A CCPS-EPSC Alliance

RAST

Risk Analysis Screening Tool

User's Manual

An AIChE Technology Alliance

CCPS

Center for Chemical Process Safety

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Risk Analysis Screening Tool (RAST) User's Manual

Purpose

This document provides a reference for using RAST and to users attending classroom training for the Risk Analysis Screening Tool (RAST) workshop.

Feedback Request:

Please provide feedback or comments on the content of this document to the RAST Committee, via the CCPS webpage (www.aiche.org/ccps)

Revision History:

A complete document history is located at the end of this document.

Disclaimer

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1. INTRODUCTION

Intended Audience

The intended audience for Risk Analysis Screening Tool (RAST) software is personnel performing Screening Level Hazard Evaluation or Risk Analysis (such as a Layers of Protection Analysis) for existing and future manufacturing facilities including:

- Manufacturing personnel
- Research and Development Engineers
- Process Engineers
- Other Process Safety roles

User's Manual Objectives

The overall objective for the RAST manual is to:

- Develop familiarity with the RAST tool such that Evaluation Teams with the help of Facilitators and Process Safety personnel should be able to perform *screening level* Hazard and Risk Evaluations.
- Provide an example problem so that users understand the limitations of this tool and when to utilize more advanced methods or to engage a Subject Matter Expert.

Sections

There are 9 sections included in the Risk Analysis Screening Tool User's Manual including:

1. Introduction
2. Getting Started with RAST
3. Chemical Properties
4. Evaluation of Reactivity Hazards
5. Additional Inputs and Reports
6. Scenario Development
7. Layers of Protection Analysis
8. Case Study
9. Wrap-up

Process Risk Management

Process Risk is a measure of human injury, environmental damage, or economic loss resulting from an incident in terms of both likelihood and magnitude of the loss or injury. Risk Management is the systematic application of management policies and procedures in analyzing, assessing, and controlling risk. It utilizes both *Risk Analysis* and *Risk Assessment.* Process Risk management is intended to continuously improve safety, health, and environmental performance of manufacturing plants over the long term by addressing risk to people, property, and the environment. RAST supports risk analysis in providing a consistent evaluation based on a company's specific criteria.

What is RAST?

RAST is a collection of process safety and risk analysis screening tools used to assist when performing a Hazard Identification and Risk Analysis (HIRA) study that draws upon common input information. Included are:

- Dow Fire and Explosion Index (FEI)
- Dow Chemical Exposure Index (CEI)
- Reaction Hazards Evaluation
- Identification of Common Scenarios
- Hazards and Consequence Evaluation Summary
- Relief Device Effluent Screening
- Risk Analysis (modified Layers of Protection Analysis or LOPA)

RAST is intended as a productivity tool to aid evaluation teams in performing Hazard Identification and Risk Analysis (HIRA) studies providing consistency among analysis teams while reinforcing company protocol and criteria. It utilizes simplified and often empirical methods in quantifying hazards, consequences and risk. These methods have been quality checked and reasonably correlate to complex algorithms of other commercially developed software

RAST bridges the gap between qualitative and detailed quantitative risk evaluation and allows application of greater rigor and detail for high risk scenarios (Figure 1.1). In some cases, other software or rigorous evaluation methods may be needed beyond the capability of RAST to meet a company's risk analysis requirements. For these cases, RAST accommodates the entry of results from other software or methods (including qualitative estimates) in the overall study.

