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Improve Effectiveness of Process Hazard Analysis

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GOALS

- Enhance Efficiency and Effectivity of PHAs
- Focus on actual risk levels
- Risk level Assurance

Background

Objective of PHA

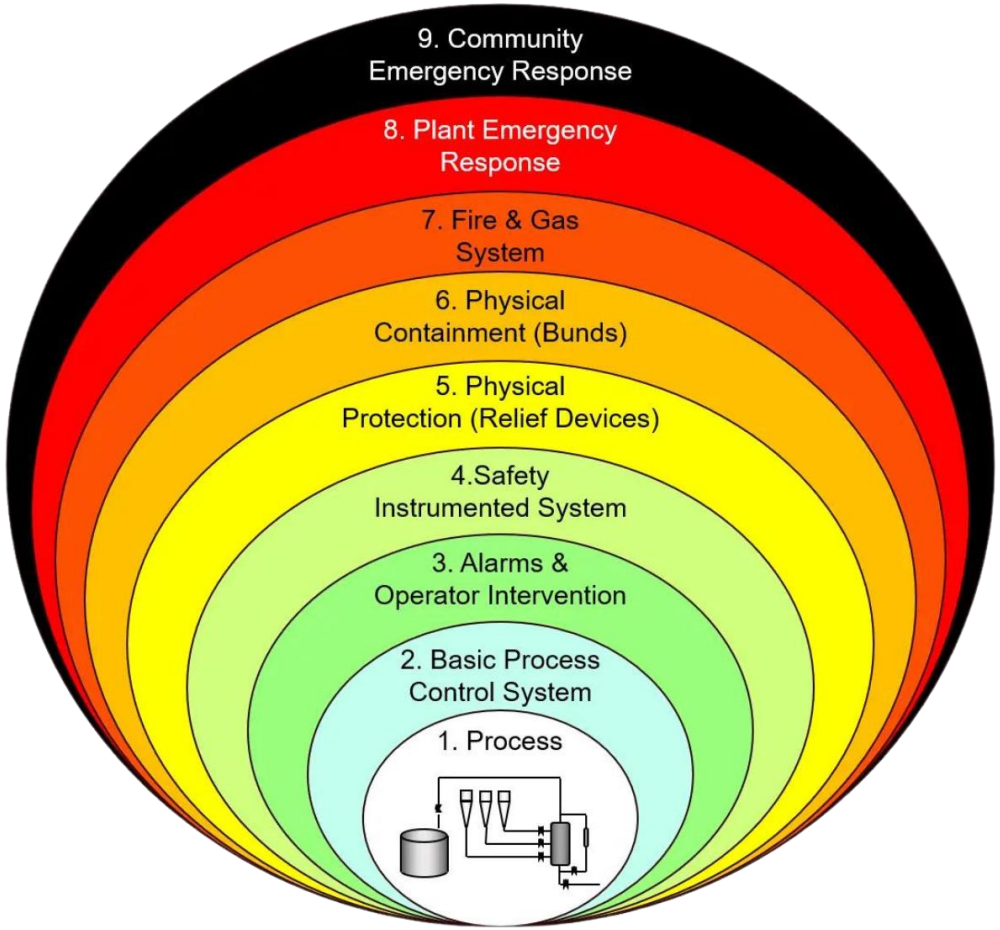
- Reduce Design Process Safety Risks

Why Process Safety Incidents occur

- Design deficiencies
- Protection Layer Integrity Compromised

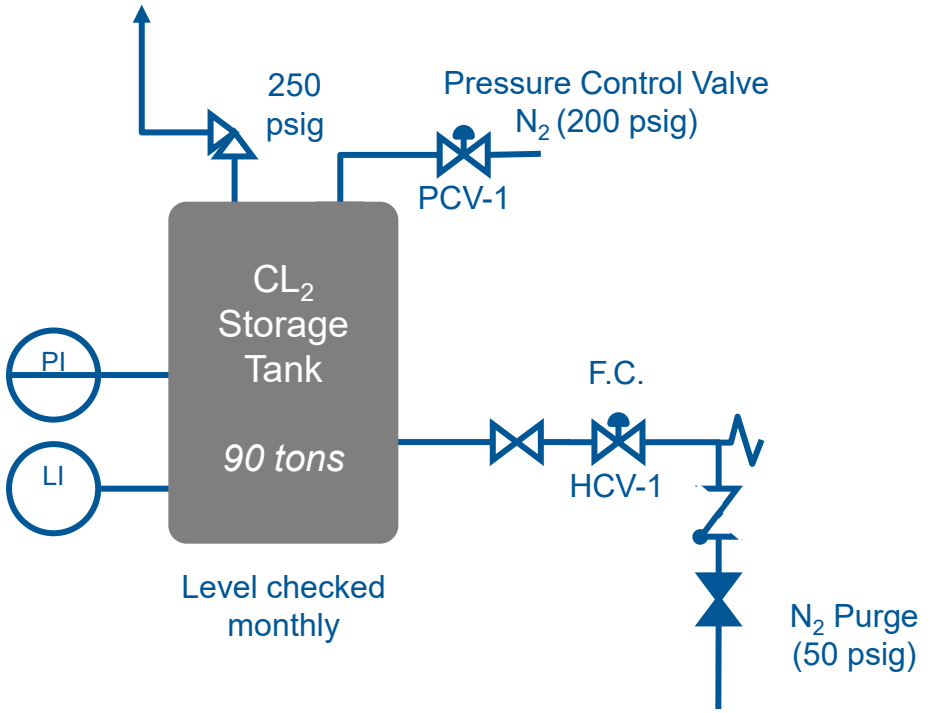
Current Industry Practice

- **Identification** of Design risks & mitigations through PHA studies. Mostly using:
  - HAZOP
  - LOPA studies

