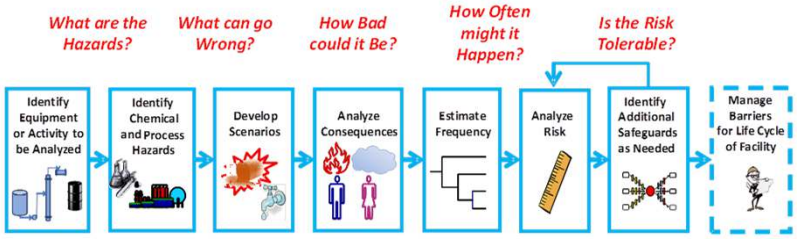
Risk Analysis Screening Tools (RAST)

Case Study – CAI and Arnel

CONFINED SPACE EXPLOSION
Danvers, Massachusetts
November 22, 2006

Case Study – CAI and Arnel

Hazard Identification and Risk Analysis (HIRA) Study



We begin the study by **Identifying the Equipment or Activity** for which we intend to perform an analysis. RAST uses the operation of a specific equipment item containing a specific chemical or chemical mixture to define the activity. For example, the operation of a storage tank, a reactor, a piping network, etc. Inputs are chemical data, equipment design information, operating conditions, and plant layout.

Case Study – CAI and Arnel
Process Description

The Danversport , MA plant is a 12000 ft^2 ink and paint manufacturing facility jointly owned by CAI and Arnel Companies. This facility began operations in the early 1960s within a minimally populated peninsula. Over several years, a large marina and many single family and duplex homes have located adjacent to the manufacturing plant, some homes as close as 150 ft. away.

The CAI production manager and five employees manufactured solvent-based inks in the Danvers facility. At the end of each day, they loaded the day's production of ink products onto a truck and delivered it to the Georgetown warehouse. CAI stored alcohols, heptane, other solvents, and pigments and resins in the building and in three 3000-gallon underground storage tanks (USTs).

Nine Arnel employees worked in the Danvers facility, which was the company's only business location. Arnel manufactured solvent- and water-based stains, lacquers, coatings, and paints, as well as polyurethane coatings and adhesives. They stored alcohols and other solvents, pigments, paint resins, and industrial grade nitrocellulose at the facility.

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

Risk Analysis Screening Tools (RAST) Overview / Demonstration

Case Study – CAI and Arnel
Process Description

CAI and Arnel mixed solvents, pigments, resins and nitrocellulose to produce inks and paints in 1000 to 3000 gallon vessels. Vessels contained top mounted agitators and a steam heating jacket. Mix tanks 1 and 2 were fully open on top while mix tanks 3 and 4 were equipment with a 12 inch diameter access hatch to keep debris from falling into the tank but allowed vapor or air to pass through the opening.

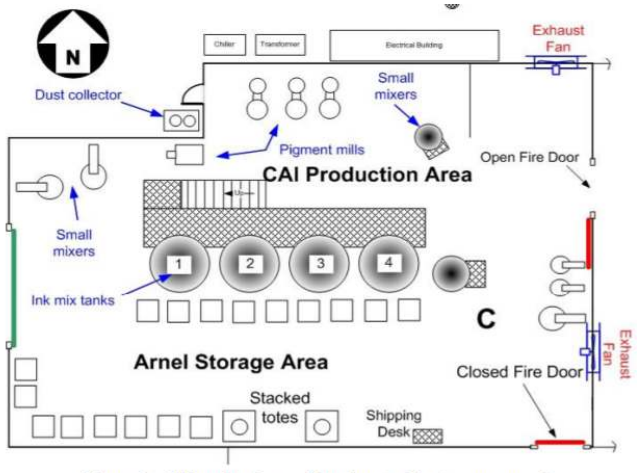


Figure 6. CAI production and Arnel materials storage, area C.

Case Study – CAI and Arnel

Process Description

The initial mixture of more than 2000 gal. of heptane and propyl alcohol is added to the tank from 500 gal. totes. Resin is hand loaded from fiber drums to the top of the tank. This mixture is then heated to between 90 and 120°F to dissolve the resin. Temperature control is achieved by manually opening a ¼ inch steam valve leading to the steam heating jacket. Following a quality control check, the liquid is pumped out the bottom of the mix tank to smaller pigment mixers, as needed. Unused resin-solvent mixture would remain in the mix tank until it was all utilized in specific ink products.

