Introduction: Trinseo and who am I

- Global number one supplier of styrene butadiene / latex
- One of the world's largest suppliers of polystyrene
- Raw material delivered by our Ethylbenzene and Styrene monomer plants

- 70 years of technology leadership
- Split in 2010 from Dow Chemical

- Manufacturing sites in 16 countries around the world
- Trinseo has 2,500 – 3,000 employees

Trinseo is an active user of the CHEF and RAST tool

CHEF & RAST

Chemical Hazard Engineering Fundamentals
Risk Analysis Screening Tools

Process Safety Technology Leader EBSM: Jeroen de Maat

RAST History

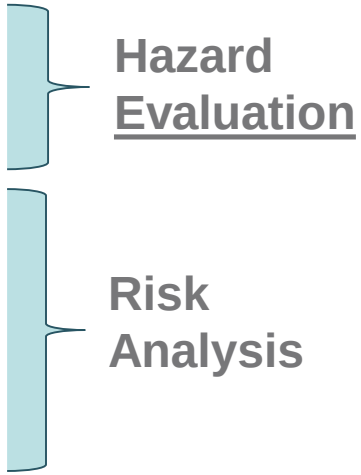
- First version of RAST launched by The Dow Chemical Company in 2006
  The tool is made in MS Excel.

- Since 2018 it is a public tool can become for free via EPSC and CCPS.
  In the years it became a reliable scenario identification and risk evaluation tool

- Together with RAST the CHEF tool was issued for public

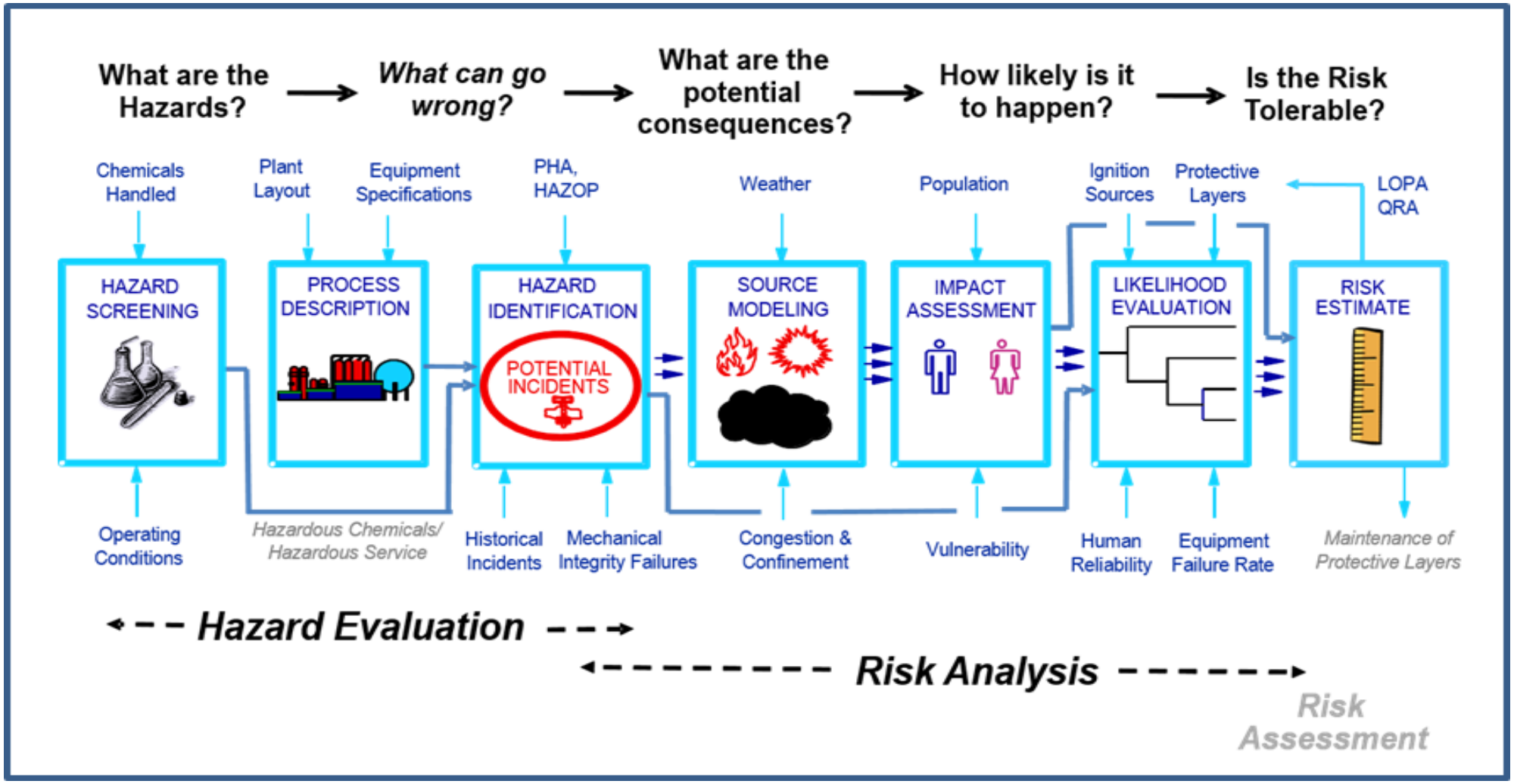
Difference between CHEF and RAST

- **CHEF** calculation for a single User <u>selected scenario</u>
  Used for one LOPA scenario
  - What are the Hazards?
  - What can go wrong?
  - What are the potential consequences?
  - How likely is it to happen?
  - Is the Risk Tolerable?