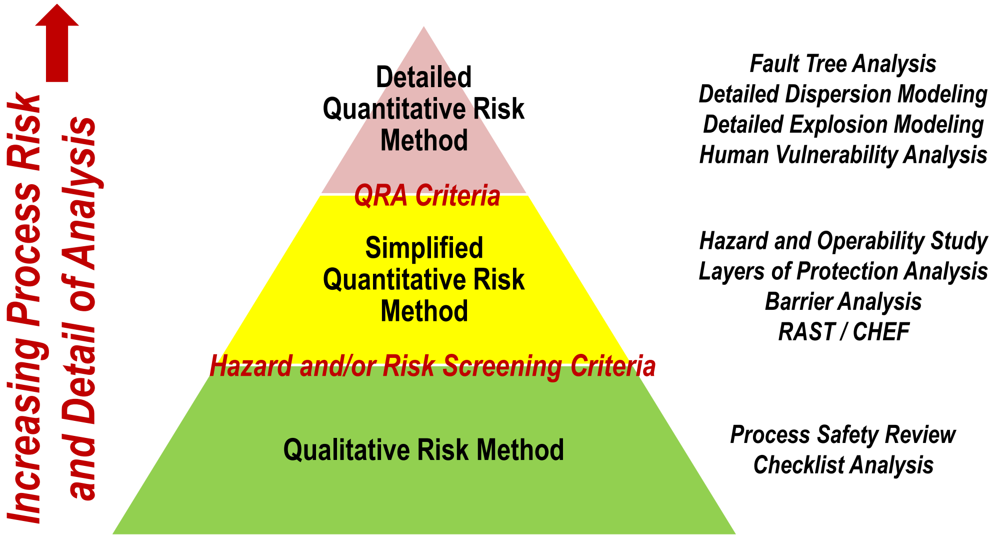


Figure 1.1 Hierarchy of Risk Analysis Methods

Hazard Identification and Risk Analysis is a collective term that encompasses all activities involved in identifying hazards and evaluating risk at facilities, throughout their life cycle, to make certain that risks to employees, the public, or the environment are consistently controlled within the organization's risk tolerance. RAST is based on a suggested HIRA work process (Figure 1.2) to answer basic questions involving:

- What are the Hazards?
- What can go Wrong?
- How Bad can it be?
- How Often might it happen?
- Is the Risk Tolerable?

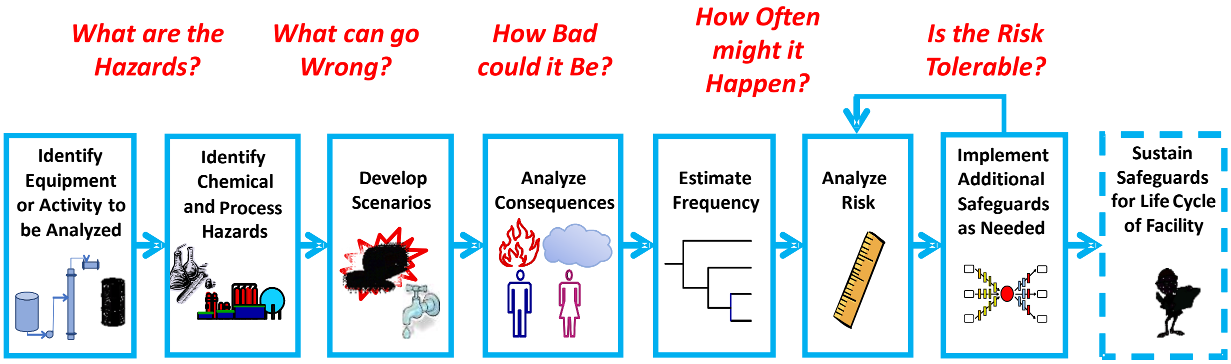


Figure 1.2 Hazard Identification and Risk Analysis Work Flow

RAST and the accompanying Chemical Hazards Engineering Fundamentals (CHEF) materials are based on performing HIRA tasks in a specific order. The order of task execution is based on an overall work flow such that results of a specific estimate (such as a source model) being available as input for the subsequent task (such as vapor dispersion). RAST is set up to use minimal information to get started with the addition of more information over time to improve the analysis and generate additional reports.

The overall Work Process for HIRA within RAST includes:

Identify 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.

Identify Chemical and Process Hazards or "inherent chemical or physical characteristics that have the potential for causing damage to people, property, or the environment". RAST considers both Chemical and Operational related hazards. Chemical Hazards include flammability, toxicity, corrosivity, and reactivity (stored chemical energy). Operational Hazards include stored pressure-volume energy, high or low temperature (potential for thermal burns) and, to some extent, electrical conductivity (potential for static discharge). RAST contains administrative screening parameters (such as flash point for consideration of flammability hazard, ERPG-3 concentration for consideration of toxicity hazard, etc.) to aid in determining what hazards to consider,

RAST contains a data table of chemical properties (for 250 chemicals as of the date of this manual) that are used for quantifying hazards and in source models to determine leak rate. Users may enter properties for additional chemicals as needed in the HIRA study. There are several limitations relative to chemical properties, the most significant being that vapors are addressed as ideal gases and thermodynamic properties are correlated as simple linear relationship with temperature. Some source models for chemical processes operating near the critical point (critical temperature and critical pressure) will be less accurate than processes operating at or below the normal boiling point.