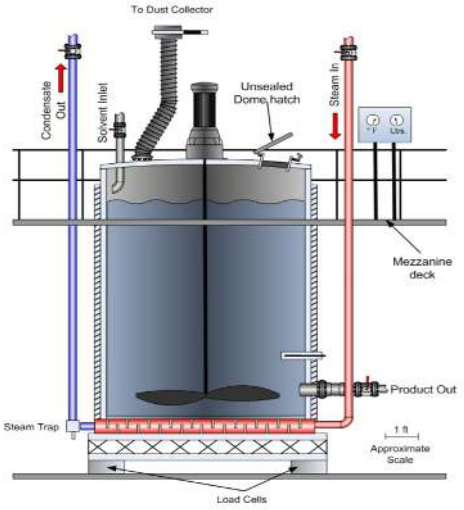


Figure 8. CAI ink vehicle insulated mix tank 3.

Risk Analysis Screening Tools (RAST)

Case Study – CAI and Arnel

We will start by entering information for the Formulation Mixing Tank. At some point, we may decide to include other equipment in the study.

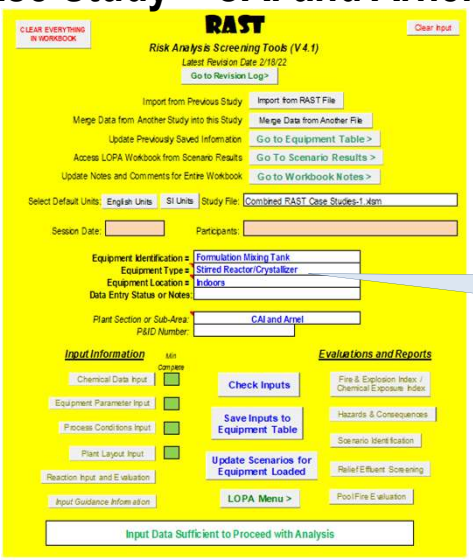
One the Main Menu, enter the equipment identification as the **Formulation Mixing Tank**, equipment type as **Stirred Reactor/Crystallizer** and location as **Indoors**.

Chemical Data – RAST requires a chemical or chemical mixture that is representative of the hazards. RAST does not perform time-dependent or location-dependent composition changes (such as within a reactor or distillation column). Where hazards may be significantly different between reactor feed and products, or distillation overheads versus bottoms; evaluation of the equipment may be repeated using different composition (such as Reactor A with feed composition and Reactor B with products composition).

Risk Analysis Screening Tools (RAST)

Case Study – CAI and Arnel

Begin by entering information on the Main Menu worksheet. Start with the Formulation Mixing Tank



Enter Equipment Identification, Equipment Type and Location

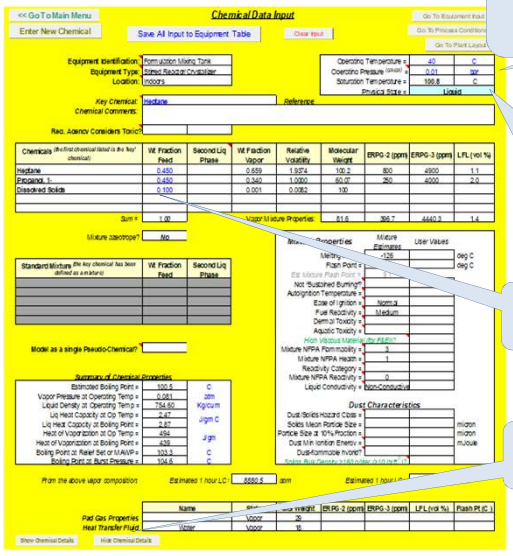
Case Study – CAI and Arnel

Chemical Data

Fortunately, all the chemicals needed in this evaluation are already in the Chemical Data Table internal to RAST.

The solvent mixture concentration is assumed equal fractions of heptane and 1-propanol with a small amount of dissolved solids to represent the nitrocellulose resin is used as representative of the hazards.