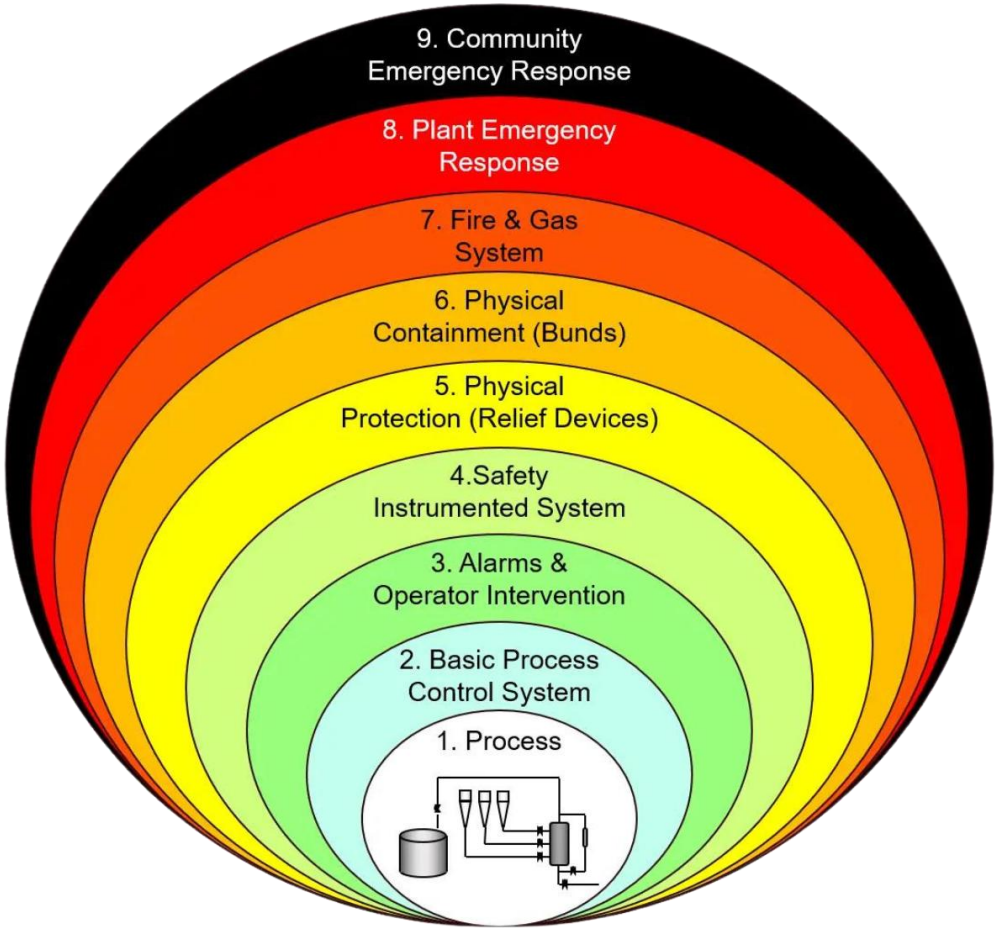


ADVANTAGES

- ✓ Thoroughness
- ✓ Systematic
- ✓ Team-Based
- ✓ Creative approach
- ✓ Exhaustive
- ✓ Leading to improved safety



