CHAPTER 4

The Roles & Responsibilities of Chemical Engineers

Contents

By the end of this section you should:

- **Be aware of the responsibilities for chemical process safety**
- **Be aware of the responsibilities for environmental protection**

Roles of Chemical Engineers

Many chemical engineers design and operate large-scale and complex chemical production facilities supplying diverse chemical products to society.

The engineer may become involved in raw materials extraction, intermediate materials processing, or production of pure chemical substances; in each activity, the minimization and management of waste streams will have important economic and environmental consequences.

Roles of Chemical Engineers

Chemical engineers are involved in production of bulk and specialty chemicals, petrochemicals, integrated circuits, pulp and paper, consumer products, minerals, and pharmaceuticals.

Chemical engineers also find employment in research, consulting organizations, educational institutes.

Roles of Chemical Engineers

As engineers assume such diverse roles, it is increasingly important that they be aware of their responsibilities to the general public, colleagues and employers, the environment, and also to their profession.

One of the central roles of chemical engineers is to design and operate chemical processes yielding chemical products that meet customer specifications and that are profitable.

Roles of Chemical Engineers

Another important role is to maintain safe conditions for operating personal and for residents in the immediate vicinity of a production facility.

Finally, chemical process designs need to be protective of the environment and of human health. Environmental issues must be considered not only within the context of chemical production but also during other stages of a chemical's life cycle, such as transportation, use by customers, recycling activities, and ultimate disposal.

Responsibilities for Process Safety

A major objective for chemical process design is the inclusion of safeguards that minimize the number and severity of accidental release of toxic chemicals and incidence of fire and explosions.

If not,

loss of life,

permanent disability,

destruction of chemical plant, equipment

& neighboring residences.

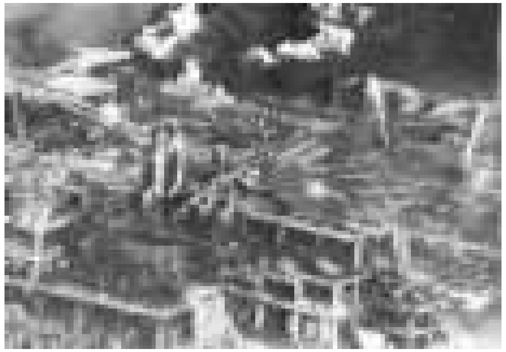
Responsibilities for Process Safety

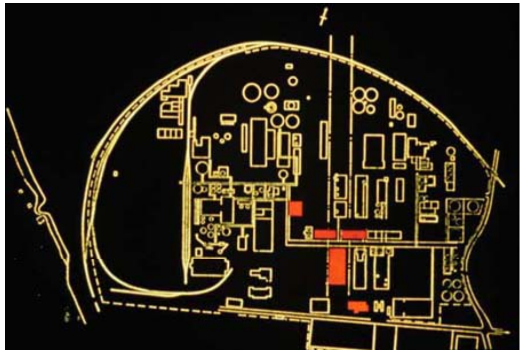
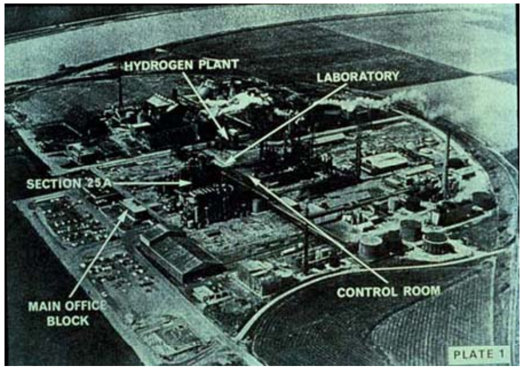
Flixborough Works of Nypro Limited (1974. 6.1, Sat)

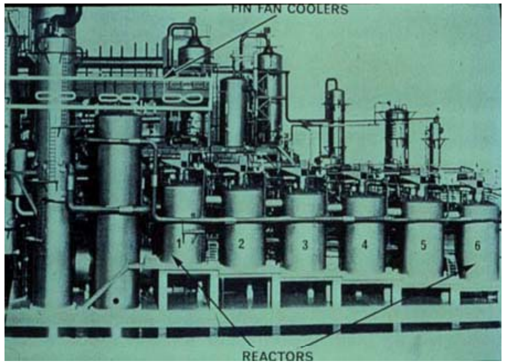
- 70,000 ton, caprolactam for nylon (cyclohexane is oxidized to cyclohexanol in air within a series of six catalytic reactors)
- Under process conditions, cyclohexane vaporizes upon depressurization, forming a cloud of flammable vapor mixed with air.
- Reactor 5 was found to have a crack. Bypass with 20” pipe rather than 28”
- 30 tons of cyclohexane in a cloud was released by leak to air, then unknown ignition source caused the cloud to explode.
- 28 died, 36 injured, damage extended to nearby 1821 houses, 167 shops, and factories by 10 days burning.
- if proper safety design, operation, reducing inventory of flammable liquid on site could have been prevented the disaster