The operating pressure is essentially atmospheric such that 0.01 bar gauge is entered.



The operating temperature of 40 C represents a mixture at 90 to 120 F. The operating pressure entered as 0.01 bar gauge

Saturation temperature is estimated as the boiling point at the operating pressure. The physical state is "liquid"

RAST allows up to 5 components.

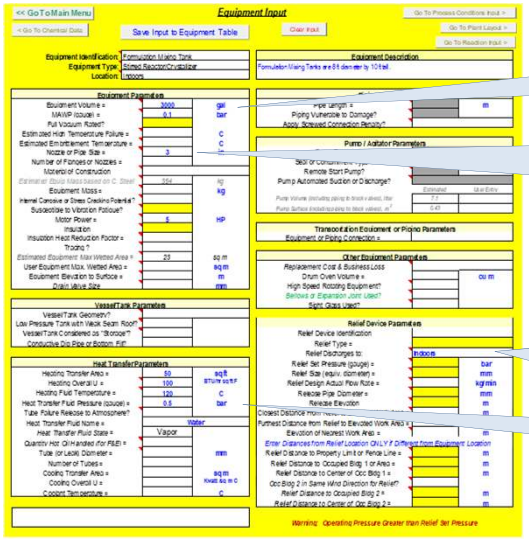
Chemical details may be shown or hidden

Case Study – CAI and Arnel
Equipment Input

The relief device is essentially the 12 inch access hatch on the top of the vessel and vented "Indoors" which is not typical.

The vessel jacket/bottom head is roughly 50 ft^2 and heated by low pressure steam.

Only minimal data will be entered at this time.



The equipment volume and maximum allowable working pressure

A largest "working" nozzle of 3 inches is entered representing the bottom liquid outlet.

The relief device is considered the 12 in hatch which vents indoors.

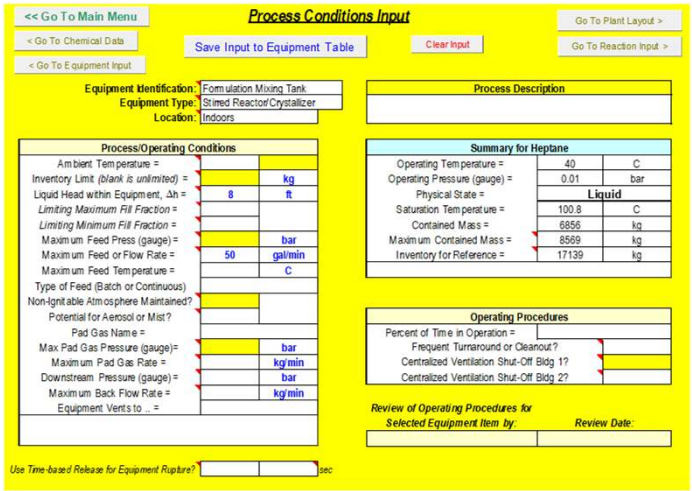
Heat transfer information is entered.

Case Study – CAI and Arnel
Process Conditions

Ambient temperature of 25 C has been assumed (input left blank such that the default value is used).

The maximum flowrate to the tank is approximately 50 gal/min. from 500 gallon totes.

The maximum liquid height in the vessel is 8 ft.



Case Study – CAI and Arnel

Site Layout

The enclosed production area (denoted as C, D, and E) is approximately 10,000 ft^2. Areas denoted A and B contained offices and a laboratory. For an average building height of 20 ft, the enclosed volume is nearly 200,000 ft^3. Fiber drums of nitrocellulose were stored in trailers east of the building.