PITFALLS

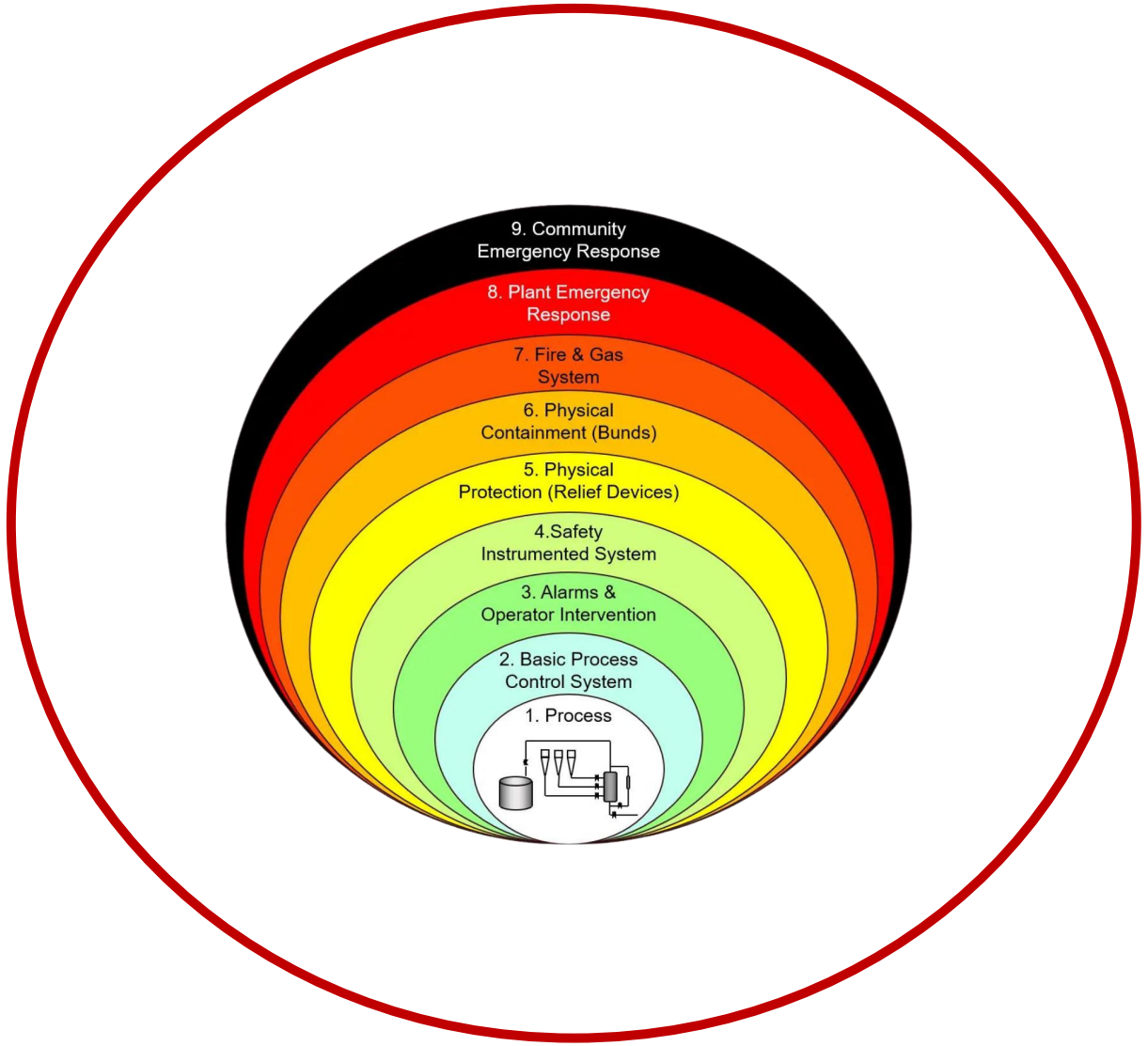


- Identification of Design risk only
- Dependence on team expertise
- Time-consuming
- Qualitative
- Second level of Risk analysis – LOPA
- Wrong sense of security of risks level of the plant - Layer Of Protection management risks

Proposal

Proposal

- Use of DOW Index for Methodology selection
- Integrate Protection layers Integrity in the PHA studies & optimize revalidation process
- Reduce Judgements in PHA studies
- Extend risk matrix - Identification of Layers of Protection to achieve Acceptable Risk levels
- Use of preset basis for Consequences
- Use of data for likelihood - Initiating Frequencies & PFDs



Methodology Selection

PHA Methodology selection based on DOW Index

Evaluate Process Plant:

- Dow Fire Explosion Index (FEI)
- Dow Chemical Exposure Index (CEI)

Degree of Severity	DOW Fire and Explosion Index	Dow Chemical Exposure Index	Type PHA Required
Heavy to Catastrophic	>128	>200	HAZOP
Serious	97-127	70-200	HAZOP or SWIFT
Minor to Moderate	61-96	25-69	SWIFT
Minor to None	1-60	<25	Check List

Revised Methodology & Revalidation Process

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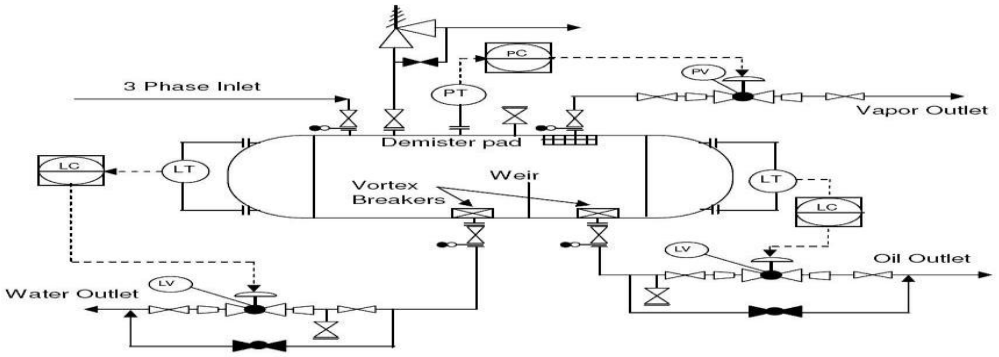
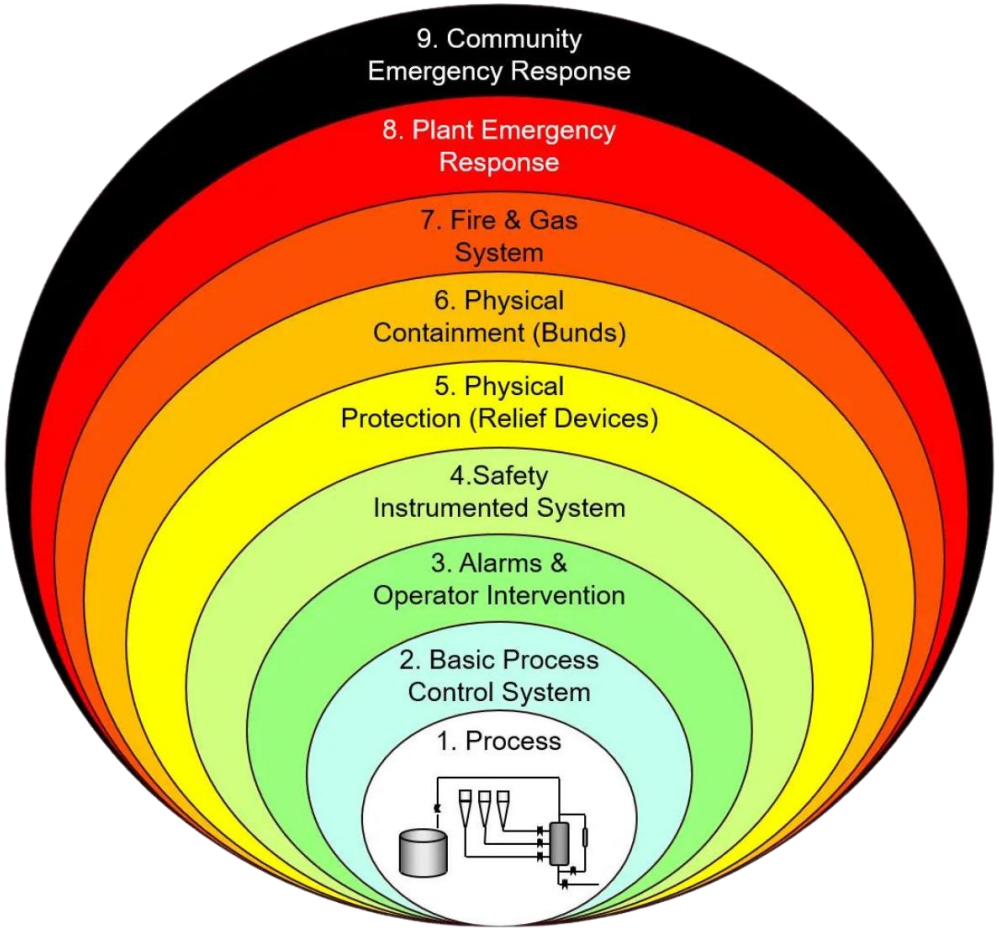
Revised Methodology & Revalidation Process

