Layer of Protection Analysis (LOPA) – Introduction

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Disclaimer

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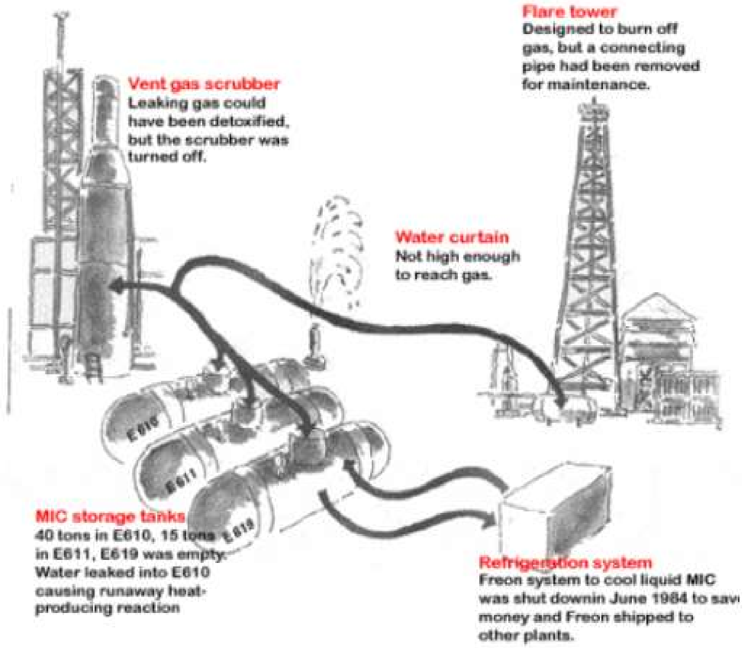
Bhopal Incident



Vent gas scrubber
Leaking gas could have been detoxified, but the scrubber was turned off.

Flare tower
Designed to burn off gas, but a connecting pipe had been removed for maintenance.

Water curtain
Not high enough to reach gas.

MIC storage tanks
40 tons in E610, 15 tons in E611, E619 was empty. Water leaked into E610 causing runaway heat-producing reaction

Refrigeration system
Freon system to cool liquid MIC was shut downin June 1984 to sav money and Freon shipped to other plants.

