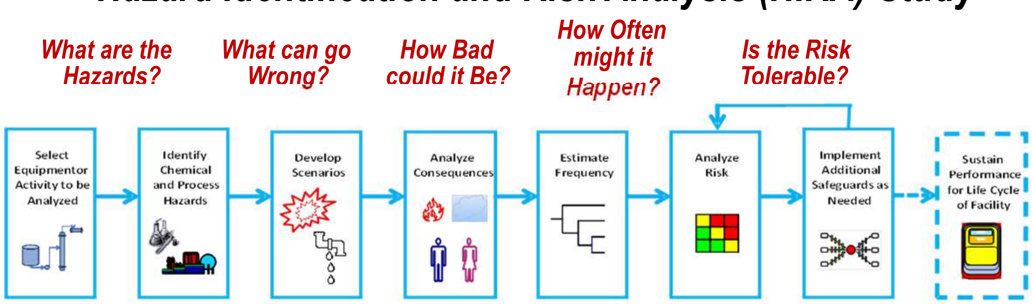
Chemical Hazard Engineering Fundamentals (CHEF)

Case Study – BP Texas City

Refinery Explosion And Fire
Texas City, Texas
2005

Case Study – BP Texas City

Hazard Identification and Risk Analysis (HIRA) Study



This study begins by **Identifying the Equipment or Activity** for the analysis. We will use the operation of a specific equipment item containing a specific chemical or chemical mixture to define the activity, such as the operation of a storage tank, a reactor, or a piping network, etc. Inputs include chemical data, equipment design information, operating conditions, and plant layout.

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Process Description

The ISOM unit provided higher octane components for unleaded gasoline (petrol), consisting of four sections: an Ultrafiner desulfurizer, a Penex reactor, a vapor recovery / liquid recycle unit, and a raffinate splitter. At the BP Texas City refinery, the ISOM unit converted straight-chain normal pentane and hexane into branched-chain isopentane and isohexane for gasoline blending and chemical feedstocks.

This study focuses on the raffinate splitter section where a hydrocarbon mixture is separated into light and heavy components. About 40 percent of the raffinate feed was recovered as light raffinate (primarily pentane/hexane). The remaining raffinate feed was recovered as heavy raffinate. The raffinate splitter section could process up to 45,000 barrels per day (approximately 1,300 gallons/minute) of raffinate feed.

This is an illustrative example and does not reflect a thorough or complete study.

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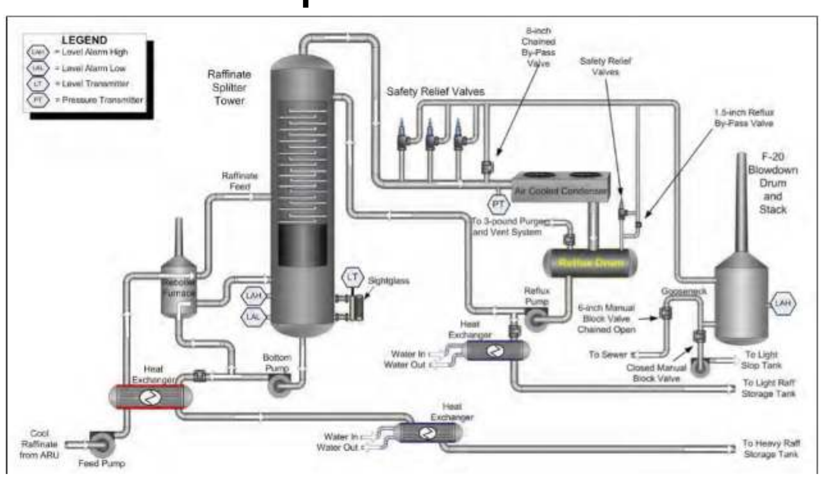
Process Description

The process equipment in the raffinate splitter section consisted of a feed surge drum, a distillation tower, a furnace with two heating sections (one used as a reboiler for heating the bottoms of the tower and the other preheating the feed), air-cooled fin fan condensers, an overhead reflux drum, pumps,and heat exchangers.



Raffinate Splitter Tower System of the ISOM Unit

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Process Description

Liquid raffinate feed was pumped into the raffinate splitter tower near the tower's midpoint. An automatic flow control valve adjusted the feed rate. The feed was pre-heated by a heat exchanger using heavy raffinate product and again in the preheat section of the reboiler furnace, which used refinery fuel gas. Heavy raffinate was pumped from the bottom of the raffinate splitter tower and circulated through the reboiler furnace, where it was heated and then returned below the bottom tray. Heavy raffinate product was also taken off as a side stream at the discharge of the circulation pump and sent to storage. The flow of this side stream was controlled by a level control.

Light raffinate vapors flowed overhead, was condensed by air-cooled fin fan condensers, and then deposited into a reflux drum. Liquid from the reflux drum was then pumped back into the raffinate splitter tower above the top tray.