- Integrate Protection Layers Integrity in the PHA studies & optimize revalidation process
  - Design Risks
  - Protection layers Integrity Risks





High Risk operation PHA

- Use of data rather than judgement for risk assessment
- First PHA study – Design Risk
- Revalidation:
  - Design Verification:
    - Validate previous study - Did previous study identified all scenarios
    - MOCs risks mitigated
    - Identify Risks using data
    - Recommend Layers of protection required based on PFD/Likelihood data
  - Integrity Check
    - Identify Risk based on actual Integrity management of layers of Protection

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High Risk operation PHA

Drawing #	
Equipment #	
Node #	
Substances	
Process Conditions	
Safe Design Envelope	

Reference Sheets	Risk Matrix
	Process Safety Incident Severity Determination Guidelines
	Explanation of terms

Worksheet

Guide Words			Design Review								Integrity Check				
Deviations	Causes	Consequences Refer to Data for Risk Assessment	Consequence Rating Refer to Data for Risk Assessment	Existing Protection(s) / Initiating Event(s) / Equipment(s) to prevent LOPC / Operator Action	Probability / Frequency	Risk	Recommendation(s) to bring Risk to acceptable	Probability / Frequency	Risk (Based on Recommendations)	Action Required	Integrity Check	Yes/ No	Risk	Action Required	Recommendation
Equipment Registration by Regulatory Authorities			C1		1.E-01	Major		1.E-01	Significant	Approval to be obtained	Is the testing / inspection / training / audit program as per applicable requirements?	No	Major	Approval to be obtained	
											Were adequate actions taken if last results were not in acceptable limits?	Yes			
					1.E+00			1.E-01			Is the testing / inspection / training / audit program as per applicable requirements?	Yes			
											Were adequate actions taken if last results were not in	No			

Low Risk operation PHA

- Experienced based checklist:
  - For each Equipment
- Design Check
- Integrity Check

Low Risk operation PHA

- First PHA study – Design Risk
- Revalidation:
  - Design Verification:
    - Fill-in the checklist to conduct initial assessment.
    - Review the initial assessment developed
    - Identify Risks using data
    - Recommend Layers of protection required based on PFD/Likelihood data
  - Integrity Check
    - Actual Risks – How Layers Of Protection are managed

Low Risk Operations PHA studies

Drawing #	
Equipment #	
Node #	

Exchanger Check List

			Design Review								Integrity Review				
S. No.	Description	Yes / No / Not Applicable	Tag # / Document # of Existing Protection	Consequences if "No"	Consequence Rating	Overall Probability of failure of safeguard / Initiating event frequency	Risk	Recommendation(s) to bring Risk to acceptable	Is the Risk after Recommendation in Tolerable Risk zone	Action Required	Integrity Check	Yes/ No	Probability	Risk	Action Required
1	Is the low pressure side protected against tube leakage scenario, adequately?	No			C1	1.E-01	Major		No	Approval to be obtained	Is the testing/inspection program as per applicable requirements?	No	1.E+00	Major	Approval to be obtained
											Were adequate actions taken if last results were not in acceptable limits?	Yes			
2	Is the shell side protected against maximum inlet pressure, adequately?	No			C2	1.E-05	Insignificant		Yes	No Action Required	Is the testing/inspection program as per applicable requirements?		1.E+00	Major	Approval to be obtained
											Were adequate actions taken if last results were not in acceptable limits?				
3	Is the tube side protected against maximum inlet pressure, adequately?	No				1.E+00	Enter Consequenc e Rating & Probability				Is the testing/inspection program as per	Yes	1.E+00	Enter Conse	

Reduce Judgements in PHA studies

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Reduce Judgements in PHA studies

- Extend risk matrix - Identification of Layers of Protection to achieve Acceptable Risk levels
- Use of preset basis for Consequences
- Use of Initiating Frequencies & PFDs

Risk Matrix

Risk Matrix

Levels of Likelihood	Consequences-Severity/Risk Rating				
	1 - Very Low	2 - Low	3 - Moderate	4 - High	5 - Very High
L-5 Almost Certain	(M) - Moderate	(H) - High	(Ex) - Extreme	(Ex) - Extreme	(Ex) - Extreme
L-4 Likely	(M) - Moderate	(H) - High	(H) - High	(Ex) - Extreme	(Ex) - Extreme
L-3 Possible	(L) – Low	(M) - Moderate	(H) - High	(H) - High	(Ex) - Extreme
L-2 Unlikely	(L) – Low	(L) - Low	(M) - Moderate	(H) - High	(H) - High
L-1 Rare	(L) - Low	(L) – Low	(L) - Low	(M) - Moderate	(H) - High

Extend Risk matrix to acceptable level for each severity

Consequences

Reduce judgement for Consequences/Severity identification

- Use consequences as given in API 754
- Use of software to produce graphs for chemicals used in the plant
- Use generic graphs
- Use of Formula for identification of release rate for severity identification
- Use of Rule of Thumb

							Likelihood							
							L7*	L6*		L5	L4	L3	L2	L1
							Probability per annum (Operational)							
							≤0.0001 %	>0.0001 % -0.003%		≤0.01%	>0.003%-0.3%	>0.3-1%	>1-10%	>10%
							Frequency							
		Financial (US$) at Site Level	Reputation	Injury / Illness	Other Consequences									
										Very Unlikely	Unlikely	Possible	Likely	Very Likely
Consequence	C1					Very High								
	C2					High								
	C3					Moderate								
	C4					Low								
	C5					Very Low								

