine (grapes, dates, palm), cider
- Egypt, Sumerian

Early Living Standards

10th Century in Europe

- Life expectancy: ~ 30 years
- Food scarce, monotonous, often stale or spoiled
- Much labor required with few rewards
- Gradually the practice of science reduced the burdens of existence

Chemical Industry: History IV

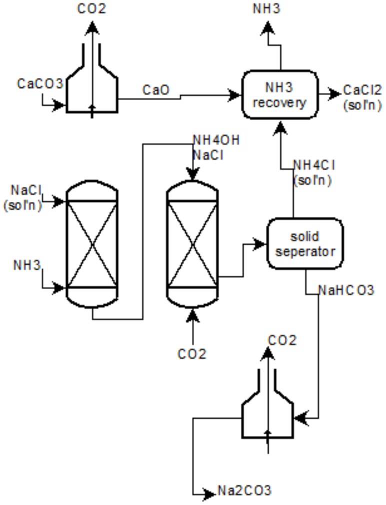
17th and 18th Centuries

- **Food preservatives (inorganic chemicals)**
- **Dyes, fabrics, soap**
- **Gunpowder**
- **First American chemical plant in Boston, 1635, made saltpeter (potassium nitrate): gunpowder, tanning of hides**

Chemical Industry: Na_2CO_3

18th Century

- Nicolas LeBlanc process (Paris, 1791) for soda ash from salt, NaCl. First large-scale process
- HCl: first large-scale industrial pollution
- From 1861-1880 was gradually replaced by Solvay Process (simpler & less expensive)



Chemical Industry: History V

Modern Era

- After 1850: coal-tar dyes, drugs, nitroglycerin explosives
- Celluloid plastics, fiber
- Lightweight metals
- Synthetic rubber
- Fuels





Chemical Industry: History VI

1930's

- Neoprene, polyethylene, nylon, fiberglass

After 1945

- Rapid expansion of petroleum refining and chemical process industries
- Use, handling, & storage of chemicals presented more potential hazards

Chemical Industry: History VII

After 1950

- **Chemical processing more disciplined**
- **Larger inventories, higher T, P conditions**
- **More emphasis on design & process changes**
- **More review of effects from modifications**
- **Today: U.S. & European chemical industries among safest of all industries**

What is a Chemical Engineer?

a) An ***Engineer*** **who manufactures chemicals**

b) A ***Chemist*** **who works in a factory, or**

c) A glorified ***Plumber*?**

d) "None of the above"

(However, chemical engineering students bored with the relentless "pipe-flow example" during fluid dynamics class may begin to think of themselves as simply "glorified plumbers")

All Right, So What is a Chemical Engineer?

- **Who are comfortable with chemistry.**
- **But they do much more with this knowledge than just make chemicals.**
- **Who draws upon the vast and powerful science of chemistry to solve a wide range of problems.**
- **Sometimes described as the "universal engineer"**

So What Exactly Does This "Universal Engineer" Do?

- **During the past Century, chemical engineers have made tremendous contributions to our standard of living. To celebrate these accomplishments, the American Institute of Chemical Engineers (AIChE) has compiled a list of the "10 Greatest Achievements of Chemical Engineering."**

The Atom, as Large as Life:

- **Ability to split the atom and isolate isotopes**
  - **Biology, medicine, metallurgy, and power generation**
  - **production of the atomic bomb**
  - **use isotopes to monitor bodily functions**
  - **accurately date their historical findings**

The Plastic Age:

- **Mass produced polymers = Plastic Age**
  - **A viable economic reality**
  - **Bakelite -1908**

  - Electric insulation, plugs & sockets, clock bases, iron cooking handles, and fashionable jewelry

The Human Reactor:

- "Unit operations" consisting of heat exchangers, filters, chemical reactors and the like = Human body.
- Improve clinical care
  - Diagnostic and therapeutic devices
  - Artificial organs

Wonder Drugs for the Masses:

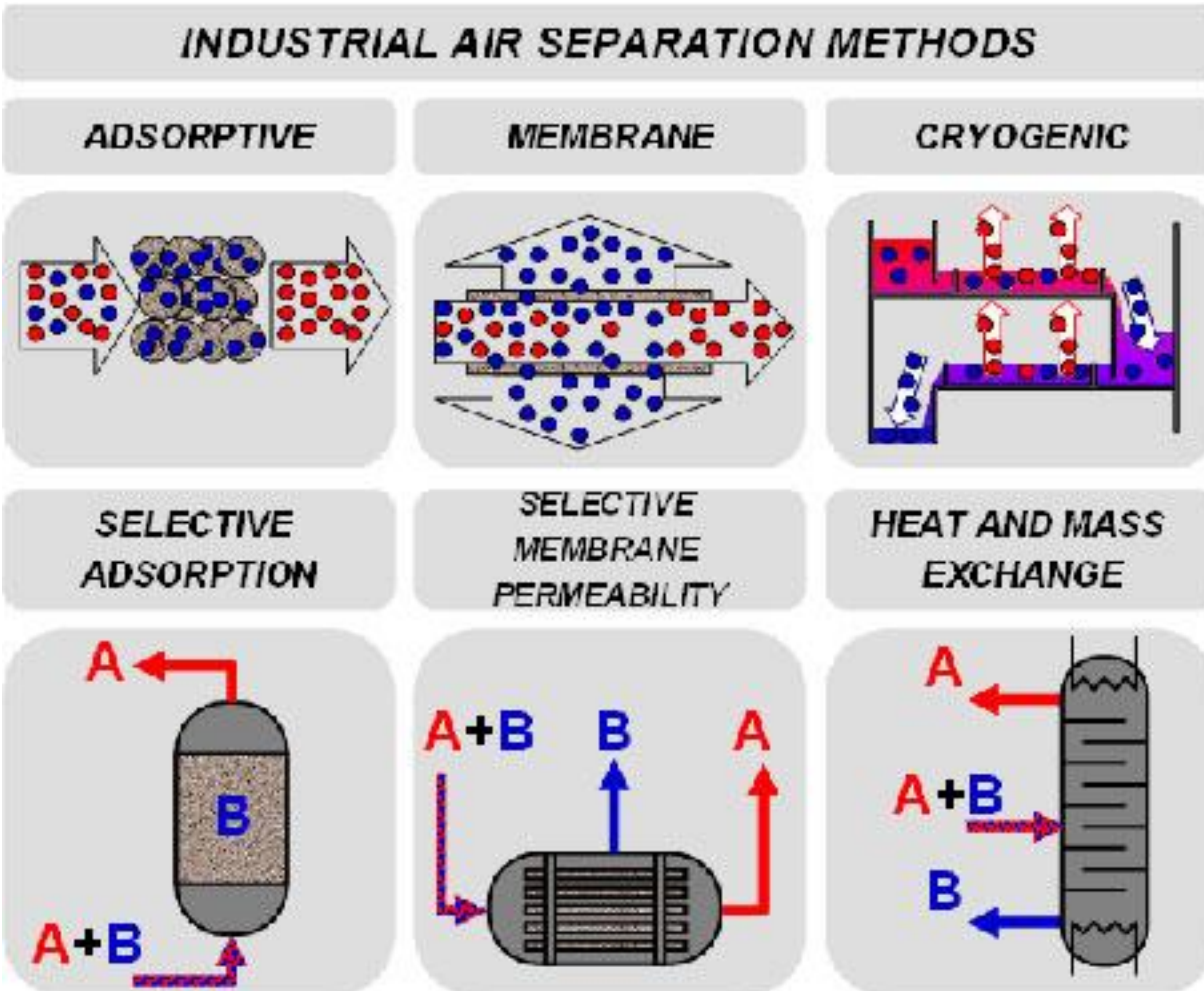
- Mutation and special brewing techniques
  - increase antibiotics' yields
- Low price, high volume, drugs enables.

Synthetic Fibers, a Sheep's Best Friend:

- **Keep us warm, comfortable, and provide a good night's rest**
- **Help reduce the strain on natural sources of cotton and wool tailored to specific applications.**
  - **Nylon stockings make legs look young and attractive**
  - **Bullet proof vests keep people out of harm's way.**

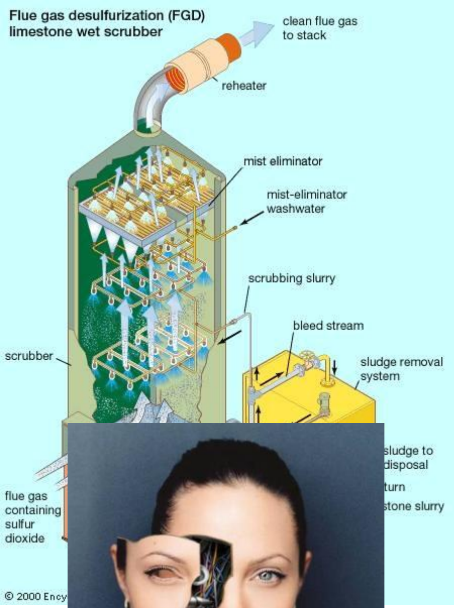
Liquefied Air, Yes it's Cool:

- **Air separation**
  - **Purified nitrogen; to recover petroleum, freeze food, produce semiconductors, or prevent unwanted reactions**
  - **Oxygen; to make steel, smelt copper, weld metals together, and support the lives of patients in hospitals.**


INDUSTRIAL AIR SEPARATION METHODS
ADSORPTIVE
MEMBRANE
CRYOGENIC
SELECTIVE ADSORPTION
SELECTIVE MEMBRANE PERMEABILITY
HEAT AND MASS EXCHANGE
A
B
A+B
A+B
B
A
A
A+B
B

The Environment

- **Provide economical answers to clean up yesterday's waste and prevent tomorrow's pollution.**
  - **Catalytic converters**
  - **Reformulated gasoline**
  - **Smoke stack scrubbers**
  - **Synthetic replacements**
  - **More efficient processing, and new recycling technologies**



Food, "It's What's For Dinner":

- Chemical fertilizers can help provide these nutrients to crops
- Forefront of food processing where they help create better tasting and most nutritious foods

Petrochemicals, "Black Gold, Texas Tea":

- **Form many useful products from petroleum by developing processes like catalytic cracking**
  - **gasoline, lubricating oils, plastics, synthetic rubber, and synthetic fibers**

Running on Synthetic Rubber:

- **Developing today's synthetic rubber industry**
  - **During World War II, synthetic rubber capacity suddenly became of paramount importance.**
  - **Tires, gaskets, hoses, and conveyor belts (not to mention running shoes)**

Chemical Engineering Today & Tomorrow

- **The highest paid of the "Big Four" (civil, mechanical, electrical, chemical)**
- **Upper management position**
  - **3M, Du Pont, General Electric, Union Carbide, Dow Chemical, Exxon, BASF, Gulf Oil, Texaco, and B.F. Goodrich**
- **70,000 practicing chemical engineers in the United States**

Safety & Process Safety

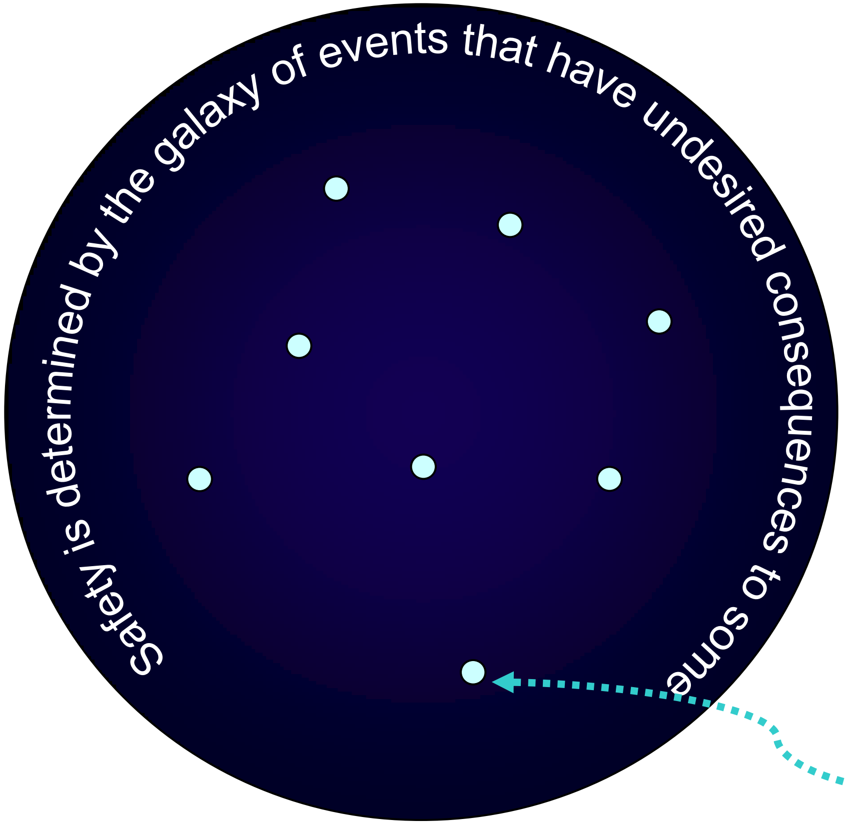
The superior man, when resting in safety, does not forgot that danger may come…. When all is orderly, he does not forget that disorder may come.

