



Qualitative and Semi-Quantative Risk Assessment Techniques

February 2026

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Growth Platforms across Energy, Consumer and Technology Businesses

- **Largest** digital services provider in **India** – **439.3 mn⁽³⁾ subscribers** in six years since launch
- **India's Largest FTTH Provider** with >9mn connected premises⁽⁴⁾
- **Building the World's Largest and Most Advanced 5G Network** – Current coverage of over 2300 cities

- **India's largest and most profitable retailer** and among the **fastest growing retailers globally**
- Widest physical presence in India with **18,040 retail stores⁽³⁾** across **65.6mn sq. ft. of retail space**
- Leading O2O platform on the back of digital commerce and offline retail



India's Largest Company By:

\$194bn	\$118.8bn	\$18.8bn
Market Cap ⁽¹⁾	Revenue ⁽²⁾	EBITDA ⁽²⁾

Target to become net carbon zero by 2035

- **Deep integration, competitive cost position and wide product portfolio** reduces earnings volatility
- **Among the world's largest and most integrated O2C businesses** including the world's largest single site refinery at Jamnagar
- **Among global top 10 rankings** in key products

- Investment of ~**\$9bn targeted over the next 3 years** to pursue opportunities in new energy business
- Plan to build **5 Giga Factories** across Solar PV modules, energy storage batteries, hydrogen electrolyzers, fuel cells and power electronics
- Develop an enabling ecosystem of services across EPC and project financing to **rollout 100 GW new solar capacity by 2030**

Emerging market consumer growth platform complementing global O2C leadership

What are Process Safety Incidents?

- Incident involving the release of hazardous substances or release of energy that directly involves process equipment, on-site storage and handling of process materials.



- This does not include incidents involving injuries that are associated with personal safety not directly related to or caused by process equipment.

Major Process Safety Incidents

Bunce field



Texas City



Vizag



Pasadena



Major Process Safety Incidents

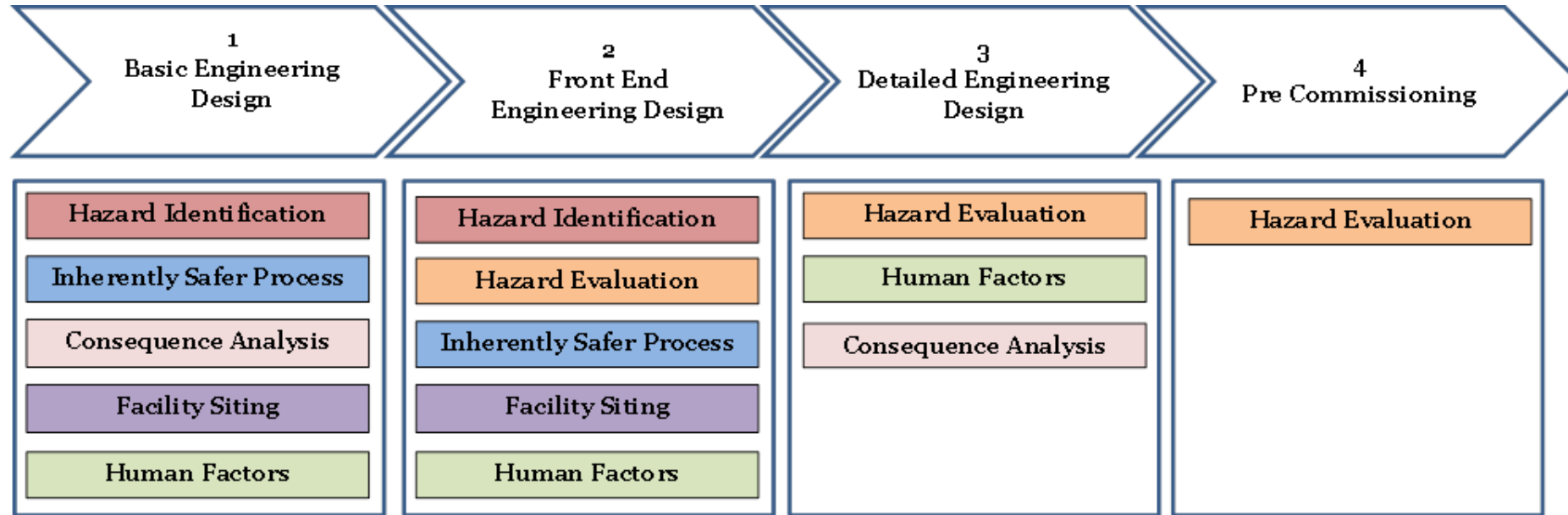
- Buncefield Tank Farm, UK Explosion: **11th Dec 2005, 0600**, Vapour cloud Explosion, **300T gasoline spilled-with 30T vapour cloud**, 40 injuries, 23 tanks destroyed. 1 bar overpressure at 200M. Overpressures of 0.01 bar felt up to 1Kms. Ignition source from generator house or a car.
- Vizag HPCL Refinery India explosion (14th Sept. 1997, 0600 hrs.), LPG release from pipeline, Vapour cloud Explosion /Jet fire/Pool fire, over 60 dead, entire administration facility buildings collapsed, Several processing units, spheres and tanks destroyed
- Texas City Refinery Explosion, Texas, USA (23rd Mar, 2005). Hexane and Heptane release from flare stack, Vapour cloud Explosion, 15 dead, 1 psi overpressure at 100M distance
- Pasadena (Phillips 66, USA) disaster (23rd Oct, 1989)-39 T of ethylene/Isobutene release from 8" open valve and Vapour cloud Explosion (2.5T TNT Eq.), 23 killed, two polyethylene plants destroyed,. 1.5billion US \$ loss, Admin building 800M away damaged, debris flew 10 Km away. (recorded 3.5 on Richter scale.)