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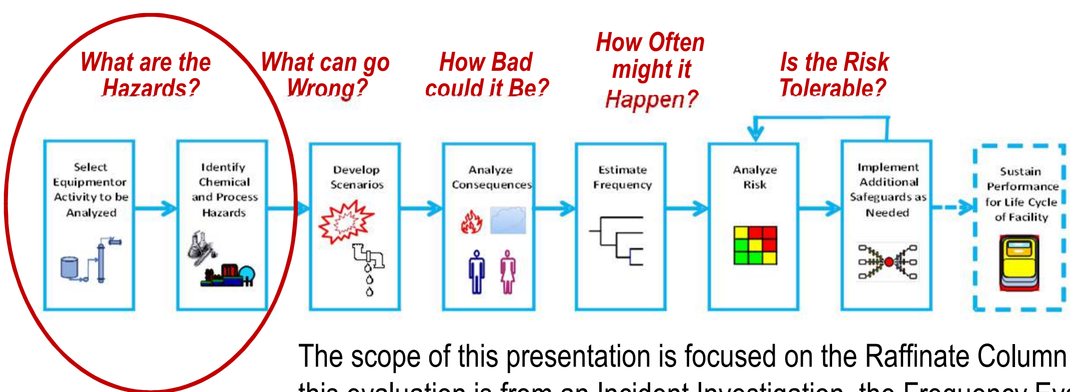
Hazard Identification and Risk Analysis (HIRA) Study



The scope of this presentation is focused on the Raffinate Column. Since this evaluation is from an Incident Investigation, the Frequency Evaluation and Risk Analysis will not be addressed - the incident has already occurred and the weak protection layers already known. Thus, a "worst case" consequence that might be evaluated during risk analysis is addressed.

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Raffinate Composition

Raffinate splitter column simplified composition model (Fisher, 2006)

Compound	Weight Fraction
n-pentane	0.0383
2-methyl butane	0.0263
n-hexane	0.1519
2-methyl pentane	0.2950
n-heptane	0.3072
n-octane	0.1300
n-nonane	0.0409
Heavies as n-decane	0.0104
Total	1.0000

Typical Raffinate composition *per Refinery Explosion and Fire*, CSB Report No. 2005-04-I-TX page 259

For entry into CHEF, the mixture is simplified to:

0.06 n-pentane
0.45 n-hexane (including isohexane)
0.31 n-heptane
0.18 n-octane
1.00 Total

At the time of the incident, it was the normal federate of 55 kg/sec.

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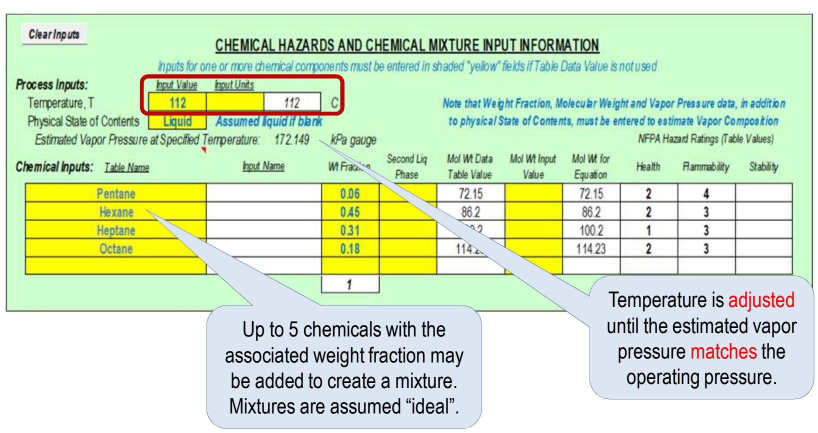
Chemical Hazards Worksheet

A composition (weight fraction):

0.06 n-pentane
0.45 n-hexane
0.31 n-heptane
0.18 n-octane

The operating pressure was 25 psig (172 kPa gauge) and the operating temperature of 112 C was estimated as the saturation temperature or temperature such that the estimated vapor pressure matches the operating pressure for a boiling liquid.



The chemical property inputs for the various worksheets are estimated from this composition at the appropriate temperature

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Chemical Hazards Worksheet

ESTIMATED MIXTURE LFL and MINIMUM FLASH POINT
equation 2-1

Chemical Name	Mol Fract Vapor / LFL
Pentane	0.15581
Hexane	0.53656
Heptane	0.14130
Octane	0.03813

The Minimum Flash Point for any Component is: **-48.15** C

$\Sigma\, y_i / LFL_i =$ 0.87180

$LFL_{Mixture} = 1 / (\Sigma\, y_i / LFL_i) =$ **1.15** Vol %

ESTIMATED MIXTURE ERPG-2 and ERPG-3
Dose adjusted ERPG per equation 3-1 and mixture ERPG per equation 3-3

Based on Exposure Duration of 60 min

Chemical Name	ERPG-2 (t /60)1/	Mol Fract Vapor / ERPG-2 (t /60)$^{1/n}$	ERPG-3 (t /60)1/	Mol Fract Vapor / ERPG-3 (t /60)$^{1/n}$
Pentane	32500.0	0.00001	190000.0	0.00000
Hexane	2900.0	0.00020	8600.0	0.00007
Heptane	800.0	0.00019	4900.0	0.00003
Octane	385.0	0.00009	5000.0	0.00001

$\Sigma\, y_i / ERPG\text{-}2'_i =$ 0.00050 $\quad \Sigma\, y_i / ERPG\text{-}3'_i =$ 0.00011

$ERPG\text{-}2'_{Mixture} = 1 / (\Sigma\, y_i / ERPG\text{-}2'_i) =$ **2005.61** ppmv $\quad ERPG\text{-}3'_{Mixture} =$ **9196.07** ppmv

Note: n is assumed 2 for interpolation of exposure duration less than one hour and 1 for extrapolation of exposure duration to greater than one hour if not entered

- ✓ An estimated mixture flashpoint of -48 C (the minimum of any component) and estimated lower flammable limit of 1.15 volume % indicates a *potentially high flammability hazard*.
- ✓ An estimated ERPG-2 of >2,000 ppm would indicate a low to moderate toxicity hazard. The NFPA Health Ratings for these materials range from 1 to 2 also indicating a low to moderate hazard.
- ✓ There may be other hazards to consider such as thermal radiation due to a maximum process temperature greater than 60 to 80 C.