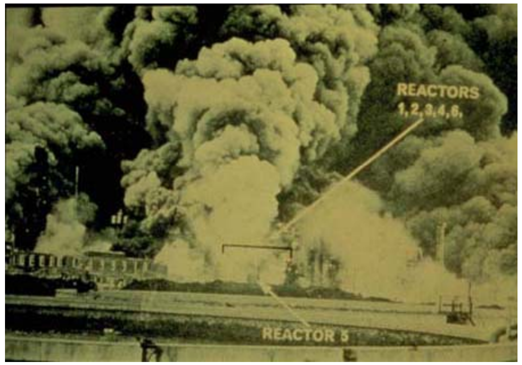
Responsibilities for Process Safety

Flixborough



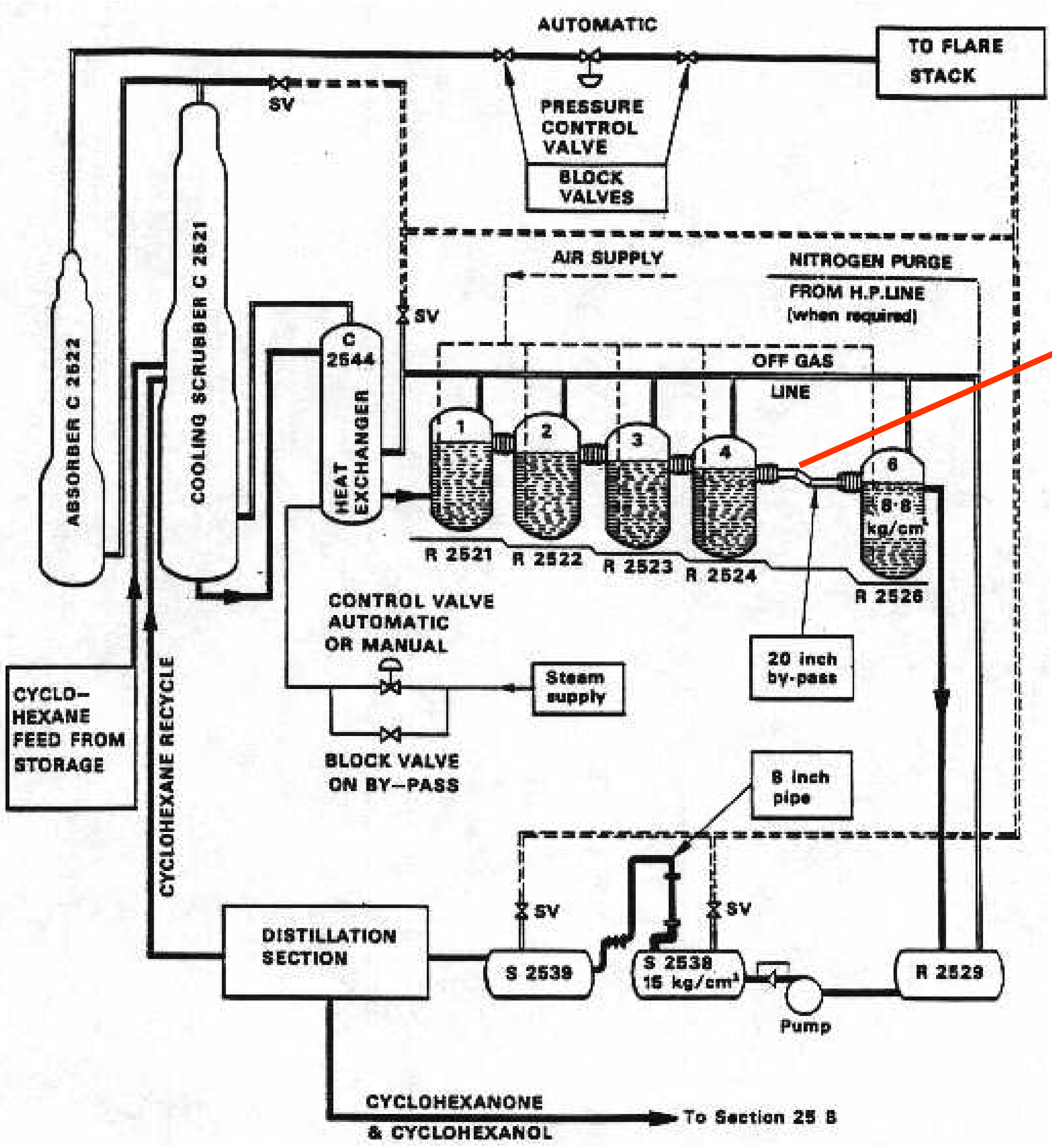



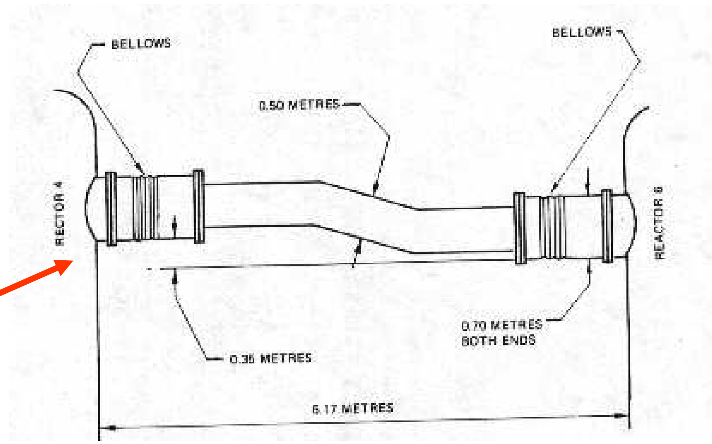


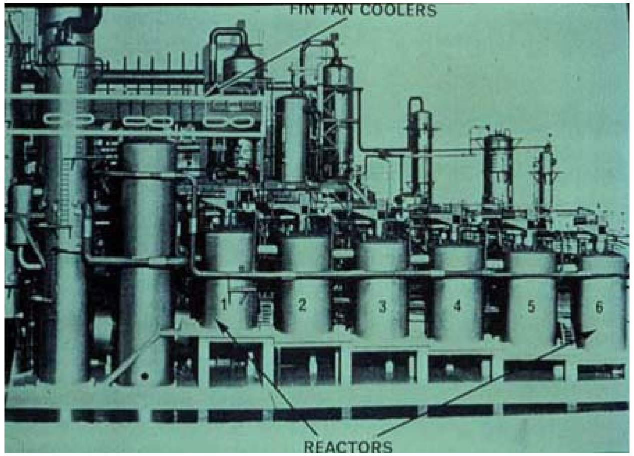


Responsibilities for Process Safety

Responsibilities for Process Safety







Cyclohexane Oxidation Plant

Responsibilities for Process Safety

Bhopal, India, (1984.12. 2, Sun)

(Union Carbide/Locals, Pesticides)

- Release of MIC gives 2000 death, 20,000 injuring nearby residents by respiratory damage.
- Liquid MIC at ambient, boils at 39.1 C, vapor is heavier than air, very toxic at even very low concentration (maximum allowable exposure concentration of MIC for workers during 8-hr is 0.02 ppm) Reacts with water exothermically, but slowly and the heat released can cause MIC to boil if cooling is not provided)

MIC (methyl isocyanate): CH_3-N=C=O

Responsibilities for Process Safety

Unit using MIC was not operating due to a labor dispute

- storage with MIC was contaminated with water (500L)
- reaction was occurred in tank
- heated above b.p. of MIC
- vapor was generated and escaped the pressure relief valve on the tank and were diverted control system
- unfortunately the relief valve 3 was not operating
- 25 tons of MIC vapor was released to community with catastrophe.

☪ if proper safety review procedures for low inventory of MIC or by using alternative reaction chemistries that eliminate MIC could have been prevented the disaster

Responsibilities for Process Safety

- Gauges measuring temperature and pressure in the various parts of the unit, including the crucial MIC storage tanks, were so notoriously unreliable that workers ignored early signs of trouble (Weir, pp.41-42).

-The refrigeration unit for keeping MIC at low temperatures (and therefore less likely to undergo overheating and expansion should a contaminant enter the tank) had been shut off for some time (Weir, pp.41-42).

-The gas scrubber, designed to neutralize any escaping MIC, had been shut off for maintenance. Even had it been operative, post-disaster inquiries revealed, the maximum pressure it could handle was only one-quarter that which was actually reached in the accident (Weir, pp.41-42).

-The flare tower, designed to burn off MIC escaping from the scrubber, was also turned off, waiting for replacement of a corroded piece of pipe. The tower, however, was inadequately designed for its task, as it was capable of handling only a quarter of the volume of gas released (Weir, pp.41-42).