Confucius (551 BC – 479 BC)

Basic Terms I

- ***Safety***: **prevention of loss incidents by identification, control, or elimination of hazards**
- ***Hazard***: **A physical situation with a potential for human injury, damage to property, damage to the environment, or some combination of these**
- ***Risk***: **The likelihood of a specified undesired event occurring within a specified period or in specified circumstances.**
  - ***Nomenclature for Hazard and Risk Assessment in the Process Industries*** **- David Jones, UK Institution of Chemical Engineers, 1992**

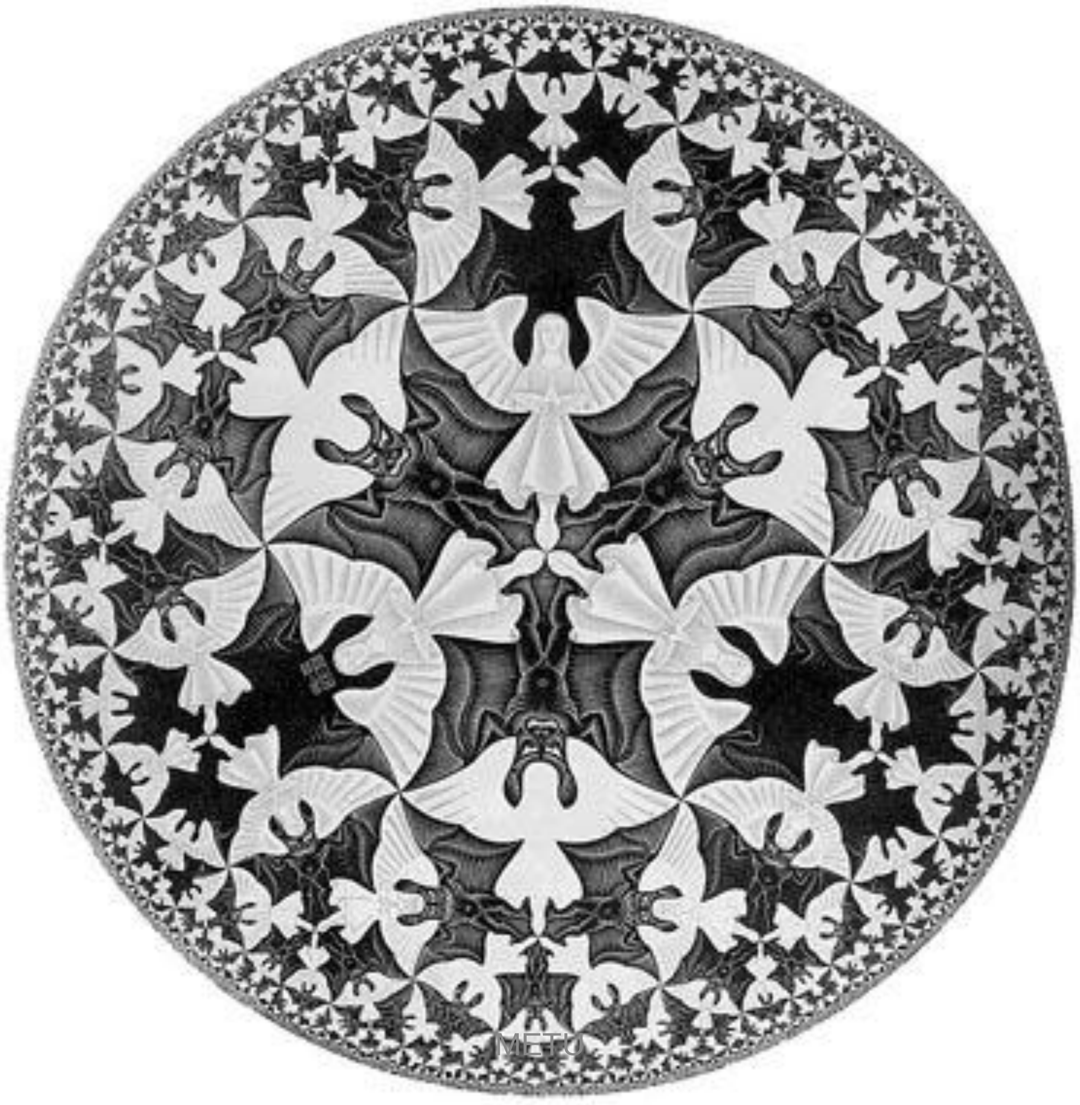
Basic Terms II



Risk deals with well defined events(○) about which norms have been negotiated amongst different stakeholders. Technology must be designed such that these norms are met.

True and Perceived Risks 0

True and Perceived Risks 0



True and Perceived Risks I

- Probability of deaths by disaster (tornado, plane crash) overestimated by the public
- More ordinary risks (auto accident, smoking, stroke, heart attack) are underestimated
  - ☞ Public ranks disease and accidents ~ equally, but disease causes ~ 15 times more deaths.

True and Perceived Risks II

- 400,000 smoking-related deaths/year
- 40,000 deaths/year on U.S. highways
- An airline crash with 300 deaths draws far more attention over a longer time.

True and Perceived Risks III

- Example: Three years old kid killed in water knee-deep by an alligator: reported nationally
  - Only 7 recorded fatalities by alligator
- Primary hazards were minimum supervision and shallow water.
- In 1995, 300 children under 4 years old drowned at home: reported locally

Voluntary or Involuntary

- Choice affects perceived risk.
  - Accept risk by coercion vs. by choice
  - Accept the risk of smoking
  - Voluntarily drive a motorcycle
  - Protest a plant with a much smaller risk

Moral or Immoral

- **Deaths by moral means are more acceptable than by immoral means**
- **Far more driving deaths than murders per year but murder is much less acceptable.**

Detectable *vs* Undetectable Risks I

- People fear the undetected or the risks that may take years to appear.
  - Collapse of a dam in India (1979) killed thousands and perhaps more than killed in the Bhopal tragedy (1984)
  - People are concerned far more about chemical engineering than civil engineering disasters.

Detectable *vs* Undetectable Risks II

- **Water is a familiar chemical, so hazards are less noticed or are accepted.**
- **Pesticides and radioactivity poorly understood, so they are feared.**
- **NIMBY, BANANA**
- **PIMFY**

Not in My Back Yard

Build Absolutely Nothing Anywhere Near Anybody

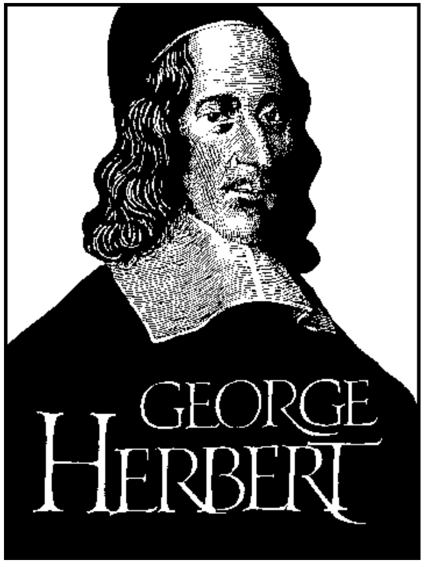
Please in My Front Yard

Safety Program

- System
  - To record what needs to be done to have an outstanding safety program
- Attitude
  - Positive attitude
- Fundamentals
  - Understand and use the fundamentals of chemical process safety in the design, construction and operation of their plants
- Experience
  - Read and understand case histories of past accident
- Time
  - Time to study, time to do work, time to share experience
- You
  - Take the responsibility to contribute to the safety program

Impact of Accidents

- All for the want of a nail…..



For want of a nail, the shoe was lost,
For want of a shoe, the horse was lost,
For want of a horse, the rider was lost,
For want of a rider, a message was lost,
For want of a message, the battle was lost,
For want of a battle, the kingdom was lost,
And all for the want of a nail…..

George Herbert, in outlandish proverbs(1640)


OPPAU, 21.09.1921,
GERMANY

Oppau

- **Location: Oppau, Germany**
- **Company: BASF**
- **Date: September 21, 1921**
- **Killed: 430**
- **Injured: unknown**
- **Financial: N/A**
- **Type of Plant: Fertilizer**

- **Trigger: Blasting Powder being used to break up a 50:50 mixture of ammonium sulfate and ammonium nitrate**

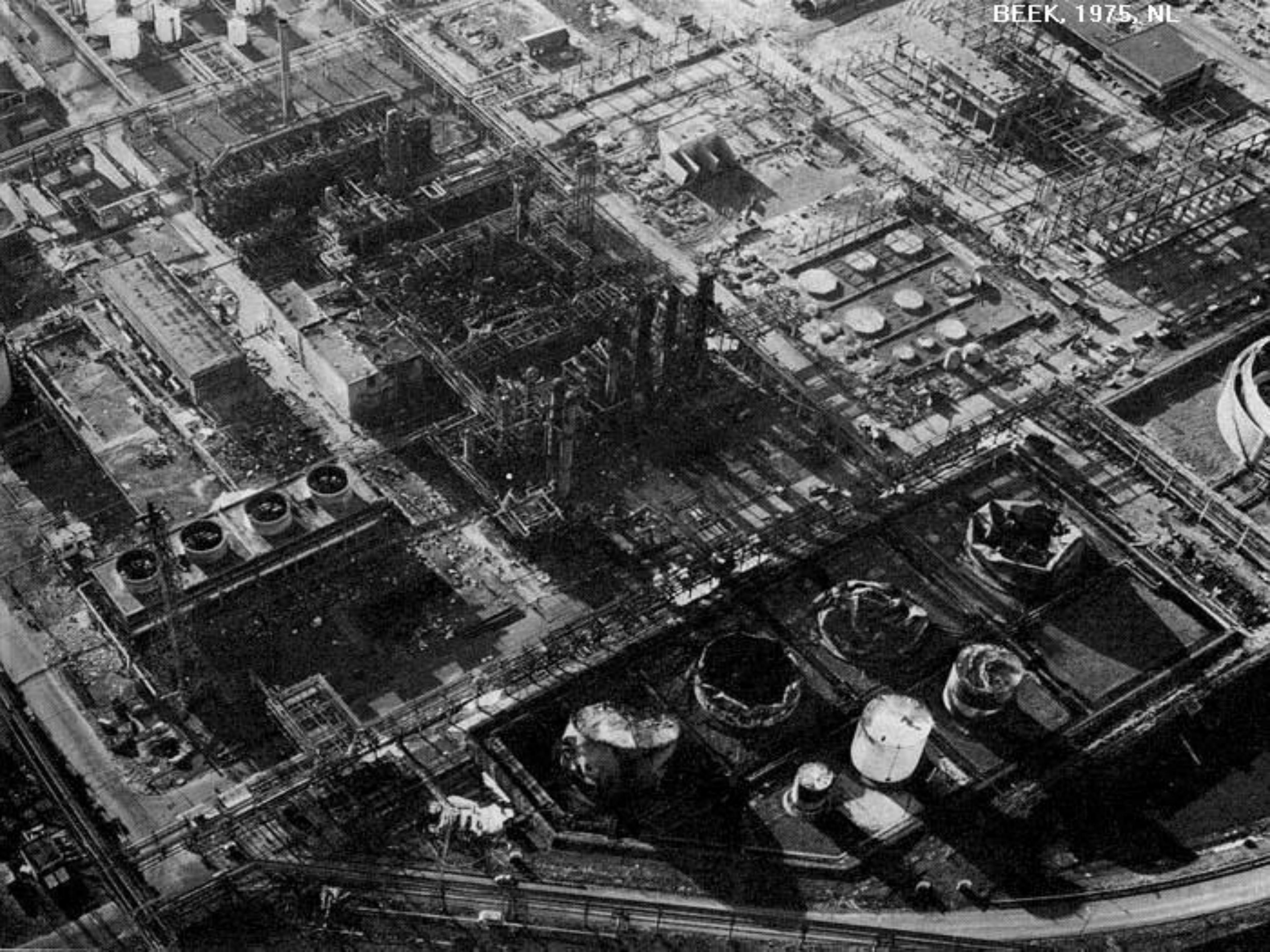
Texas City

- **Location: Texas City, Texas, USA**
- **Company: Monsanto**
- **Date: April 16, 1947**
- **Killed: 552**
- **Injured: about 3000**
- **Financial: N/A**
- **Type of Plant: petrochemical**
- **Trigger: fire on ship at dock – ammonium nitrate**


FILXBOROUGH, 01.06.1974,
UK

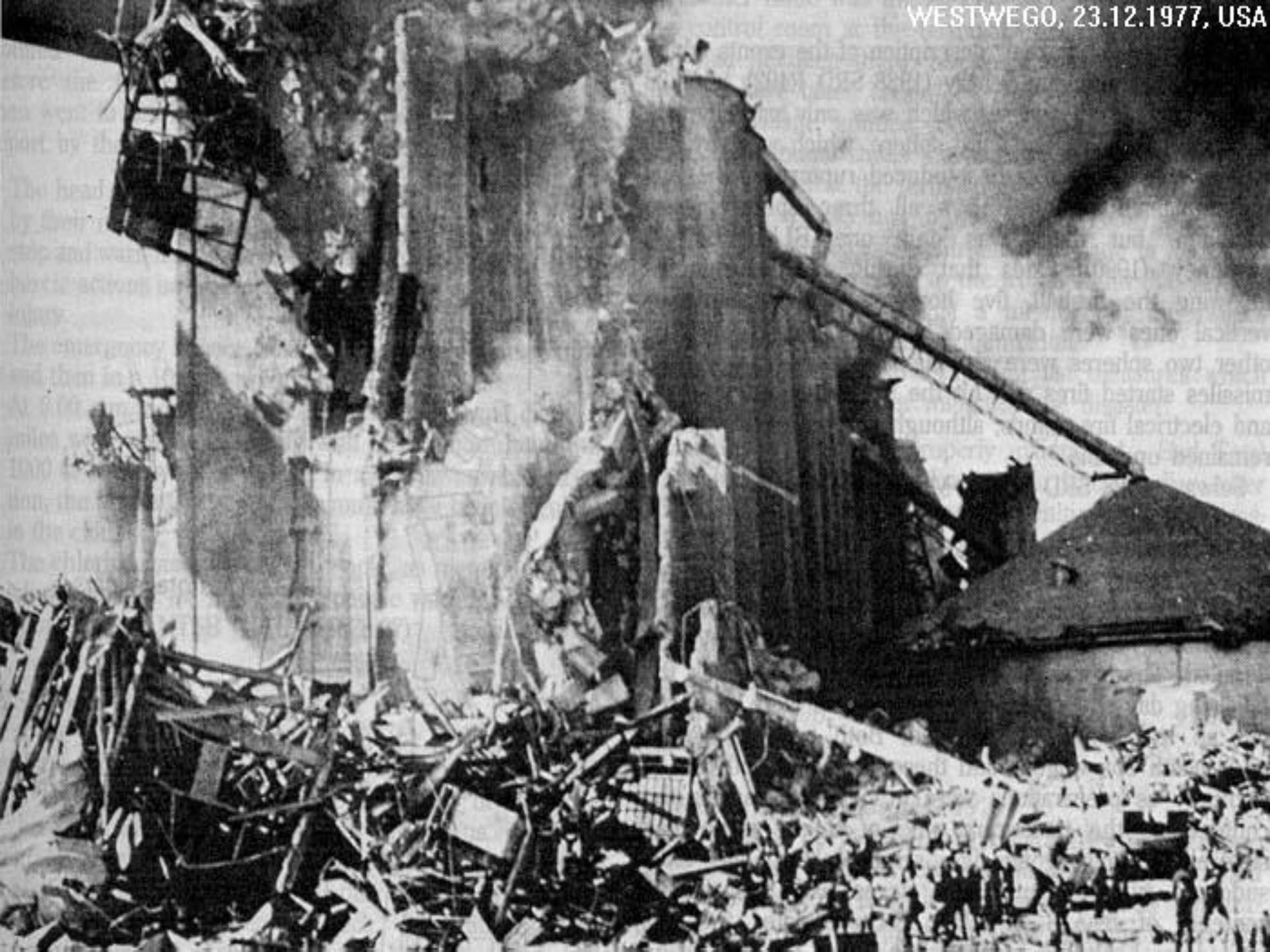
Flixborough

- Location: Flixborough, UK
- Company: Nypro
- Date: June 1, 1974
- Killed: 28
- Injured: 104
- Financial: $635,900,000
- Type of Plant: cyclohexane oxidation (→Nylon)
- Trigger: Vapor Cloud Explosion