API 754

Table D.1—Tier 1 PSE Severity Weighting

Severity Points	Consequence Categories				
	Safety/Human Health [c]	Direct Cost from Fire or Explosion	Material Release Within Any 1-hr Period [a d e]	Community Impact	Off-site Environmental Impact [b c]
1 point	Injury requiring treatment beyond first aid to an employee, contractor, or subcontractor. (Meets the definition of a U.S. OSHA recordable injury.)	Resulting in $100,000 ≤ direct cost damage < $1,000,000.	Release volume 1× ≤ Tier 1 TQ < 3× outside of secondary containment.	— Officially declared shelter-in-place or public protective measures (e.g. road closure) for < 3 hours, or — officially declared evacuation < 3 hours.	Resulting in $100,000 ≤ acute environmental cost < $1,000,000.
3 points	— Days away from work injury to an employee, contractor, or subcontractor, or — injury requiring treatment beyond first aid to a third party.	Resulting in $1,000,000 ≤ direct cost damage < $10,000,000.	Release volume 3× ≤ Tier 1 TQ < 9× outside of secondary containment.	— Officially declared shelter-in-place or public protective measures (e.g. road closure) for > 3 hours, or — officially declared evacuation > 3 hours < 24 hours.	— Resulting in $1,000,000 ≤ acute environmental cost < $10,000,000, or — small-scale injury or death of aquatic or land-based wildlife.
9 points	— A fatality of an employee, contractor, or subcontractor, or — a hospital admission of a third party.	Resulting in $10,000,000 ≤ direct cost damage < $100,000,000.	Release volume 9× ≤ Tier 1 TQ < 27× outside of secondary containment.	Officially declared evacuation > 24 hours < 48 hours.	— Resulting in $10,000,000 ≤ acute environmental cost < $100,000,000, or — medium-scale injury or death of aquatic or land-based wildlife.
27 points	— Multiple fatalities of employees, contractors, or subcontractors, or — multiple hospital admission of third parties, or — a fatality of a third party.	Resulting in ≥ $100,000,000 of direct cost damages.	Release volume ≥ 27× Tier 1 TQ outside of secondary containment.	Officially declared evacuation > 48 hours.	— Resulting in ≥ $100,000,000 of acute environmental costs, or — large-scale injury or death of aquatic or land-based wildlife.

[a] Where there is no secondary containment, the quantity of material released from primary containment is used. Where secondary containment is designed to only contain liquid, the quantity of the gas or vapor being released and any gas or vapor evolving from a liquid must be calculated to determine the amount released outside of secondary containment.

[b] Judging small-, medium-, or large-scale injury or death of aquatic or land-based wildlife should be based on local regulations or Company guidelines.

[c] The severity weighting calculation includes a category for "off-site environmental impact" and injury beyond first aid (i.e. OSHA "recordable injury") level of safety/human health impact that are not included in the Tier 1 PSE threshold criteria. However, the purpose of including both of these values is to achieve greater differentiation of severity points for events that result in any form of injury or environmental impact.

[d] For the purpose of severity weighting, general paving or concrete under process equipment, even when sloped to a collection system, is not credited as secondary containment.

[e] Material release is not tabulated for fires or explosions. These events severity will be determined by the other consequence categories in this table.

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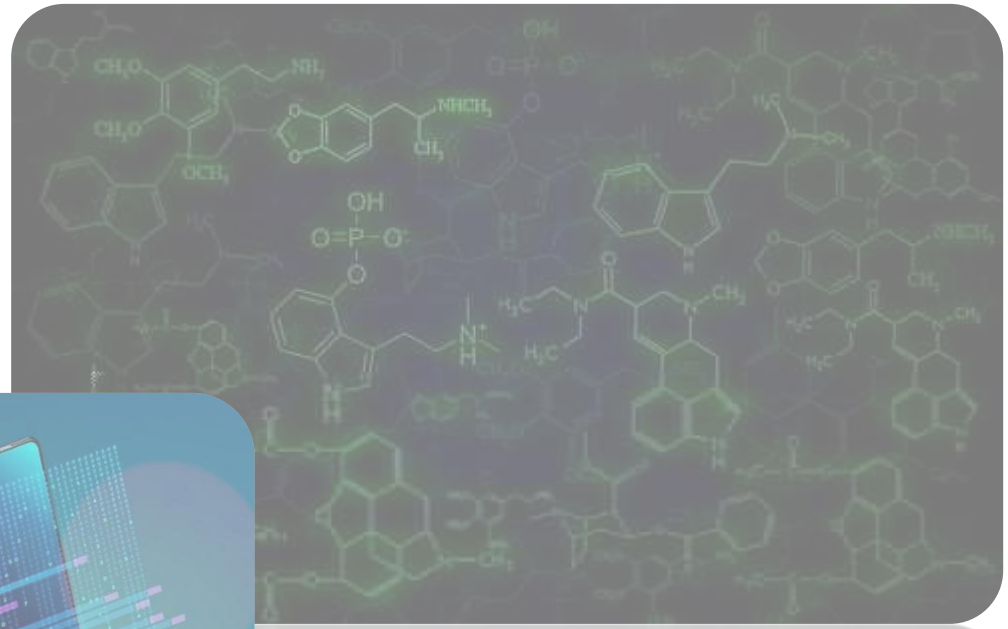
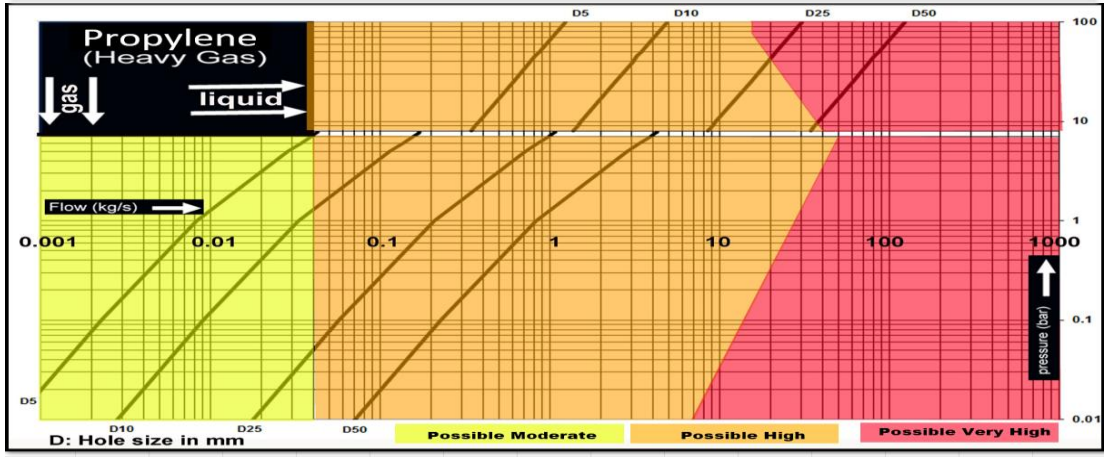
Use of software to produce graphs for chemicals used in the plant

