Process Safety Engineering: Concepts & Topics

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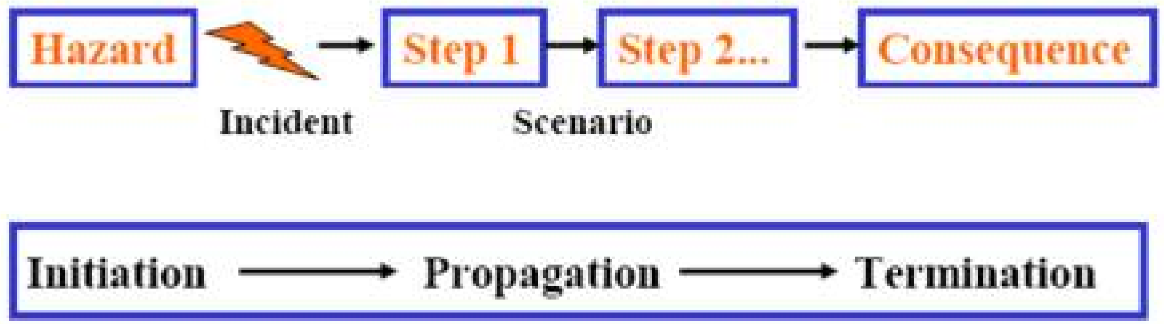
The accident's three-step sequence

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).



Example

A worker walking across a high walkway in a process plant stumbles and falls toward the edge. To prevent the fall, he grabs a nearby valve stem. Unfortunately, **the valve stem shears off and flammable liquid begins to spew out. A cloud of flammable vapor rapidly forms and is ignited by a nearby truck. The explosion and fire quickly spread to nearby equipment**. The resulting fire lasts for six days until **all flammable materials in the plant are consumed**, and the plant is completely destroyed.

- *Check another Example 1-6 Page 19*

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	Firefighting equipment and procedures Relief systems Sprinkler systems Installation of check and emergency shutoff valves

Process Hazard Analysis

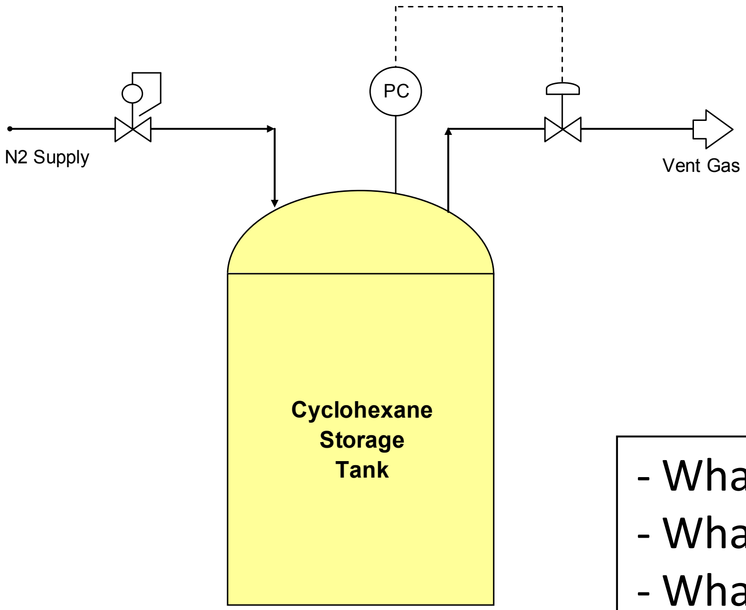
- Process Hazard Analysis (PHA) is a technique for determining the RISK of operating a process or unit operation.

- PHAs are required by law for process handling threshhold quantities for certain listed Highly Hazardous Chemicals (HHC) or flammables.

- Approved techniques for conducting PHAs:
  - HAZOP (Hazard and Operability)
  - What If?
  - FMEA (Failure Mode and Effects Analysis)

- In general, a PHA is conducted as a series of facilitated, team brainstorming sessions to systematically analyze the process.