BEEK, 1975, NL

Beek

- Location: Beek, NL
- Company: Dutch State Mines (DSM)
- Date: November 7, 1975
- Killed: 14
- Injured: N/A
- Financial: $114,700,000
- Type of Plant: petrochemical
- Trigger: propylene


WESTWEGO, 23.12.1977, USA

Westwego

- **Location: Westwego, La, USA**
- **Company: Continental Grain**
- **Date: December 23, 1977**
- **Killed: 35**
- **Injured: 9**
- **Financial: N/A**
- **Type of Plant: Grainery**
- **Trigger: Corn dust explosion in grain elevator**

Photo - Courtesy : Pablo Bartholomew


KILLER
KILLER
CARBIDE
CARBIDE

Bhopal

- **Location: Bhopal, India**
- **Company: Union Carbide**
- **Date: December 3, 1984**
- **Killed: 4000 – 20,000**
- **Injured: 100,000 + asymptomatic**
- **Financial: ($470,000,000 settlement)**
- **Type of Plant: pesticide**
- **Trigger: Release of MIC**

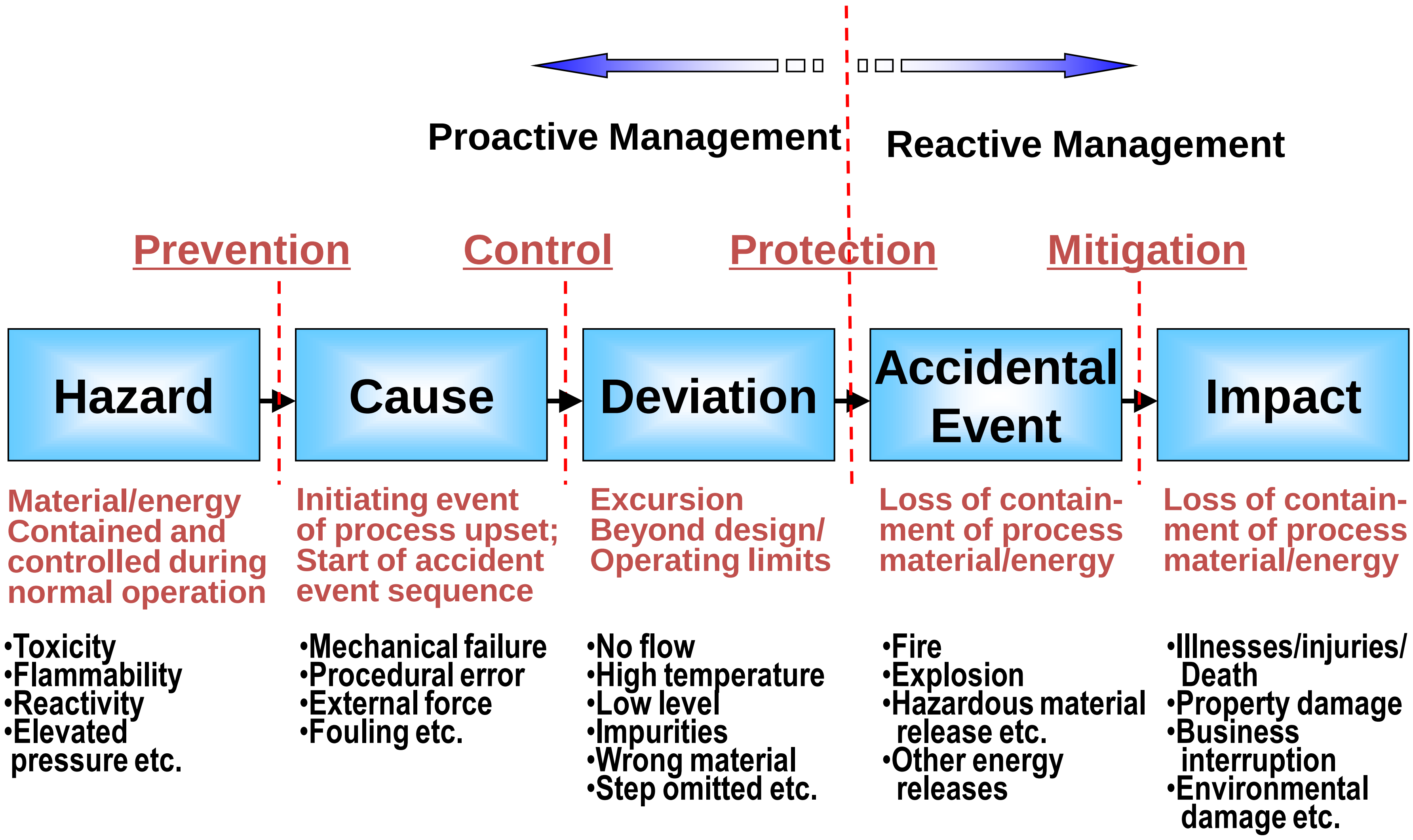

PASADENA, 23.10.1989, USA


PASADENA, 23.10.1989, USA

Phillips

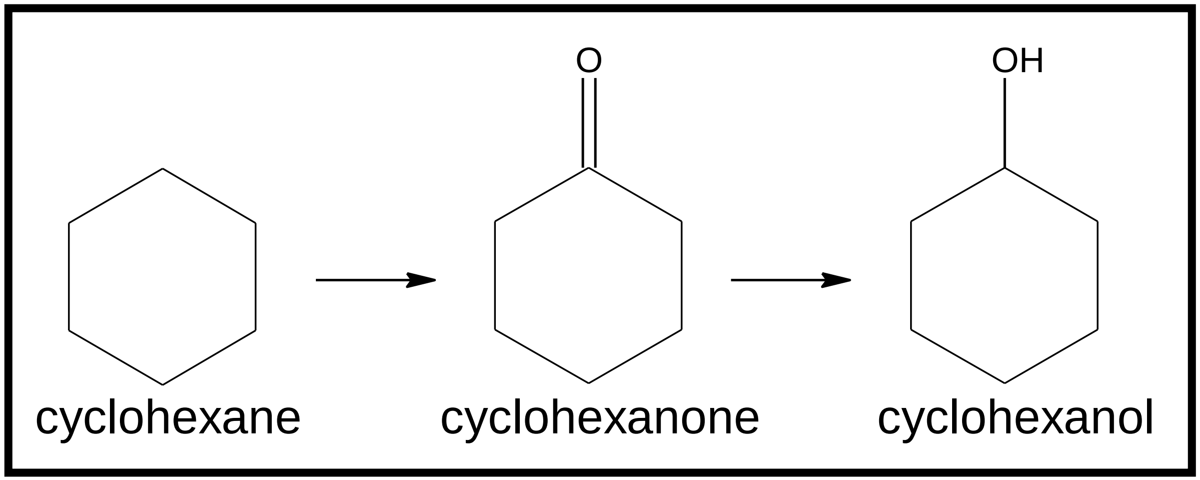
- **Location: Pasadena, Texas, USA**
- **Company: Phillips 66**
- **Date: October 23, 1989**
- **Killed: 23**
- **Injured: 130-300**
- **Financial: $623,500,000 – 1,770,000,000***
- **Type of Plant: polyethylene**
- **Trigger: isobutane**