- **RAST** creates multiple scenario overview for process plant
  Used for unit LOPA overview (and other PS reports)
- Hazard identification, scenario development, consequence evaluation, and risk analysis. As a part of this screening, RAST can assists users by providing a comprehensive Layer of Protection Analysis (LOPA), as well.

RAST in one picture



Input RAST:

- **1. Chemical Data**
  - Input sheet data
  - Standard list of 366 Chemicals
  - Can create a chemical mixture
  - Adding a new chemical possible
- **2. Equipment Data**

  Parameter input sheet
  - Selection possible for 30 different types of equipment
- **3. Process Conditions**
- **4. Plant Layout Info**
  - Local information
  - Enclosed process area data
  - Building data
  - Environmental inputs
- **5. Reactivity Input and Evaluation**
  - Input sheet data
  - Reactivity screening
  - Reactivity evaluation

Input failure in Input Error Check sheet

RAST

CLEAR EVERYTHING IN WORKBOOK

Clear Input

Risk Analysis Screening Tools (v.5.0.0)

Check Current Version Available

Import from Previous Study | Import from File

Import from Standard LOPA Workbook | Import from LOPA Worksheet

Update Previously Saved Information | Go to Equipment Table >

Select Default Units: English Units | SI Units | Study File: RAST-V 5.0 for Manual Development.xlsm

Session Date: | Participants:

Equipment Identification = V-101
Equipment Type = Vessel/Tank
Equipment Location = Outdoors

Plant Section or Sub-Area:
P&ID Number:

Input Information (Min Complete)

- Chemical Data Input
- Equipment Parameter Input
- Process Conditions Input
- Plant Layout Input
- Reaction Input and Evaluation
- Input Guidance Information

Check Inputs

Save Inputs to Equipment Table

Update Scenarios for Equipment Loaded

LOPA Menu

Evaluations and Reports

- Fire & Explosion Index / Chemical Exposure Index
- Hazards & Consequences
- Scenario Identification
- Pump Deadhead Summary
- Relief Effluent Screening
- Pool Fire Evaluation

Chemical Data Input

<< Go To Main Menu | Enter New Chemical | Save All Input to Equipment Table | Clear Input | Go To Equipment Input > | Go To Process Conditions > | Go To Plant Layout >

Equipment Identification: R201
Equipment Type: Stirred Reactor/Crystallizer
Location: Indoors

Operating Temperature =	160	C
Operating Pressure (gauge) =	4	bar
Saturation Temperature =	169.0	C
Physical State =	Liquid	

Key Chemical: Tetrachloropyridine | Reference:
Chemical Comments:

Reg. Agency Considers Toxic? Yes — *ERPG-3 Values, LC1, LC50, and/or Categories for Aquatic Toxicity or Dermal Toxicity must be entered*

Chemicals (the first chemical listed is the 'key' chemical)	Wt Fraction Feed	Second Liq Phase	Wt Fraction Vapor	Relative Volatility	Molecular Weight	ERPG-2 (ppm)	ERPG-3 (ppm)	LFL (vol %)
Tetrachloropyridine	0.500	Yes	0.126	0.1085	216.9	1200	3000	
Sodium Hydroxide in Aqueous Solution*	0.125		0.000	0.0000	10.52056053			
Water	0.375		0.874	1.0000	18.02			
Sum =	1.00		Vapor Mixture Properties:		20.4	101048.2	252620.6	

Mixture azeotrope? Yes

Standard Mixture (the key chemical has been defined as a mixture)	Wt Fraction Feed	Second Liq Phase

Model as a single Pseudo-Chemical?

Summary of Chemical Properties

Estimated Boiling Point =	112.7	C
Vapor Pressure at Operating Temp =	3.954	atm
Liquid Density at Operating Temp =	1.10	gm/ml
Liq Heat Capacity at Op Temp =	0.73	cal/gm C
Liq Heat Capacity at Boiling Point =	0.72	
Heat of Vaporization at Op Temp =	460	cal/gm
Heat of Vaporization at Boiling Point =	488	
Heat of Reaction at Relief Set		
Heat Capacity at Burst		

above vapor

Pad Gas
Heat Tra

Mixture Properties

	Mixture Estimates	User Values	
Melting Point =	-20	-20	deg C
Flash Point =	1000	1000	deg C
Est Mixture Flash Point =			
Not "Sustained Burning"?	No	No	
AutoIgnition Temperature =	2000	2000	deg C
Ease of Ignition =	Low	Low	
Fuel Reactivity =	High	High	
Dermal Toxicity =	Corrosive	Corrosive	
Aquatic Toxicity =	Harmful	Harmful	
High Viscous Material (for F&EI)?			
Mixture NFPA Flammability =	0		
Mixture NFPA Health =	3		
Reactivity Category =	NA	NA	
Mixture NFPA Reactivity =	3		
Liquid Conductivity =	Semi-Conductive		

Dust Characteristics

Dust/Solids Hazard Class =			
Solids Mean Particle Size =			micron
Particle Size at 10% Fraction =			micron
Dust Min Ignition Energy =			mJoule

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: R201
Equipment Type: Stirred Reactor/Crystallizer
Location: Indoors