PSM Guidelines proposed by OSHA in Nov 1990 and issued in Feb 1992

What is Process Hazard Analysis?

- PHA is **Organized, methodical** approach which combines science, skill and engineering judgment **to identify, evaluate & develop methods to control** process hazard.
 - Hazard Identification
 - Hazard Evaluation
 - Consequence analysis
 - Inherently safer process evaluation
 - Facility siting evaluation
 - Human factors
 - Risk Assessment
- Useful information for emergency planning, and training of personnel involved in operating and maintaining the process.

When to Perform PHA?



What are Process Safety Hazards?

Significant inventories

- Flammable materials
- Combustible materials
- Unstable materials
- Corrosive materials
- Asphyxiants
- Shock sensitive materials
- Reactive materials
- Toxic materials
- Inert gases
- Combustible dusts

Physical condition

- Combustible dusts
- High temperatures
- Cryogenic temperatures
- High pressures
- Vacuum
- Pressure cycling
- Temperature cycling
- Vibration/liquid hammering
- Pyrophoric materials
- Radioactive materials

- Scenario based – predictive and analytical
 - What If / Checklist
 - Failure Mode and Effect (FMEA)
 - Hazard and Operability Study (HAZOP)
 - Fault-Tree Analysis (FTA)
- What can go wrong and
- What safeguards are in place
- Each scenario starts with cause/initiating event resulting in deviation leading to consequence

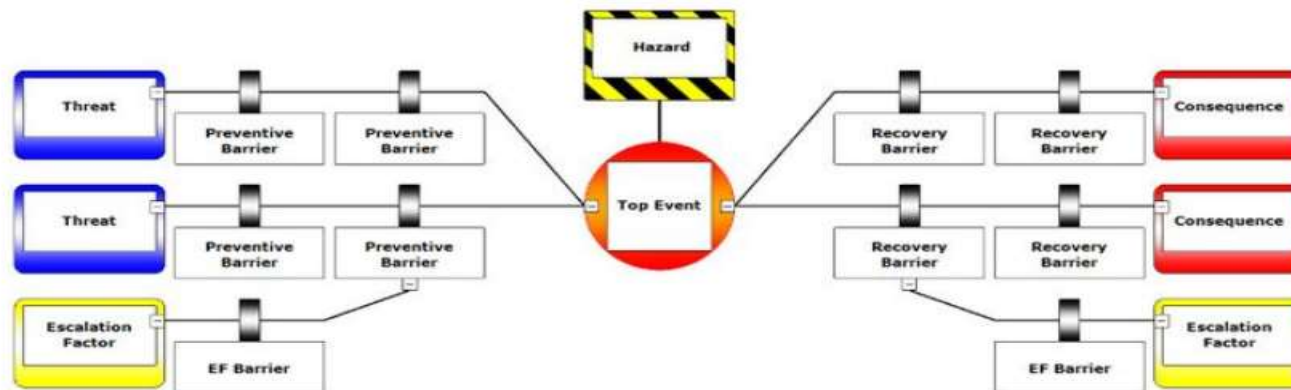
Process Hazard Evaluation-Definition

- Systematic and comprehensive study of the hazardous events that could occur in the process including all of the ways that each hazardous event can occur.
- Using specific methodologies, the team evaluates the possible consequences or harmful effects of each event and decides whether the existing protection in the system is adequate, or whether additional protection is needed.
- Evaluate the scenario in sufficient detail to make a reasonable judgment of risk.
- Recommendations for additional protection are made where appropriate.
- *Understand the **availability and reliability** of each significant protection.*