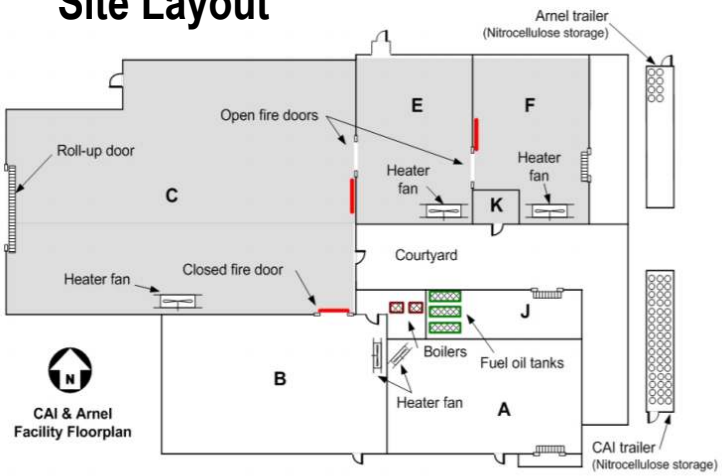


Figure 3. CAI/Arnel building layout. Production areas are highlighted.

Approximately 100 ft

Risk Analysis Screening Tools (RAST) Overview / Demonstration

Case Study – CAI and Arnel

Site Layout

A marina is adjacent to the site, approximately 150 ft east of the manufacturing area. A residential community is approximately 100 ft north with the nearest houses 150 ft away. The population density is typical of a suburban area.

The CAI and Arnel facility is circled in the photograph.

Approximately 500 ft

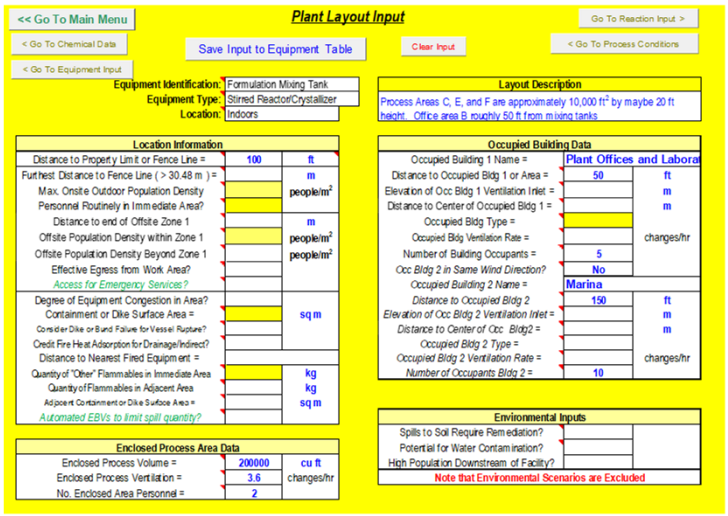
Case Study – CAI and Arnel

Site Layout

There is a total of 15 employees between CAI and Arnel. For now, it is assumed that during normal work hours, 2 people might be in the production area and 5 in the offices and laboratory.

There has been assumed to be 10 people located at the marina between customers, maintenance and sales staff.

The enclosed process area is estimated to be 200,000 ft^3. There are two 6,000 cfm exhaust fans allowing roughly 3.6 air changes per hour when running.



Plant Layout Input

<< Go To Main Menu | < Go To Chemical Data | < Go To Equipment Input | Save Input to Equipment Table | Clear Input | Go To Reaction Input > | < Go To Process Conditions

Equipment Identification: Formulation Mixing Tank
Equipment Type: Stirred Reactor/Crystallizer
Location: Indoors

Layout Description

Process Areas C, E, and F are approximately 10,000 ft^2 by maybe 20 ft height. Office area B roughly 50 ft from mixing tanks

Location Information

Distance to Property Limit or Fence Line =	100	ft
Furthest Distance to Fence Line (> 30.48 m) =		m
Max. Onsite Outdoor Population Density		people/m^2
Personnel Routinely in Immediate Area?		
Distance to end of Offsite Zone 1		m
Offsite Population Density within Zone 1		people/m^2
Offsite Population Density Beyond Zone 1		people/m^2
Effective Egress from Work Area?		
Access for Emergency Services?		
Degree of Equipment Congestion in Area?		
Containment or Dike Surface Area =		sq m
Consider Dike or Bund Failure for Vessel Rupture?		
Credit Fire Heat Adsorption for Drainage/Indirect?		
Distance to Nearest Fired Equipment =		
Quantity of "Other" Flammables in Immediate Area		kg
Quantity of Flammables in Adjacent Area		kg
Adjacent Containment or Dike Surface Area =		sq m
Automated EBVs to limit spill quantity?		