- DNV's Safeti and Phast,
- BakerRisk's SafeSite3G©,
- DNV KFX

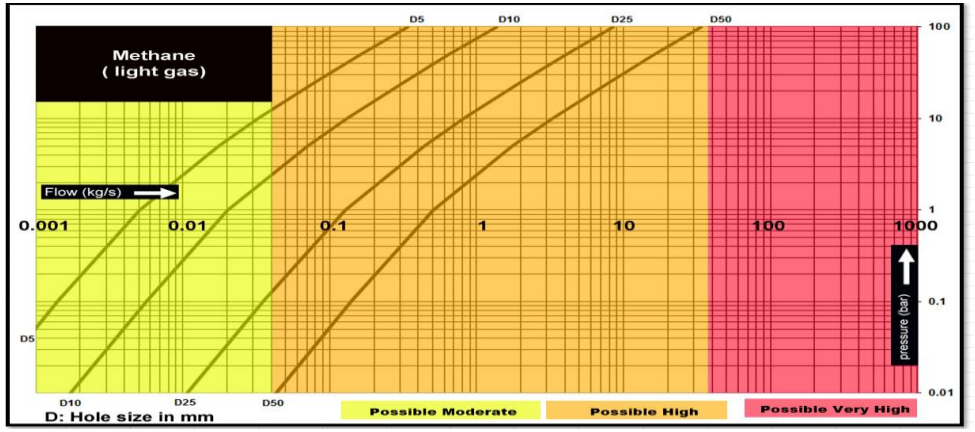


Use Generic Graphs

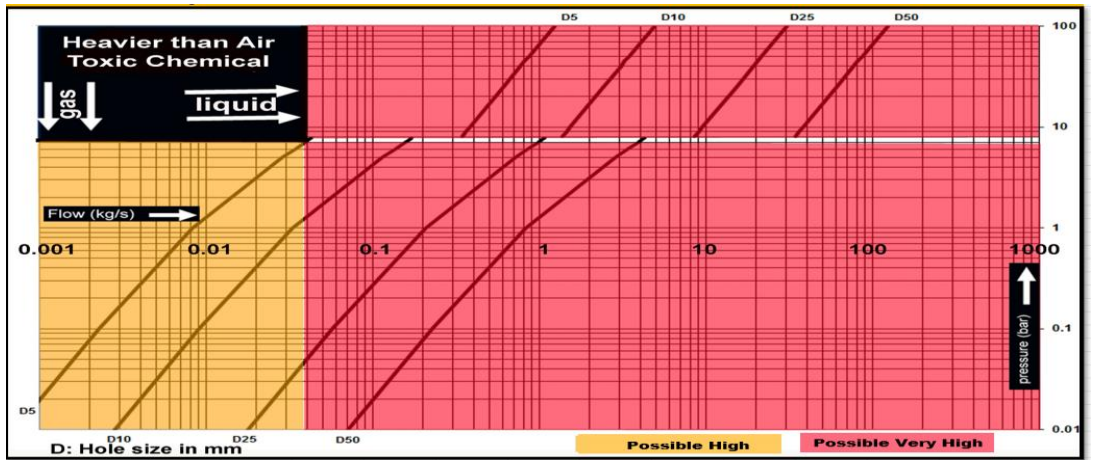
Severity of Fire & Explosion as a result of Heavy Chemicals (Propylene)



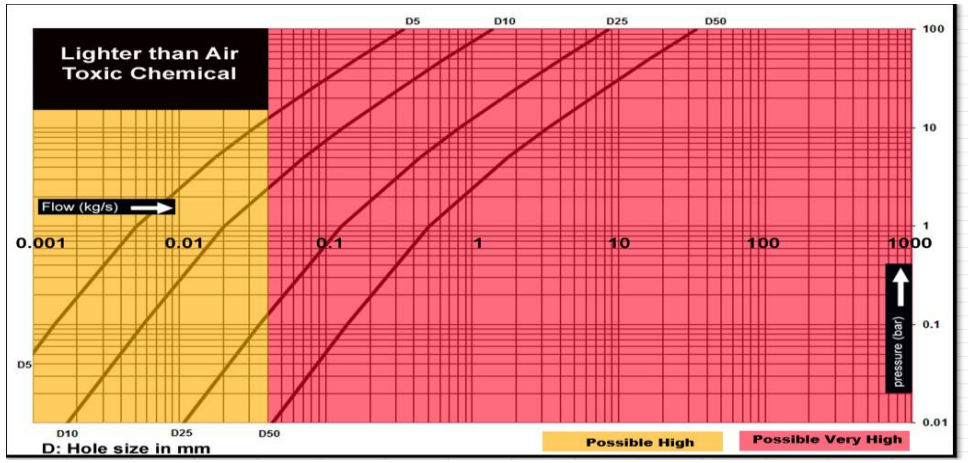
Severity of Fire & Explosion as a result of Lighter Chemicals (Methane)



Severity of release of heavier than air Toxic chemicals



Severity of release of Lighter than air Toxic chemicals



Use of Formula for identification of release rate for severity identification

Release rate for Heavy Chemical (Propylene)