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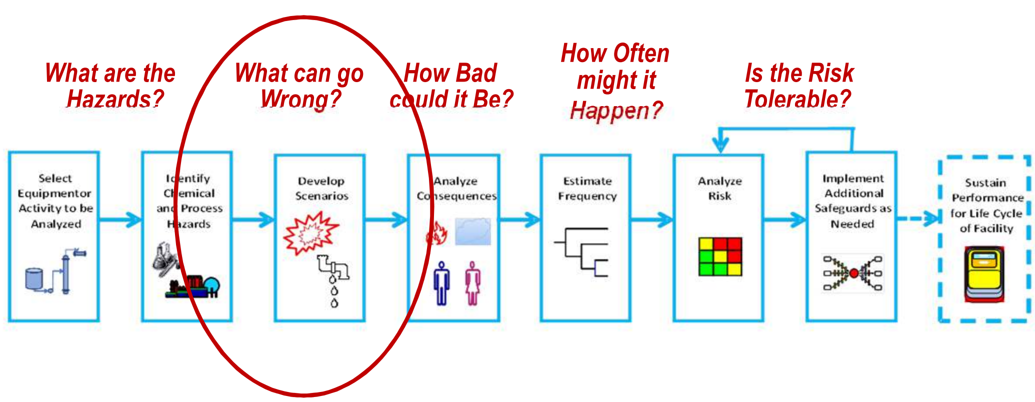
Hazard Identification and Risk Analysis (HIRA) Study



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Partial List of Hazard Scenarios per CHEF Example Scenarios

Scenario or Hazard Category	Parameter/ Deviation	Applicable Equipment	Initiating Events *(Partial List)*	Loss Event*	Incident Outcome
Mechanical Integrity Failure - Large	Flow-Loss of Containment	All - to address Residual Failures	Residual Failure	Very Large Hole Size Leak	Flammable Release Toxic Release Chemical Exposure
Mechanical Integrity Failure - Small	Flow-Loss of Containment	All - to address Residual Failures	Residual Failure	Very Small Hole Size Leak	Flammable Release Toxic Release Chemical Exposure
Overfill, Overflow, or Backflow	Level-High Flow-Backflow	All Liquid Containing Equipment	Level Control Failure Procedure Failure (Human Error)	Overflow Release Equipment Damage Equipment Rupture	Flammable Release Toxic Release Physical Explosion Business Loss
Overflow - Flooding or Plugging	Level-High	Adsorber/Scrubber Distillation Vapor Quench	Level Control Failure Pressure Control Failure Flow Control Failure	Overflow Release Equipment Damage Equipment Rupture	Flammable Release Toxic Release Physical Explosion Business Loss
Physical Damage or Puncture	Flow-Loss of Containment	Drum/IBC Handling Piping Pump**	Procedure Failure (Human Error)	Full-Bore Leak	Flammable Release Toxic Release

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Suggested Scenarios for Raffinate Column

WORKING WITH YOUR EVALUATION TEAM:

- ❑ **Review the suggested list of scenarios. Do these represent what you would expect for a distillation column?**
- ❑ **Are there scenarios missing? (Possibly similar scenarios with different Initiating Events)**
- ❑ **Utilize an Appropriate Hazard Evaluation Technique (HAZOP, What If, etc.) to capture additional scenarios.**

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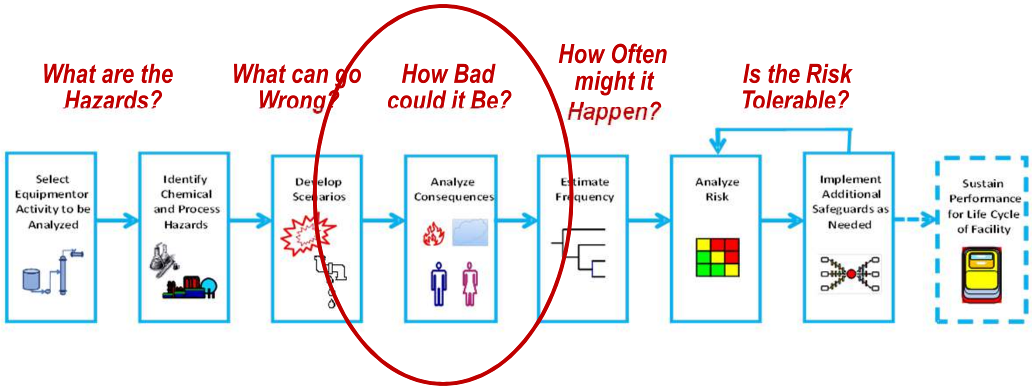
Hazard Identification and Risk Analysis (HIRA) Study