Qualitative Techniques

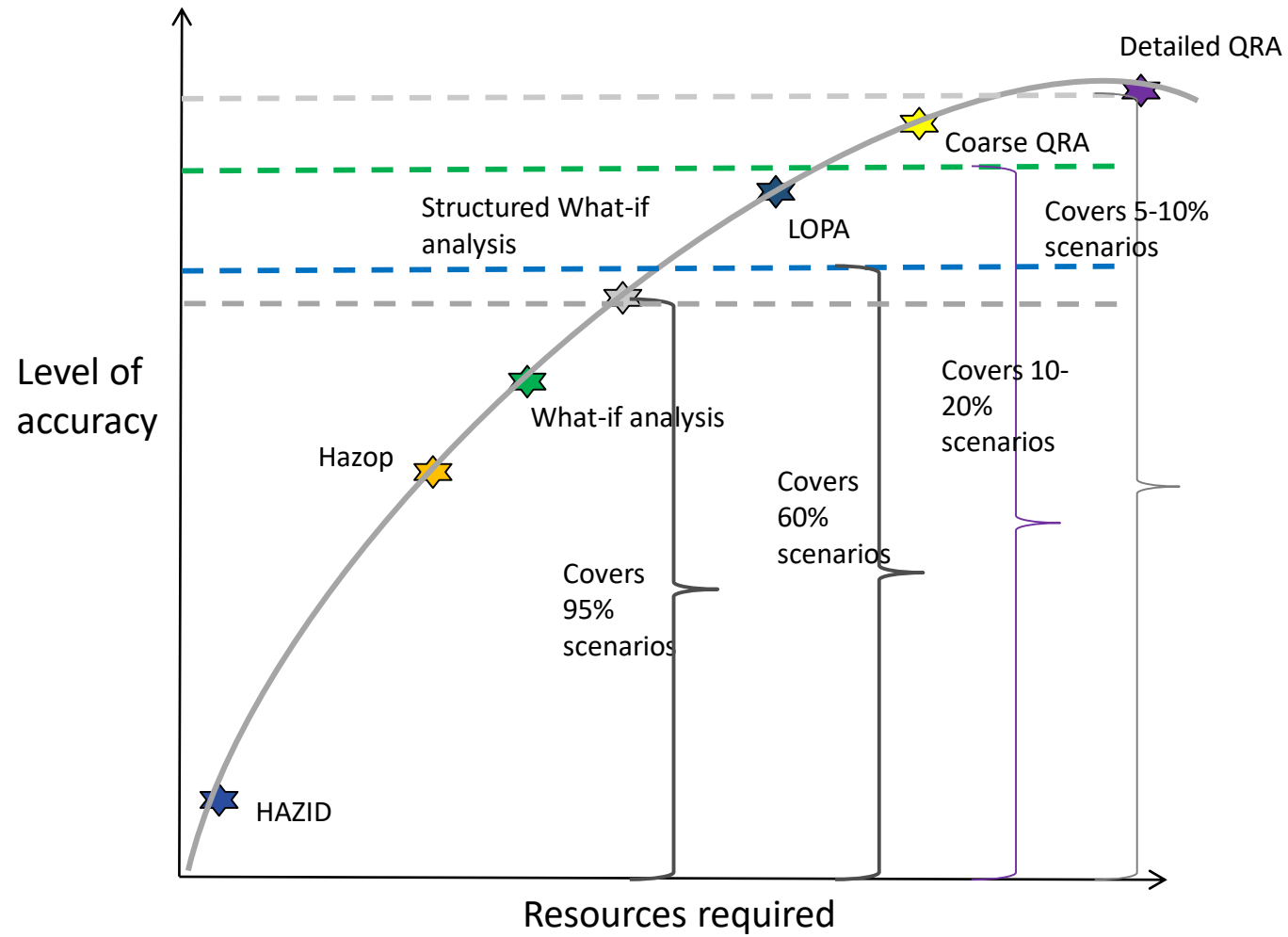
- **Hazard and Operability (HAZOP) Analysis:** A systematic method in which potential operating problems are identified using a series of guide words to investigate process deviations. Can be applied to any mode of operation of a flow process and can also be applied to any procedure or flowchart.
- **Failure Modes and Effects Analysis (FMEA):** A systematic, tabular method for evaluating and documenting the effects of known types of component failures. Applies to electrical/mechanical systems. Can also be applied to flow systems where very high reliability factors are needed (such as fire-fighting water supply systems).
- **Bow-Tie Analysis :** Pictorial representation of end-to-end scenario of a top event leading to ultimate undesirable consequences with barriers depicted



- **Layer of Protection Analysis (LOPA):** Semi-quantitative method using pre-defined values for initiating events, independent protection layers and consequences to provide an order-of-magnitude estimate of risk. Scenarios are identified elsewhere (typically in a qualitative hazard evaluation).
- **Dow Fire and Explosion Index (F&EI):** Method for ranking the relative potential of fire & explosion or toxic risk effect radius and property damage/business interruption impacts associated with a process. Analysts calculate various hazard and exposure indexes using material characteristics and process data.
- **Fault Tree Analysis (FTA):** A logic model that graphically portrays the combinations of failures that can lead to a specific main failure or incident of interest (Top event). This method using Boolean Logic (And & Or logic gates).
- **Quantitative Risk Assessment (QRA)** - Used where there is potential offsite impact or major onsite impact

- Qualitative
 - Combined qualitative evaluations of both the consequence and frequency of the incident
- Quantitative
 - Application of traditional QRA techniques
 - For each event, consequence modeling and frequency estimation techniques are applied
 - Tolerability of the risk is then determined by comparison to accepted risk guidelines