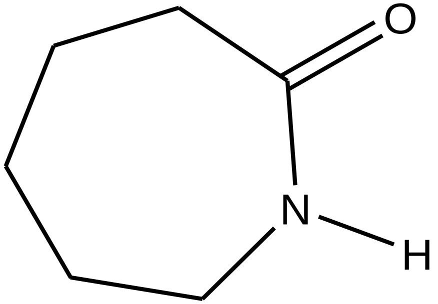
Accidental Flow



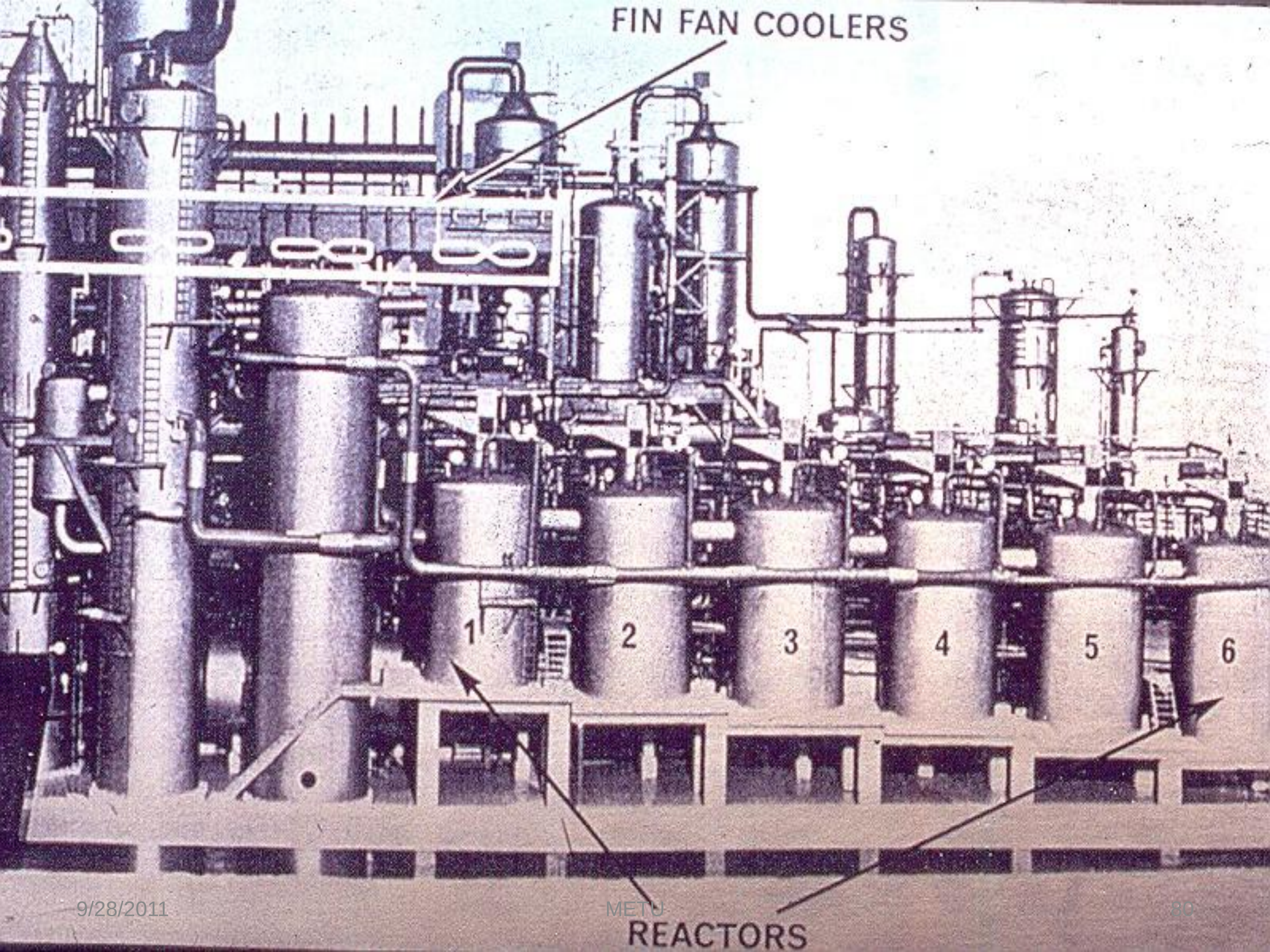
Flixborough

The Chemistry

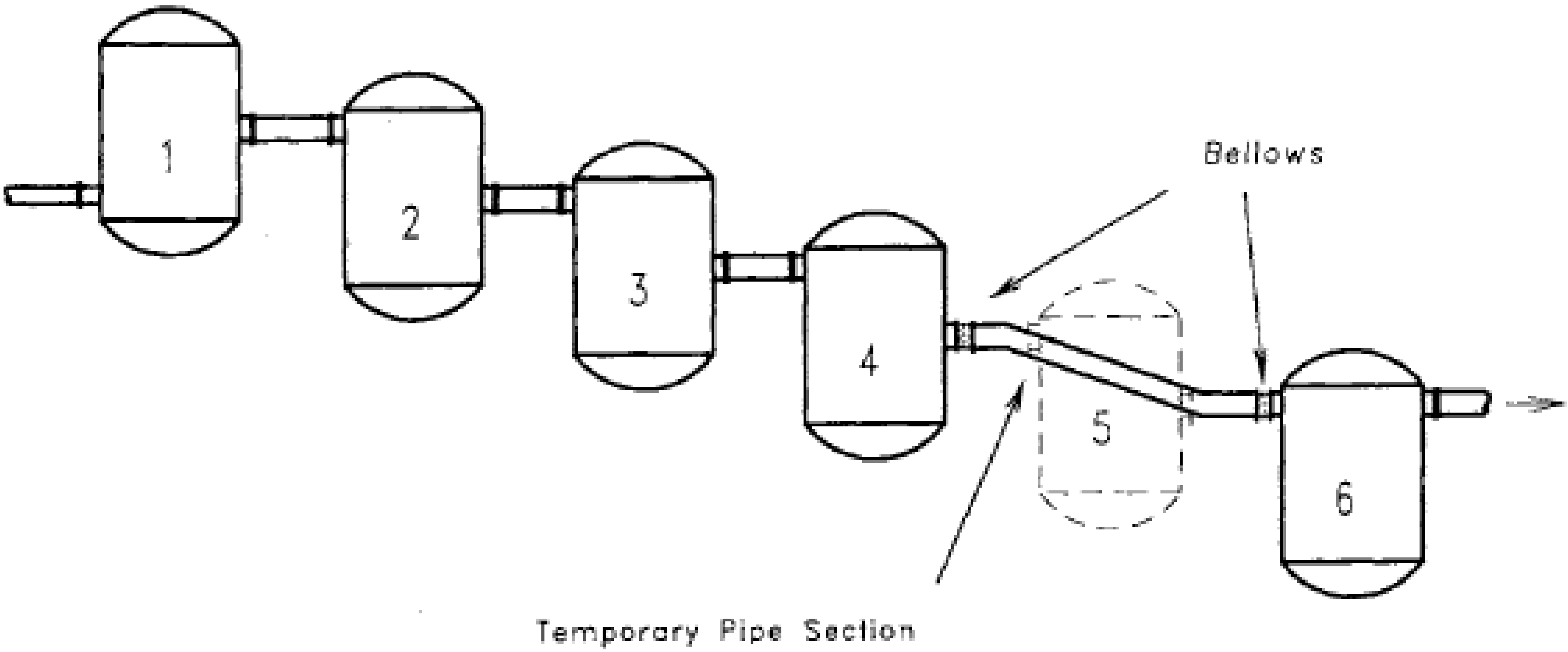




caprolactam


FIN FAN COOLERS
1
2
3
4
5
6
REACTORS

The Reactor Train

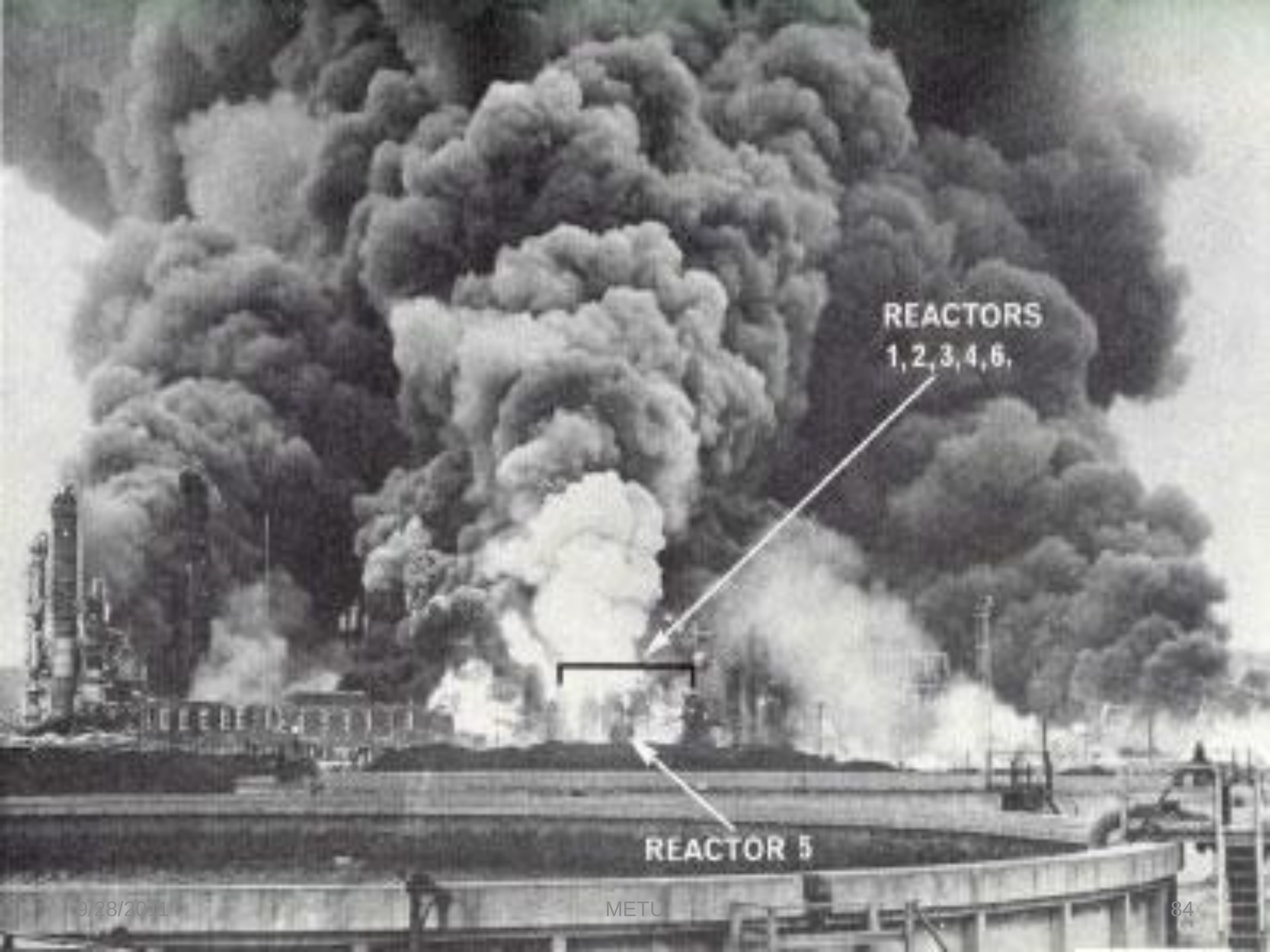


Problems with New Process

- **Serious technical and financial problems**
- **Hazardous process to produce cyclohexanone**
- **Office building close to plant**
- **Control room was within plant**

Events of June 1,1974

- Cyclohexane circulated
- Pipe assembly ruptured
- Uncontrolled vapor cloud explosion


REACTORS
1,2,3,4,6.
REACTOR 5

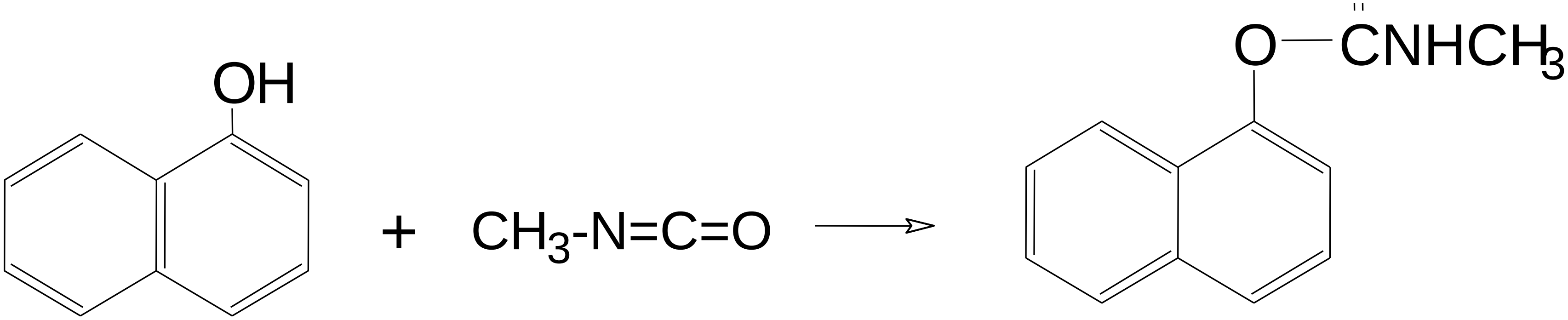
The Possible Causes

- **No qualified engineer on the site**
- **Connections between 4 and 6 were expedient**
- **“Hurry up” attitude of management ← Only Profit!**

BHOPAL DISASTER

- MIC Released at Bhopal, India
- December 3, 1984
- Over 2000 Fatalities

The Chemistry



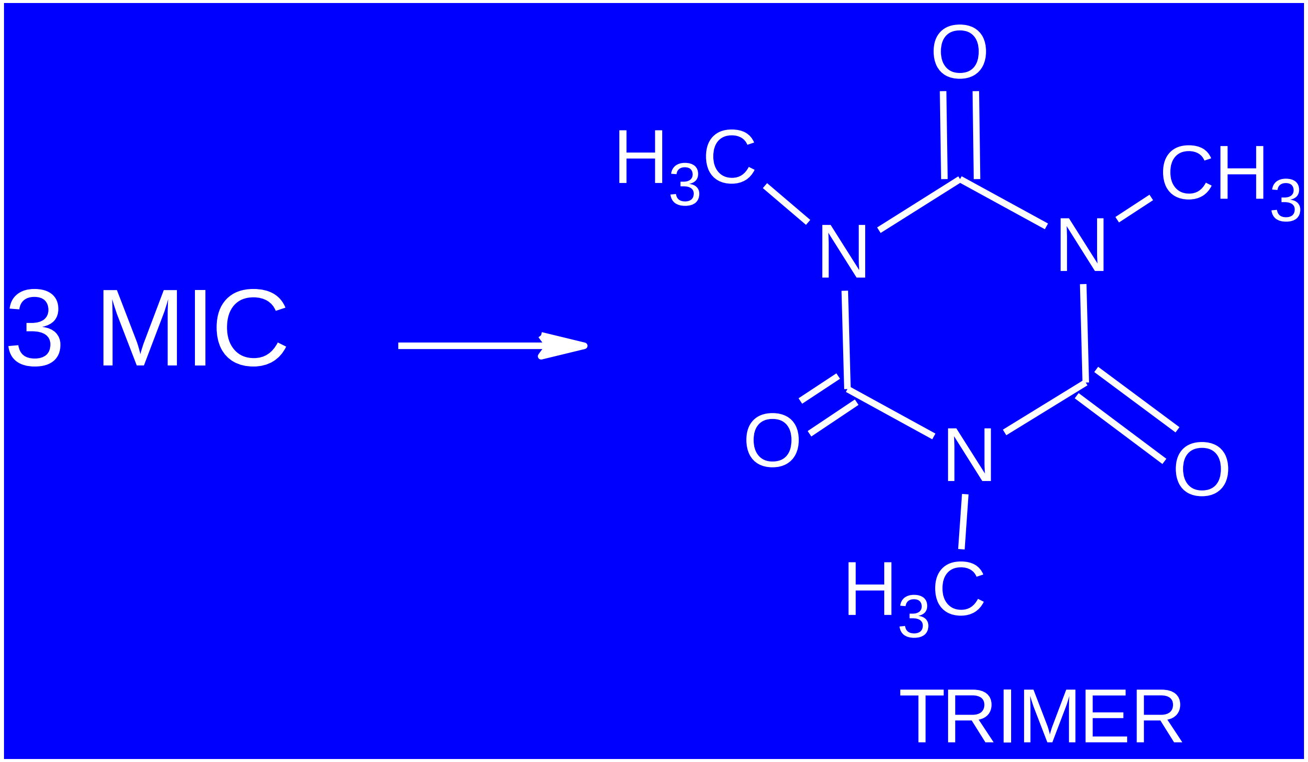
α-Napthol MIC Carbaryl

Critical Properties of MIC

Boiling point	**39.1°C**
Molecular weight	**57**
PEL(p.54)	**0.02ppm**
IDLH(P.56)	**3 ppm**
Odor threshold	**2 ppm**

Exothermic Reactions with Water and Itself

MIC + H_2O ⟶ 1,3,5 Trimethyl Biuret + CO_2



Runaway Scenarios

- Loss of cooling or refrigeration
- Loss of Agitation
- Unexpected addition of heat
- Human error

Condition before Accident

- Refrigeration turned off.
- Flare down for maintenance.
- Scrubber in standby mode.

Accident

- Vessel vented at 180 psig
- Released for 2 hours
- MIC heavier than the air
- 2000 fatalities

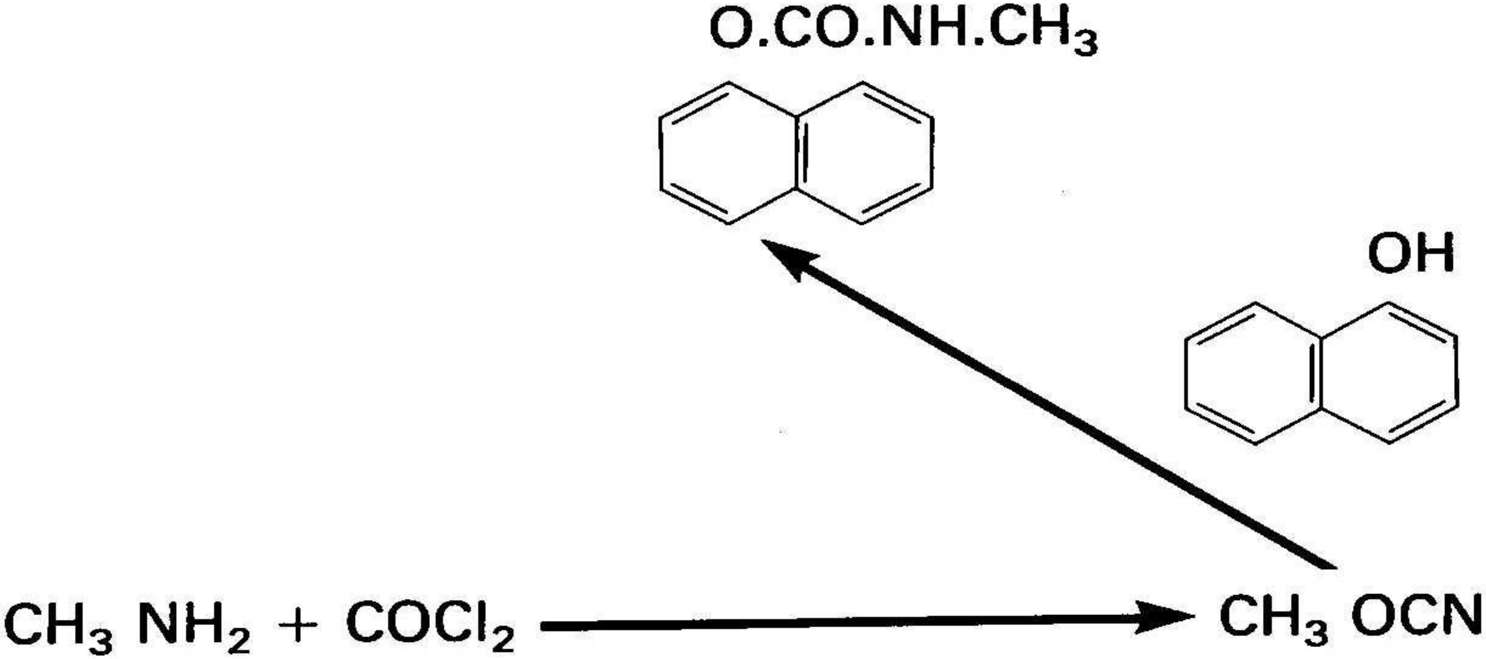
The traditional method of identifying hazards was to build the plant and see what happens - ‘every dog is allowed one bite’. Until it bit someone, we could say that we did not know it would do so. This method is no longer acceptable now that we keep dogs as big as Flixborough.