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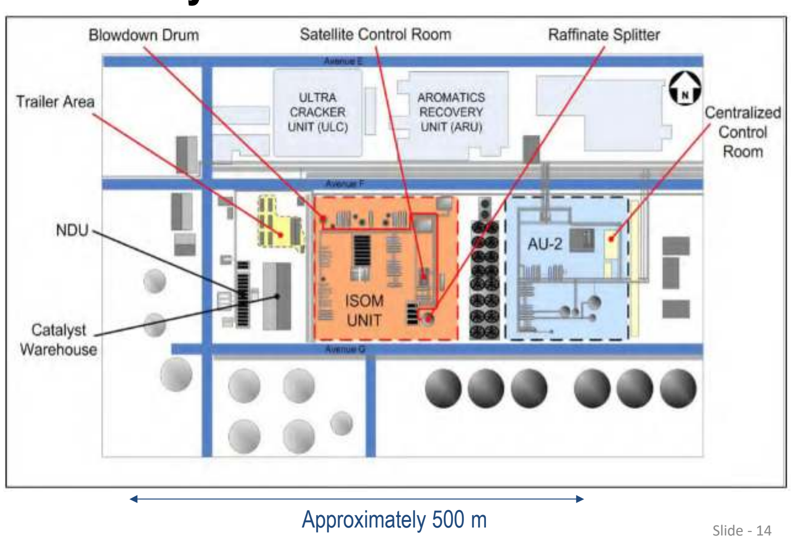
Site Layout

Several wooden trailers are located approximately 200 m from the Raffinate Splitter housing 20 people. The trailers are "low strength" construction. In addition, the process area appears to be relatively "*low*" equipment congestion.

The Blowdown Drum receives the discharge from the Raffinate Splitter relief devices is located 50 m from the wooden trailers and vents at an elevation of 36 m.



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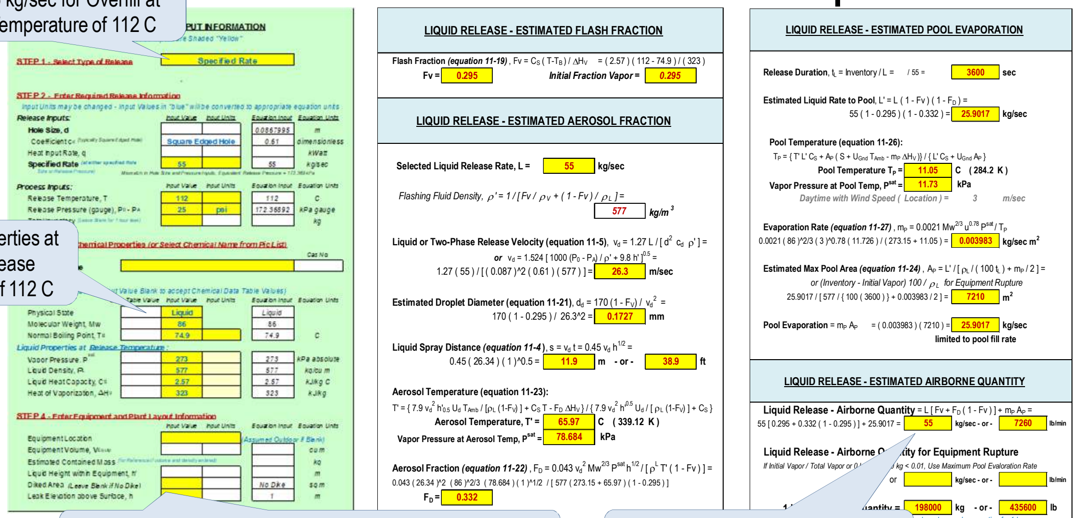
Source Models Worksheet - Consequences

Use a Specified Release rate equal to feed rate of 55 kg/sec for Overfill at the Release Temperature of 112 C

Chemical Properties at Column Release Temperature of 112 C



Leave Elevation Blank for now as Discharge was to a Blowdown Tank which then Overflowed to the Atmosphere

Total Airborne Rate of 55 kg/sec with a liquid pool of 7210 m² *after 1 hour*

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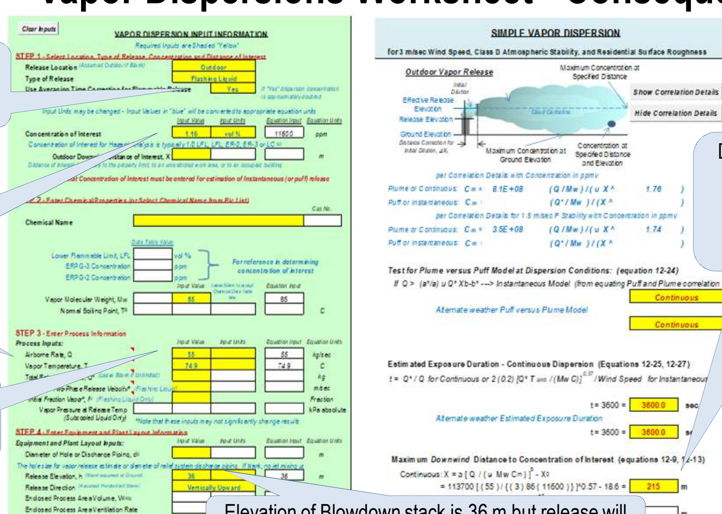
Vapor Dispersions Worksheet - Consequences

Use a Flashing Liquid Release with Averaging Time Correction for Flammable Evaluation

Chemical Properties at Blowdown Tank Release Temperature of 74.9 C (estimated normal boiling point)

Vapor Rate from Source Model of 55 kg/sec.