Each company has the ability to update the default screening parameters provided on hidden worksheets within RAST to utilize their specific criteria. CCPS does not endorse any specific criteria but provides initial values needed for the program to run and for the company to consider.

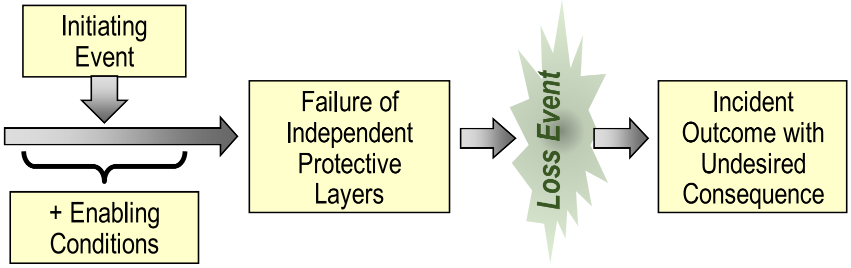
If hazard severity is considered reasonably low, then a HIRA study may not be required (in other words "screened out"), provided there is no regulatory or other requirement. In that case the RAST Hazard Summary Report may be used to document why the study team considers the hazard to be low.

Development of Scenarios involves "a detailed description of an unplanned event or incident sequence that results in a loss event and its associated impacts, including the success or failure of safeguards involved in the incident sequence". In addition to Cause (or Initiating Event) and Consequence (or Incident Outcome), a RAST scenario contains one unique Loss Event. Details of the Loss Event help clarify the event sequence for the analysis team. In addition, the Loss Event is linked to a specific Source Term that allows RAST to perform a simple Consequence Analysis.

It should be noted that a RAST scenario contains only one Loss Event (Figure 1.3). If the overall event sequence contains more than one loss event, it is addressed as multiple RAST scenarios. For example: a spill of flammable liquid (first loss event) that ignites causing a pool fire that heats an adjacent vessel to the point of either ruptures or activates a relief device (second loss event) would be addressed as multiple RAST scenarios (the second loss event being a domino effect of the first). Each spill of flammable material which could ignite and create a pool fire impacting another vessel in the area would be addressed as separate scenarios. The heating from pool fire resulting in relief venting, rupture or damage would be addressed as an additional scenario. This is consistent with the Layer of Protection Analysis methodology.

Standardized lists of Initiating Events and Incident Outcome are also used to develop the scenario in RAST. Common parameter deviations for the type of equipment being analyzed is used to link some Loss Events with Initiating Events consistent with a Hazard and Operability Study (HAZOP) approach. RAST generates a list of suggested scenarios for consideration by the study team.

The suggested list of scenarios provided by RAST is not intended to represent all scenarios needed for an effective HIRA study, but a starting point that the evaluation team may build upon.



Scenario = Initiating Event + Loss Event + Incident Outcome

Partial List of Initiating Events

- ☐ Human Error
- ☐ Mechanical Failure
- ☐ Regulator Failure
- ☐ Pump Seal Failure
- ☐ Heat Ex Tube Failure
- ☐ Hose Failure
- ☐ Loss of Agitation
- ☐ Utility Failure

Partial List of Loss Events

- ☐ Small Hole Leak
- ☐ Medium Hole Leak
- ☐ Full Bore Leak
- ☐ Overfill Release
- ☐ Vapor Release-Fire
- ☐ Vapor Release-Reaction
- ☐ Equipment Rupture
- ☐ Equipment Damage

Partial List of Incident Outcome

- ☐ Flash Fire
- ☐ Building Explosion
- ☐ Vapor Cloud Explosion
- ☐ Fireball or BLEVE
- ☐ Toxic Release
- ☐ Toxic Infiltration
- ☐ Environmental Damage
- ☐ Business Loss

Figure 1.3 Scenario Development in RAST

RAST also considers operational limits to evaluate the feasibility of a scenario. For example, does the maximum system pressure exceed the design limits of the equipment or the relief device set pressure? Finally, RAST is "live" so that updates of Input information will automatically update the list of scenarios for consideration.