-Kletz and Lawley

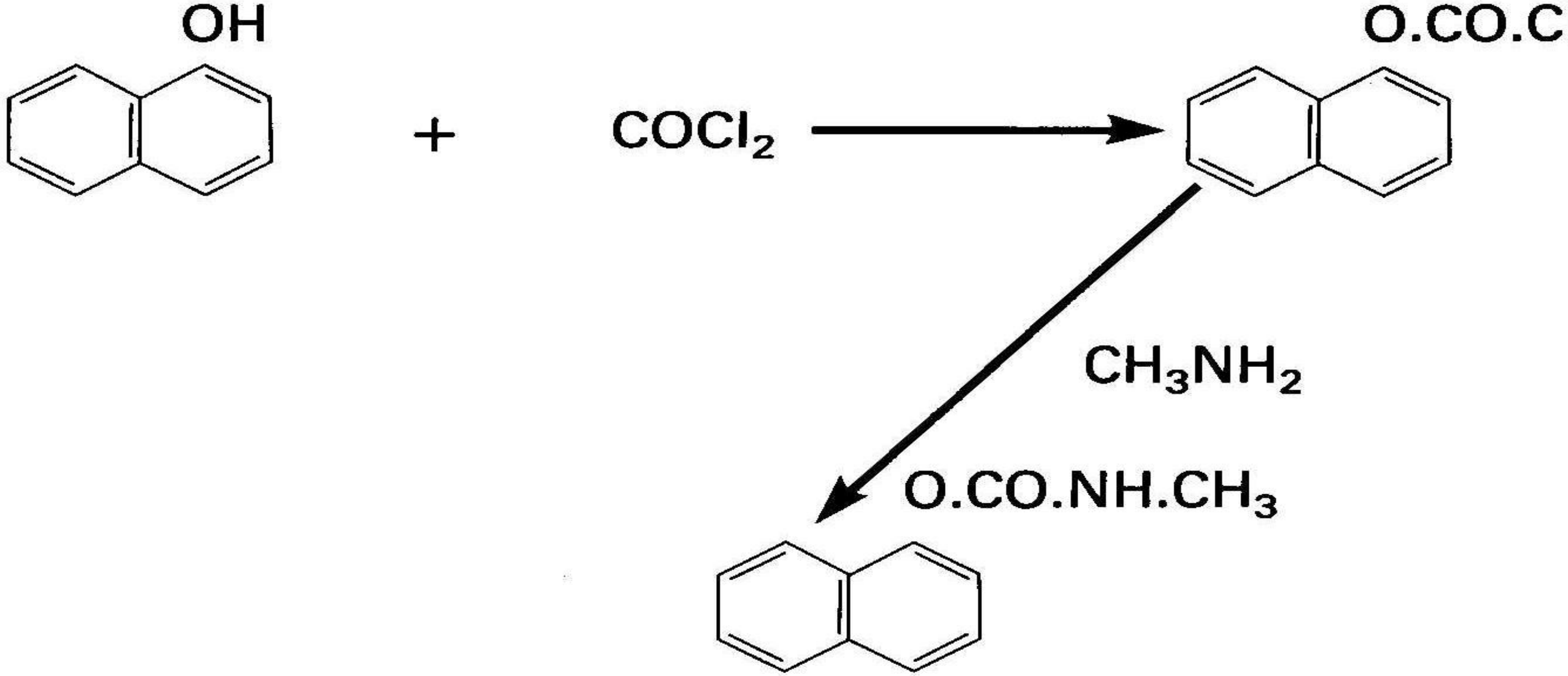
To Prevent Accidents We Need Knowledge In

- Design (inherently safe)
- Thermodynamics
- Kinetics
- Control
- Management and ethics

Routes to Carbaryl, Bhopal



Routes to Carbaryl, Alternative



Measurement of Safety

- How to measure safety of a process?
- Is a safety procedure effective?
- Incident and loss statistics models
- Perspective of risk, real and perceived, is needed for assessment of results of these models

Measure Danger of a Job

1. **Number of fatalities in a job or group**
2. **Fatality Rate (FR):** $$\frac{\#\ fatalities/\ year}{\#\ population}$$

   Independent of exposure time

3. **Relative Risk Index (RRI):** $$\frac{FR\ group}{FR\ all}$$

   Compare risk to average job

Measure Danger of a Job

RRI (fatalities), 1995

Finance, insurance, real estate:	0.4
Chemical industry:	0.6
Average job:	1.0
Petroleum refining:	1.8
Truck driving:	5.3
Metal workers:	13.1

Measure Danger of a Job

Fatal accident rate (FAR)

$$\#\, fatalities / 10^8\, hr$$

$$FAR = \frac{10^8(\#\, fatalities)}{hours\ worked}$$

Dependent on exposure time, unlike FR

Fatal Accident Rate

- **The FAR period of time,10^8 hours, is based on 1,000 employees working for a lifetime.**
- **Work lifetime is assumed to be 50 years**
- **One work year is 2,000 hr[250•8]**
- **1,000(2,000 hr/yr)(50 yr) = 10^8 hours**

FAR Statistics for Industry

- Chemical industry improved from a FAR of 4.0 in 1986 to 1.2 in 1990 (Crowl, Tab. 1-3, p. 8)
- Causes of fatalities divided about equally between physical accidents and chemical exposures.
- FAR of 1.2 for all manufacture vs 3.7 for agriculture (synthetic vs natural fibers)

Accident Statistics for Various Selected Industries

Table 1-3 Accident Statistics for Selected Industries

Industry	OSHA incident rate (cases involving days away from work and deaths)		FAR (deaths)	
	1985[1]	1998[2]	1986[3]	1990[4]
Chemicals and allied products	0.49	0.35	4.0	1.2
Motor vehicles	1.08	6.07	1.3	0.6
Steel	1.54	1.28	8.0	
Paper	2.06	0.81		
Coal mining	2.22	0.26	40	7.3
Food	3.28	1.35		
Construction	3.88	0.6	67	5.0
Agricultural	4.53	0.89	10	3.7
Meat products	5.27	0.96		
Trucking	7.28	2.10		
All manufacturing		1.68		1.2

FAR for Chemical Worker

- For 1000 workers during lifetime (50 years) in chemical industry‡
- 2 work deaths (1 physical and 1 chemical)
- 20 non-work accident deaths
- 370 non-work disease deaths
- Some common activities more dangerous than chemical plant work (Crowl, Tab. 1-4, p. 9)

- ‡ T.A. Kletz, *Chem. Eng.* (Apr. 1, 1985)

Fatality Statistics for Common Nonindustrial Activities

Table 1-4 Fatality Statistics for Common Nonindustrial Activities[1,2]

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}

OSHA Incident Rate (IR)

- Based on work-related injuries, illness, and fatalities or lost workdays for 100 worker years
- 50 weeks/yr x 40 hr/wk = 2,000 hr/yr
- 100 yr x 2,000 hr/yr = 200,000 hr

OSHA Incident Rate (IR)

Deaths, injuries, and illnesses:

$$OSHA\ IR = \frac{\#\, incidents}{hours\ worked} \frac{1}{hr} 2 \cdot 10^5\, hr$$

Lost workdays:

$$IR = \frac{\#\, lost\ workdays}{hours\ worked} 2 \cdot 10^5$$

Dependent on exposure time, like FAR

The Nature of the Accident Process

Type of Accident	Probability of occurrence	Potential for fatality	Potential for economic loss
Fire	High	Low	Inter-mediate
Explosion	Inter-mediate	Inter-mediate	High
Toxic release	Low	High	Low

Safety in the Chemical Industry

- **Risks, perceptions often misunderstood**
- **Chemical industry is held to a higher than average safety standard.**
- **This responsibility must be accepted to work for an accident free workplace.**
- **Continuous improvement is necessary for credibility and the public trust.**

Losses in Chemical Industry

- **Largest causes of loss: mechanical failure and operator error (Crowl, Fig. 1-7, p.16)**
- **Losses are sometimes divided into mechanical failure (#1) and operator error (#2).**

Causes of loses in the largest hydrocarbon-chemical plant accident

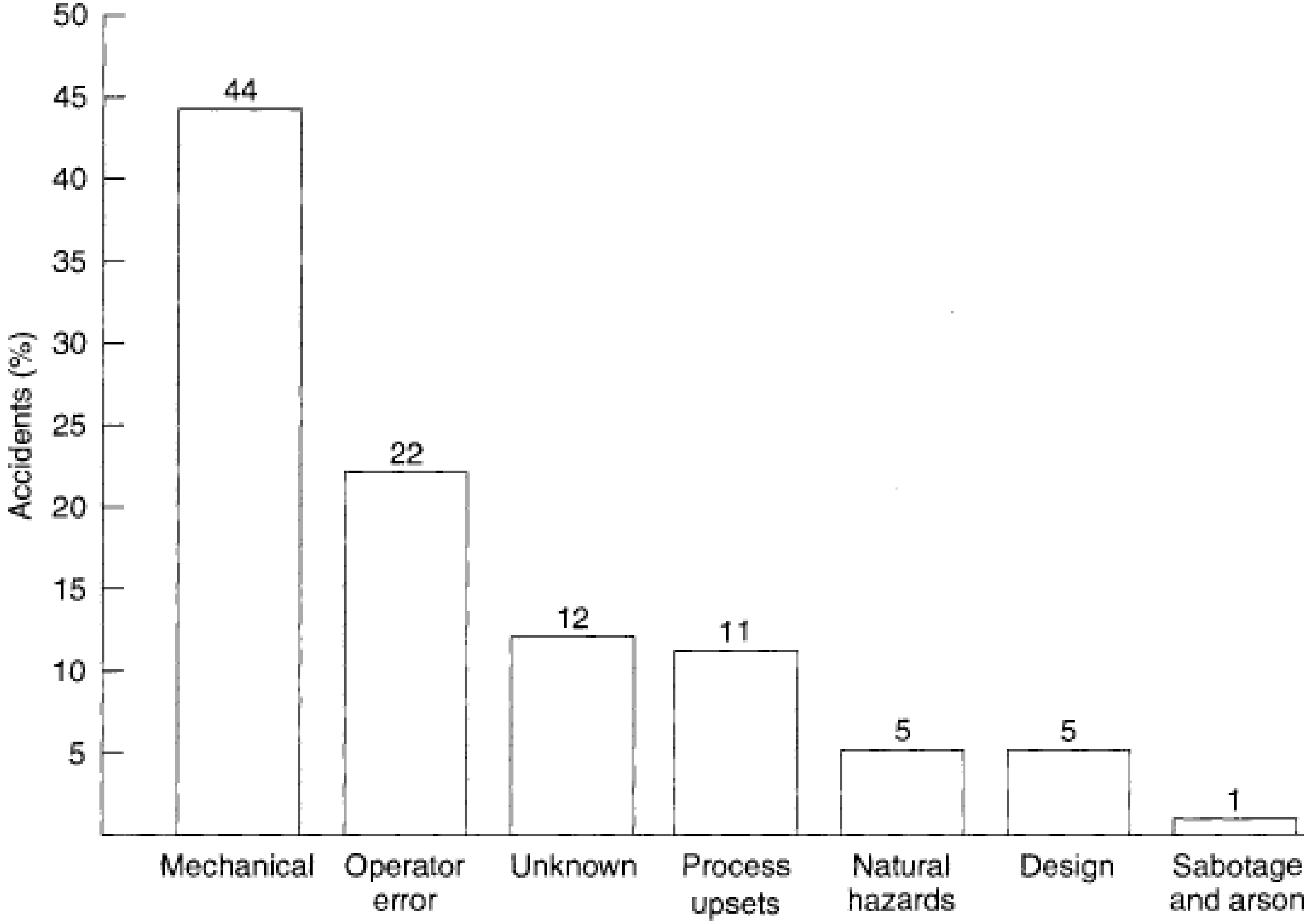


Figure 1-7 Causes of losses in the largest hydrocarbon-chemical plant accidents. Source: *Large Property Damage Losses in the Hydrocarbon-Chemical Industries: A Thirty-Year Review* (New York: J & H Marsh & McLennan Inc., 1998), p. 2. Used by permission of Marsh Inc.