Maturing on Tools for Risk Assessments



Hazard Evaluation – Key Steps during review

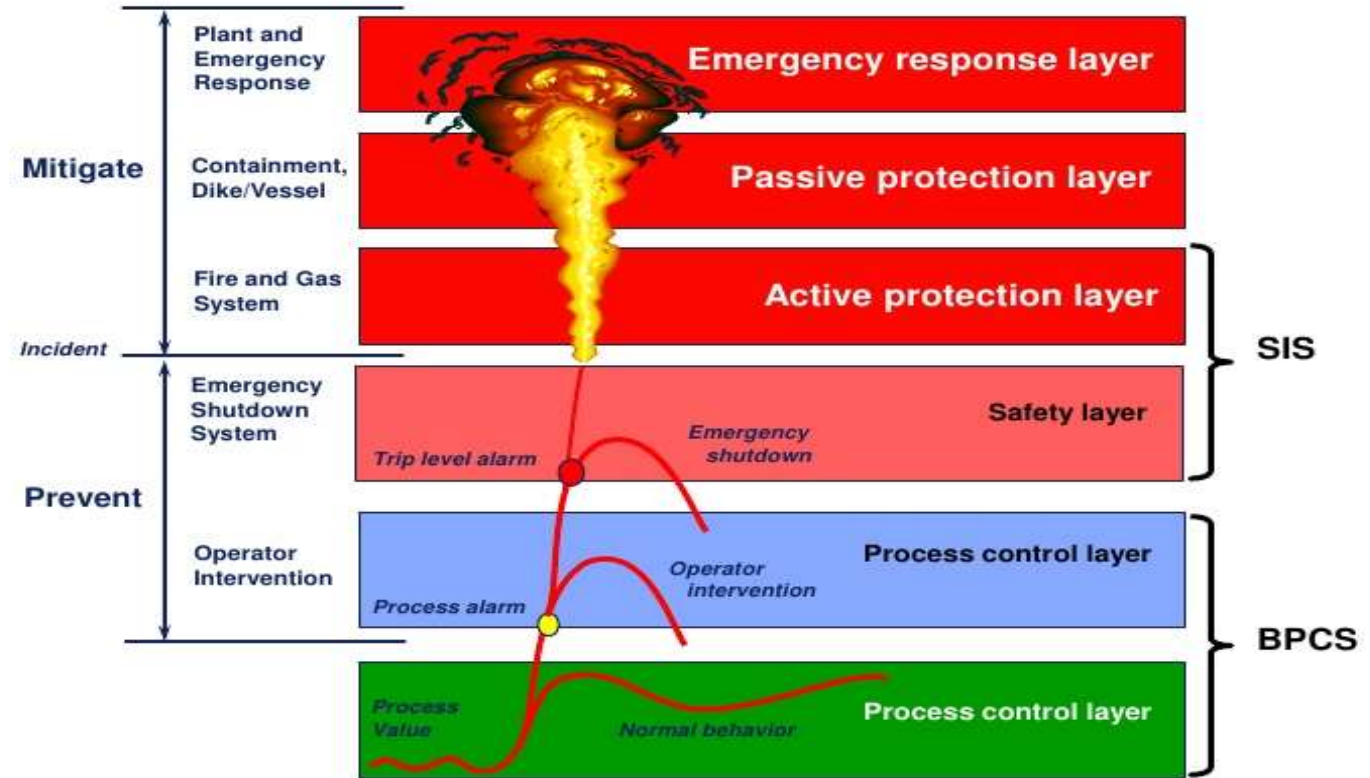
1. Develop meaningful scenarios (causes/hazards)
2. Identify all scenarios (causes/hazards) for the deviations
3. Identify all major consequences (safety, reliability, operability, quality, environment) related to all causes considering failure of all safeguards

- Document **how each cause results in ultimate consequences** (personnel, health, environmental, reliability, quality, operability) **including all intermediate events in the order of occurrence**
- Identify all effective safeguards in the **order of activation** that will prevent initiating event (cause), intermediate event (high level, overpressure, loss of containment, etc.) and/or mitigate ultimate consequence (final event)
- Determine severity/consequence rating considering all safeguards fail (without any safeguards taking into account **consequence analysis information if available** and probability or frequency rating (qualitatively or quantitatively if required)