Pressure	Hole Size			
Bar	5 mm	10 mm	25 mm	50 mm
0.001	0.00022266	0.000890625	0.005566406	0.022265625
0.01	0.00070313	0.002812500	0.017578125	0.070312500
0.1	0.00226563	0.009062500	0.056640625	0.226562500
1	0.00820313	0.032812500	0.205078125	0.820312500
5	0.02851563	0.114062500	0.712890625	2.851562500
6	0.03347656	0.133906250	0.836914063	3.347656250
7	0.03867188	0.154687500	0.966796875	3.867187500
7.5	0.04140625	0.165625000	1.035156250	4.140625000
7.75	0.04257813	0.170312500	1.064453125	4.257812500
8	0.34023438	1.360937500	8.505859375	34.023437500
9	0.36093750	1.443750000	9.023437500	36.093750000
10	0.38046875	1.521875000	9.511718750	38.046875000
25	0.60312500	2.412500000	15.078125000	60.312500000
40	0.76445313	3.057812500	19.111328125	76.445312500
45	0.81132813	3.245312500	20.283203125	81.132812500
50	0.85585938	3.423437500	21.396484375	85.585937500
100	1.21992188	4.879687500	30.498046875	121.992187500

Release rate for Lighter Chemical (Methane)

Pressure	Hole Size			
Bar	5 mm	10 mm	25 mm	50 mm
0.001	0.000137	0.000547	0.003418	0.013672
0.01	0.000430	0.001719	0.010742	0.042969
0.1	0.001406	0.005625	0.035156	0.140625
1	0.005078	0.020313	0.126953	0.507813
5	0.017578	0.070313	0.439453	1.757813
10	0.032813	0.131250	0.820313	3.281250
25	0.079297	0.317188	1.982422	7.929688
50	0.160547	0.642188	4.013672	16.054688
100	0.338281	1.353125	8.457031	33.828125

Rules of Thumb for Severity

Rule of thumb for an explosion is a pressure rise by a factor of 8, relative to the design pressure in bar. This holds for both a gas explosion (deflagration) and a dust explosion.

Example: A reactor is operated at 0.5 barG. The maximum explosion pressure will be 8 (1.0 + 0.5) bar = 12 bar = 11 barG.*

Pressure of <1.0 barG as per above example will have potential of recordable injuries.

Pressure ≥ 1.0 - <8 barG: the effect will have potential of fatalities caused by flying fragments up to 20 meters.

Pressure > 8-10 barG: the effect will have potential of fatalities cause by flying fragments up to 50 meters.

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Likelihood

Reduce judgement for Likelihood/Probability

Levels of Likelihood	Consequences-Severity/Risk Rating				
	1 - Very Low	2 - Low	3 - Moderate	4 - High	5 - Very High
L-5 Almost Certain	(M) - Moderate	(H) - High	(Ex) - Extreme	(Ex) - Extreme	(Ex) - Extreme
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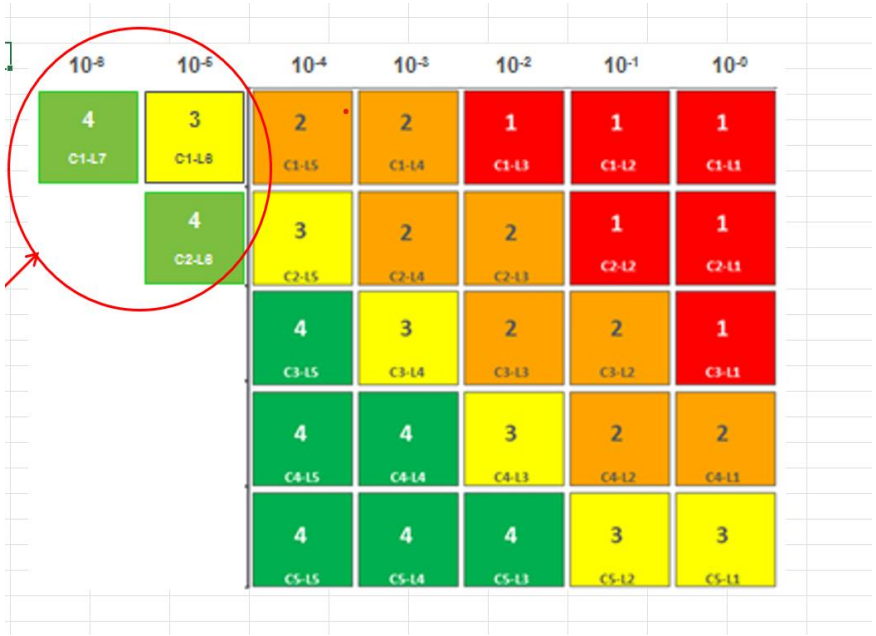


- Use Initiating Event frequency
- Use PFDs
- Use of event condition & Condition Modifier

Data Driven Likelihood

Initiating Event Frequencies

Equipment	Type	Description of failure	Frequency	Source of Data
Atmospheric Tank	Single walled	MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-04	CCPS p. 102
		Catastrophic failure (Instantaneous release of whole inventory)	1.00E-05	CCPS p. 100
	Double walled	MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-06	HSE p. 13
Refrigerated Vessel	Single walled	MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-04	HSE p. 19
		Catastrophic failure (Instantaneous release of whole inventory)	1.00E-05	HSE p. 19
	Double walled	MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-05	HSE p. 19
Pressure Vessel	Single walled	MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-05	CCPS p. 104
		Catastrophic failure (Instantaneous release of whole inventory)	1.00E-06	CCPS p. 104
Pressure Vessel/ Reactor/Distillation Column	Non-Lined	MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-05	HSE p. 20/30
		Catastrophic failure (Instantaneous release of whole inventory)	1.00E-06	HSE p. 20/30
	Lined	MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-04	expert judgement
		Catastrophic failure (Instantaneous release of whole inventory)	1.00E-05	expert judgement
Teflon/PVC/ Fiber Glass Vessels		MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-04	expert judgement
		Catastrophic failure (Instantaneous release of whole inventory)	1.00E-05	expert judgement
Underground Tanks/Vessels		MCE (Continuous Leak from 10 mm Diameter Opening)	1.00E-05	expert judgement
		Catastrophic failure (Instantaneous release of whole inventory)	1.00E-06	expert judgement
		Third Party Interference Inside	1.00E-03	expert judgement
		Third Party Interference Outside	1.00E-02	expert judgement
Above Ground Piping	diameter ≤ 150 mm	MCE Piping Leak (0.1 × pipe diameter) per meter Pipe Length	1.00E-05	CCPS p. 110
		Catastrophic Rupture per meter Pipe Length	1.00E-06	
	diameter > 150 mm	MCE Piping Leak (0.1 × pipe diameter with up to a maximum of 50 mm) per meter Pipe Length		
		Catastrophic Rupt… per mete…		