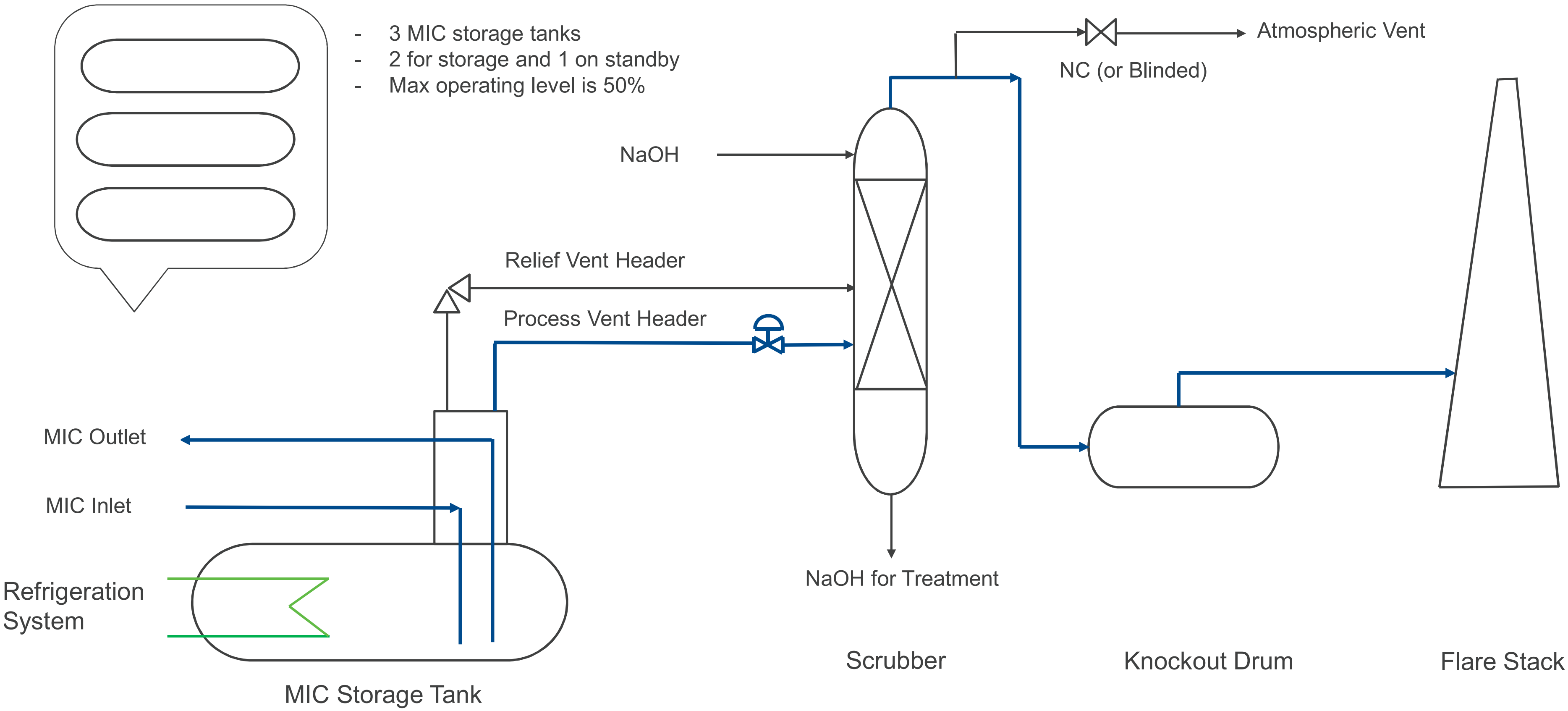
Source: Bhopal.org

On 3 December 1984, a Union Carbide plant in Bhopal, India leaked **the deadly gas methyl isocyanate (MIC)**

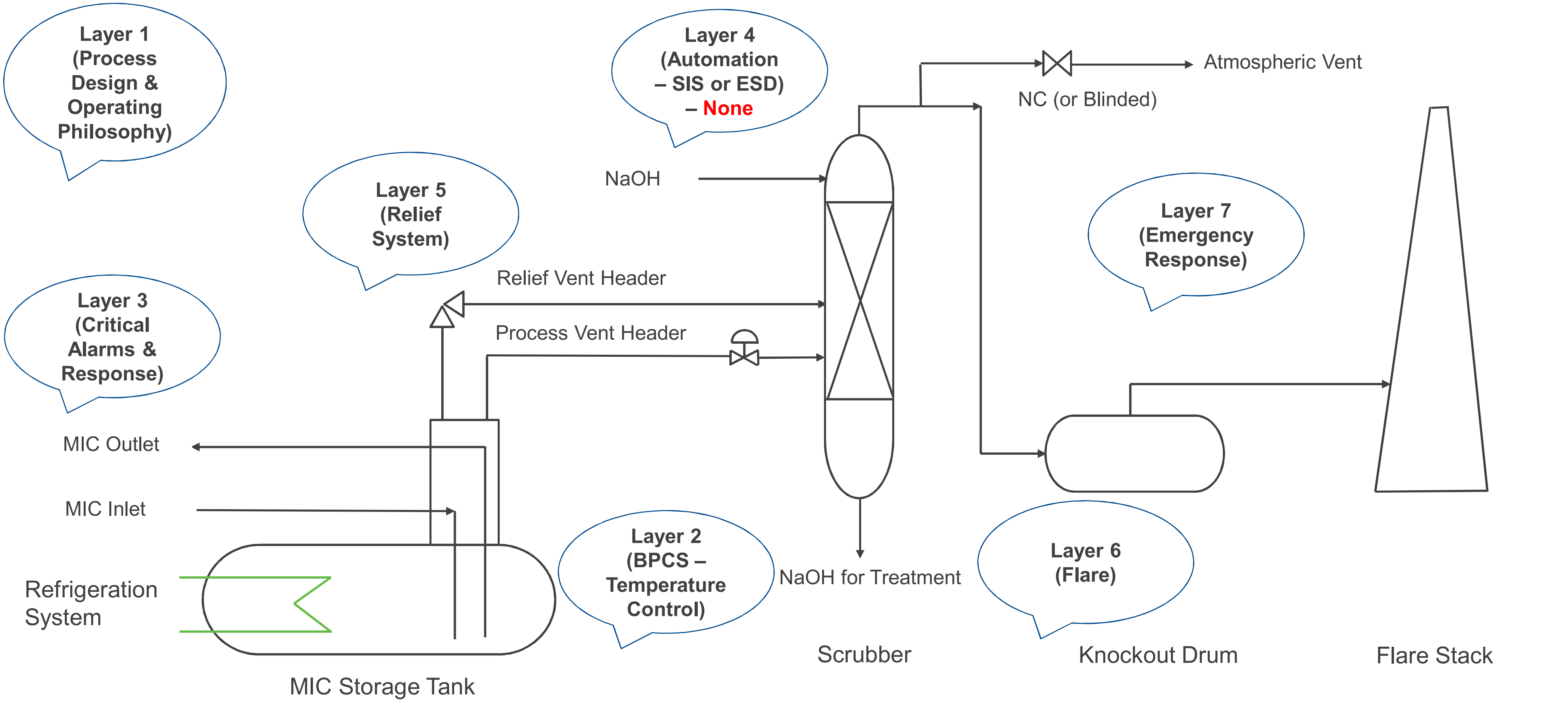
None of the **safety systems** designed to contain such a leak were **operational,** allowing the gas to spread throughout the city of Bhopal