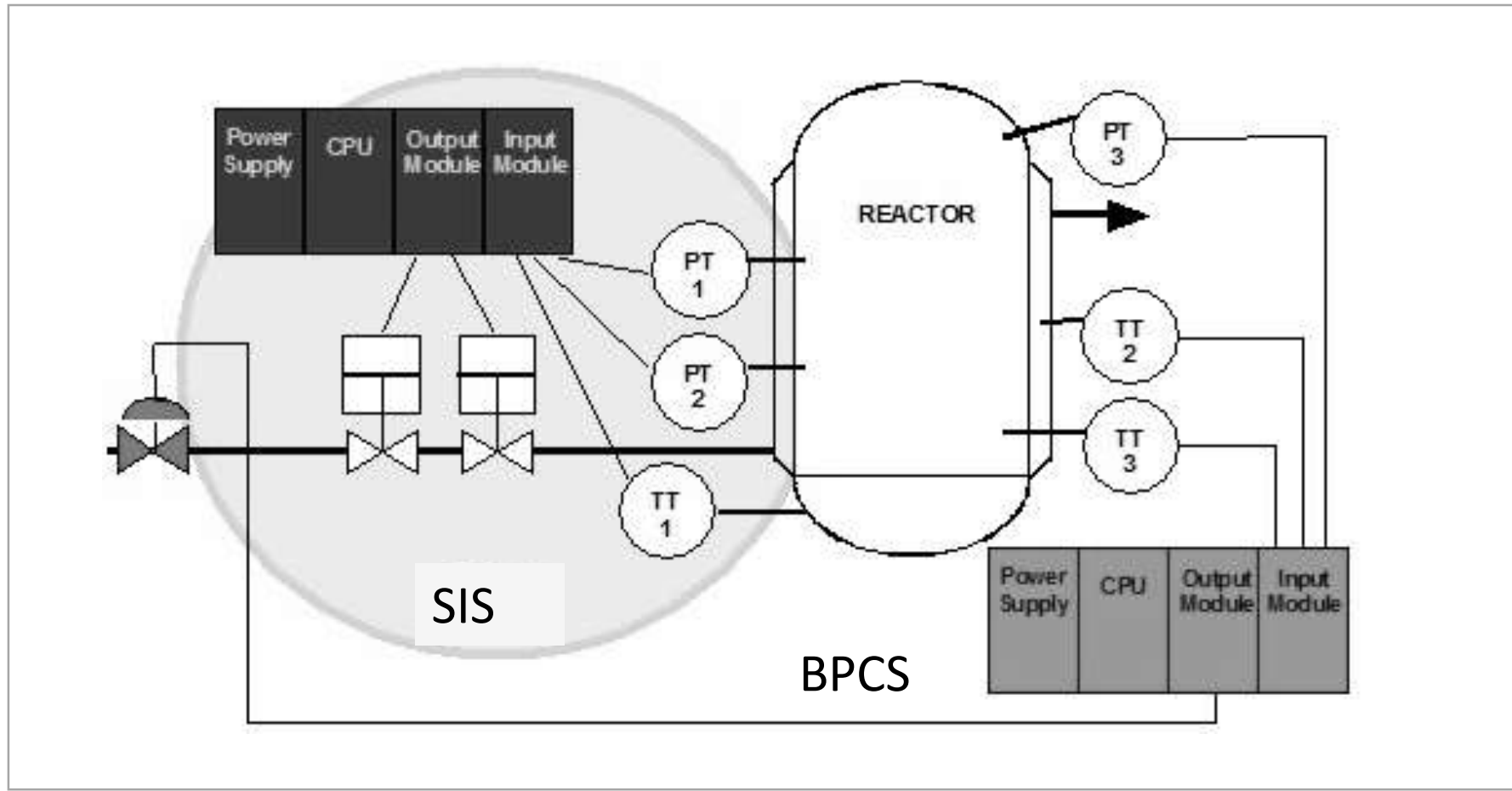
1. Markup “nodes” on P&IDs
2. Define the intent of node under evaluation
3. Choose a deviation (guideword + parameter) in the node
4. Identify the possible causes that could result in chosen deviation
5. Develop a scenario – from cause to consequence
6. Evaluate worst credible risk – when all safeguards fail
7. Evaluate net risk – taking credit of available safeguards
8. Recommend additional safeguards if net risk is not tolerable