Distance to Concentration of Interest (lower flammable limit) is 215 m at the default wind speed of 3 m/sec and Class D Stability

Elevation of Blowdown stack is 36 m but release will be assumed ground elevation for a flashing liquid

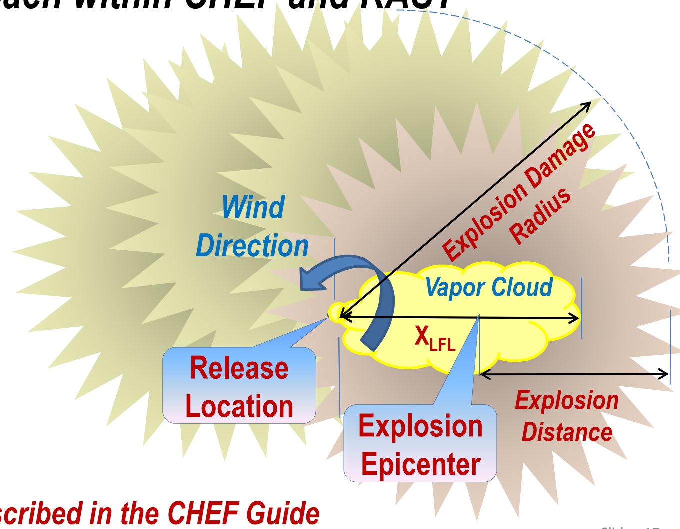
Vapor Cloud Explosion

Simple Modeling Approach within CHEF and RAST

The entire vapor cloud is considered a single Potential Explosion Site with epicenter at the center of the flammable cloud (0.5 X_{LFL}).

An single overall level of congestion and confinement for the entire cloud is used.

Wind direction is assumed toward greatest population or building with highest occupancy.



Methodology is described in the CHEF Guide

Site Layout

Congestion or Obstacle Density Categories

The method described in CHEF is limited to consideration of the entire cloud volume as a single Potential Explosion Site (PES) at an overall or average category of process equipment congestion. This technique does not account for small localized areas of higher congestion where blast overpressure will be higher.

Low – Only 1-2 layers of obstacles. One can easily walk through the area relatively unimpeded.

Medium – 2-4 layers of obstacles. One can walk through an area, but it is cumbersome to do so.

High – Many layers of repeated obstacles. One could not possibly walk through the area and little light penetrates the congestion .

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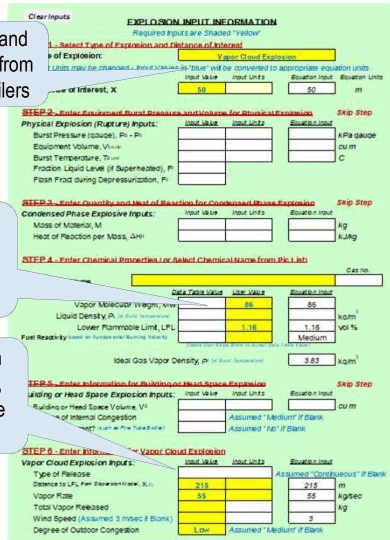
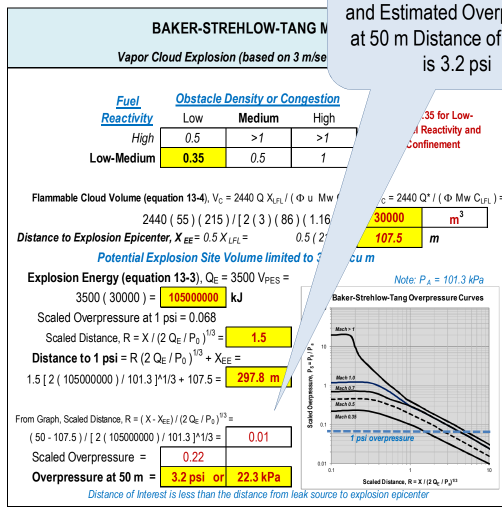
Explosions Worksheet - Consequences

Use Vapor Cloud Explosion and Distance of Interest as 50 m from Release Point to Project Trailers

Chemical Properties at Blowdown Tank Release Temperature of 74.9 C (estimated normal boiling point)

Enter Distance to LFL from Vapor Dispersion estimate, vapor rate and "low" degree of congestion





Estimated Distance to 1 psi Blast Overpressure is 298 m and Estimated Overpressure at 50 m Distance of Interest is 3.2 psi