Layout Description

Location Information

Distance to Property Limit or Fence Line =	40	m
Furthest Distance to Fence Line (> 40 m) =	40	m
Max. Onsite Outdoor Population Density	0.0001	people/m²
Personnel Routinely in Immediate Area?	Yes	
Distance to end of Offsite Zone 1	40	m
Offsite Population Density within Zone 1	0.0001	people/m²
Offsite Population Density Beyond Zone 1	0.00001	people/m²
Effective Egress from Work Area?	Yes	
Access for Emergency Services?	Partially Adequate	
Degree of Equipment Congestion in Area?	Low	
Containment or Dike Surface Area =	40	sq m
Consider Dike or Bund Failure for Vessel Rupture?	No	
Credit Fire Heat Adsorption for Drainage/Indirect?	No	
Distance to Nearest Fired Equipment =	No Fired Equipment	
Quantity of "Other" Flammables in Immediate Area	0	kg
Quantity of Flammables in Adjacent Area		
Adjacent Containment or Dike Surface Area =		
Automated EBVs to limit spill quantity?		

Occupied Building Data

Occupied Building 1 Name =	Control room	
Distance to Occupied Bldg 1 or Area =	5	m
Elevation of Occ Bldg 1 Ventilation Inlet =	3	m
Distance to Center of Occupied Bldg 1 =	7	m
Occupied Bldg Type =	ical Construction	
Occupied Bldg Ventilation Rate =	20	changes/hr
Number of Building Occupants =	5	
Occ Bldg 2 in Same Wind Direction?	No	
Occupied Building 2 Name =	Neighbour	
Distance to Occupied Bldg 2	40	m
Elevation of Occ Bldg 2 Ventilation Inlet =	1	m
Distance to Center of Occ Bldg2 =	60	m
Occupied Bldg 2 Type =	Low Strength	
Occupied Bldg 2 Ventilation Rate =	10	changes/hr
Number of Occupants Bldg 2 =	20	

Enclosed Process Area Data

Enclosed Process Volume =	200	
Enclosed Process Ventilation =	20	
No. Enclosed Area Personnel =	2	

Reaction Data Input and Evaluation

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

Equipment Tag = R201
Key Chemical = Tetrachloropyridine
Physical = Liquid

Reactivity Data Input

	Table / User	User Value
Assess Reactive Scenarios Only?	No	
Data Reference:	Table / User	User Value
Ken First	Ken First	
Heat of Reaction, ΔHR (cal/g mix) =	-74	-74
Activation Energy, ΔE (Kcal/g mole) =	30	30
Detected Onset, T_o (C) =	65	65
Detected Rate, R_o (C/min) =	1	1
Gas Generation, k (g mole/cc mix) =		
Gas Generation precedes Exotherm	No	No
Inhibited Monomer?	No	No
Thermal Inertia (ARC or other), ϕ =		
Test Method =	Theoretical	Theoretical
Limiting Reaction Rate =	1.5	cal/g mix-min
Intended reaction for this Equipment?	Yes	
Potential Catalyzed Reaction?	No	
Potential for "Pooling" of Reactants	Yes	
Reactants in Separate Liquid Phase	Yes	
Reaction of Reaction Heat for "Poolin	0.6	Typically < 1.0
Potential Mis-Loading of Reactants	Yes	
Multiple of Reaction Heat for Mis-Loa	2	Typically > 1.0
Potential for Mixing Incompatible Mater	Yes	
Intended Exothermic Reaction (for R	Hydrolysis	
Intended Endothermic Reaction (for R	No Endothermic Reaction	
Considered Condensed Phase Explos		

sure may result is loss of reactant flow causing reactio
Separate Equipment Tag with Data for Incompatible Re

Potential for Insulation or Packing Fire

Britton's Method, Z =	2.00	Potential =	HIGH

Estimation of Frank-Kamenetskii Critical Diameter

Material Thermal Conductivity	watt / m C	
F-K Critical Diameter at 160 deg C		cm

Estimation of Activation Energy from ARC Data

Temperature, C		
Observed Rate, C/min		
Fraction Conversion		
Activation Energy =		Kcal/gm mole

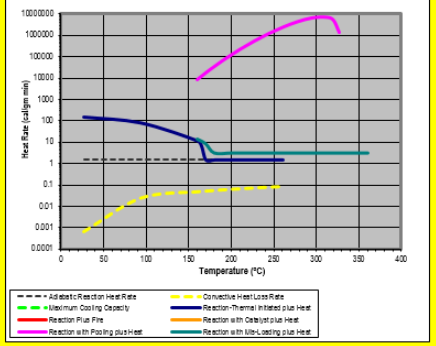
Estimation of Gas Generation

Observed Press (atm abs) and Temp		
Estimated Vapor Pressure + Inert Ps	0.92	atm
Estimated Gas Generation, k =		gm mole/cc mix

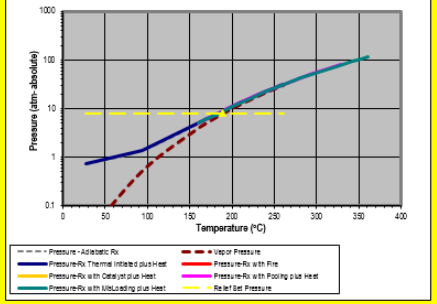
me to Maximum Rate at Specified Starting Temperatur