Enclosed Process Area Data

Enclosed Process Volume =	200000	cu ft
Enclosed Process Ventilation =	3.6	changes/hr
No. Enclosed Area Personnel =	2	

Occupied Building Data

Occupied Building 1 Name =	Plant Offices and Laborat	
Distance to Occupied Bldg 1 or Area =	50	ft
Elevation of Occ Bldg 1 Ventilation Inlet =		m
Distance to Center of Occupied Bldg 1 =		m
Occupied Bldg Type =		
Occupied Bldg Ventilation Rate =		changes/hr
Number of Building Occupants =	5	
Occ Bldg 2 in Same Wind Direction?	No	
Occupied Building 2 Name =	Marina	
Distance to Occupied Bldg 2	150	ft
Elevation of Occ Bldg 2 Ventilation Inlet =		m
Distance to Center of Occ Bldg2 =		m
Occupied Bldg 2 Type =		
Occupied Bldg 2 Ventilation Rate =		changes/hr
Number of Occupants Bldg 2 =	10	

Environmental Inputs

Spills to Soil Require Remediation?	
Potential for Water Contamination?	
High Population Downstream of Facility?	

Note that Environmental Scenarios are Excluded

Chemical Processing Indoors

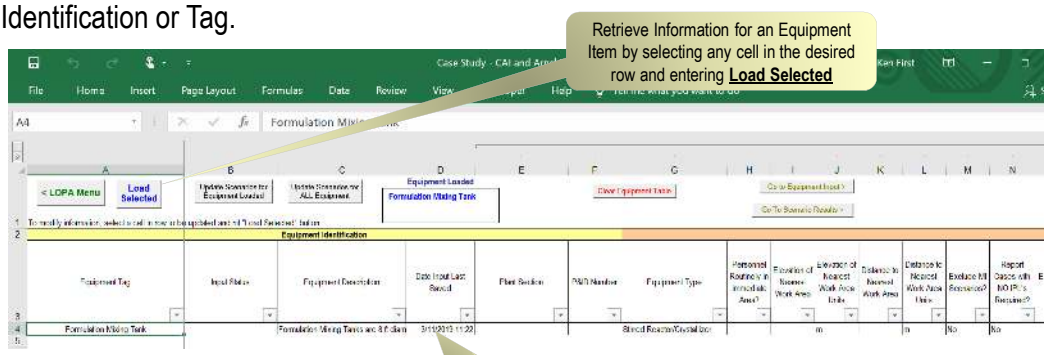
Indoor Chemical Processing often intensifies hazards as dilution of airborne chemicals is minimized. Release quantities to reach flammable or toxic concentrations may be very small.

An enclosed manufacturing volume of 1000 m^3 only requires approximately 40 kg flammable vapor (such as 38 kg propane) for the entire volume to reach the lower flammable limit. A chemical with ERPG-3 of 150 ppm would only require 0.15 m^3 of toxic vapor (such as 0.23 kg HCl) to reach a potentially toxic concentration within the enclosed process area.

Risk Analysis Screening Tools (RAST)

Case Study – CAI and Arnel

Select <u>Save Inputs to Equipment Table</u> (blue macro button). All Input Information will be stored in the Equipment Table in a single row identified by a unique Equipment Identification or Tag.

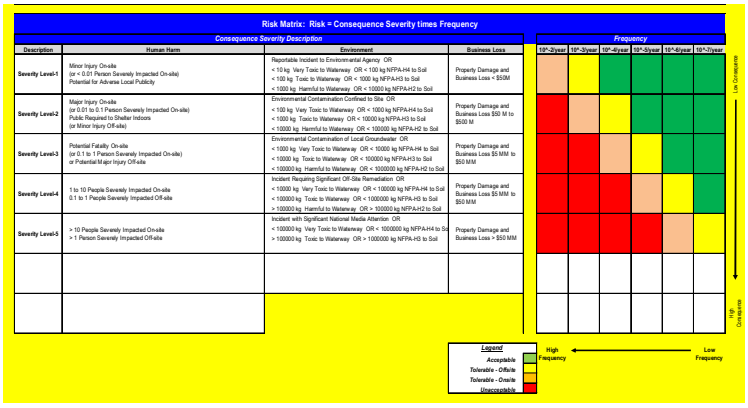


Risk Analysis Screening Tools (RAST)