PFDs

Equipment / Protection	PFD	Source of Data
Class-1 Relief device with no block valves	1.00E-02	Because MSHEM has stringent testing frequencies and management of Relief valves. CCPS P 180
Class II & III Relief device with no block valves	1.00E-03	Because MSHEM has stringent testing frequencies and management of Relief valves. CCPS P 182
Relief device with car sealed block valves	1.00E-02	MSHEM must be fully implemented and then 10-2 is acceptable. Otherwise 10-1 supported by CCPS page 194
Relief device requiring heat tracing.	1.00E-01	Heat trace systems of reliefs are low reliability due to insulation requirements and the complexity of tracing on the inlet outlet and relief itself.
Relief device with upstream rupture disc	1.00E-02	Should require pressure transmitter to monitor interspace with alarm to SIS (SIL1) and response in 24 hours. Human response per CCPS pg 258.
Rupture disc with no block valves and no heat tracing required.	1.00E-03	CCPS P 192
Rupture disc with heat tracing and/or block valves	1.00E-02	Heat trace systems of reliefs are low reliability due to insulation requirements and the complexity of tracing on the inlet outlet and relief itself
SIL-3 SIF	1.00E-03	IEC61511
SIL-2 SIF	1.00E-02	IEC61511
SIL-1 SIF	1.00E-01	IEC61511
Diking or Bunding	1.00E-02	CCPS P 138
Overflow line - open	1.00E-03	CCPS pg 132
Overflow line - fluid filled	1.00E-01	CCPS pg 134
Open vent (no valve)	1.00E-02	
Single check valve	1.00E-01	CCPS P 222
Double Check valve	1.00E-02	See CCPS 326
ESD/ROSOV/ROIV	1.00E-01	Designed as SIF
Continious pilot burner for furnace/boiler/flare	1.00E-01	CCPS P 226
Mechanical overspeed on turbines	1.00E-01	CCPS P 242
Automatic Explosion supression system	1.00E-01	CCPS P 244
Automatic fire supression system	1.00E-01	CCPS P …
Adjustable movement limiting device	1.00E-01	CCP…
Non-adjustable movement limiting device	1.00E-02	
PPE	1.00…	
…hanically activated emergency …isolation device		
…tion with automa…		

Event Condition & Conditional Modifier

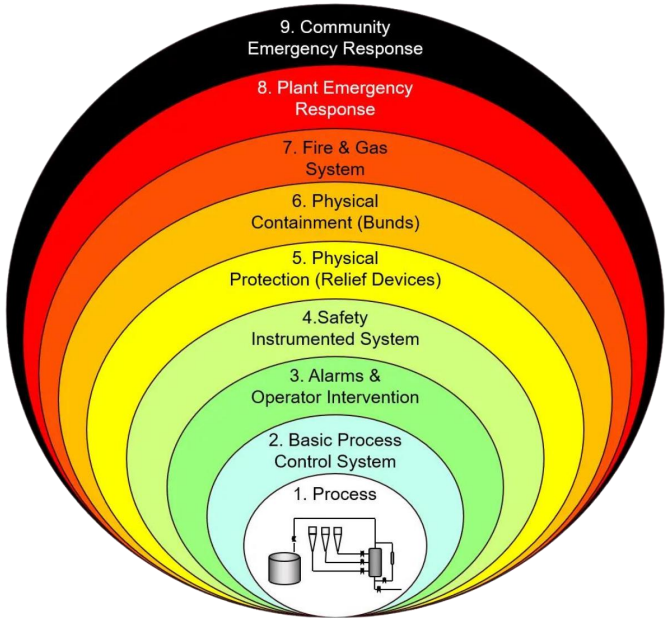
EC/CM	Data		
Process Condition Related	Identify number of hours the cause will result in process deviation resulting in potential consequences/hours of operations*		
Mechanical Failure Related	Identify number of hours the equipment will be in a condition that potentially will result in consequences/hours of operations*		
Activity Related	Identify number of hours that an activity is carried out that may result in potential consequences/8000 hrs*		
Climate Condition Related	Identify number of hours the climate condition may result in deviation resulting in potential consequences/hours of operations*		
Probability of personnel presence independent of the scenario	Number of hours a person is in the area present where the potential consequence is identified/hours of operations*		
Probability of consequence	Will only be considered for detailed quantitative risk assessment.		
Timely evacuation to outside the potential consequence area	0.1		
Probability of ignition	**Type of release**	**Amount of release**	**Probability**
	Release Rate Gas	> 100 kg/s	1.E+00
		10 - 100 kg/s	1.E-01
		< 10 kg/s	1.E-02
	Release Rate Flammable Liquid	> 100 kg/s	1.E-01
		< 100 kg/s	1.E-02
	Release Rate Combustible Liquid	> 100 kg/s	1.E-02
		< 100 kg/s	1.E-03

*** Continuous plant = 8000 hrs/year**

Batch plant = actual operations hours/year

Improve Effectiveness of Process Hazard Analysis

- Integrate Protection layers Integrity in the PHA studies & optimize revalidation process
- Reduce Judgements in PHA studies



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