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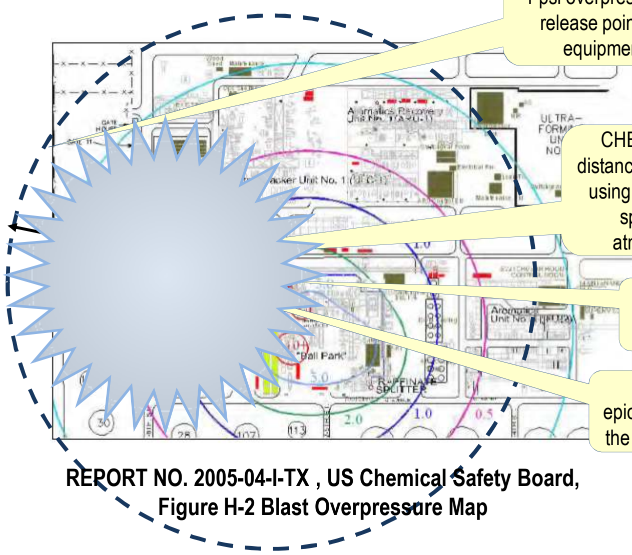
Consequence Analysis

A simplification when estimating risk is choosing a wind direction toward the highest population. This is quite reasonable in a Risk Analysis where the wind direction is unknown.

In the actual incident, the wind direction was toward the southeast rather than west toward the wooden trailers.

Wind Direction represents a key difference between estimates for Risk Analysis versus Incident Investigation. *Blast overpressure at the wooden trailers would likely have been higher if the wind direction was toward the trailers.*



CHEF estimated maximum 298 m 1 psi overpressure distance from release point assuming "low" equipment congestion.

CHEF estimated 215 m distance to LFL concentration using default 3 m/sec wind speed and class D atmospheric stability

Release Point – Blowdown Stack

The explosion epicenter is selected as the center of LFL cloud

REPORT NO. 2005-04-I-TX , US Chemical Safety Board, Figure H-2 Blast Overpressure Map

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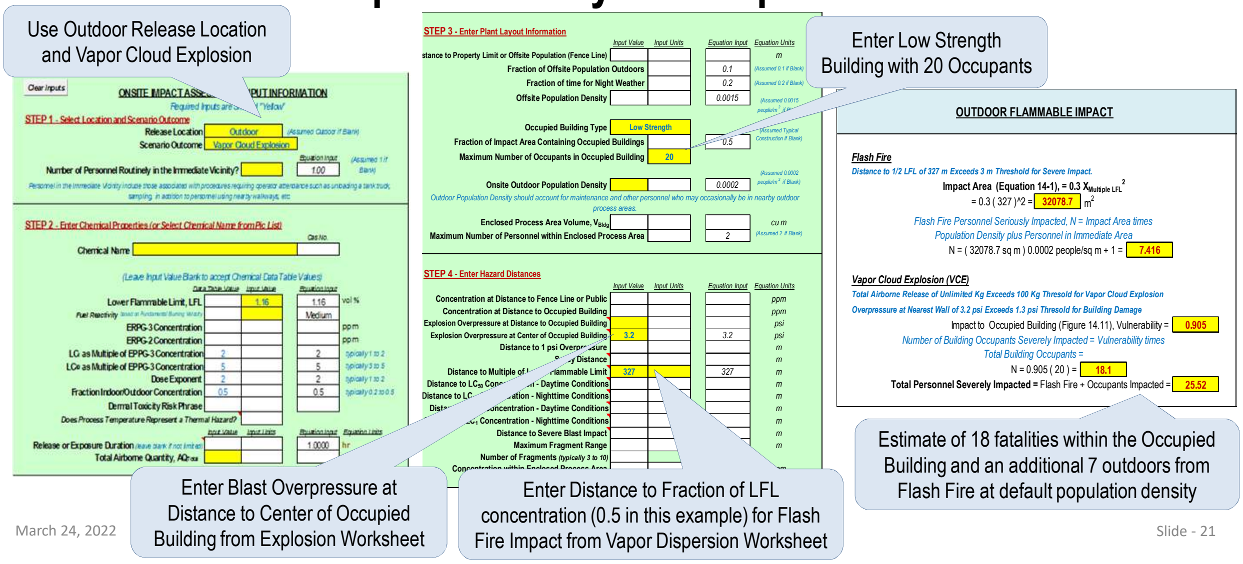
Consequence Analysis – Impact Estimation



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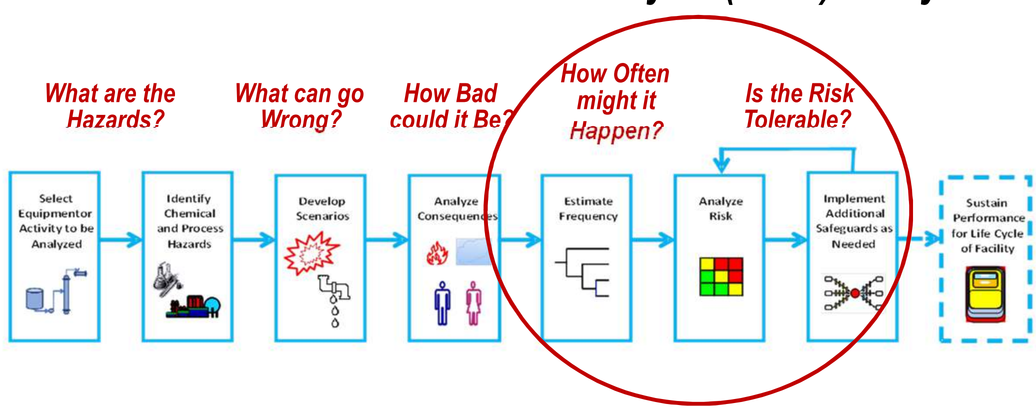
Hazard Identification and Risk Analysis (HIRA) Study



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Case Study – BP Texas City
Risk Analysis / Layers of Protection Analysis (LOPA)

Initiating Event – either Basic Level Control System failure (instrument was not indicating the correct level) or Human Performance Failure as "operators routinely deviated from written procedures maintaining a high liquid level during startup to minimize the potential for costly damage to the fired heaters". From the CCPS Book, Layers of Protection Analysis, a frequency of 0.1 per year may be appropriate.