The tank that leaked the MIC gas

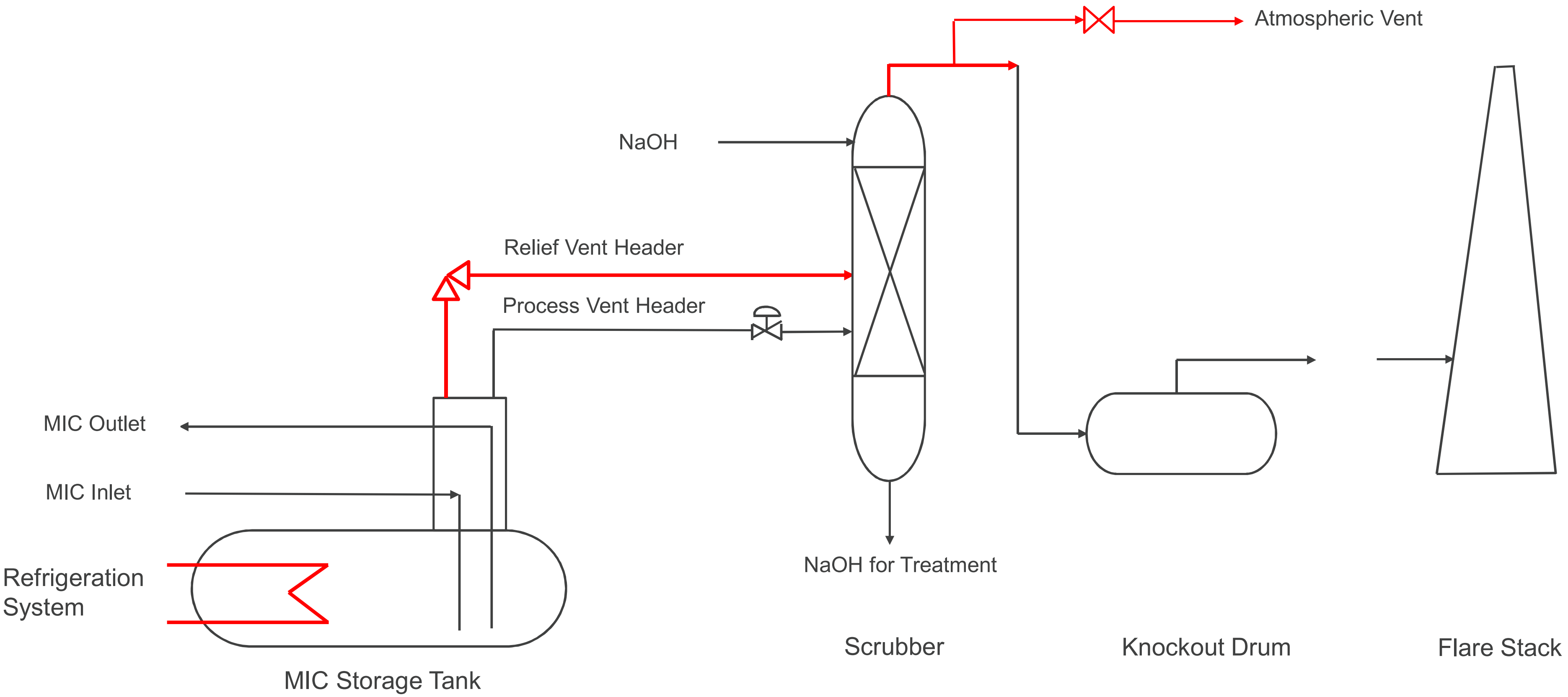
Normal Operation