Responsibilities for Process Safety

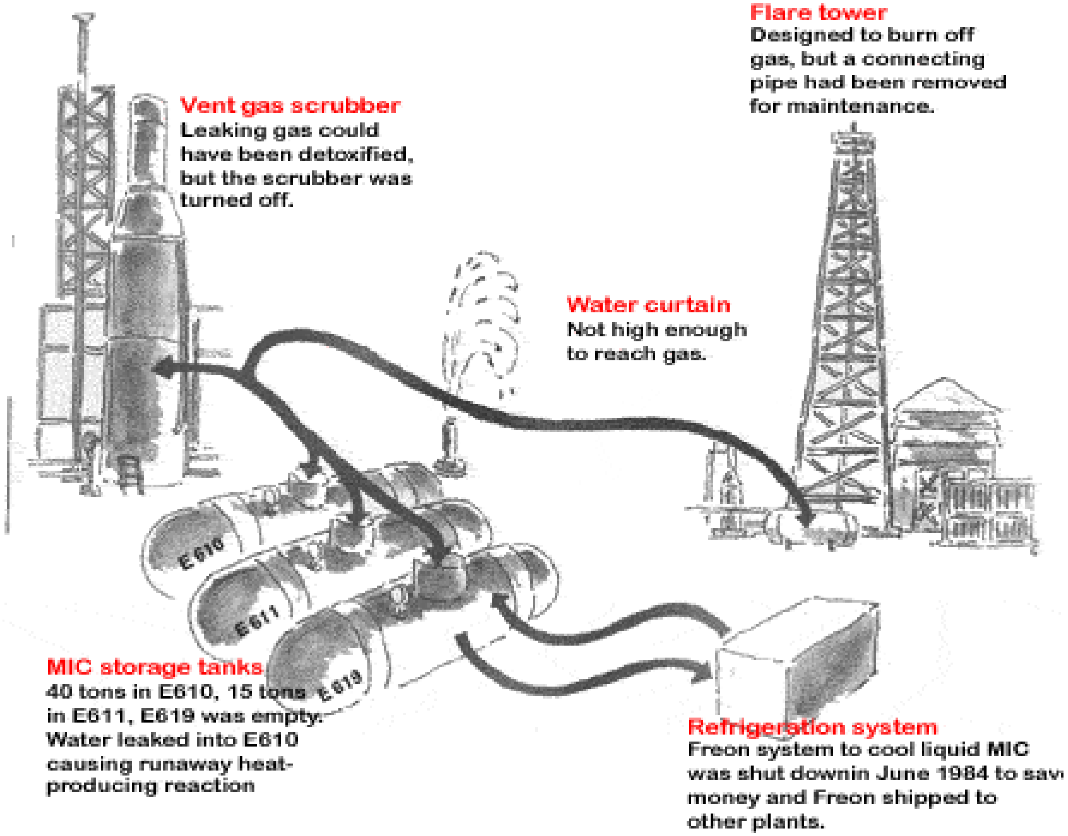
-The water curtain, designed to neutralize any remaining gas, was too short to reach the top of the flare tower, from where the MIC was billowing (Weir, pp.41-42).

-The lack of effective warning systems; the alarm on the storage tank failed to signal the increase in temperature on the night of the disaster (Cassels, p.19).