Risk Assessment Example



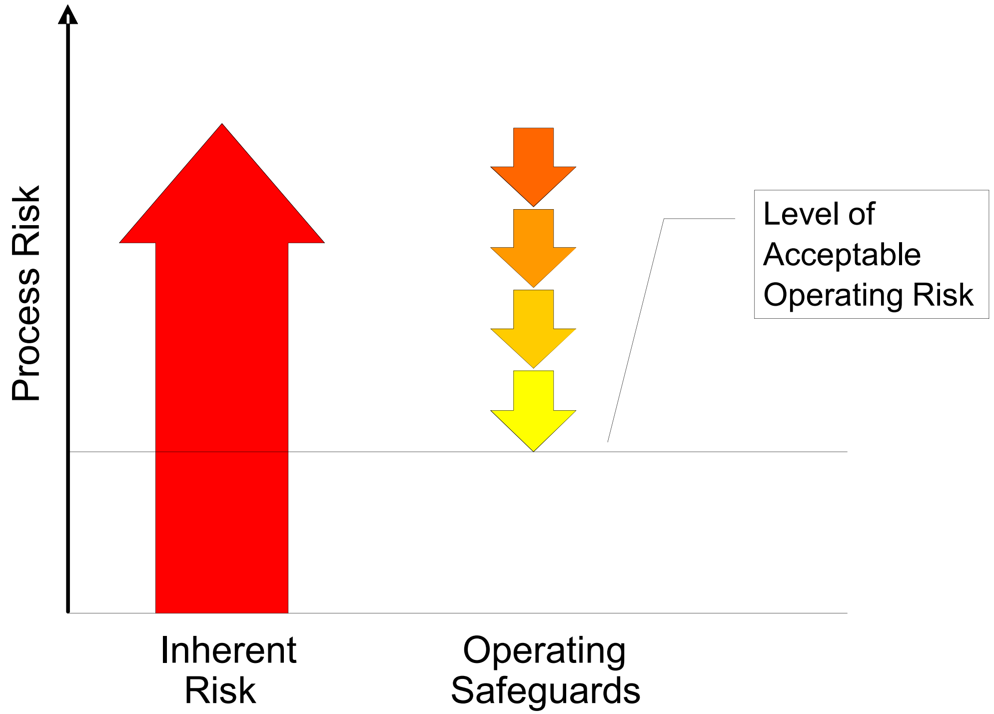
- Consider a low design pressure API storage tank filled with cyclohexane.
- Assume that the storage tank is equipped with a "pad/de-pad" vent system to control pressure.

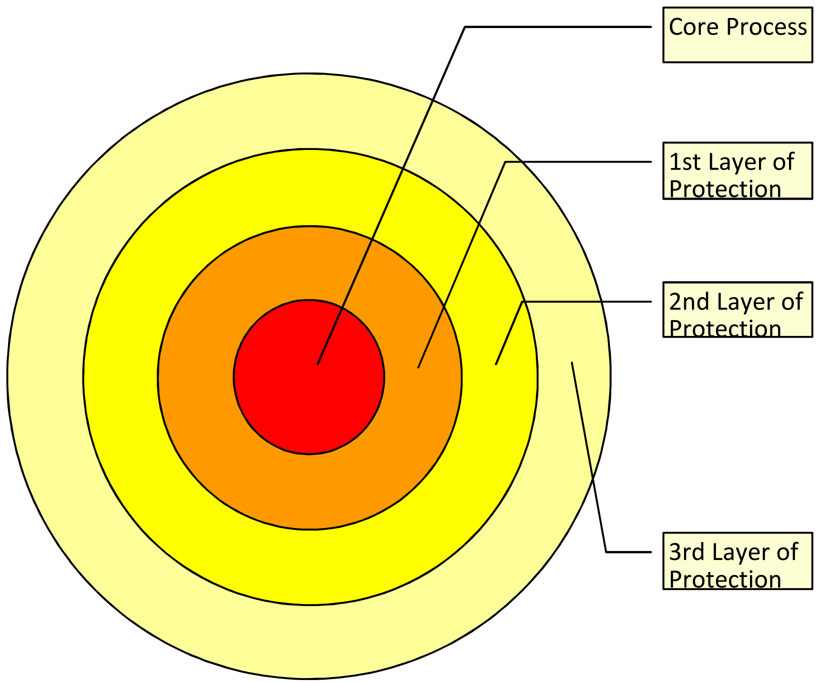
- What hazard scenarios might occur from this system?
- What are the consequences of these scenarios?
- What Safeguards might we choose to mitigate the risk?