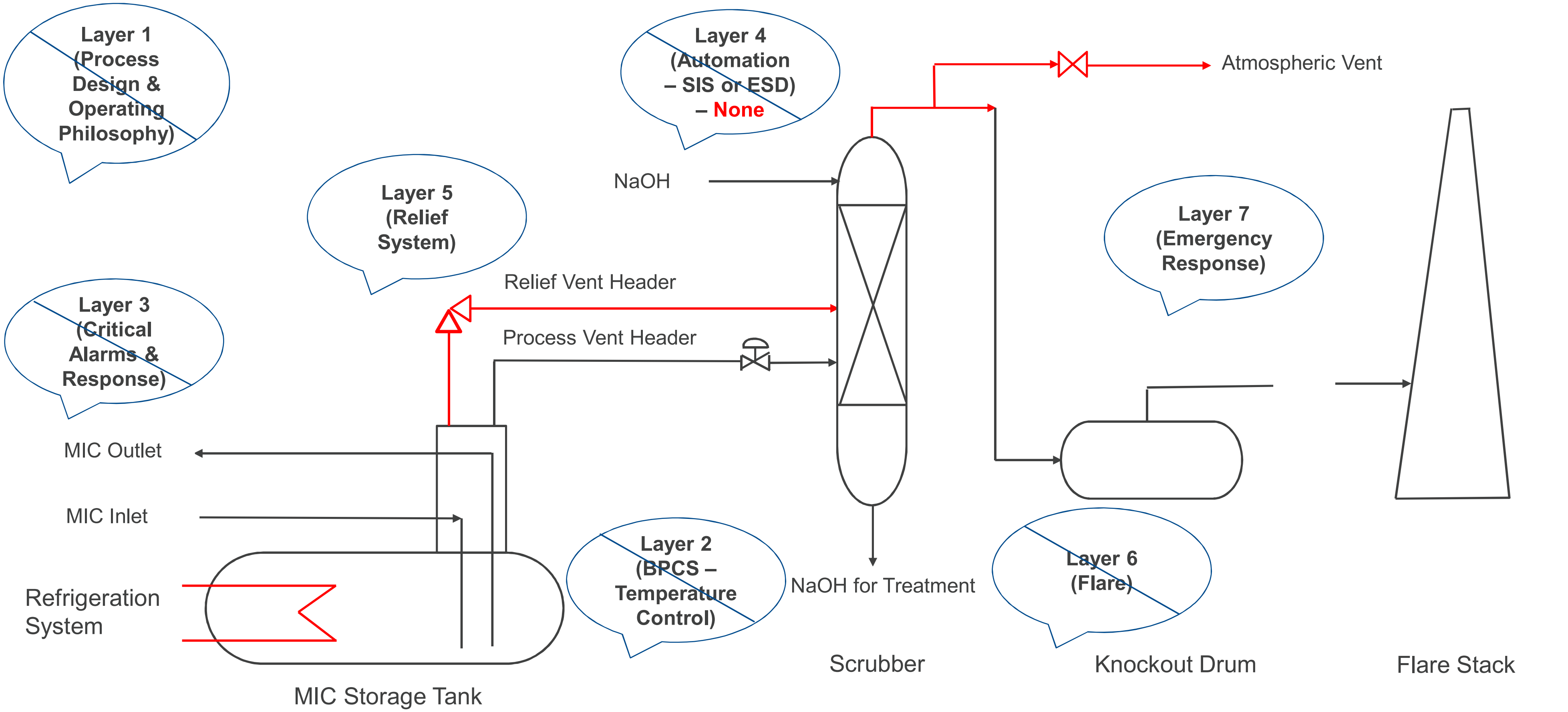
Original Design Considerations



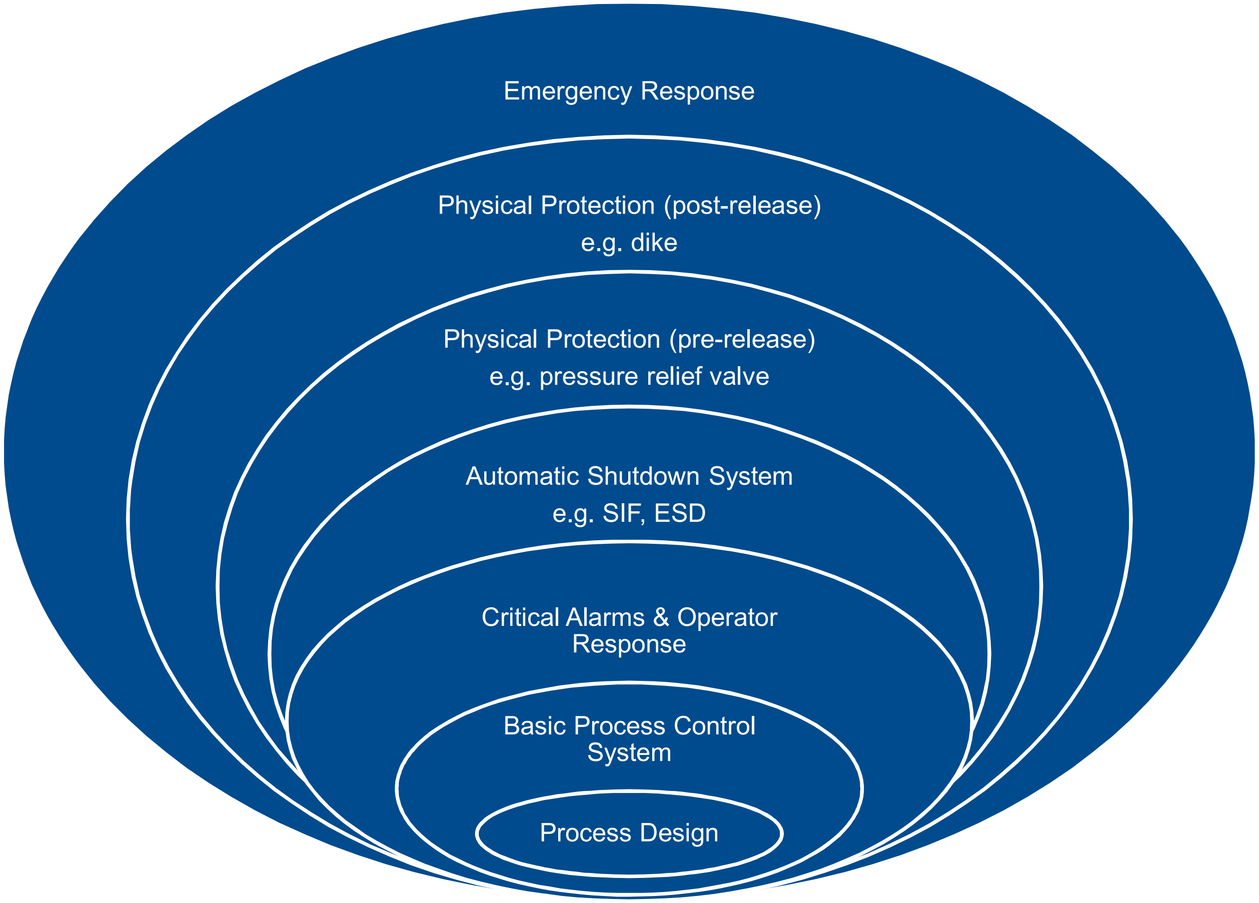
What happened?