Loss Event – Overfill of the Raffinate Splitter Column to the Blowdown Tank with subsequent release of flammable material to the atmosphere.

Incident Outcome and **Consequence** – Vapor Cloud Explosion resulting in greater than 10 potential fatalities.

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Risk Matrix

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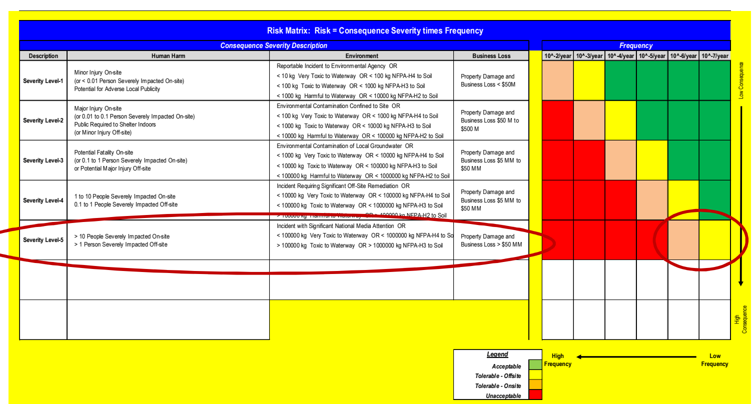
Risk Analysis Screening Tool (RAST)

To understand the Consequence Severity and Tolerable Frequency, the values for key Study Parameters and a Risk Matrix may be viewed on the Workbook Notes worksheet. These values may be updated on hidden worksheets and should reflect the company's specific risk criteria.



For this case study, the Risk Matrix (right) has been used. The Human Harm criteria is based on an estimated number of people severely impacted (severe injury including fatality).

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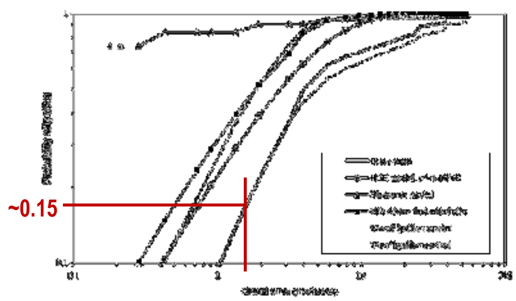
Risk Analysis / Layers of Protection Analysis (LOPA)

Conditional Modifier – the probability of ignition for an unknown source assuming "good " ignition controls



UK HSE Research Report 226, *Development of a method for the determination of on-site ignition probabilities* (2004)

Cloud Area ~ 0.3 (235 m)^2 = 16568 m^2 = 1.66 hectares

Ignition Source Type	Ignition Source	Strength "S"	Source
Point Sources	Fired heater	0.9	Moosemiller
	Boiler (outside)	0.45	TNO
	Boiler (inside)	0.23	TNO
	Flare	1.0	TNO, HSE
	Motor vehicle	0.3	TNO
	Ship	0.4	TNO
	Diesel train	0.4	TNO
	Electric train	0.8	TNO
	Hot surfaces	See discussion below table	
Line Sources	High-power electrical line	0.001 x length of line covered by cloud (ft)	TNO, Moosemiller
	Roadway (if area of cloud is known)	1 - 0.7^V (V=average number of vehicles covered by the cloud)	Moosemiller
Area Sources	Process unit (if area of cloud is known)	0.9 x fraction of unit covered by the flammable cloud	Modified TNO
	Residential population (if area of cloud is known)	1 - 0.99^N (N=number of people covered by the cloud)	Modified TNO, Moosemiller
	High-density process area (outdoor)	0.25(a)	UKEI/HSE
	Medium-density process area (outdoor)	0.15(a)	UKEI/HSE
	Low-density process area	0.1	UKEI/HSE
	Confined space with ~ no equipment	0.02	Moosemiller
	Process area outdoor storage	0.1	HSE, Moosemiller
	Remote outdoor storage area	0.025	Assumed, relative to previous row
	Office space	0.05	UKEI

CCPS, Guidelines for Determining the Probability of Ignition of a Released Flammable Mass, (2014)

A reasonable probability of ignition for this case may be 0.1 to 0.15 as the process area is likely electrically classified with "good controls".