Reaction Scenario Type =	Reaction		
Temperature (C)	TMR	me to Relief	189.2 deg C
25	49.3	79.8	Minutes
50	49.3	67.6	Minutes
100	49.3	43.3	Minutes
150	49.3	19.0	Minutes

Reaction Heat Gain or Cooling Loss versus Temperature
(Exothermic Reaction Assuming First Order Kinetics)



Reaction Pressure versus Temperature
(Adiabatic Exothermic Reaction Assuming First Order Kinetics)



Reaction Screening Calculations

Initial Temperature =	160.0	C	Rate at Initial Temp =	######## cal/gm-min
Max Adiabatic Temp =	260.5	C	Reactivity Parameter =	16.1
Max Adiabatic Pressure =	31.35	atm	Insulated?	No
Temp of No Return, TNR =	>TNR	C	Positive HT Coefficient =	0.01 Kwatt/sq m C
TNR with Cooling =	>TNR	C		

Equipment Input

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

Equipment Identification: R201
Equipment Type: Stirred Reactor/Crystallizer
Location: Indoors

Equipment Description
R201 Hydrolyser

Equipment Parameters

Equipment Volume =	7	cu m
MAWP (gauge) =	7	bar
Full Vacuum Rated?	Yes	
Estimated High Temperature Failure =	400	C
Estimated Embrittlement Temperature =	-20	C
Nozzle or Pipe Size =	100	mm
Number of Flanges or Nozzles =	10	
Material of Construction	Corrosion Resistant Alloy	
Estimated Equip Mass based on C. Steel	3001	kg
Equipment Mass =		kg
Internal Corrosive or Stress Cracking Potential?	No	
Susceptible to Vibration Fatigue?	No	
Motor Power =	20	Kwatt
Insulation	No	
Insulation Heat Reduction Factor =		
Tracing ?		
Estimated Equipment Max Wetted Area =	17	sq m
User Equipment Max. Wetted Area =		sq m
Equipment Elevation to Surface =		m
Drain Valve Size		mm

Vessel/Tank Parameters

Vessel/Tank Geometry?	Vertical
Low Pressure Tank with Weak Seam Roof?	No
Vessel/Tank Considered as "Storage"?	No
Conductive Dip Pipe or Bottom Fill?	No

Heat Transfer Parameters

Heating Transfer Area =	16	sq m
Heating Overall U =	30	Kwatt /sq m C
Heating Fluid Temperature =	170	C
Heat Transfer Fluid Pressure (gauge) =	3	bar
Tube Failure Release to Atmosphere?	No	
Heat Transfer Fluid Name =		
Heat Transfer Fluid State =		
Quantity Hot Oil Handled (for F&E) =		
Tube (or Leak) Diameter =		mm
Number of Tubes =		
Cooling Transfer Area =		sq m
Cooling Overall U =		Kwatt /sq m C
Coolant Temperature =		C

Piping Parameters

Pipe Length =	10	m
Piping Vulnerable to Damage?	No	
Apply Screwed Connection Penalty?	No Penalty	

Pump / Agitator Parameters

Pump Type =	Centrifugal	
Seal or Containment Type =	Double Mech	
Remote Start Pump?	Yes	
Pump Automated Suction or Discharge?	No	
	Estimated	User Entry
Pump Volume (including piping to block valves), liter	15.1	
Pump Surface (including piping to block valves), m	0.69	

Transportation Equipment or Piping Parameters

Equipment or Piping Connection =	

Other Equipment Parameters

Replacement Cost & Business Loss		
Drum Oven Volume =		cu m
High Speed Rotating Equipment?		
Bellows or Expansion Joint Used?		
Sight Glass Used?		

Relief Device Parameters

Relief Device Identification		
Relief Type =	Rupture Disk	
Relief Discharges to:	Vent Header to Blow-down Tan	
Relief Set Pressure (gauge) =	7	bar
Relief Size (equiv. diameter) =	400	mm
Relief Design Actual Flow Rate =	300	kg/min
Release Pipe Diameter =		mm
Release Elevation	4	m
Closest Distance From Relief to Elevated Work Area =	4	m
Furthest Distance from Relief to Elevated Work Area =	10	m
Elevation of Nearest Work Area =	4	m
Enter Distances from Relief Location ONLY if Different from Equipment Location		
Relief Distance to Property Limit or Fence Line =	40	m
Relief Distance to Occupied Bldg 1 or Area =	7	m
Relief Distance to Center of Occ Bldg 1 =	10	m
Occ Bldg 2 in Same Wind Direction for Relief?	No	
Relief Distance to Occupied Bldg 2 =		m
Relief Distance to Center of Occ Bldg 2 =		m

Process Conditions Input

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

Equipment Identification: R201
Equipment Type: Stirred Reactor/Crystallizer
Location: Indoors

Process Description

Process/Operating Conditions

Ambient Temperature =	25	C
Inventory Limit (blank is unlimited) =	6	cu m
Liquid Head within Equipment, Δh =	2	m
Limiting Maximum Fill Fraction =	0.9	
Limiting Minimum Fill Fraction =	0.1	
Maximum Feed Press (gauge) =	3	bar
Maximum Feed or Flow Rate =	40	kg/min
Maximum Feed Temperature =	25	C
Type of Feed (Batch or Continuous)	Continuous	
Non-Ignitable Atmosphere Maintained?	Yes	
Potential for Aerosol or Mist?	No	
Pad Gas Name =		
Max Pad Gas Pressure (gauge)=		bar
Maximum Pad Gas Rate =		kg/min
Downstream Pressure (gauge) =		bar
Maximum Back Flow Rate =		kg/min
Equipment Vents to .. =		

Summary for Tetrachloropyridine

Operating Temperature =	160	C
Operating Pressure (gauge) =	4	bar
Physical State =	Liquid	
Saturation Temperature =	169.0	C
Contained Mass =	6	cu m
Maximum Contained Mass =	7	cu m
Inventory for Reference =	9	cu m

There is not enough Inventory for Overfill

Operating Procedures

Percent of Time in Operation =	Greater than 10%
Frequent Turnaround or Cleanout?	Yes
Centralized Ventilation Shut-Off Bldg 1?	Yes
Centralized Ventilation Shut-Off Bldg 2?	