What happened?



Layers of Protection – Process Related Hazards



Emergency Response

Physical Protection (post-release)
e.g. dike

Physical Protection (pre-release)
e.g. pressure relief valve

Automatic Shutdown System
e.g. SIF, ESD

Critical Alarms & Operator Response

Basic Process Control System

Process Design

What is LOPA?

- LOPA is a semi-quantitative risk assessment tool for analyzing and assessing the risks of the scenarios with higher consequence of concern (e.g. major accident scenarios)
  - The risk is compared against the company's risk tolerance criteria
  - If the risk is at an unacceptable level, additional protection layers (i.e. control measures) are identified and suggested for implementation

- Risk is a function of likelihood and severity (i.e. consequence)

- The LOPA uses order-of-magnitude estimates for determining the likelihood

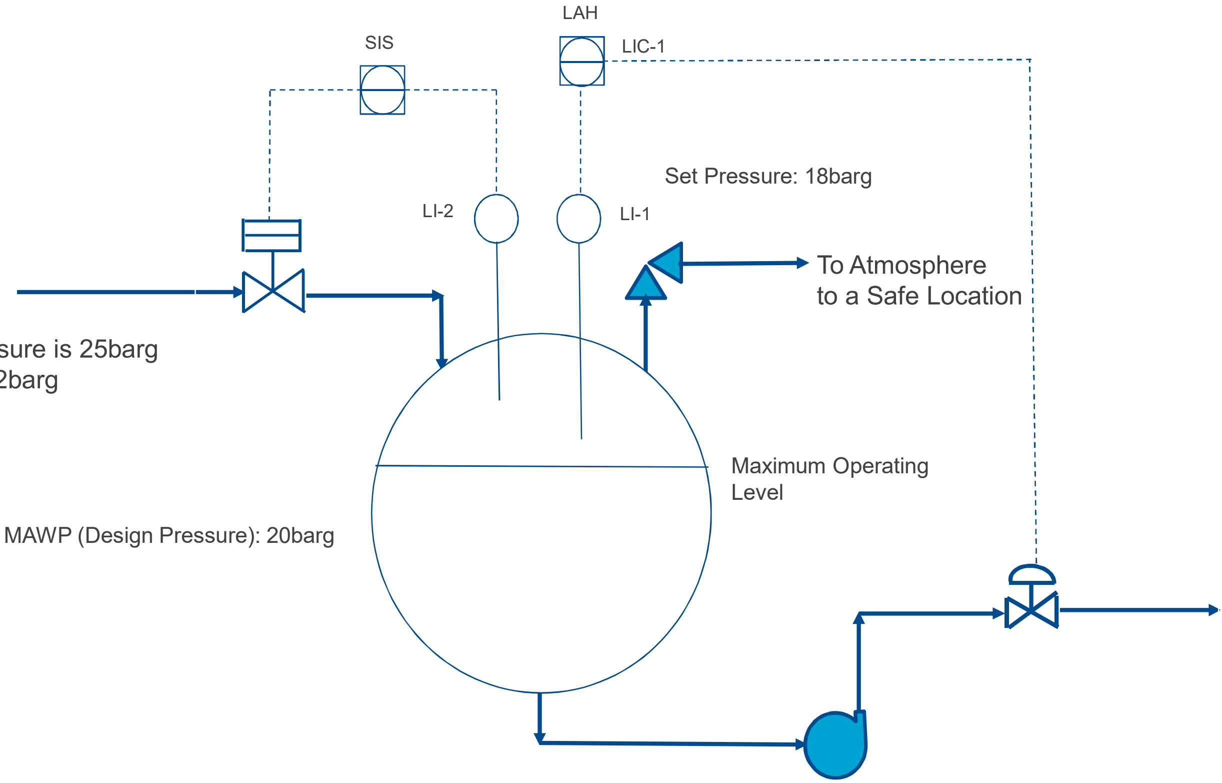
- The severity is typically assessed qualitatively in reference to the company Risk Matrix definitions
  - Alternatively, mathematical consequence analysis results can be used to assess the severity (if required)