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Risk Analysis / Layers of Protection Analysis (LOPA)

Scenario Number:	Equipment Identification:	Scenario Title:	
	Raffinate Column	Overfill Scenario during Startup	
Date:	***Description***	**Probability**	**Frequency (per year)**
Consequence Description/ Category	Column Overfill resuting in flammable release to the atmosphere and vapor cloud explosion.		
Risk Tolerance Criteria (Category or Frequency)	Potential for greater than 10 fatalities		**1.E-06**
Initiating Event (typically a frequency)	Failure of Level Control Loop or Human Performance Failure for filling the colmn above level reading during startup		1.E-01
Enabling Condition or Event			
Conditional Modifiers (if applicable)			
	Probability of Ignition	1.E-01	
	Probability of Personnel in Affected Area		
	Probability of Fatal Injury		
	Others		
Frequency of Unmitigated Consequence			**1.E-02**

Independent Protection Layers (IPLs)			
BPCS	High Pressure Alarm shutting off heat to the column reboiler	1.E-01	
Human Intervention	Blowdown Tank High Level Alarm with Procedure Close Manual Valves on Feeds	1.E-01	
SIF	Raffinate Column High Level Alarm with Automated Shut Off of Heat and Feeds	1.E-01	
Pressure Relief Device			
Other Protection Layers (must justify	Restricted Access near Isom Unit during Startup and Operation	1.E-01	
Safeguards (Non-IPLs)			
Total PFD for all IPLs		**1.E-04**	
Frequency of Mitigated Consequence			**1.E-06**
Risk Tolerance Criteria Met? (yes/no)		**Yes**	
Actions Required to Meet Risk Tolerance Criteria	Ensure all Protections noted are Inspected, Tested and Maintained to company standards. Restrict temporary occupied buildings to beyond the 05 psi blast contour unless a blast resistent builing.		
Notes	Meets Tolerable Criteria for On-site Personnel.		
References (link to originating hazard review, PFD, P&ID, etc.)			
LOPA Analysis (and Team Members)			

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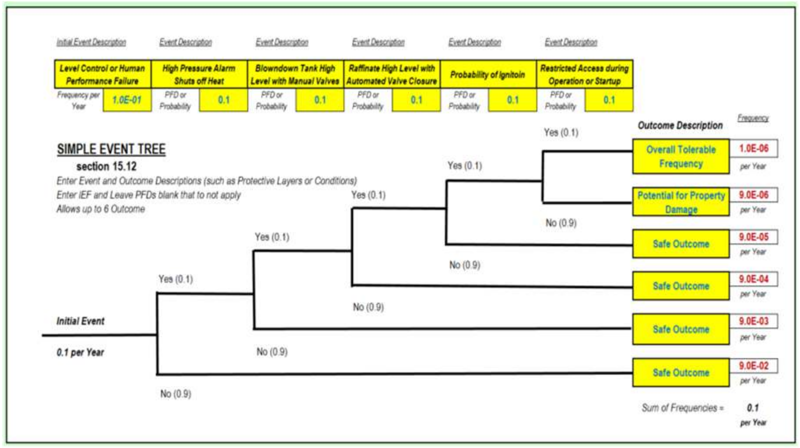
Frequency Evaluation Worksheet

The existing safeguards were close to sufficient for managing this scenario to a tolerable risk level had they been adequately maintained and some actions automated rather rely only on operator response to an alarm. In addition to those listed in the LOPA worksheet, several other alarms existed (such as high pressure) that may have contributed to reducing the overall scenario frequency if the potential for column overfill would have been recognized.



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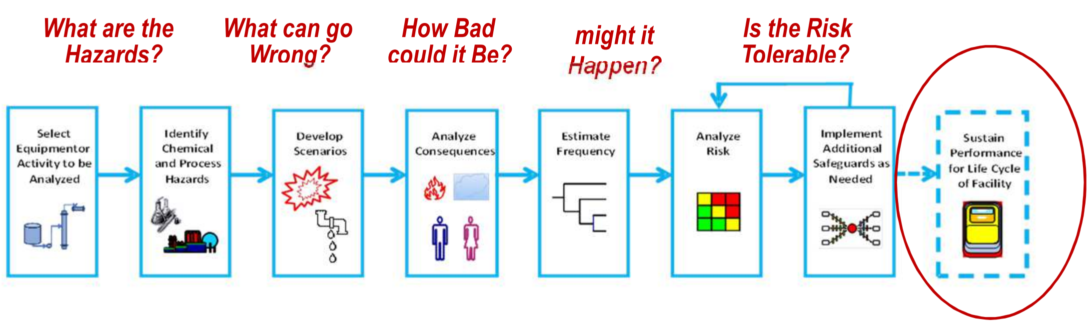
Sustaining Performance



The existing safeguards were sufficient for managing this scenario to a tolerable risk level had they been adequately maintained and some actions automated rather rely only on operator response to an alarm. In addition to those listed in the LOPA worksheet, several other alarms existed (such as high pressure) that may have contributed to reducing the overall scenario frequency if the potential for column overfill had been recognized.

CHEF and RAST Estimates
Case Study – BP Texas City

Risk Analysis and Incident Investigation often use similar methods to better understand the scenario. Risk Analysis "anticipates" what could go wrong and what the potential "worst" consequences may be. For Incident Investigation, the Incident Outcome and Consequences are known in addition to the actual weather conditions and wind direction.

For the Raffinate Splitter, RAST did suggest column overfill as one of many scenarios to consider. RAST also recognized that a Vapor Cloud Explosion could be a feasible Incident Outcome for an Overfill loss event. RAST was conservative in estimating blast damage as actual wind direction was not toward the wooden trailers. However, the "order of magnitude" estimate of consequences seems reasonable. The estimated number of people severely impacted in RAST was higher than the actual incident (25 versus 15 fatalities and 66 seriously injured).

Chemical Hazard Engineering Fundamentals – Case Studies

Questions?