Hardware associated with largest losses

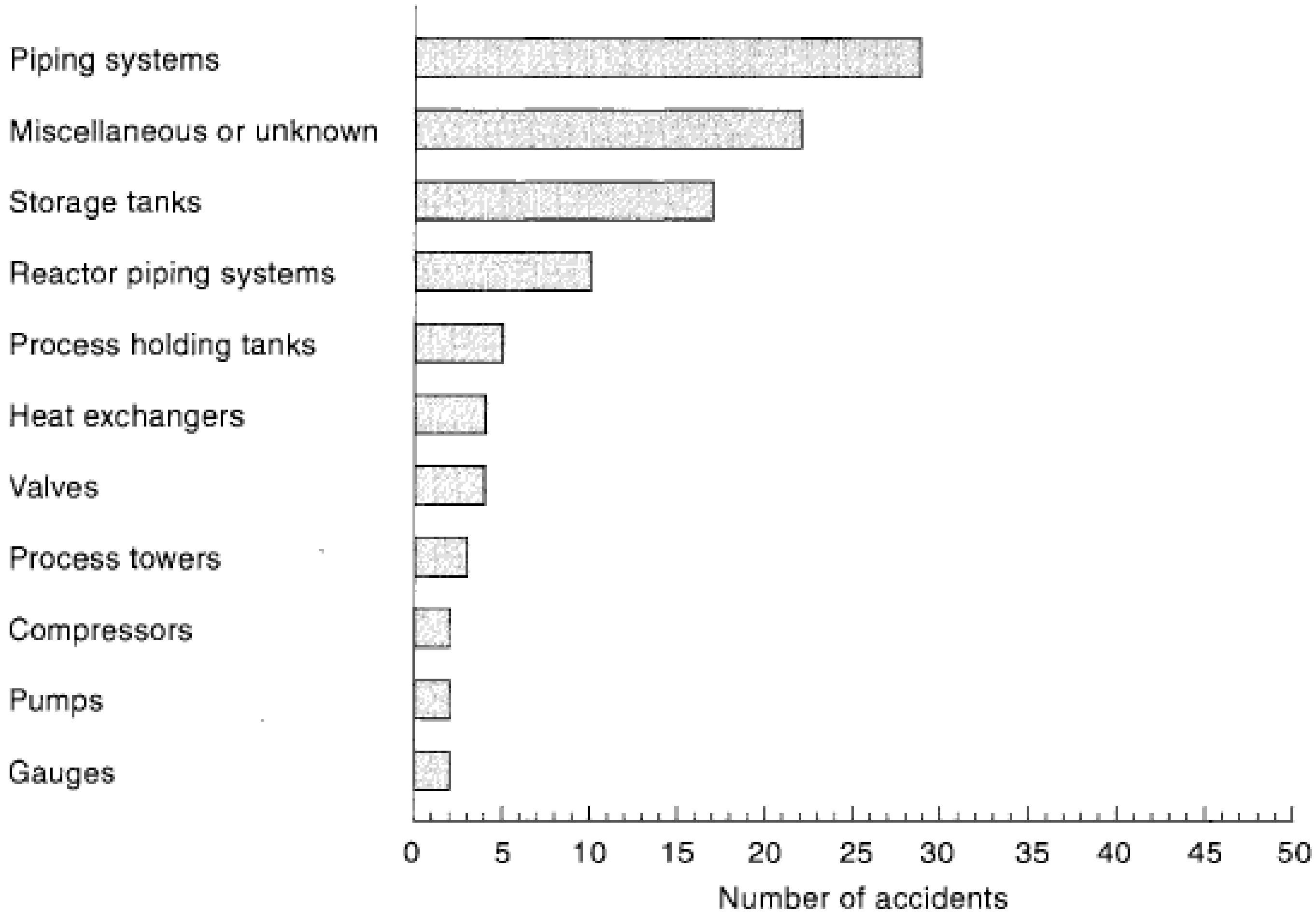


Figure 1-8 Hardware associated with largest losses. Source: *A Thirty-Year Review of One Hundred of the Largest Property Damage Losses in the Hydrocarbon-Chemical Industries* (New York: Marsh Inc., 1987). Reprinted by permission.

Loss Trends in Industry

- **Number and magnitude of losses from the 1960's have increased.**
- **Consistent with trend of larger & more complex plants and processes. Also higher pressures and temperatures.**
- **Drop is shown in Crowl, Fig. 1-9, p. 18, for 1992-1996 period, but trend is not clear.**

Figure 1-9 Loss distribution for onshore accidents for 5-year intervals over a 30-year period. (There were also 7 offshore accidents in this 30-year period.) Source: *Large Property Damage Losses in the Hydrocarbon-Chemical Industries: A Thirty-Year Review* (New York: J & H Marsh & McLennan Inc., 1998), p. 2. Used by permission of Marsh Inc.

Program to Prevent Incidents

- **Safety involves many levels: design, management, control systems, interlocks, detectors, alarms, shutdown systems, protective systems, emergency response procedures, Table 5-10, p. 214.**
- **For safer and more economical processes, it is much better to eliminate rather than to control hazards.**

Table 5-10 Release Mitigation Approaches[1]

Major area	Examples
Inherent safety	Inventory reduction: Less chemicals inventoried or less in process vessels Chemical substitution: Substitute a less hazardous chemical for one more hazardous Process attentuation: Use lower temperatures and pressures
Engineering design	Plant physical integrity: Use better seals or materials of construction Process integrity: Ensure proper operating conditions and material purity Process design features for emergency control: Emergency relief systems Spill containment: Dikes and spill vessels
Management	Operating policies and procedures Training for vapor release prevention and control Audits and inspections Equipment testing Maintenance program Management of modifications and changes to prevent new hazards Security
Early vapor detection and warning	Detection by sensors Detection by personnel
Countermeasures	Water sprays Water curtains Steam curtains Air curtains Deliberate ignition of explosive cloud Dilution Foams
Emergency response	On-site communications Emergency shutdown equipment and procedures Site evacuation Safe havens Personal protective equipment Medical treatment On-site emergency plans, procedures, training, and drills

[1]Richard W. Prugh and Robert W. Johnson, *Guidelines for Vapor Release Mitigation* (New York: American Institute of Chemical Engineers, 1988).

Inherent Safety

- **Inherent safety involves prevention or reduction of hazards**
- **Applies throughout the plant at any time but best at the design stages**
- ***Minimize* amounts, *substitute* for safer, *moderate* to reduce hazards, *simplify* to limit error, Crowl, Tab. 1-9, p. 22**

Table 1-9 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

Trend of Chemical and Energy Industries

- More dangerous operating conditions
  - high pressure, low temperature
- More toxic and environment-dependent products
- Increased work and information overload for human operators
- The public and the international society are more sensitive and regulation-minded about the safety

Future Features of Chemical Plant Accidents

- **More severe personal injuries**
- **More potential for major accidents**
  - **Fire, explosions and toxic material releases**
- **Greater economic loss**
- **International environmental damage**
- **Human casualties in the wider surrounding area**

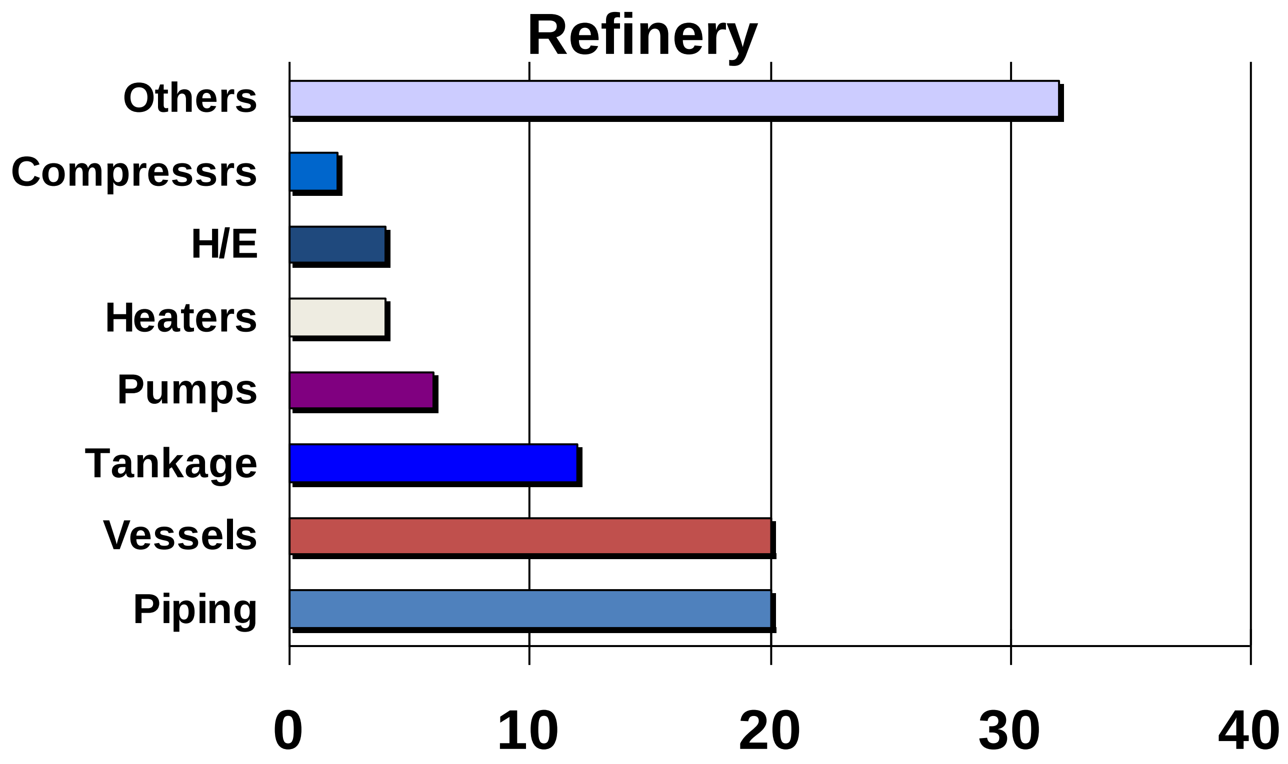
Goals for Safety and Environment in the 21st Century

- **Handle disasters with local communities**
- **Prevent pollution**
- **Operate safe plants**
- **Distribute products in a way that reduces hazards to people and the environment**
- **Protect the health of people at plant sites**
- **Promote the safe use of chemicals from manufacture to recycling and disposal**

Present Safety Problems

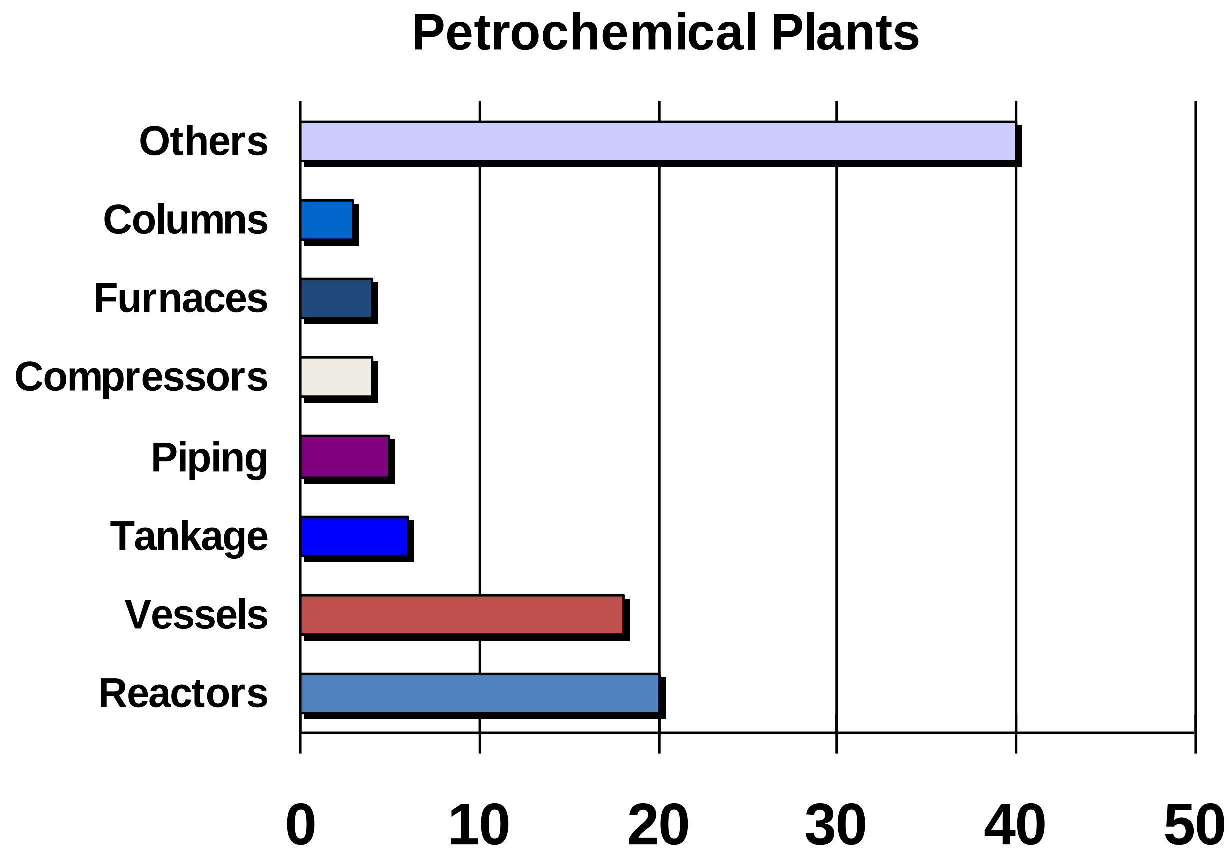
- Complex & diverse energy facilities
- Lower priority to safety-related investment
- Inspection only for facilities
- Present safety management reached its limit.