Review of Operating Procedures for Selected Equipment Item by: ***Review Date:***

e Time-based Release for Equipment Rupture? sec

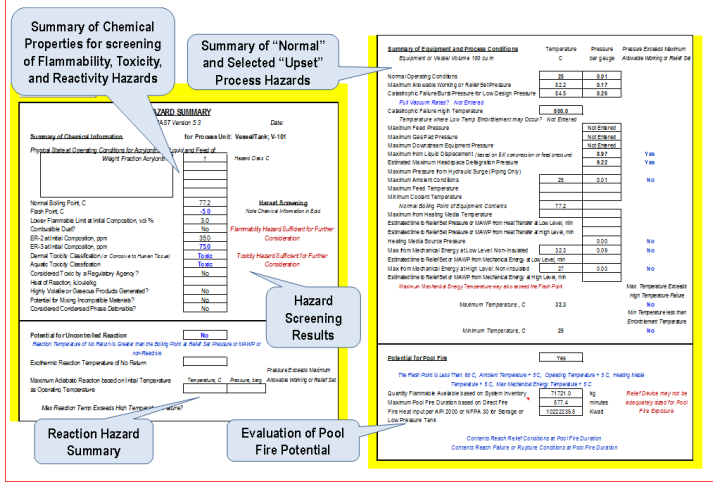
RAST INPUT SHEETS

Screening RAST

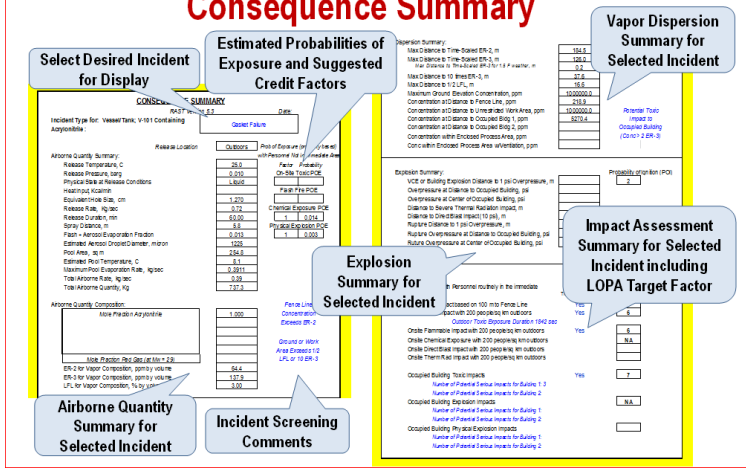
- Items for Screening is based on
  - 30 equipment types
  - 24 Initiating events type evaluations
  - 50 Incident types
  - 53 scenario types