-MIC storage tank number 610 was filled beyond recommended capacity; and

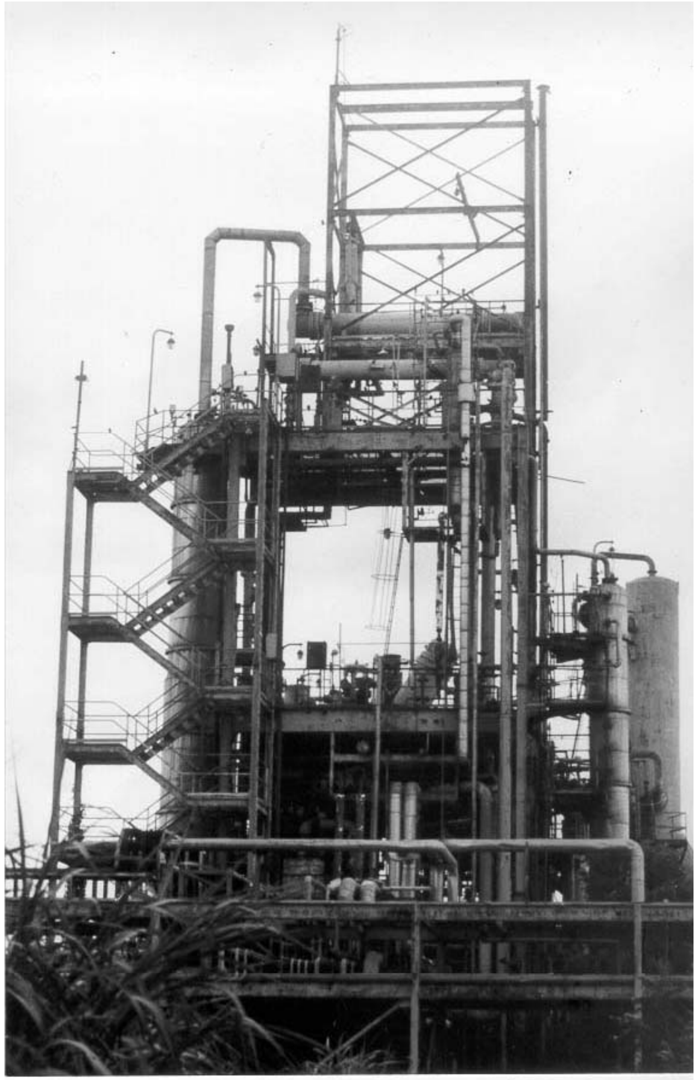
-a storage tank which was supposed to be held in reserve for excess MIC already contained the MIC (Cassels, p.19).