Safeguards

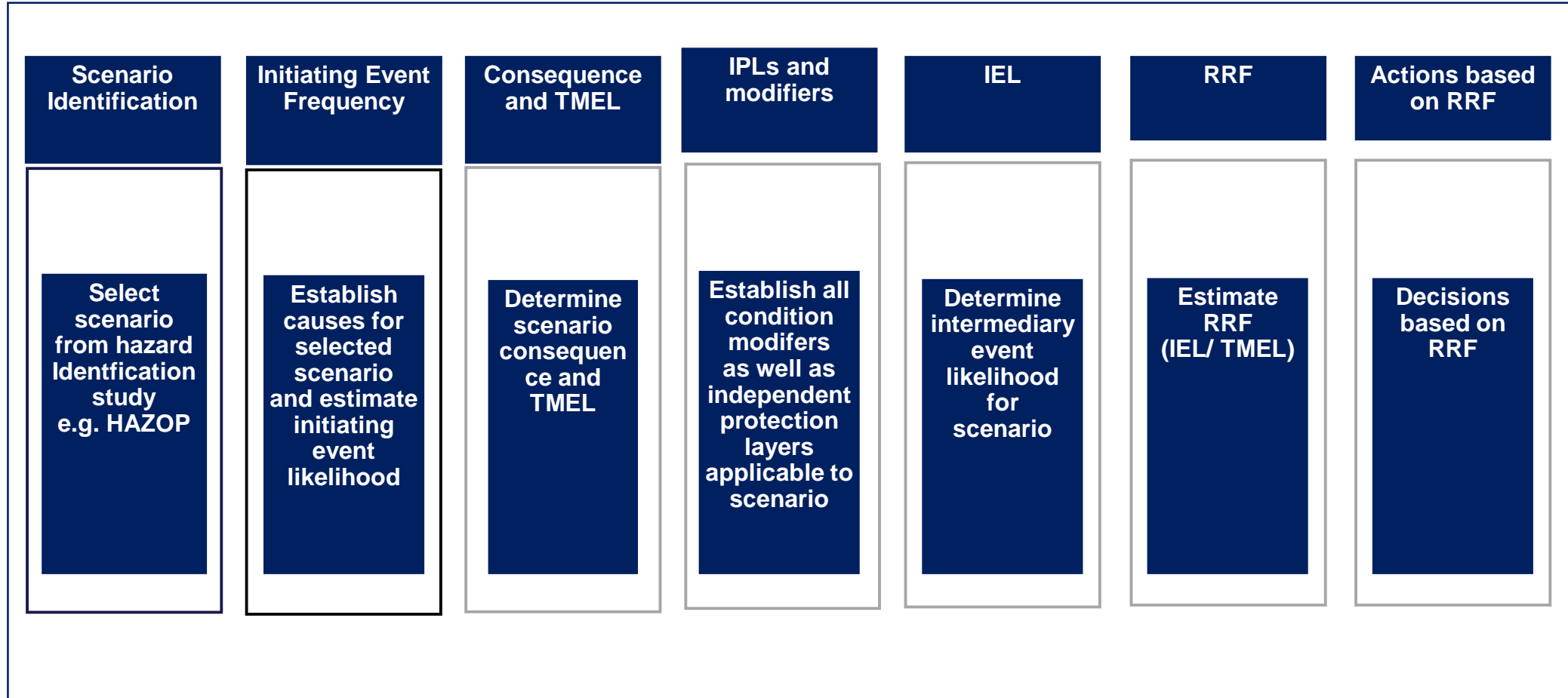
A device, system, or action that would likely interrupt the chain of events leading to loss of containment following an initiating cause (Preventive Safeguard) or that would mitigate loss of containment event impacts (Mitigative Safeguard).



BPCS and SIF

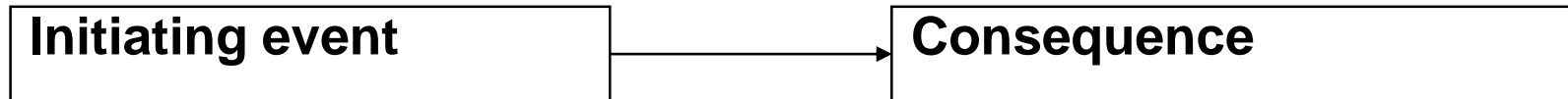


LOPA Process



Scenario Identification

- Derived from a deviation of a HAZOP (or other approved PHA methodology) node and its **unique associated set of cause (initiating event) and consequence** (for safety, environmental, and optionally for equipment damage/business value lost) pairs.



- Development and documentation to a level where a basic understanding of the event and its safeguards is achieved.

e.g. Human error resulting in incorrect closure of manual valve upstream of heat exchanger (HBG-3000). Risk of exposing B class pipework to pump shut-in pressure and catastrophic failure of line resulting in loss of hydrocarbon containment. If ignited, potential for fire and explosion resulting in fatality.

An initiating event can be a failure, error, situation, or condition that results, or may result in the propagation of a hazardous event to a defined and undesirable endpoint in the absence of IPLs.

Typically, the LOPA team consider the following as initiating causes:

- Equipment failure
- BPCS failure
- Process deviation
- Human error

An initiating event is a combination of failures (or errors) necessary to start the propagation of a hazardous event. It can comprise a single initiating cause, multiple causes or initiating cause(s) in the presence of an enabling condition.

Independent Protective Layers (IPL) are devices, systems, or actions capable of preventing a scenario from proceeding to its undesired consequence independent of

- Initiating event or
- Action of any other layer of protection associated with the scenario

There are two types of IPL:

Passive

- Dike/bund
- Vent
- Blast wall
- Flame arrestor

Active

- BPCS
- Human response to alarm
- Pressure Relief Device
- SIF/SIS

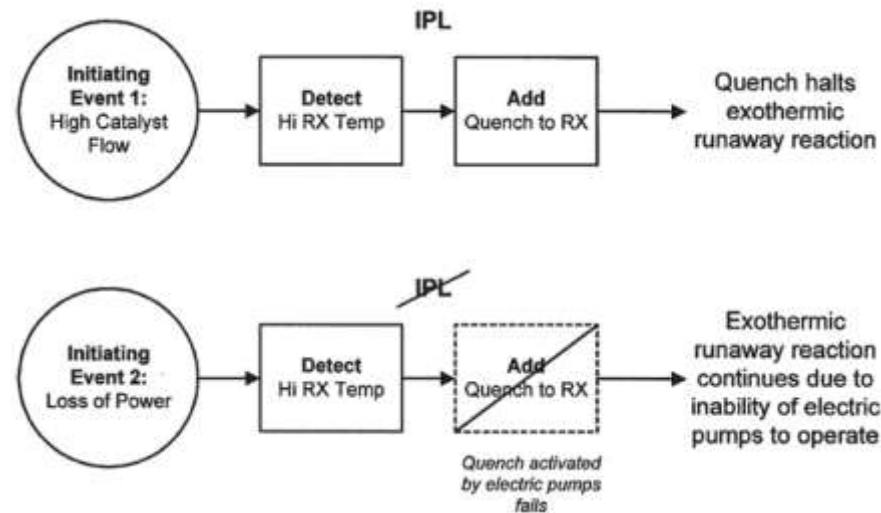
IPL must be shown to be Effective, Independent and Auditable