  - All items can be added with a self created User type

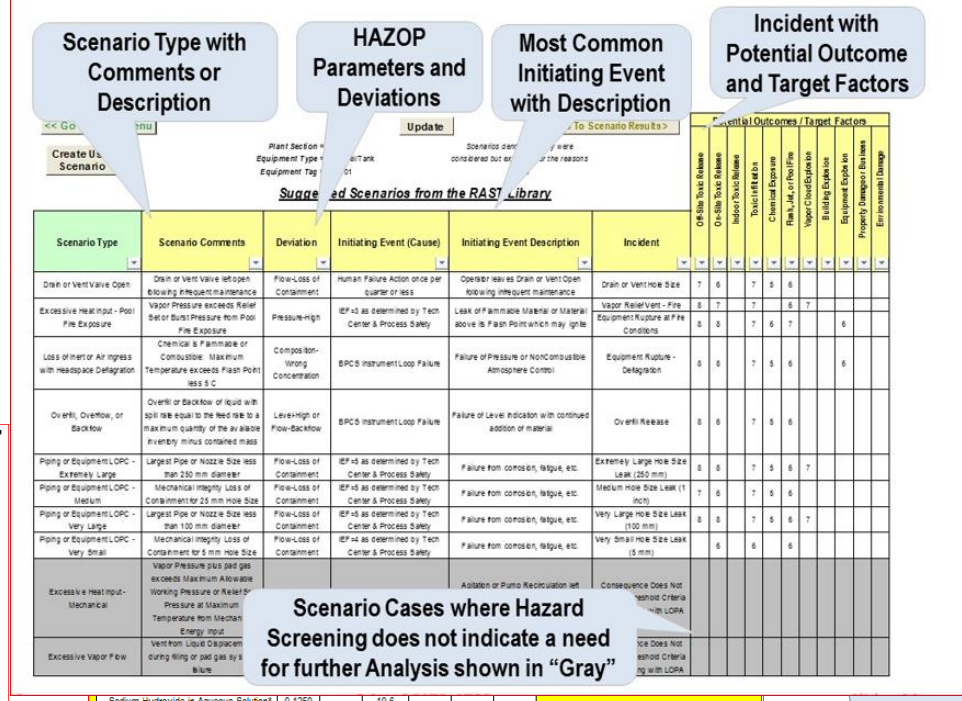
Hazard Summary in RAST

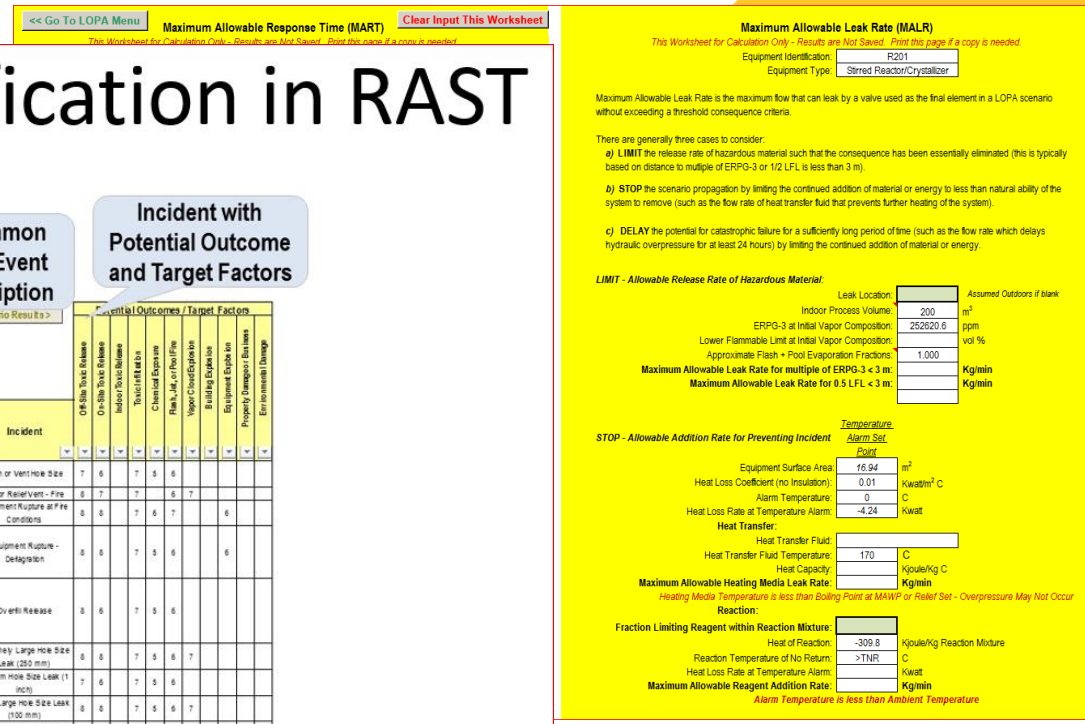


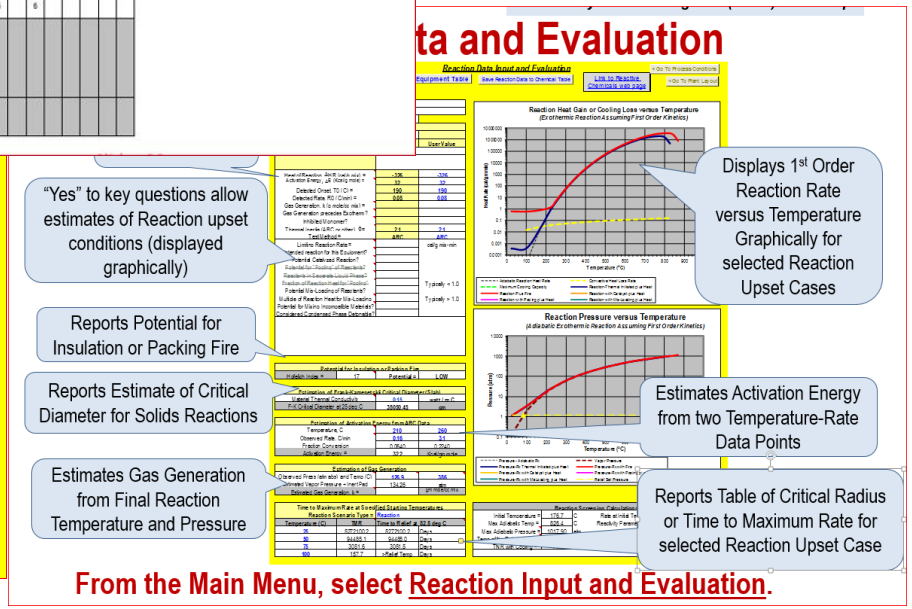
Consequence summary in RAST



Scenario Identification in RAST







Screening and Calculating

Calculation RAST

- Scenario calculation
  - Per selected equipment
  - Done for all scenarios
  - Results in an unmitigated Risk value
    - Effect Target factor
    - Probability of Ignition / Explosion
    - Probability of Exposure
    - Time at Risk (input from User)
  - This is the input for your LOPA

Example LOPA Analysis

Note Target Factor, Initiating Event Factor and Enabling Factors are Pre-Populated.