- LOPA is one of the commonly applied tools for determining the required Safety Integrity Level (SIL) in a Safety Instrumented Function (SIF)

Scenario-Based Risk Assessment Tool

- LOPA is applied to the scenario-based risk assessments
- LOPA is applied to a single initiating event and a single consequence pair
- The scenario starts with an initiating event, propagates through the cascading events and other unfavorable conditions and results in a consequence of concern
  - Initiating event refers to the cause that triggers/initiates the scenario
  - Cascading events refer to the coincident failures of other protection layers
  - Other unfavorable conditions refer to factors/conditions that must be present for the consequence to occur

Example



Propane From Upstream Unit

Maximum possible source pressure is 25barg
Normal operating pressure is 12barg

To Atmosphere
to a Safe Location

Propane
To Downstream Unit

Example - Background

- Let us assume it is an intermediate pressure storage tank that continuously takes propane from the upstream unit and feeds to the downstream unit

- From the schematic, it can be seen there is a potential for a liquid overfill to occur should there be an equipment, instrumentation and/or human failure

- In case of a loss of containment of propane to atmosphere through the pressure relief device (PRD), there is a potential for a vapor cloud explosion (VCE), flash fire, jet fire
  - Pool fire may be credible depending upon the flash fraction
  - For the discussion sake, let us assume that propane doesn't contain any toxics

- Several causes could trigger the liquid overfill scenario
  - Bottom pump failure in the pressure storage tank
  - LI-1 fails to function
  - The upstream unit sends flowrate in excess of the maximum normal flowrate

Example LOPA Scenarios

- **Scenario 1:** During the normal operation, pressure storage **bottom pump fails due to a power** loss, operator is unable to respond in time to the level high alarm from LI-1, liquid overfill occurs, LI-2 and the associated Safety Instrumented Function (SIF) fails to work on high high liquid level, the pressure storage vessel overpressures and liquid overflows through the PRD, propane releases, ignites and results in a **flash fire.** There is a potential for personnel within the flash fire zone to be fatally injured.

- **Scenario 2:** During the normal operation, pressure storage **bottom pump fails due to a power** loss, operator is unable to respond in time to the level high alarm from LI-1, liquid overfill occurs, LI-2 and the associated Safety Instrumented Function (SIF) fails to work on high high liquid level, the pressure storage vessel overpressures and liquid overflows through the PRD, propane releases, ignites and results in a **VCE.** There is a potential for personnel within the overpressure impact zone (including personnel in the occupied buildings) to be fatally/seriously injured.

LOPA Terminologies

- **Initiating Event (IE)** is a failure that starts the sequence of events that, if not interrupted by the successful operation of a protection layer (i.e. control measure) results in a hazardous outcome
  - The initiating events can be due to equipment failure, instrumentation failure, human failure and external events
  - The Initiating Event Frequency (IEF) refers to the frequency of occurrence of the initiating event

- **Independent Protection Layers (IPLs)** are control measures that can prevent the initiating event from propagating to a hazardous outcome without being adversely affected by either the initiating event or by the action (or inaction) of any other IPLs
  - Every IPL must be independent from the initiating event and other IPLs in the same scenario
  - The IPLs must be effective to address the consequence of concern
  - The IPLs must be auditable