What If…?	Initiating Cause	Consequence	Safeguards
1. There is High Pressure in the Cyclohexane Storage Tank?	1.1 Failure of the pressure regulator on nitrogen supply line.	1.1 Potential for pressure in tank to rise due to influx of nitrogen through failed regulator. Potential to exceed design pressure of storage tank. Potential tank leak or rupture leading to spill of a flammable liquid. Potential fire should an ignition source be present. Potential personnel injury should exposure occur.	1. Pressure relief vent (PRV) sized to relieve overpressure due to this scenario. 2. Pressure transmitter with high alarm set to indicate high pressure in Cyclohexane Storage Tank.

Mitigating Process Risk

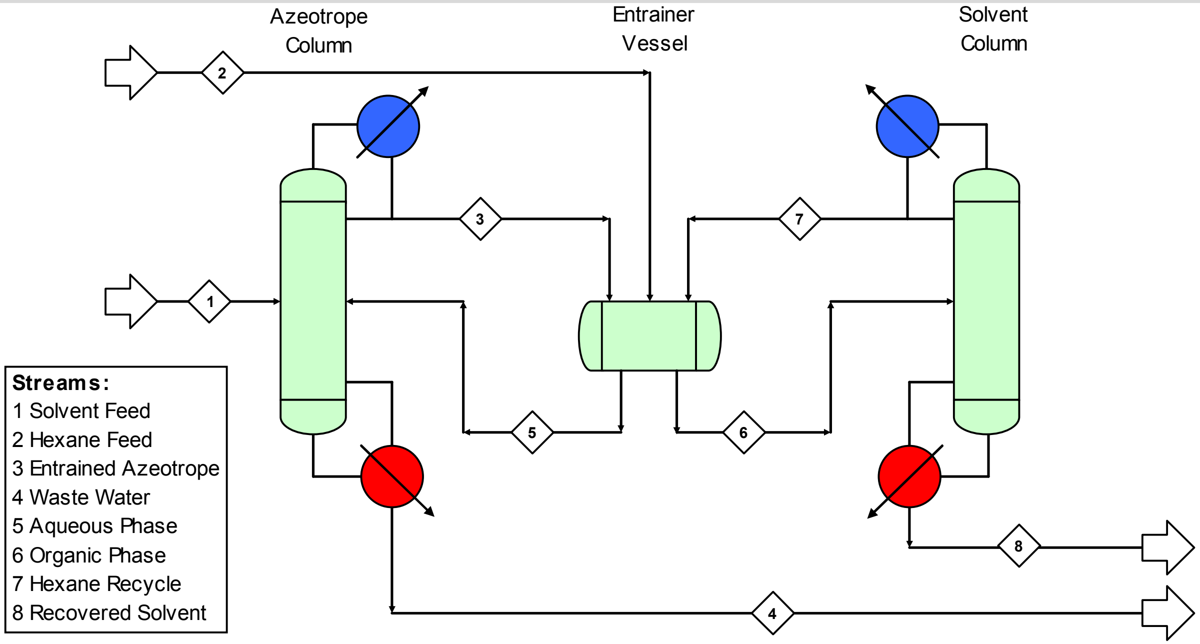
– The operating risk is determined by the PHA using an appropriate Risk Assessment Methodology.





– This risk is mitigated through the application of safeguards that reduce the risk to an acceptable level.