Enter "Yes" to Select Scenario Cases

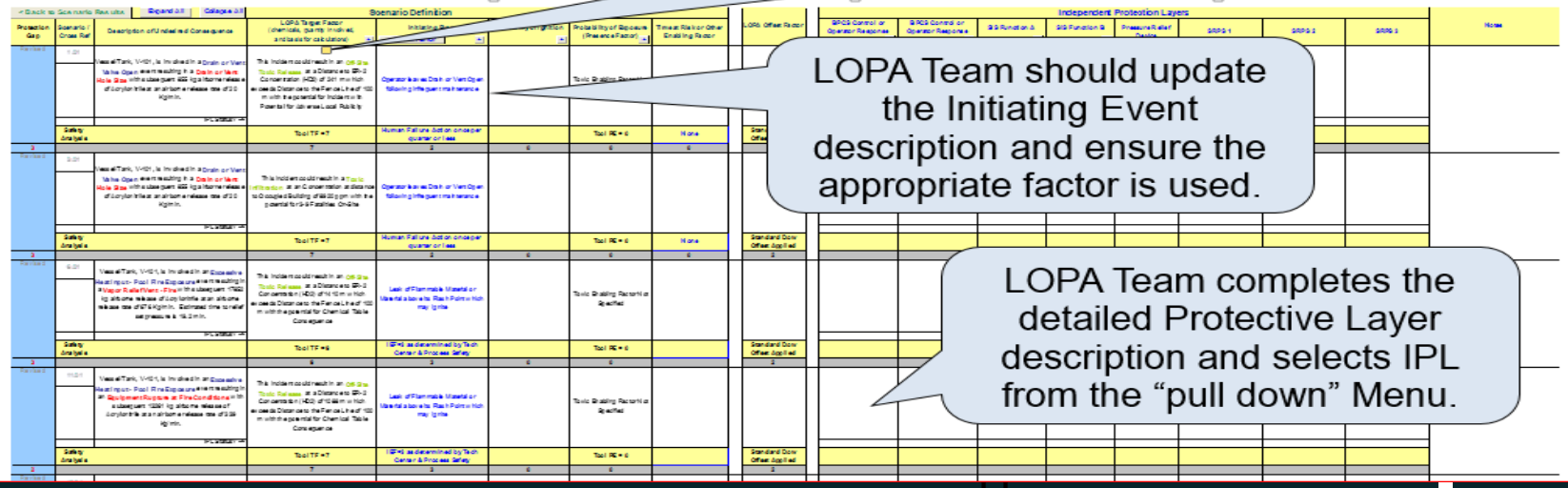
Version 50.0 | Equipment Loaded: V-101 | <<Go To LOPA Menu | Export to DexGEP | LOPA Worksheet> | Defines a Unique Scenario | LOPA Worksheet Entry | Sort | Create User Scenario | Modify User Scenario | Clear Results | Risk Summary >

SCENARIO NO	Cross Ref	Plant Section or Sub-Area	Equipment Tag	Equipment Type	Scenario Type	Initiating Event General Description	Incident Type	Outcome	Target Factor	Revised Target Factor	Target Factor Used	Initiating Event Factor	Probability of Ignition	Revised POI	POI Used	Probability of Exposure	Revised POE	POE Used	Time at Risk or Other Conditions	Offset Factor	Layers of Protection Required	Gap in Layers of Protection	Worst Case Scenario for Further Analysis	Source	Tool Version Used for Last Calc	Comparison with Last Run
1.01			V-101	Vessel/Tank	Pressure Damage	Regulator Failure	Equipment Rupture at Operating	Off-Site Toxic Release	8		8	1				0		0		2	5	5	High TF & IPL	User	5.0.0	Revised
2.01			V-101	Vessel/Tank	Drain or Vent Valve Open	Human Failure Action once per quarter	Drain or Vent Hole Size	Off-Site Toxic Release	7		7	2				0		0	0	2	3	3	High TF & IPL	Yes	Tool	5.0.0	New
3.01			V-101	Vessel/Tank	Drain or Vent Valve Open	Human Failure Action once per quarter	Drain or Vent Hole Size	On-Site Toxic Release	6		6	2				0		0	0	2	2	2			Tool	5.0.0	New
4.01			V-101	Vessel/Tank	Drain or Vent Valve Open	Human Failure Action once per quarter	Drain or Vent Hole Size	Toxic Infiltration	7		7	2							0	2	3	3	High TF & IPL	Yes	Tool	5.0.0	New
5.01			V-101	Vessel/Tank	Drain or Vent Valve Open	Human Failure Action once per quarter	Drain or Vent Hole Size	Flash, Jet, or Pool Fire	6		6	2	2		2	1		1	0	2	-1	-1			Tool	5.0.0	New
6.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire Exposure	IEF=3 as determined by Tech Center &	Vapor Relief Vent - Fire	Off-Site Toxic Release	8		8	3				0		0		2	3	3	High TF & IPL	Yes	Tool	5.0.0	New
7.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire Exposure	IEF=3 as determined by Tech Center &	Vapor Relief Vent - Fire	On-Site Toxic Release	7		7	3				0		0		2	2	2			Tool	5.0.0	New
8.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
9.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
10.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
11.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
12.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
13.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
14.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
15.01			V-101	Vessel/Tank	Excessive Heat Input - Pool Fire																						
16.01			V-101	Vessel/Tank	Loss of Inert or Air Ingress																						
17.01			V-101	Vessel/Tank	Loss of Inert or Air Ingress																						
18.01			V-101	Vessel/Tank	Loss of Inert or Air Ingress																						
19.01			V-101	Vessel/Tank	Loss of Inert or Air Ingress																						
20.01			V-101	Vessel/Tank	Loss of Inert or Air Ingress																						
21.01			V-101	Vessel/Tank	Overfill, Overflow, or Backflow																						
22.01			V-101	Vessel/Tank	Overfill, Overflow, or Backflow																						
23.01			V-101	Vessel/Tank	Overfill, Overflow, or Backflow																						
24.01			V-101	Vessel/Tank	Overfill, Overflow, or Backflow																						

Example LOPA Analysis

4: Select LOPA Workbook. Information from the RAST evaluation will be captured in the LOPA Workbook for additional inputs and evaluation by the LOPA Team.