Risk Matrix

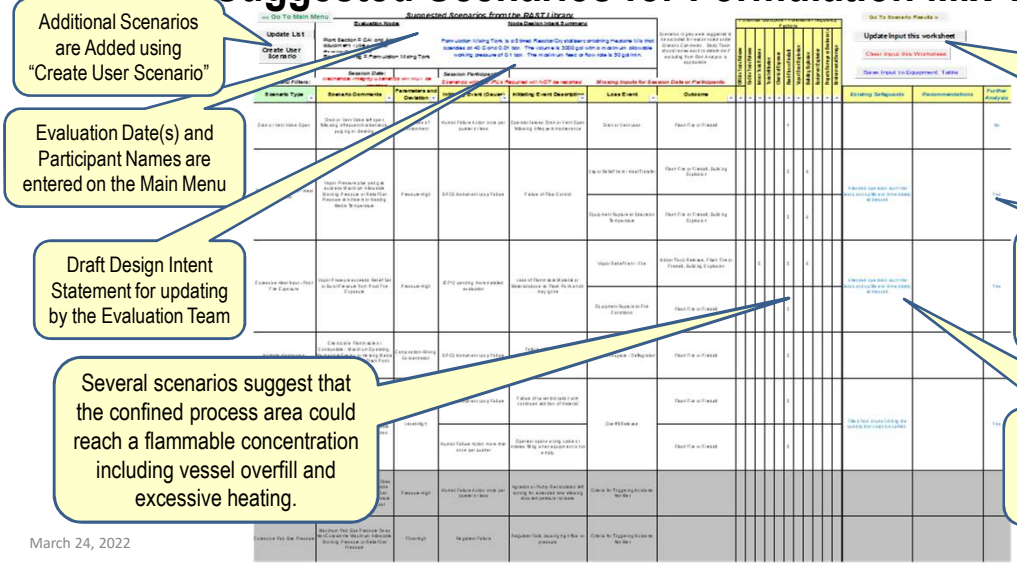
To understand the Consequence Severity and Tolerable Frequency, the values for key Study Parameters and a Risk Matrix may be viewed on the Workbook Notes worksheet. These values may be updated on hidden worksheets and should reflect the company's specific risk criteria.

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).



Case Study – CAI and Arnel

Suggested Scenarios for Formulation Mix Tank



Additional Scenarios are Added using "Create User Scenario"

Evaluation Date(s) and Participant Names are entered on the Main Menu

Draft Design Intent Statement for updating by the Evaluation Team

Several scenarios suggest that the confined process area could reach a flammable concentration including vessel overfill and excessive heating.

Once Inputs are Entered use "Update Input this Worksheet" to Save

Analysis Team captures which Scenarios warrant more Detailed Evaluation (Layers of Protection Analysis)

Analysis Team captures Existing Safeguards and Recommendations for Scenarios Identified

Case Study – CAI and Arnel

Suggested Scenarios for Formulation Mixing Tank

WORKING WITH YOUR EVALUATION TEAM:

- ❑ **Review the suggested list of scenarios. Do these represent what you would expect for a formulation or mixing tank?**
- ❑ **Are there scenarios that have been "screened out" (shown in gray) that should be considered?**
- ❑ **Are there scenarios missing? (Possibly similar scenarios with different Initiating Events)**
- ❑ **Do you agree with the "worst" Consequence (Tolerable Frequency Factor) for the scenario listed?**

Case Study – CAI and Arnel

Suggested Scenarios for Formulation Mixing Tank

WORKING WITH YOUR EVALUATION TEAM:

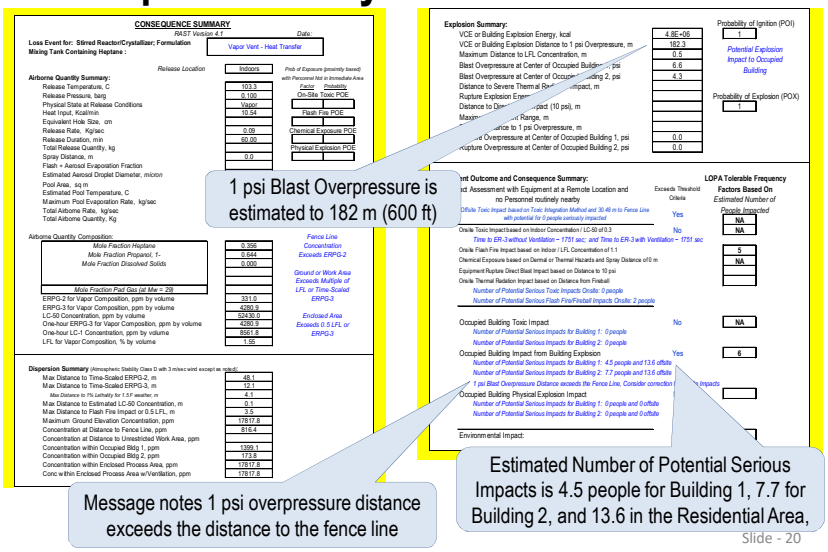
- ❑ **Utilize an Appropriate Hazard Evaluation Technique (HAZOP, What If, etc.) to capture additional scenarios.**
- ❑ **Capture existing Safeguards and Recommendations for each Scenario. Note the Dates and Names of participants in the Study.**
- ❑ **Select which Scenarios warrant more detailed Risk Evaluation (such as Layers of Protection Analysis).**

Case Study – CAI and Arnel

Consequence Analysis

For the Formulation Mixing Tank, select **Vapor Vent – Heat Transfer** as the Loss Event. This represents a "worst" Consequence for filling the enclosed area with flammable vapor.

Note under the Dispersion Summary that the enclosed area concentration is not estimated to reach the lower flammable limit if the ventilation system was running.



Case Study – CAI and Arnel

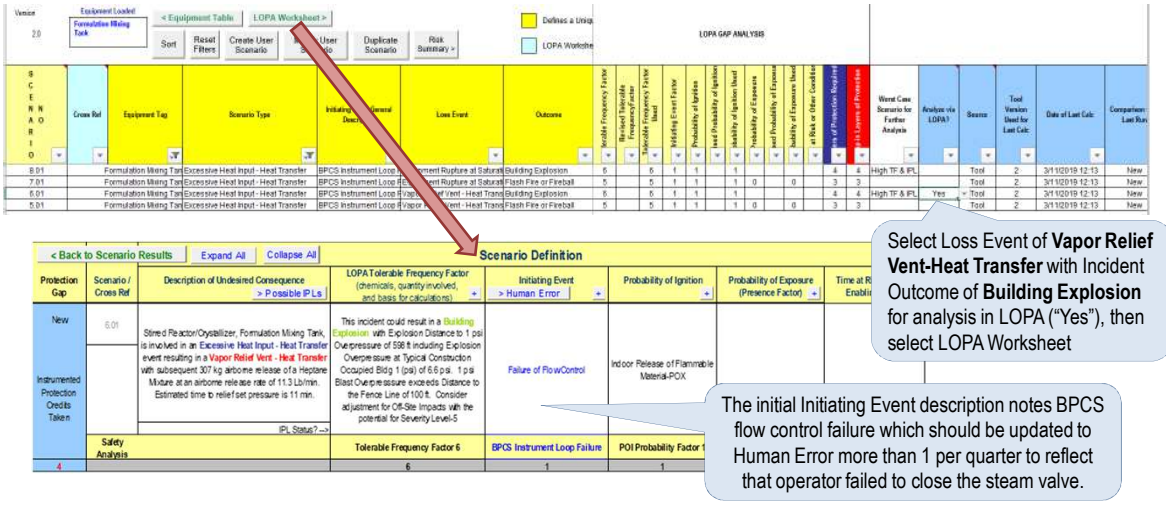
Consequence Analysis

RAST estimated maximum 182 m (600 ft) to 1 psi blast overpressure from enclosed process area which is in excellent agreement with CSB modeling.