The Nature of the Accident I



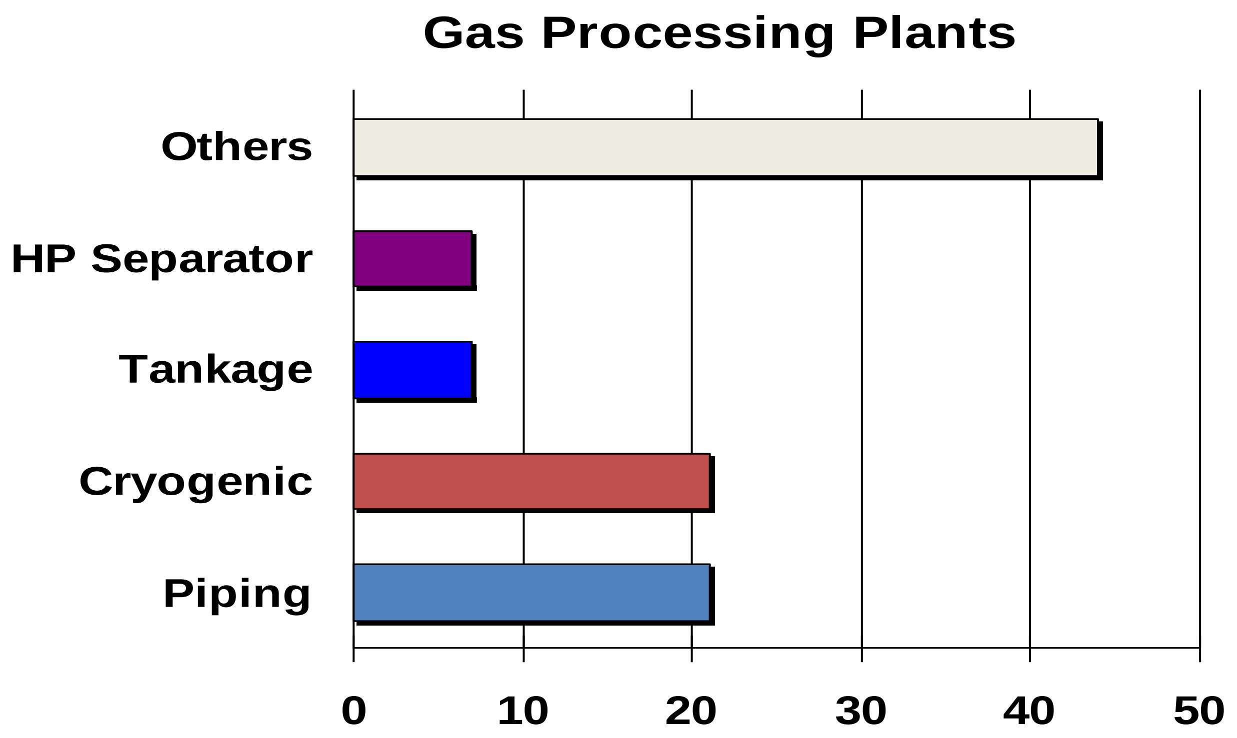
Large Property Damage Losses in the Hydrocarbon-Chemical Industries: A Thirty-Year Review, Marsh, 19th Ed. 2001

The Nature of the Accident II



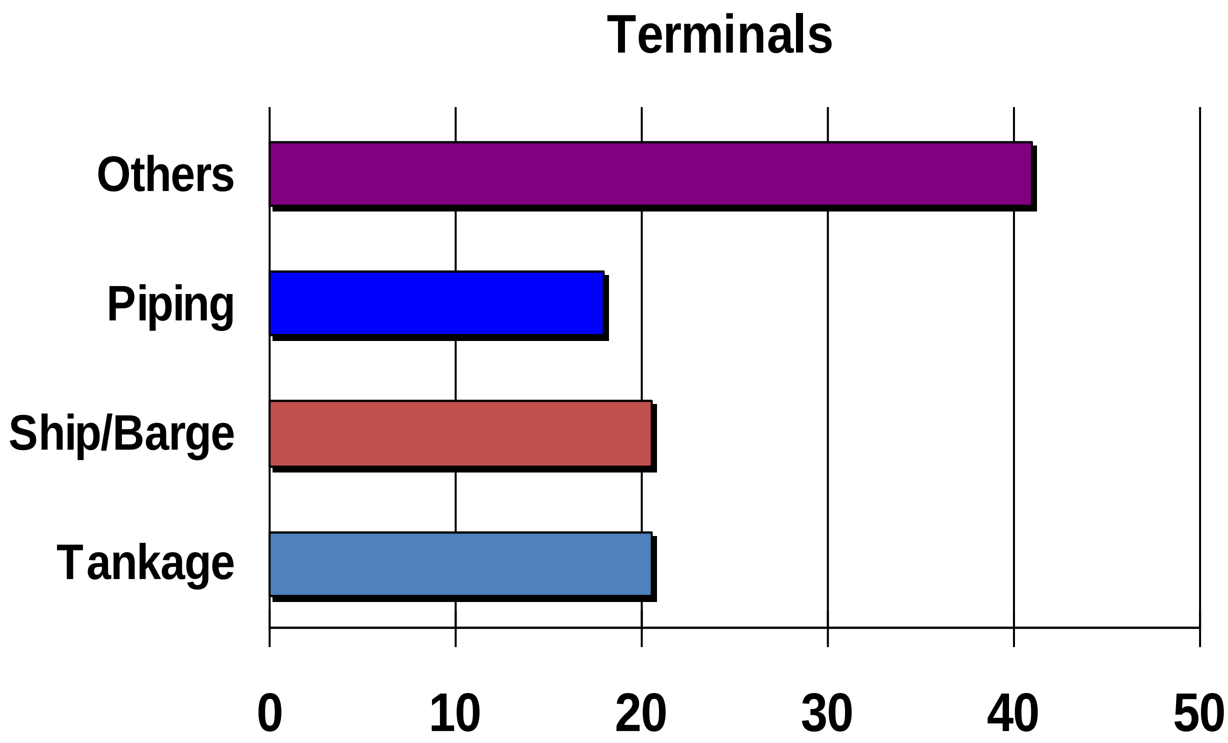
Large Property Damage Losses in the Hydrocarbon-Chemical Industries: A Thirty-Year Review, Marsh, 19th Ed. 2001

The Nature of the Accident III



Large Property Damage Losses in the Hydrocarbon-Chemical Industries: A Thirty-Year Review, Marsh, 19th Ed. 2001

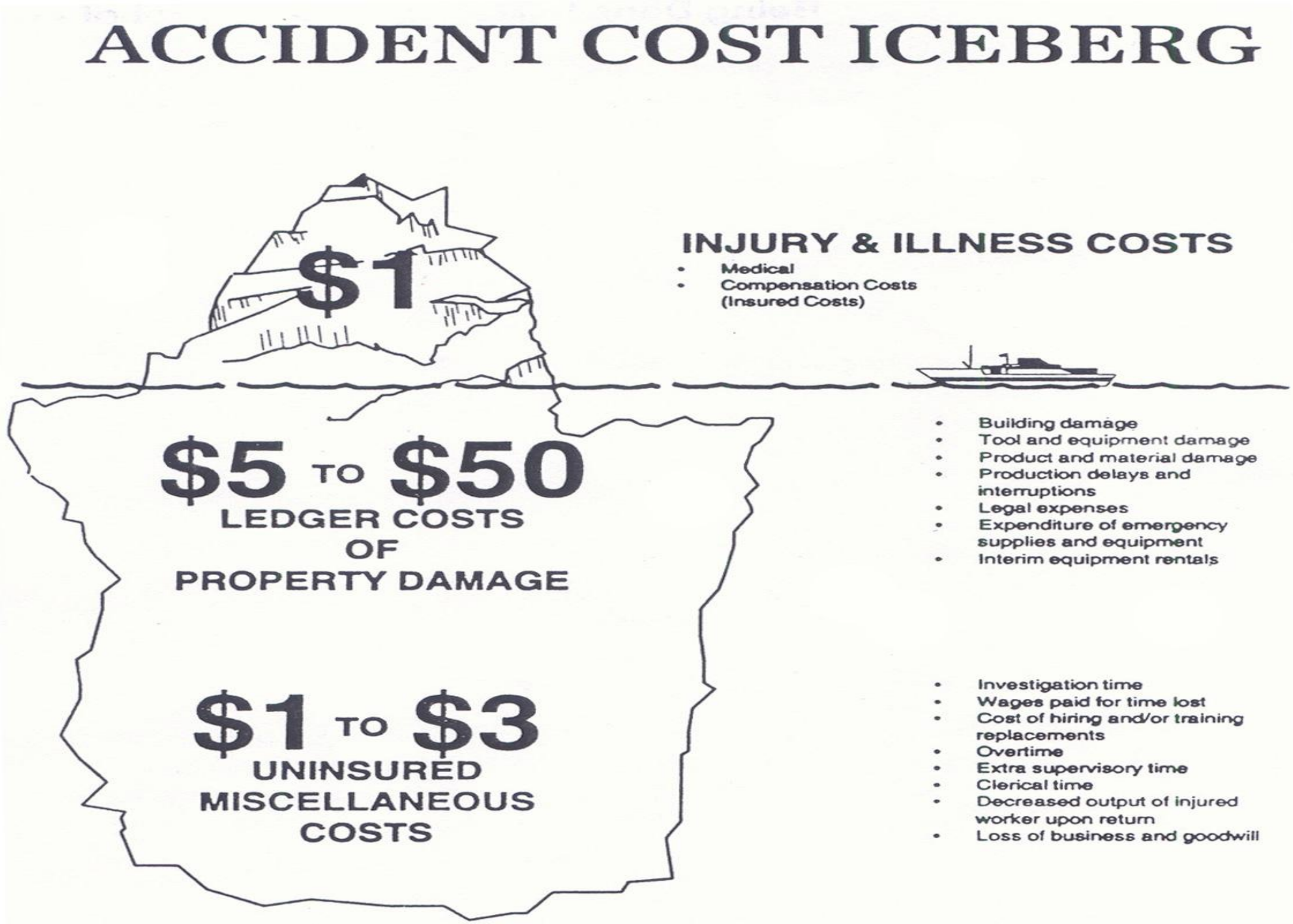
The Nature of the Accident IV



Large Property Damage Losses in the Hydrocarbon-Chemical Industries: A Thirty-Year Review, Marsh, 19^{th} Ed. 2001