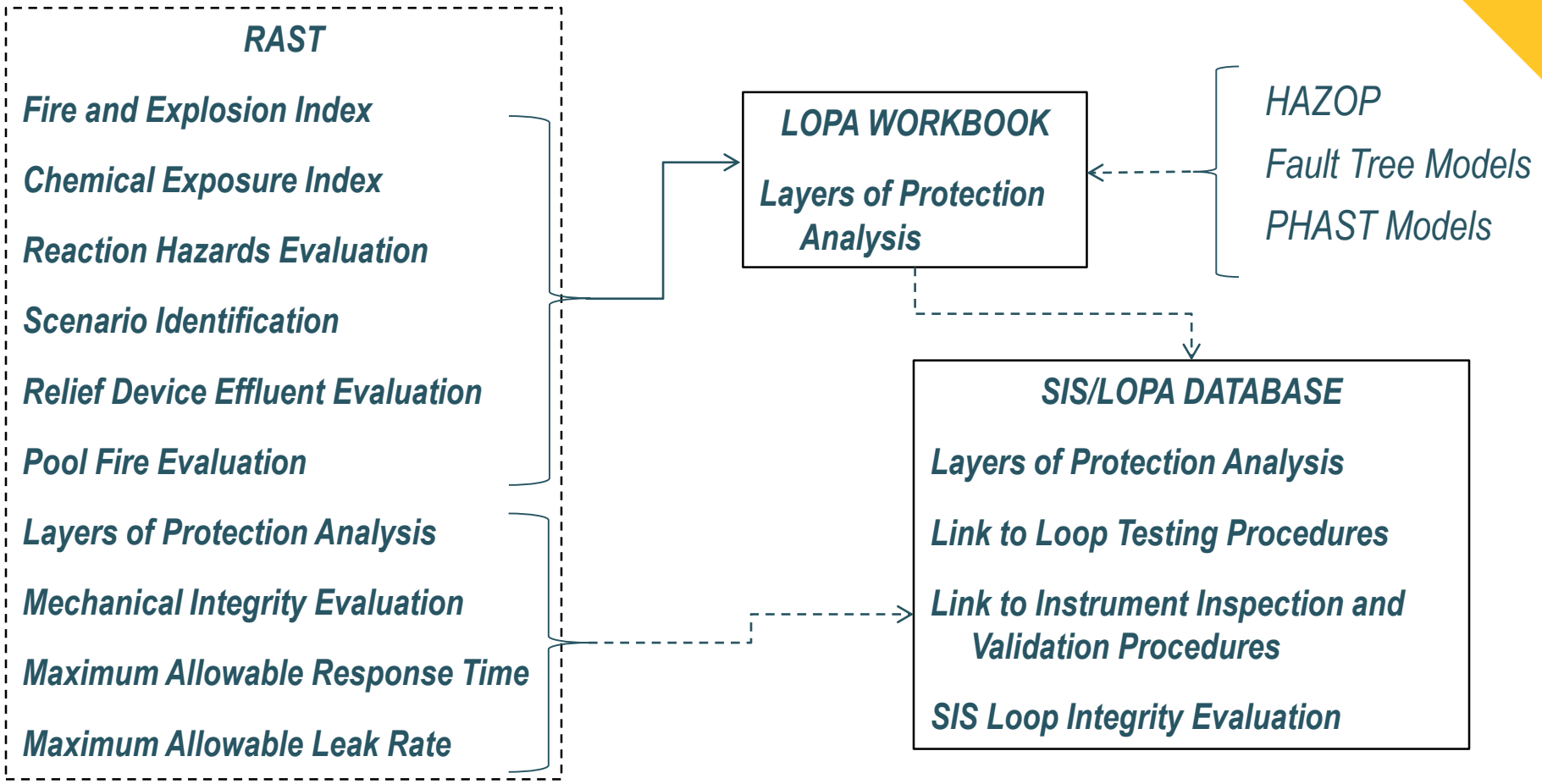
Ensure LOPA Team understands each Scenario and its consequences. Use ***Notes*** column for clarity as appropriate



LOPA Team should update the Initiating Event description and ensure the appropriate factor is used.

LOPA Team completes the detailed Protective Layer description and selects IPL from the "pull down" Menu.

Relationship of RAST, LOPA Workbook and SIS/LOPA Database



RAST is a collection of Scenario generation, identification of Risk and Process Risk Analyzing tools

How can your company obtain with these tools?

- Just download tools, presentations, manuals and cases from one of these webpages
  - EPSC - European Process Safety Centre
  - CCPS - Center for Chemical Process Safety.
- The become an experienced user join the EPSC RAST User Group
- EPSC and CCPS maintain the tools, we are now already at the third RAST upgrade