REPORT NO. 2007-03-I-MA , US Chemical Safety Board,
Figure 20. Aerial View showing estimated explosion overpressures

Case Study – CAI and Arnel

Risk Analysis / Layers of Protection Analysis (LOPA)



Select Loss Event of **Vapor Relief Vent-Heat Transfer** with Incident Outcome of **Building Explosion** for analysis in LOPA ("Yes"), then select LOPA Worksheet

The initial Initiating Event description notes BPCS flow control failure which should be updated to Human Error more than 1 per quarter to reflect that operator failed to close the steam valve.

Case Study – CAI and Arnel

Risk Analysis / Layers of Protection Analysis (LOPA)

< Back to Scenario Results | Expand All | Collapse All | Scenario Definition

Protection Gap	Scenario / Cross Ref	Description of Undesired Consequence > Possible IPLs	LOPA Tolerable Frequency Factor (chemicals, quantity involved, and basis for calculations)	Initiating Event > Human Error	Probability of Ignition	Probability of Exposure (Presence Factor)	Time at Risk or Other Enabling Factor
New Instrumented Protection Credits Taken	6.01	Stirred Reactor/Crystallizer, Formulation Mixing Tank, is involved in an Excessive Heat Input - Heat Transfer event resulting in a Vapor Relief Vent - Heat Transfer with subsequent 307 kg airborne release of a Heptane Mixture at an airborne release rate of 11.3 Lb/min. Estimated time to relief set pressure is 11 min.	This incident could result in a Building Explosion with Explosion Distance to 1 psi Overpressure of 598 ft including Explosion Overpressure at Typical Construction Occupied Bldg 1 (psi) of 6.6 psi. 1 psi Blast Overpressure exceeds Distance to the Fence Line of 100 ft. Consider adjustment for Off-Site Impacts with the potential for Severity Level-5	Failure to close Steam Valve to vessel heater upon reaching desired temperature	Indoor Release of Flammable Material-POX		
	Safety Analysis	IPL Status? -->	Tolerable Frequency Factor 6	Human Failure Action more than once per quarter	POI Probability Factor 1		
4			6	1	1	0	

RAST notes that the Consequence Severity may need to be adjusted if the Tolerable Frequency for offsite impacts is different from the Tolerable Frequency for onsite impacts..

The probability of ignition in RAST is estimated at 0.1 for an indoor flammable release into a properly electrically classified area. This is an administrative parameter on a hidden worksheet that may be updated.

Risk Analysis Screening Tools (RAST) Overview / Demonstration

Case Study – CAI and Arnel

Risk Analysis / Layers of Protection Analysis (LOPA)

Not Allowed

BPCS Control or Human Response to Alarm	BPCS Control or Human Response to Alarm	SIS Function A	SIS Function B	Pressure Relief Device	SRPS 1	SRPS 2	SRPS 3	Notes / Comments
High Temperature Closes Heating Media Valve					Building ventilation system capable of preventing concentration from reaching the lower flammable limit			
BPCS Independent of Initiating Event					1 - Other Safety related protection systems (PFD=0.1)			
1					1			

The scenario could have been managed by having a relief device set at a very low pressure or open line to vent outdoors and "sealing" the 12 inch solids loading hatch when not in use.

The existing safeguards (even if there were a high temperature alarm which automatically closes the steam valve) may not sufficient to manage a scenario of this consequence severity.

Risk Analysis Screening Tools (RAST)

Case Study – CAI and Arnel

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" consequence severity may be. For Incident Investigation, the Incident Outcome and Consequences are known in addition to the actual weather conditions, wind direction, time of day, and other factors.

For the Formulation Mixing Tank, RAST did suggest Excessive H eating as one of many scenarios to consider. RAST also recognized that a Building Explosion could be a feasible Incident Outcome. The estimate blast overpressure from RAST was in excellent agreement with CSB modeling. RAST estimated 4.5 people within the enclosed process area, 7.7 in the adjacent marina, and 13.6 people in the residential area (26 people) as potential severe impacts. Fortunately, this incident occurred at night and resulted in no fatalities but 10 serious injuries, 24 houses, and 6 adjacent business destroyed.

Questions?