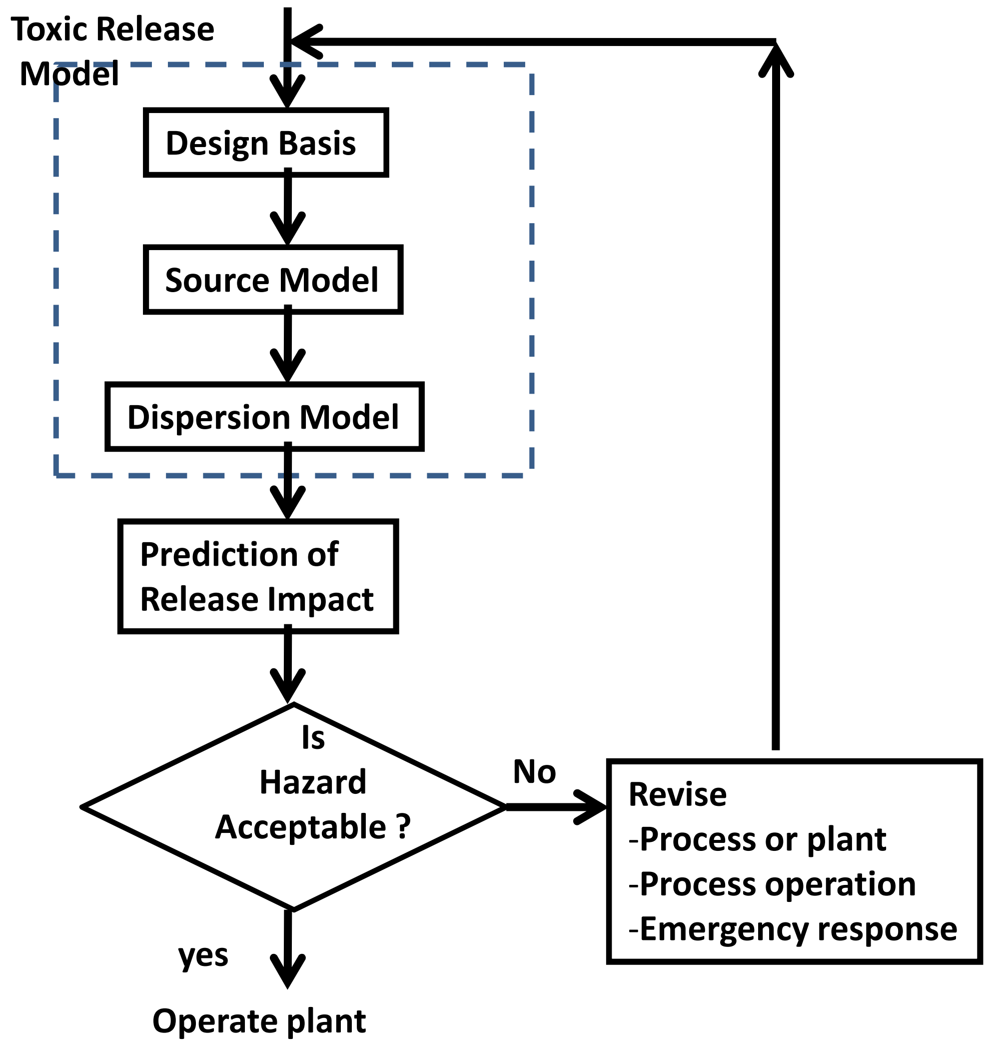
Example



What If…?	Initiating Cause	Consequence
1. There is higher pressure in the Entrainment Vessel?	1.1 External fire in the process area.	1.1 Potential increased temperature and pressure leading to possible vessel leak or rupture. Potential release of flammable material to the atmosphere. Potential personnel injury due to exposure.
	1.2 Pressure regulator for inert gas pad fails open.	1.2 Potential for vessel pressure to increase up to the inert gas supply pressure. Potential vessel leak or rupture leading to release of flammable material to the atmosphere. Potential personnel injury due to exposure.
2. There is higher level in the Entrainer Vessel?	2.1 Vessel level transmitter fails and indicates lower than actual volume.	2.1 Potential to overfill vessel with cyclohexane. Potential to flood vent line with liquid leading to flammable liquid reaching the vent gas incinerator. Potential to overwhelm incinerator leading to possible explosion. Potential personnel injury due to exposure.

Consider what types of safeguards would be required to mitigate the Process Risk due to these scenarios.