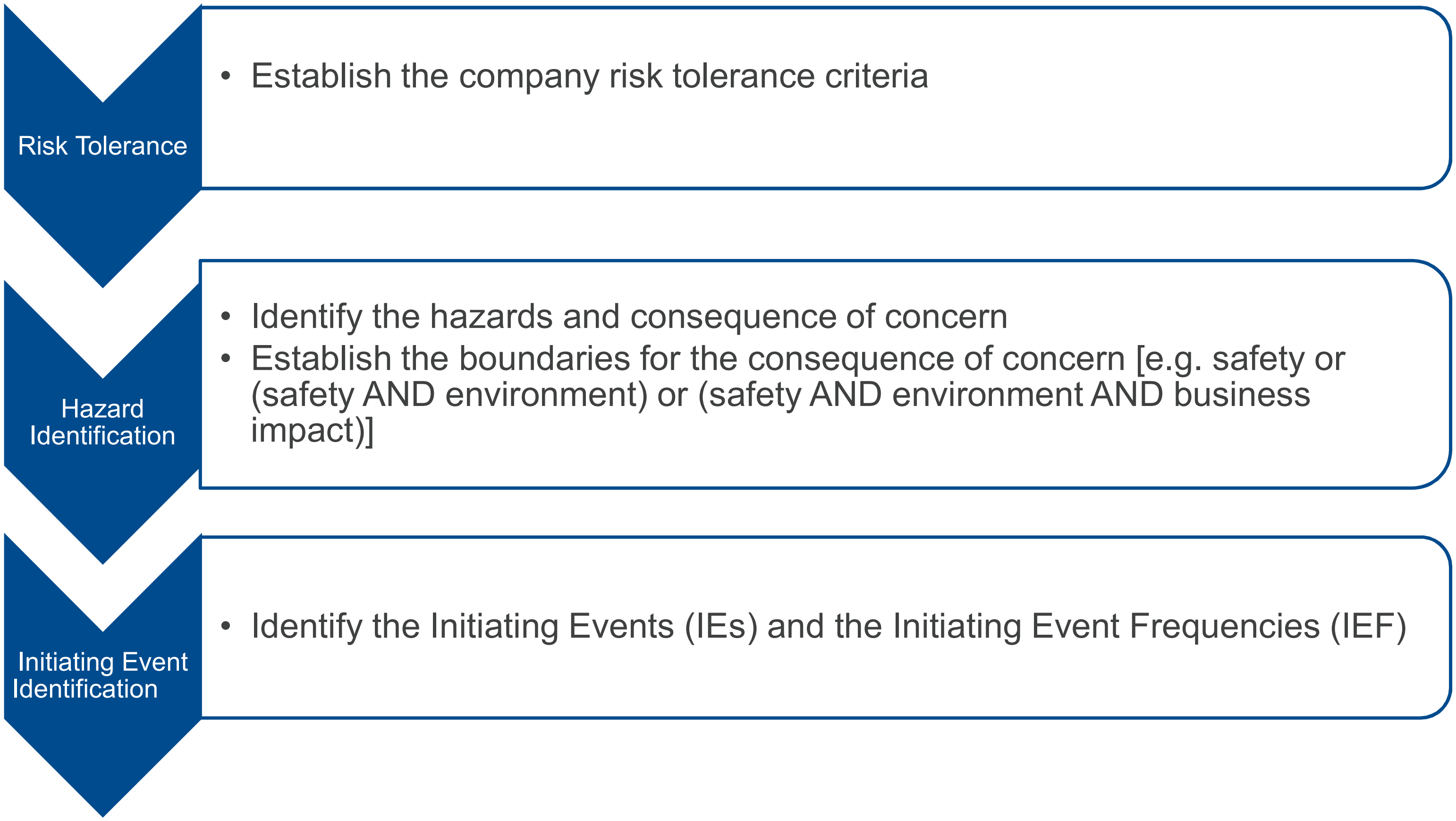
- **Probability of Failure on Demand (PFD)** is defined as the failure probability of an IPL to function and give the necessary protection when it is called upon to act

LOPA Terminologies – Cont'd

- **Enabling Conditions** are the operating conditions that are necessary for the initiating event to propagate into the hazardous outcome (i.e. time at risk factor)
  - The enabling conditions do not cause the incident to occur but must be present or active for the initiating event to propagate
  - Care must be exercised when taking a credit on these factors

- **Conditional Modifiers** refer to the probabilities of conditions (e.g. probability of ignition, probability of people presence within the harm zone) that must be present for the hazardous outcome to occur
  - Care must be exercised when taking a credit on these factors