Demonstrating Independence

Independence is required to assure an IPL does not interact with other elements to degrade its ability to prevent a consequence.

An IPL must be independent of:

- The occurrence, or consequences, of the initiating event.



- The failure of any component of an IPL already credited for the same scenario
 - Common sensor for two control loops, only one loop would be an IPL.
 - Same operator who made an error will respond correctly in a follow up corrective action.

PFD (Mechanical Devices)

Risk reduction measures	PFD	Comments
Relief valve	1 x 10 ⁻²	Clean service and PRV sized to mitigate the scenario.
Relief valve	1 x 10 ⁻³	Multiple full-load PRVs are available to mitigate scenario.
Relief valve	1 x 10 ⁻²	Multiple partial-load PRVs are available and sized such that more than one PRV would need to fail for the scenario to occur.
Relief valve	1	Plugging service with no protection.
Relief valve	1 x 10 ⁻²	Plugging service with protection.
Vessel rupture disc	1 x 10 ⁻²	Shall be designed to mitigate scenario.
Vacuum breaker	1 x 10 ⁻²	Designed for the hazard and inspected periodically.
Blow out panel	1 x 10 ⁻²	Shall be designed to mitigate scenario.

PFD (Passive IPLs)

Dike/Bund	1 x 10 ⁻²	Will reduce frequency of large consequences (widespread spill) of tank overfill/ rupture/spill.
Underground drainage system	1 x 10 ⁻²	Will reduce frequency of large consequences (widespread spill) of tank overfill/ rupture/spill.
Open vent (no valve) in plugging service	1 x 10 ⁻¹	Will prevent overpressure. Assumes that vent could be plugged from operational activities (mud, concrete, polymers, etc.) or by nature (bees nest, bird nest, etc.) which could be smaller diameters.
Open vent (no valve) in clean service	1 x 10 ⁻³	Will prevent overpressure. Assumes vent is not subject to plugging during operations and is too large to be plugged by nature.
Open vent (no valve) in clean service, freezing environment	1 x 10 ⁻²	Will prevent overpressure. Assumes vent is not subject to plugging during operations and where the vent pipe is heat traced to prevent freezing.
Fireproofing	1 x 10 ⁻²	Will reduce rate of heat input and provide additional time for depressurizing/fire-fighting.

PFD (Passive IPLs) (Contd...)

Blast wall/bunker	1 x 10 ⁻³	Will reduce frequency of large consequences of explosion by confining blast and protecting equipment/buildings.
Flame/detonation arrestors	1 x 10 ⁻²	If properly designed, installed, and maintained, should eliminate potential for flashback through piping system or into vessel or tank.
Mechanical stops	1 x 10 ⁻²	Non-adjustable, stop set and verified.
Flow restriction orifice	1 x 10 ⁻²	Shall be on a defined maintenance routine.
Mechanical overspeed trip with a trip/throttle valve on a turbine	1 x 10 ⁻¹	Typically a trip bolt. Shall be on a defined maintenance routine.

PFD (Instrumented Functions)

Risk reduction measures	PFD	Comments
Safety instrumented function (interlocks)	IEC 61508 and IEC 61511 for lifecycle requirements and additional discussion.	
SIL 1 SIF	1×10^{-2} to 1×10^{-1}	Typically consists of single sensor, single logic solver, and single final element.
SIL 2 SIF	1×10^{-3} to 1×10^{-2}	Typically consists of multiple sensors (for fault tolerance), multiple channel logic solver (for fault tolerance), and multiple final element (for fault tolerance).
SIL 3 SIF	1×10^{-4} to 1×10^{-3}	Typically consists of multiple sensors, multiple channel logic solver, and multiple final elements. Requires careful design and frequent proof tests to achieve low PFD figures.

PFD (Human Actions)

Risk reduction measures	PFD	Comments
Human action with 10 min response time	1 x 10 ⁻¹ to 5 x 10 ⁻¹	Simple well documented action with clear and reliable indications that action is required.
Human response with 20 min response time	1 x 10 ⁻¹	Simple well documented action with clear and reliable indications that action is required.

Intermediate Event Likelihood - IEL

The intermediate event likelihood for an individual cause is the product of the initiating cause frequency, enabling event probabilities, PFDs of IPLs and frequency modifiers.