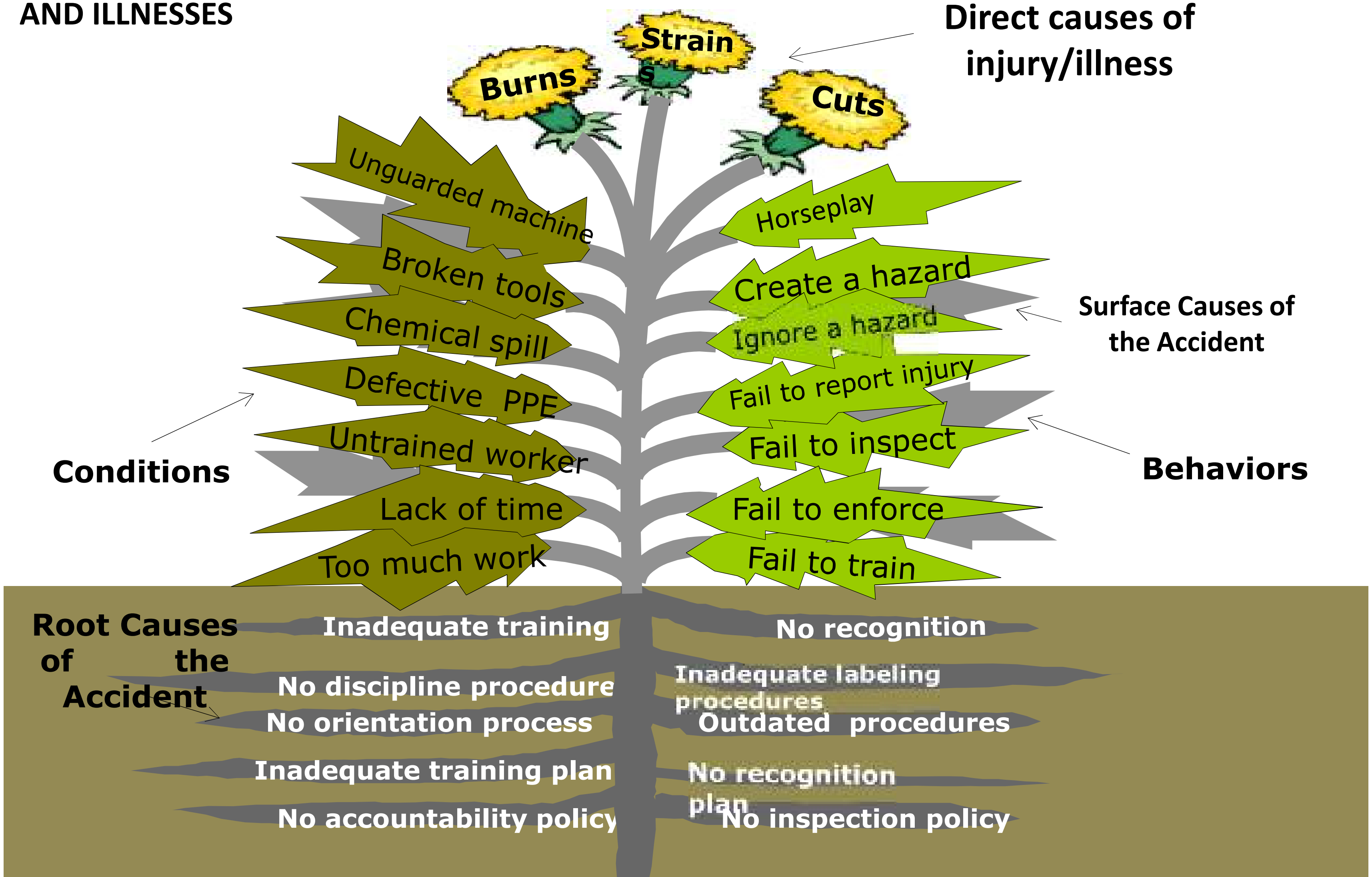
Release Mitigation Procedure



Root Cause?

To prevent future occurrences you need to determine the root cause!

WEED OUT THE CAUSES OF INJURIES AND ILLNESSES



If you eliminate the root cause of an accident, you will eliminate those accidents in the future!

Accident investigations

- Accident investigations are designed to enhance learning.
- The fundamental steps in an investigation include:

1) Developing a detailed description of the accident,
2) Accumulating relevant facts,
3) Analyzing the facts and developing potential causes of the accident,
4) Studying the system and operating methods relevant to the potential causes of the accident,
5) Developing the most likely causes,
6) developing recommendations to eliminate recurrence of this ***type*** of accident, and
7) using an investigation style that is fact-finding and not faultfinding; faultfinding creates an environment that is not conducive to learning