LOPA Work Process



Risk Tolerance

- Establish the company risk tolerance criteria

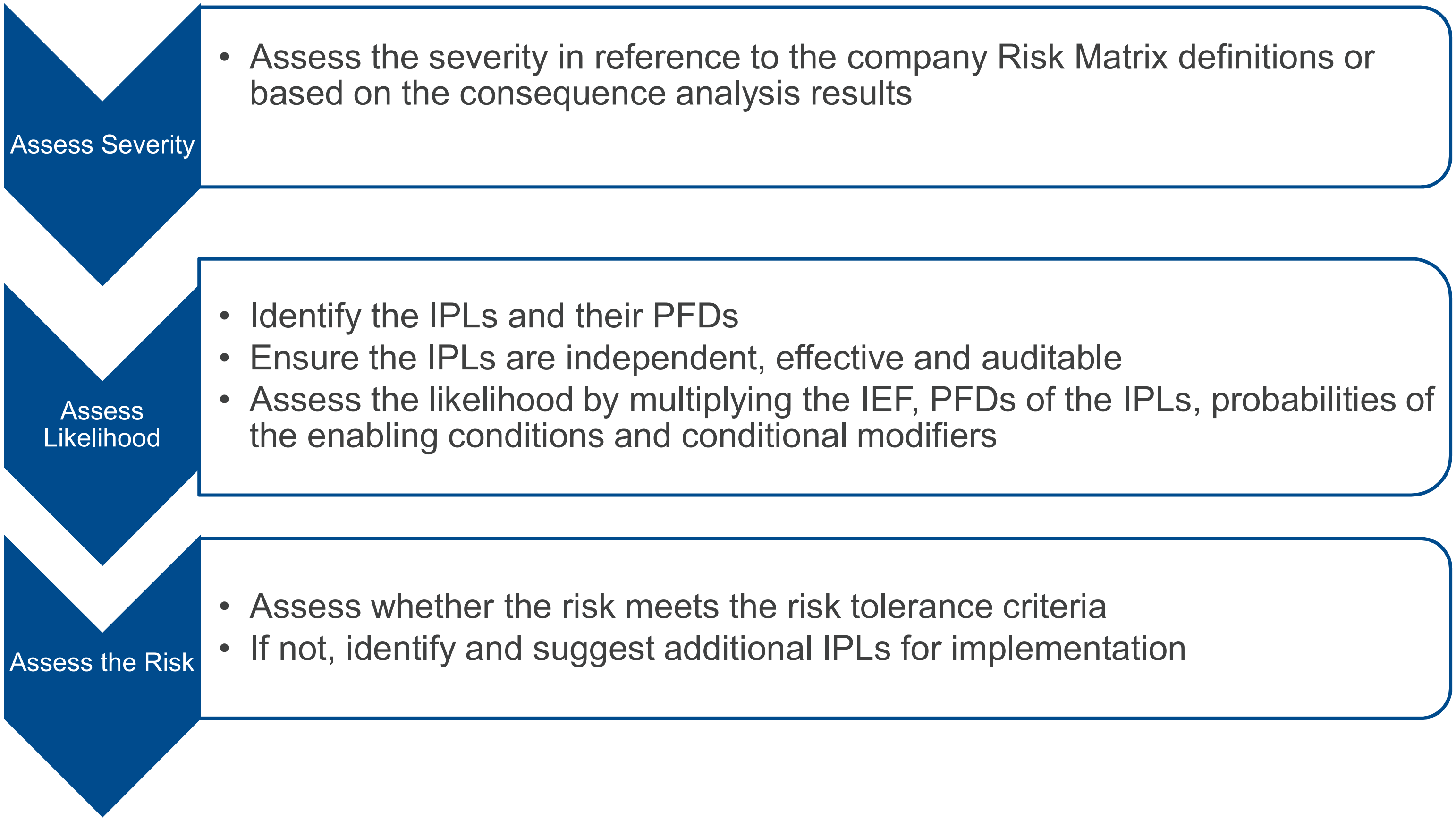
Hazard Identification

- Identify the hazards and consequence of concern
- Establish the boundaries for the consequence of concern [e.g. safety or (safety AND environment) or (safety AND environment AND business impact)]

Initiating Event Identification

- Identify the Initiating Events (IEs) and the Initiating Event Frequencies (IEF)

LOPA Work Process – Cont’d



Assess Severity

- Assess the severity in reference to the company Risk Matrix definitions or based on the consequence analysis results

Assess Likelihood

- Identify the IPLs and their PFDs
- Ensure the IPLs are independent, effective and auditable
- Assess the likelihood by multiplying the IEF, PFDs of the IPLs, probabilities of the enabling conditions and conditional modifiers

Assess the Risk

- Assess whether the risk meets the risk tolerance criteria
- If not, identify and suggest additional IPLs for implementation

Limitations of LOPA

- The LOPA may appear to be simple but it requires a lot of considerations for a proper application (e.g. when a credit can be taken)
  - The analysts involved in the LOPA study must have the required knowledge, experience and the skill-set

- LOPA is for a scenario-based risk assessment and it doesn't directly estimate the Individual Risk (IR)

- The risk tolerance criteria and the LOPA basis could vary from organization to organization
  - The results cannot be directly compared

Pitfalls – Demand Mode

- A good understanding on the demand modes is essential to produce an appropriate result
  - In general, there are two demand modes
  - If the demand on the IPL is less than once per year, then the IPL is in a low demand mode
  - If the demand on the IPL is more than once a year, then the IPL is in a high demand/continuous mode

- The approach to assess/calculate the risk differs between the two demand modes
  - Incorrect application may overestimate/underestimate the risk

Pitfalls – Failure Values

- As a first choice, it is recommended to use site-specific failure values unless and otherwise specified by the regulatory agencies
  - It is noted all the sites may not have their site-specific values
- Care must be exercised when applying the failure values given in the publications or industry standards
  - The failure values depend on the site design, operating and maintenance philosophies
- In the absence of the site-specific values, simpler calculation methods are available to determine the failure values based on the past operating history/experience

Pitfalls – Sensitivity Analysis

- Though the study is systematic, by virtue of the methodology and the availability of the failure values, there is a potential to have variations in the values used or assumptions made
  - Potential for uncertainties in the results

- To address the uncertainty, a sensitivity analysis must be performed, and the results should be validated prior to finalizing the study

Summary

- Terminologies
- Overview
- Workprocess
- Limitations
- Pitfalls

References

- **Layer of Protection Analysis**

  Simplified Process Risk Assessment

  By Center for Chemical Process Safety

- **Guidelines for Initiating Events and Independent Protection Layers in Layer of Protection Analysis**

  By Center for Chemical Process Safety

- **Guidelines for Enabling Conditions and Conditional Modifiers in Layer of Protection Analysis**

  By Center for Chemical Process Safety

Q & A