Initiating event
frequency

PFD of IPLs

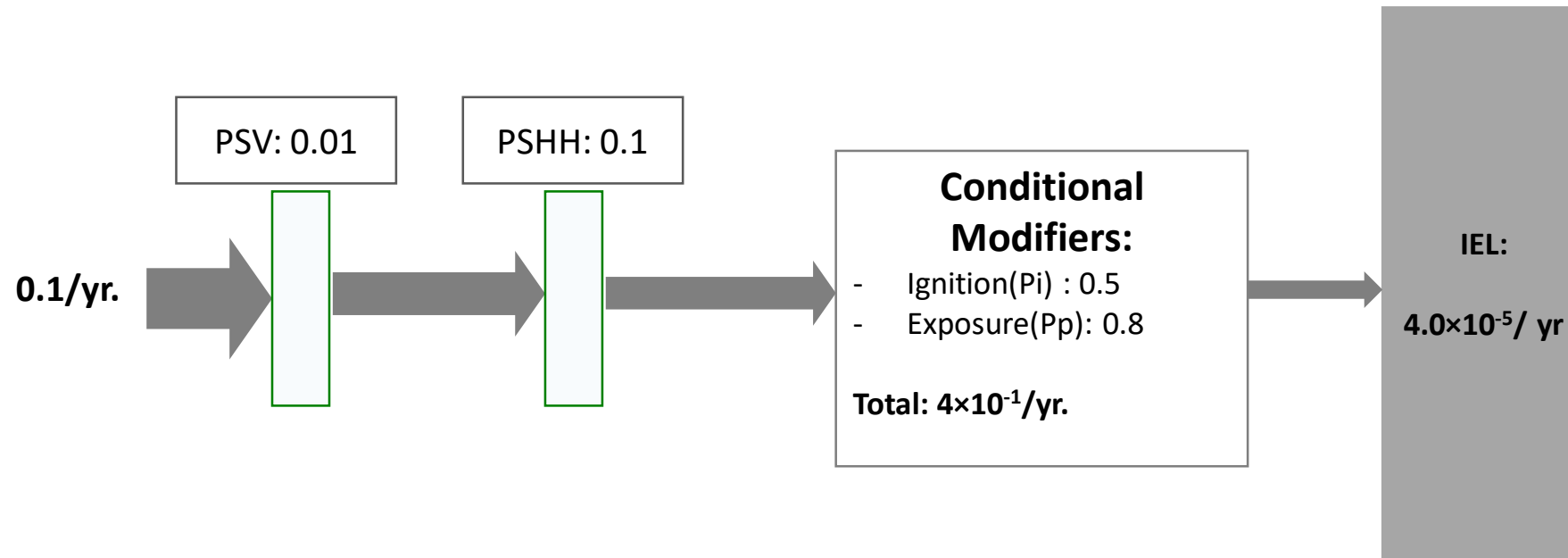
$$f_i^C = f_i^I \times P_{\text{Enabling event}} \times PFD_{i1} \times PFD_{i2} \times \dots \times PFD_{ij} \times P_{\text{Condition modifier}}$$

Probability of enabling
event taking place

Probability of
conditional modifiers

Example – Logical Sequence

Consider an over pressure scenario with PSV and HH Pressure Trip as protection



Risk reduction factor (RRF) is the measure of performance of IPLs and can be calculated by:

$$\text{RRF} = \text{IEL}/\text{TMEL}$$

If the **IEL < TMEL** then the existing IPLs can be considered adequate with no further risk reduction required. If **IEL > TMEL** then **further risk reduction** is required.

The risk reduction can be achieved by providing additional IPL in the form of SIF or Non-SIF

Step 1: The HAZOP (Qualitative Identification)

The team looks at the "Level" parameter for a tank and applies the guideword "**More.**"

Guideword/Deviation **More Level (Overfill)**

Potential Causes Inlet valve fails open; Level Controller failure

Consequences Tank rupture or spill; fire/explosion; environmental damage

Existing Safeguards 1. High-Level Alarm and Operator action

2. High-Level Trip

HAZOP Conclusion: The team decides the risk is "High" based on a risk matrix and recommends a **LOPA** to see if those safeguards are actually reliable enough.

Step 2: The LOPA (Semi-Quantitative Calculation)

Now, we assign numbers to the "High Risk" scenario identified in HAZOP.

Let's assume the company's **Target Risk Tolerance** for this event is 1×10^{-4} /year

	Initiating Event	IPL 1	IPL 2	Event Likelihood
PFD value	0.1	0.1	0.01	10^{-4}
	Level Control Loop Failure	Alarm + Operator Action	Independent High Level Trip	

The **Calculated Risk** matched the **Target Risk**. The system is considered safe enough.

In a robust Process Safety Management (PSM) framework, these tools are sequential:

HAZOP gives you the "map": It provides a broad overview of all potential hazards and operability issues.

LOPA focuses on the "danger zones": High-consequence scenarios identified in HAZOP are funneled into LOPA for rigorous mathematical validation.

Integration: Together, they ensure that safety resources are allocated to the most critical risks, moving from subjective team judgment to objective, data-driven Independent Protection Layer evaluation.

Thank You