Responsibilities for Process Safety



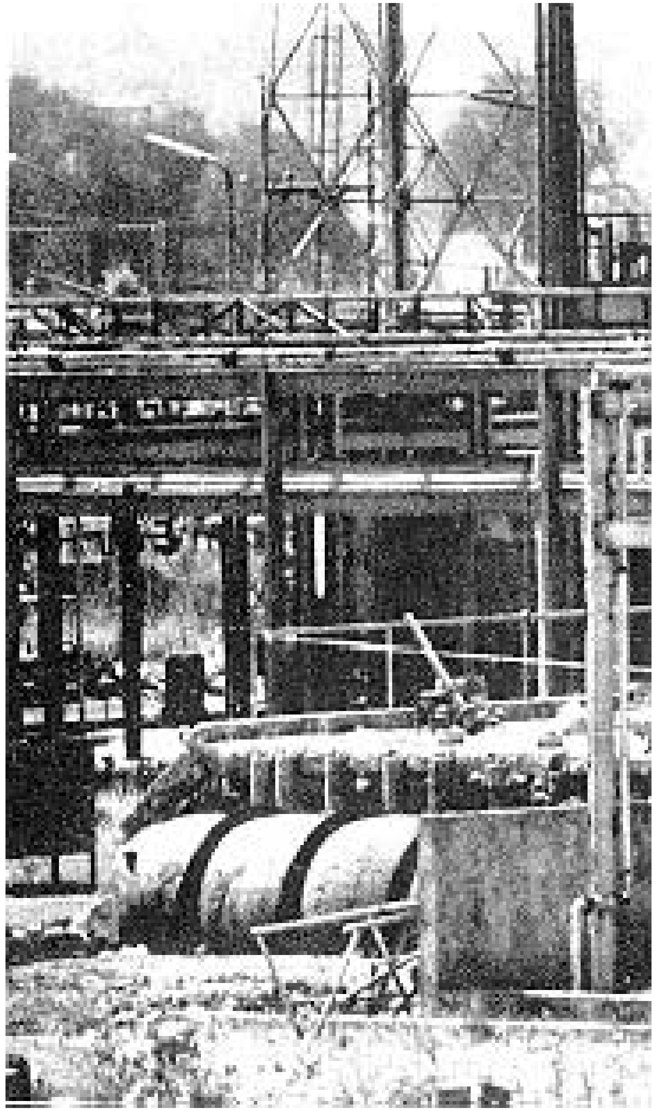
Responsibilities for Process Safety

Bhopal



Responsibilities for Process Safety

Bhopal

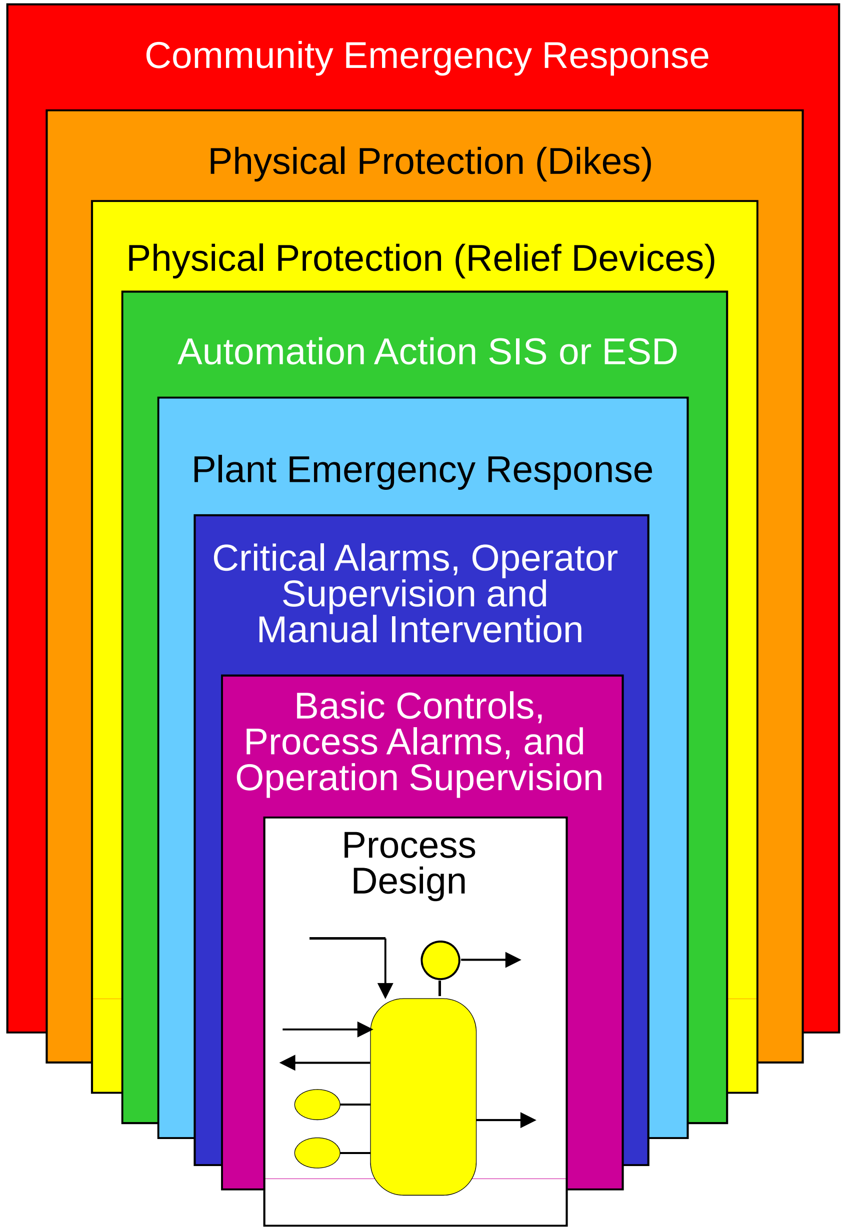


Layer of Protection

In incidents such as this, loss of life and injuries are tragic, and economic consequences are severe. Engineers have a special role to play in preventing such incidents.

Part of an engineer's professional responsibility is to design processes and products that are as safe as possible. Traditionally this meant identifying hazards, evaluating their severity and then applying several layers of protections as a means of mitigating the risk of an accident.

Figure 4.2-1 shows the layer of protection concept and includes examples of layers that might be found in a typical chemical plant.



SIS: safety interlock system
EDS: emergency shutdown

Fig. 4.2-1 *Typical layers of protection for a chemical plant*

What were the safety layers at the Bhopal plant?

First layer

Two primary MIC storage tanks with a reserve one for overflow.

Refrigeration unit to keep MIC at low temperatures to minimize overheating should the tank be contaminated with water or other compounds.

Second layer

Alarm on storage tank if temperature exceeded a critical level

Layer of Protection

Third layer

Gas scrubber to neutralize any MIC that escaped through the tank release valve

Fourth layer

Flare to combust any MIC not completely scrubbed

Fifth layer

Water curtain to neutralize any uncombusted MIC

Layer of Protection

The Event

At Bhopal there was a failure at all levels for safety; the MIC plant had been shut down six weeks prior to incident, but MIC had been stored.

1,000 to 2,000 pounds of water entered into the MIC storage tank and started a runaway chemical reaction with a rapid increase in temperature and pressure. MIC was released through the release valve.

Layer of Protection

Investigation showed:

The reserve storage tank was filled to capacity. The MIC tank was filled beyond capacity. Operating beyond plant design. Operator error.

First layer failure.

The refrigeration unit had been shut down. Some claim it was shut down to save electricity (improper plant maintenance).

First layer failure.

Layer of Protection

The gauges measuring temperature and pressure were not functioning correctly. The alarm system did not signal the temperature increase.

Second layer failure

The first sign of a problem was that workers eyes began to burn and tear. Actions taken did not stop problem.