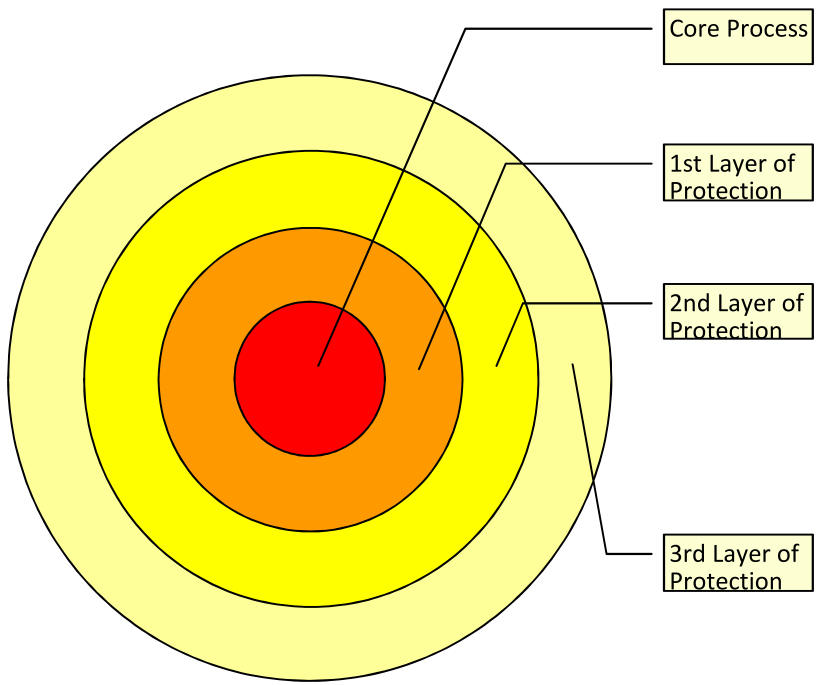
Layered Investigations

Three levels of recommendations for preventing and mitigating accidents:

First layer: immediate technical recommendations,

Second layer: recommendations to avoid the hazards,

Third layer: recommendations to improve the management system.



Example 12-1 Pool Accident

A drowning accident occurred during an open swim period. Approximately 100 children, ranging between 5 and 16 years old, were in and around a pool. An older child unknowingly pushed a 5 year old into the deep water. The pool is relatively crowded, and the 5 year old slipped under the water without being noticed by others, including the lifeguard

The facts uncovered by an investigation team are

1. the pool did not have deep and shallow markings,

2. the older child was engaged in horseplay,

3. the younger child did not know how to swim,

4. the lifeguard had many blind fields of vision,

5. the pool was overly crowded,

6. the pool did not have an orientation program, and

7. the pool did not offer swimming lessons

First layer: **Immediate technical recommendations**

1) Paint pool depths at the pool edges.
2) Add more lifeguards.
3) Reduce the number of swimmers.

Pool Accident - Layered Investigation

Second layer: **Avoiding the hazard**

1) Prohibit horseplay.
2) Zone pool to keep smaller children at shallow end of pool.
3) Add swimming lessons for all age groups.
4) Give all new swimmers (especially young children) a pool orientation.
5) Add a roving lifeguard to monitor and control pool behavior.

Third Layer: **Improving the management system**

1) Train lifeguards to alert supervision of observed potential problems.
2) Assign supervisor to make formal (documented) audits on a regular basis

Questions for Layered Accident Investigations

(1) What equipment failed?
  - How can failures be prevented or made less likely?
  - How can failures or approaching failure be detected?
  - How can failures be controlled or consequences minimized?
  - What does the equipment do?
  - What other equipment can be used instead?
  - What could we do instead?

(2) What material leaked (exploded, decomposed, etc.)?
  - How can leaks (etc.) be prevented?
  - How can leaks or approaching leak be detected?
  - What does material do?
  - Can volumes of material be reduced?
  - What materials can be substituted?
  - What could we do instead?

(3) Which people could have performed better?
  - What could they have done better?
  - How can we help them to perform better?

(4) What is the purpose of the operation involved in the accident?
  - Why do we do this?
  - What could we do instead?
  - How else could we do it?
  - Who else could do it?
  - When else could we do it?

[1]Trevor Kletz, *Learning from Accidents in Industry* (Boston: Butterworths, 1988), p. 153.

Aids for Diagnosis

Just Read through Section 12.5, from page 522 to 528.

All information should be memorized, and calculations should be exercised.

HW

Identify the initiation, propagation, and termination steps for the following accident reports. Suggest ways to prevent and contain the accidents.

An alkylation unit was being started up after shutdown because of an electrical outage. When adequate circulation could not be maintained in a deisobutanizer heater circuit, it was decided to clean the strainer. Workers had depressurized the pipe and removed all but three of the flange bolts when a pressure release blew a black material from the flange, followed by butane vapors. These vapors were carried to a furnace 100 ft away, where they ignited, flashing back to the flange. The ensuing fire exposed a fractionation tower and horizontal receiver drums. These drums exploded, rupturing pipelines, which added more fuel. The explosions and heat caused loss of insulation from the 8-ft x 122-ft fractionator tower, causing it to weaken and fall across two major pipe-lines, breaking piping, which added more fuel to the fire. Extinguishment, achieved basically by isolating the fuel sources, which took 2.5 hours.

The fault was traced to a 10-in valve that had been prevented from closing the last 3/4-inch by a fine powder of carbon and iron oxide. When the flange was opened, this powder blew out, allowing liquid butane to be released.