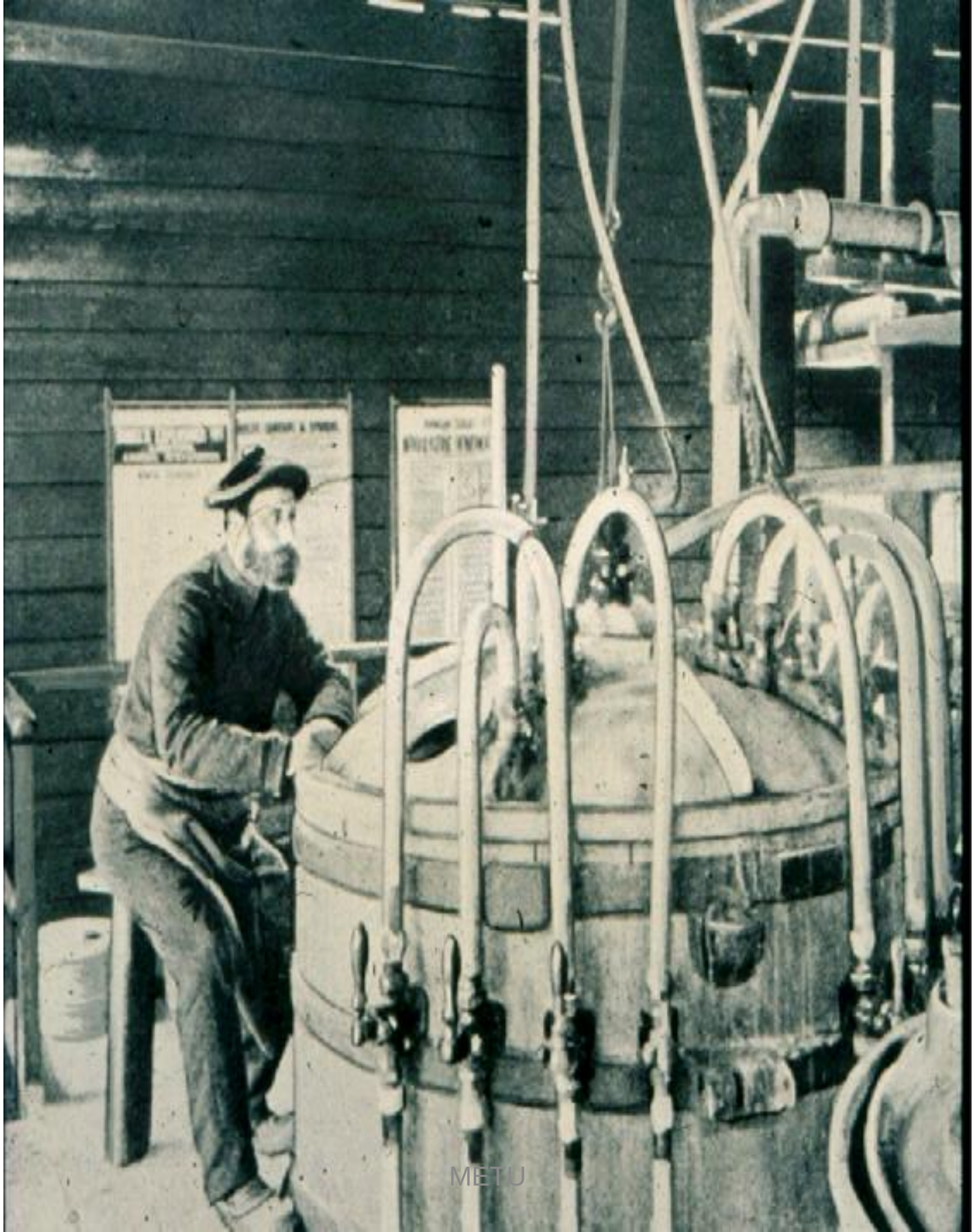
Examples of Loss by Accident

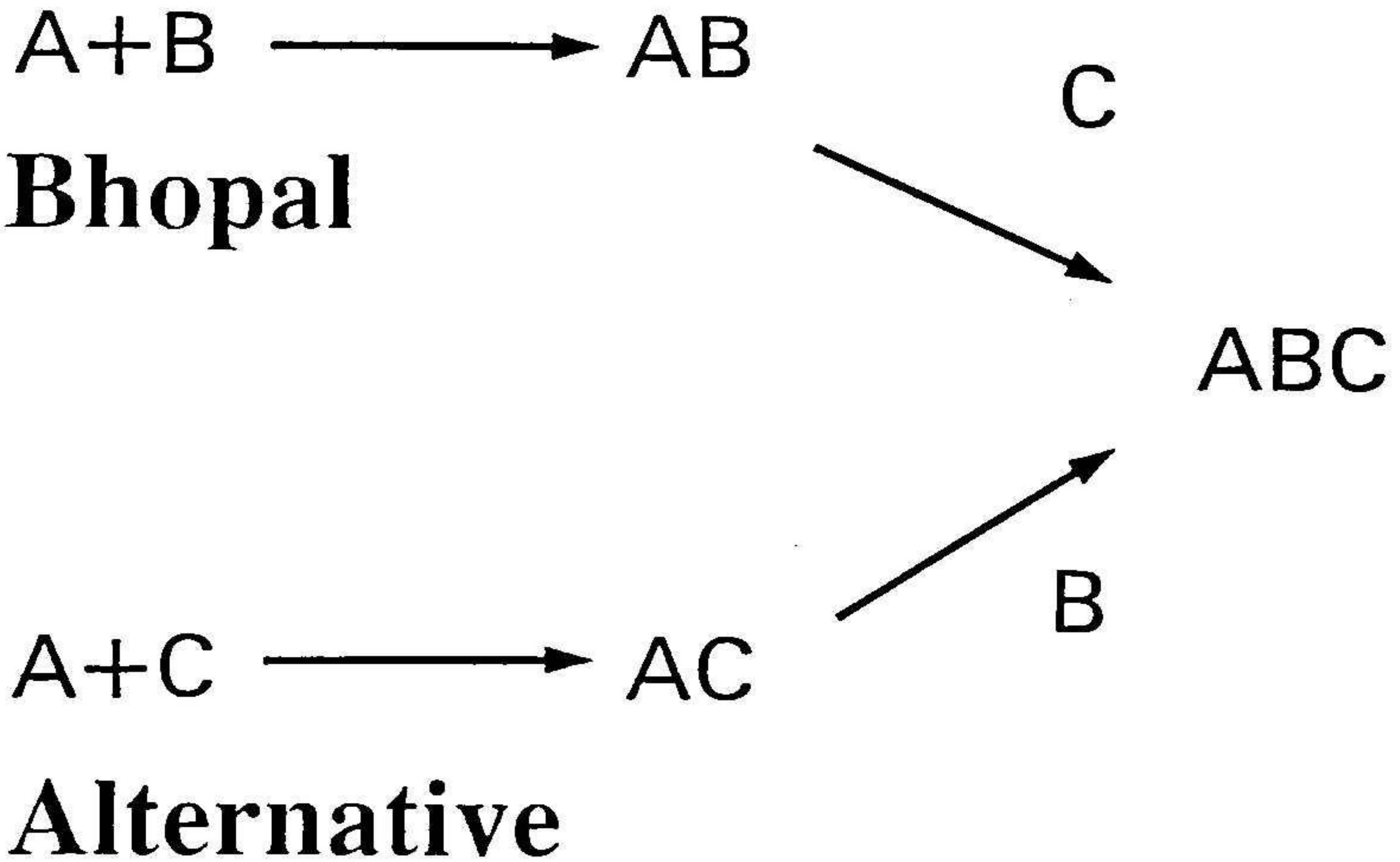
- **Direct Loss (Cost)**
  - Recovery of facility and equipment
  - Off-spec.
  - Compensation for the contractors
  - Legislation fees for suit
  - Increase in insurance
- **Indirect Loss (Cost)**
  - Production & Selling Interruption
  - Cost for Accident Investigation
  - Loss of customers & buyers
  - Disrepute



Safety Pyramid, Crowl, Fig, 1-3, p. 11

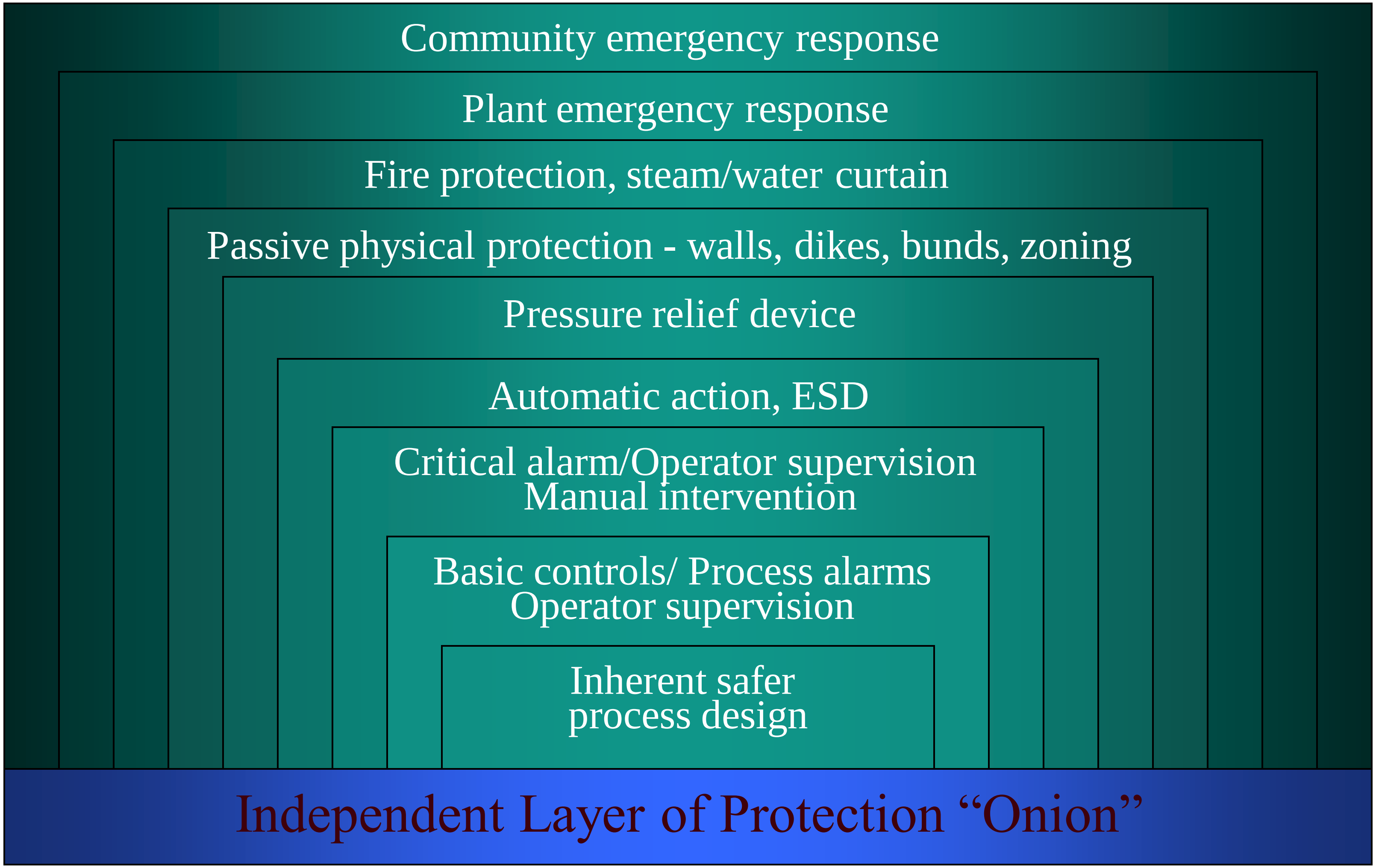
※ International Safety Rating System, DNV, 5th Ed.(1993)




A+B
AB
C
Bhopal
ABC
B
A+C
AC
Alternative

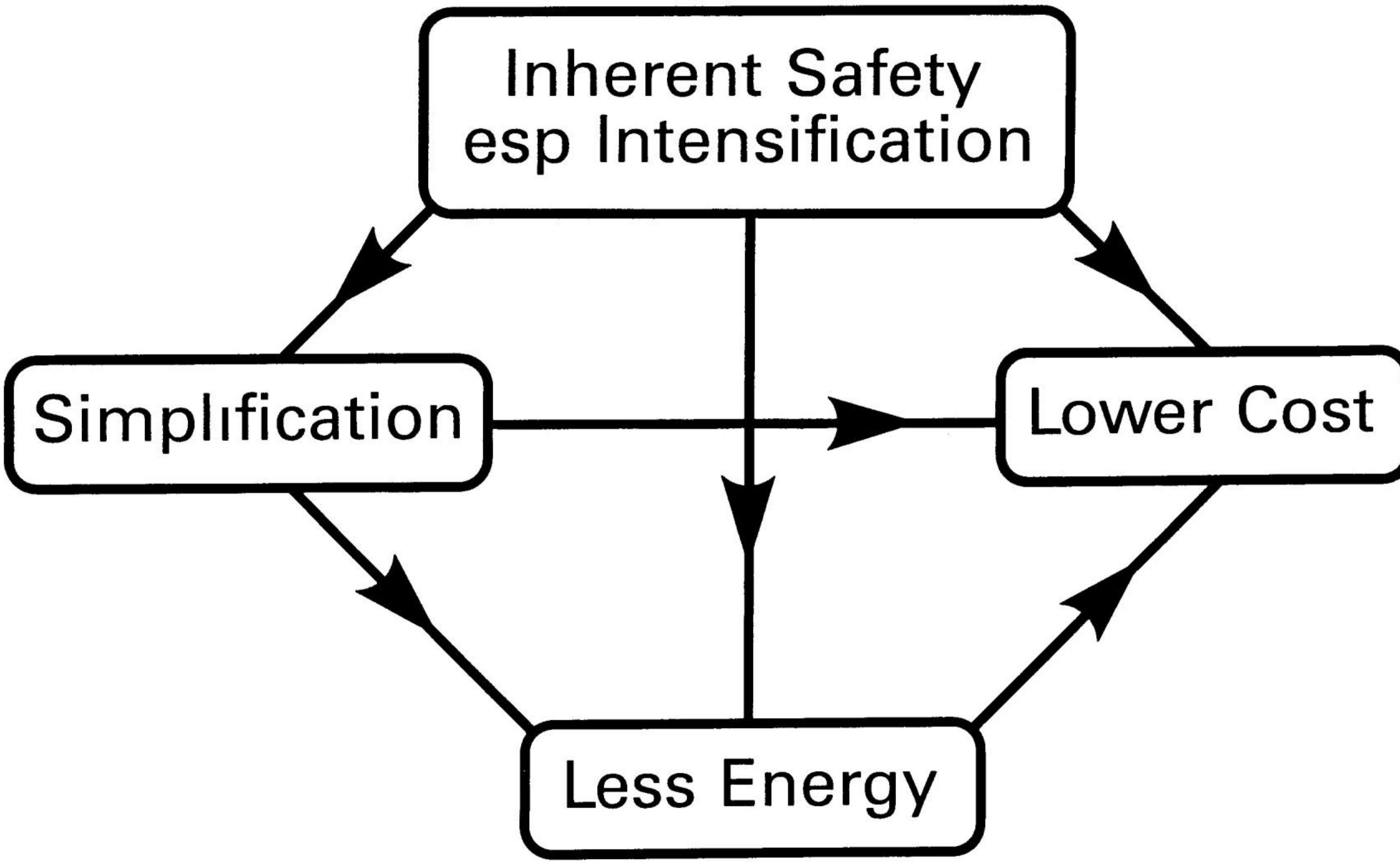
An INHERENTLY SAFER DESIGN is one that *avoids hazards instead of controlling them*, particularly by removing or reducing the amount of hazardous material or the number of hazardous operations.

Layer of Protection Analysis (LOPA)

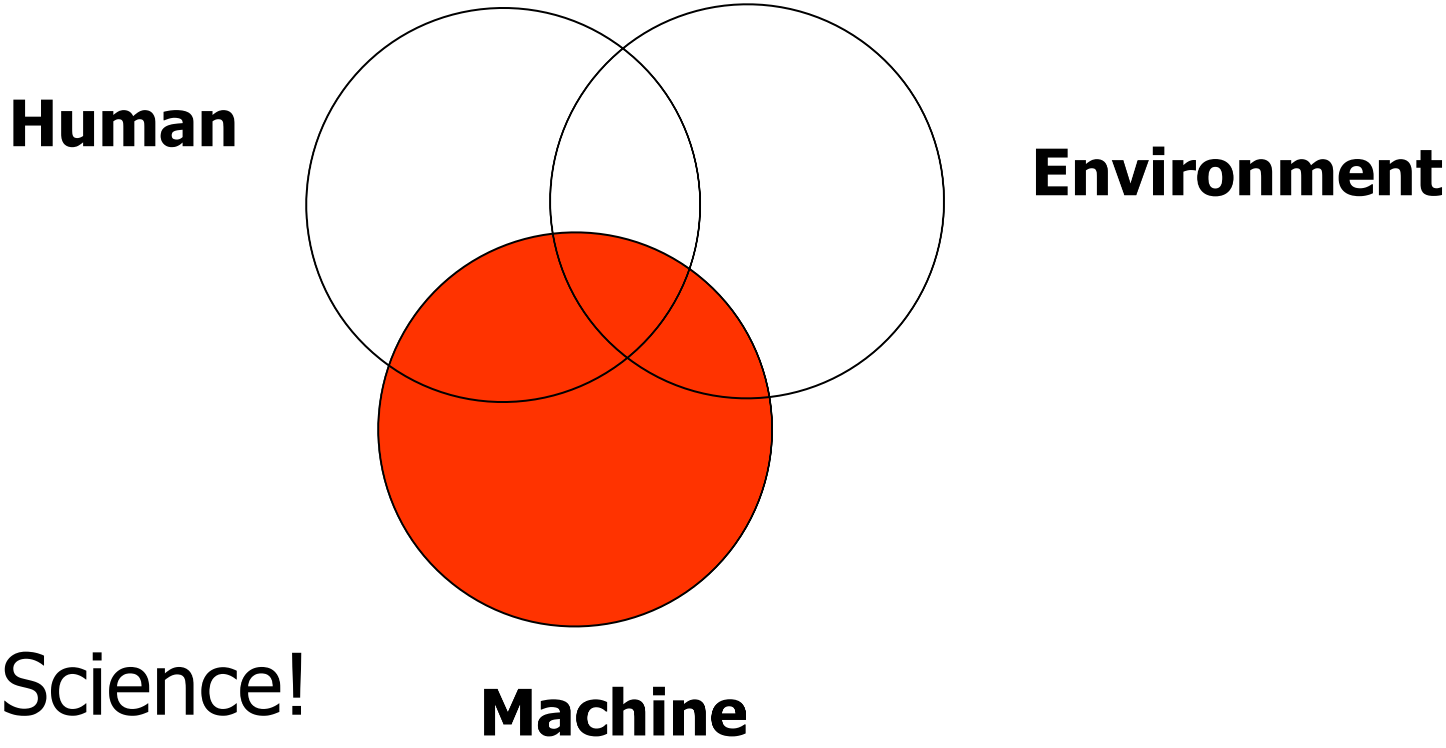


SAVINGS

1. **Less protective equipment needed, say 5-10% of capital.**
2. **Less maintenance of plant & systems.**
3. **SMALLER SIZE.**


Inherent Safety
esp Intensification
Simplıfication
Lower Cost
Less Energy

Avoid a Narrow Focus



Bad Science!

- Many accidents occur as the result of interactions between matrix elements