Second layer failure.

Layer of Protection

Gas scrubber shut off for maintenance. Also not designed at correct capacity.- Third layer failure

Flare turned off – being maintained. Fourth layer failure

Water curtain not properly designed and failed. Fifth layer failure

Alarm system in the plant functioned, but siren for community turned off in 1982 – Sixth layer failure

No community emergency response plan. Sixth layer failure

Layer of Protection

Subsequent analysis and investigation by a team of engineers indicated that sabotage may have been the root cause, although this remains very controversial. Regardless of whether or not the plant was sabotaged, the other safety devices should have prevented the release to the atmosphere. These safety devices failed.

In 1990 the U.S. Senate considered an EPA analysis that compared U.S. chemical incidents in the 1980's. There were 29 incidents reviewed. Of these, 17 had releases of sufficient volumes of chemicals with toxicity such that the potential consequences (depending on weather conditions and plant location) could have been more severe than in Bhopal.

Layer of Protection

For more information:

Investigation of Large-Magnitude Incidents; Bhopal as a case study

A. S. Kalelkar and A. D. Little

www.bhopal.com (go to information archive for PDF file)

Bhopal Disaster Spurs U. S. Industry, legislative Action

A. Bryce, U. S. Chemical Safety Board

www.chemsafety.gov/lib/bhopal01.htm

Trade and Environmental (TED) Case Studies

#233, Bhopal Disaster

www.american.edu/TED/BHOPAL.HTM

Layer of Protection

What are lessons to learn from the Bhopal event?

The best approach is to design an inherently safer facility rather than protective layers. Inherently safer design is a fundamentally different approach to chemical process safety.

Instead of working with existing hazards in a chemical process and adding layers of protection, the engineer is challenged to reconsider the design and eliminate or reduce the source of the hazard within the process. Approaches to the design of inherently safer processes have been grouped into the four categories listed below.

Layer of Protection

Layer of protection as a means of mitigating the risk of accident. This approach can be very effective and has resulted in significant improvement of the safety performance of chemical process.

Layer of Protection has a limitation

(1) the layers are expensive to build and maintain

(2) hazard remains and there is always a finite risk that an accident will happen despite the layers of protection

Design of inherently safer processes

Inherently safe design is fundamentally different approach to chemical process safety.

Instead of working with existing hazards in a chemical process and adding layers of protection, the engineer is challenged to reconsider the design and eliminate or reduce of hazard within the process.

Design of inherently safer processes

Approaches to the design of inherently safer processes have been grouped into four categories.

Minimize	Use smaller quantities of hazardous substances
Substitute	Use a less hazardous materials in place of a more hazardous substance
Moderate	Use less hazardous conditions or facilities which minimize the impacts of a release of a hazardous material or energy
Simplify	Design facilities which eliminate unnecessary complexity and make operating errors less likely, and which are forgiving of errors that are made

Checklist for inherently safer process

Minimize Use smaller quantities of hazardous substances

- *Have all in-process inventories of hazardous materials in storage tanks been minimized?*
- *Are all of the proposed in-process storage tanks really needed?*
- *Can other types of unit operations or equipment reduce material inventories?*

(ex. Continuous in-line mixers in place of mixing vessels)

Checklist for inherently safer process

Substitute Use a less hazardous materials
in place of a more hazardous substance

- *Is it possible to completely eliminate hazardous raw materials, process intermediates, or byproducts by using an alternative process or chemicals ?*

- *Is it possible to substitute less hazardous raw materials or to substitute noncombustible for flammable solvents ?*

Checklist for inherently safer process

Moderate Use less hazardous conditions or facilities which minimize the impacts of a release of a hazardous material or energy

- *Can the supply pressure of raw materials be limited to less than the working pressure of the vessels they are delivered to ?*
- *Can reaction conditions (T, P) be made less severe by using a catalyst, or by using a better catalyst ?*

Checklist for inherently safer process

Simplify Design facilities which eliminate unnecessary complexity and make operating errors less likely, and which are forgiving of errors that are made.

- *Can equipment be sufficiently designed to totally contain the maximum pressure generated, even if the worst event occur ?*

Checklist for inherently safer process

More checklist can be found in

the Center for Chemical Process Safety (CCPS) publication

CCPS, Center for Chemical Process Safety, *Guidelines for Engineering Design of Process Safety*, New York, AIChE, 1993

Crowl, D.A. ed., *Inherently Safer Chemical Processes: A Life Cycle Approach*, Center for Chemical Process Safety, AIChE, 1996

New Generation of inherently safer process

Traditional Approach

- rely on designing layers of protection around process hazards
- focus on designs that treat wastes

New Generation Approach

- rely on designs that reduce hazards,
  rather than providing protection from hazards
- designed so that they do not generate waste

4.3 Responsibilities for Environmental Protection

At what stage in the design should environmental considerations be considered?

(1) Definition of a primitive problem

(identify the chemical to be produced and annual quantity)

(2) Process creation step (choose reaction chemistry, use of design heuristics to identify process equipment and operating conditions, flow-sheet, simulations, etc.)

(3) Detailed design

(detailed process synthesis of separation, heat integration analysis, simulation of flow-sheet, profitability analysis, optimization)

(4) Final step (plant-wide controllability assessment, startup assessment, reliability and safety analysis)

CMA Pollution Prevention Code of Management Practices

CMA: Chemical Manufacturers Association
(Now American Chemistry Council)

Outlines tangible steps along a path to continuous reduction in the amounts of all contaminants released to air, water, and soil.

These practices demonstrate a clear commitment by senior management, a path to quantify waste generation and prioritize waste reduction, a preference for source reduction, reuse/recycle rather than pollution control, and a plan to measure and report on progress in achieving reduction goals.

Table 4.3-1 *Pollution prevention Code of management practices*

Table 4.3-1 CMA Pollution Prevention Code of Management Practices (Now the American Chemistry Council)

This Code is designed to achieve ongoing reductions in the amount of all contaminants and pollutants released to the air, water, and land from member company facilities. The Code is also designed to achieve ongoing reductions in the amount of wastes generated at facilities. These reductions are intended to help relieve the burden on industry and society of managing such wastes in future years.

Management Practices

Each member company shall have a pollution prevention program that shall include:

1. A clear commitment by senior management through policy, communications, and resources, to ongoing reductions at each of the company's facilities, in releases to the air, water, and land and in the generation of wastes.
2. A quantitative inventory at each facility of wastes generated and releases to the air, water, and land, measured or estimated at the point of generation or release. **(Chapter 8)**
3. Evaluation, sufficient to assist in establishing reduction priorities, of the potential impact of releases on the environment and the health and safety of employees and the public. **(Chapters 1, 2, 5, 8, and 11)**
4. Education of, and dialogue with, employees and members of the public about the inventory, impact evaluation, and risks to the community.
5. Establishment of priorities, goals and plans for waste and release reduction, taking into account both community concerns and the potential health, safety, and environmental impacts as determined under items 3 and 4.
6. Ongoing reduction of wastes and releases, giving preference first to source reduction, second to recycle/reuse, and third to treatment. These techniques may be used separately or in combination with one another. **(Chapters 7, 9, and 10)**

Fig. 4.3-1 *(continued)*

7. Measurement of progress at each facility in reducing the generation of wastes and in reducing releases to the air, water, and land, by updating the quantitative inventory at least annually. **(Chapter 8)**
8. Ongoing dialogue with employees and members of the public regarding waste and release information, progress in achieving reductions, and future plans. This dialogue should be at a personal, face-to-face level, where possible, and should emphasize listening to others and discussing their concerns and ideas.
9. Inclusion of waste and release prevention objectives in research and in design of new or modified facilities, processes, and products.
10. An ongoing program for promotion and support of waste and release reduction by others, which may, for example, include:
    a. Sharing of technical information and experience with customers and suppliers;
    b. Support of efforts to develop improved waste and release reduction techniques;
    c. Assisting in establishment of regional air monitoring networks;
    d. Participation in efforts to develop consensus approaches to the evaluation of environmental, health, and safety impacts of releases;
    e. Providing educational workshops and training materials;
    f. Assisting local governments and others in establishment of waste reduction programs benefiting the general public.
11. Periodic evaluation of waste management practices associated with operations and equipment at each member company facility, taking into account community concerns and health, safety, and environmental impacts and implementation of ongoing improvements.
12. Implementation of a process for selecting, retaining, and reviewing contractors and toll manufacturers taking into account sound waste management practices that protect the environment and the health and safety of employees and the public.
13. Implementation of engineering and operating controls at each member company facility to improve prevention of and early detection of releases that may contaminate groundwater.
14. Implementation of an ongoing program for addressing past operating and waste management practices and for working with others to resolve identified problems at each active or inactive facility owned by a member company taking into account community concerns and health, safety, and environmental impacts.

Homework #4

Further Reading in Engineering Ethics

- *Process safety and environmental protection are not the only responsibilities of professional engineers. Engineers also have responsibilities to clients, to colleagues and to the professions.*

AIChE Web

http://www.aiche.org/membership/ethics.htm

Problems 1 by April 6