Consequence Analysis in RAST uses various source and effect models from CCPS and other literature sources. Loss events are categorized as related to hole size (vapor, liquid, or two-phase), material balance (such as overfill), heat balance (such as vaporization resulting from fire exposure), rupture (instantaneous release) or equipment damage. If the release is liquid or two-phase, vapor rate is estimated from simple flashing, aerosol evaporation and pool evaporation models.

A generic Event Tree (Figure 1.4) is used with RAST to determine Incident Outcome resulting from the Loss Event using criteria based on release location, release quantity and physical state, concentration at distance to the public, occupied buildings or on-site personnel location, in addition to process area congestion and other criteria. Administrative Incident Outcome criteria in RAST may be updated to reflect a company's standards on which a judgment or decision may be based. Parameter values provided in the RAST software are example criteria for the company to consider.

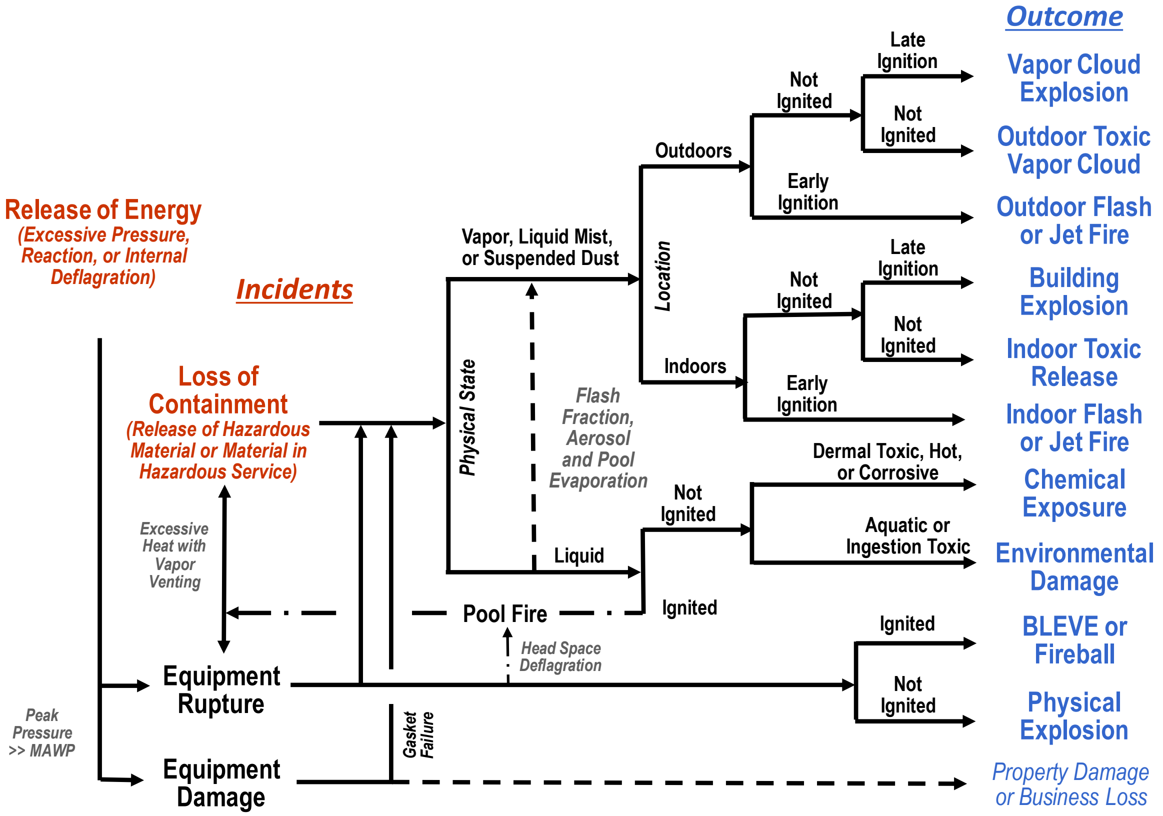


Figure 1.4 Generic Incident Outcome Event Tree used in RAST

RAST estimates a single "worst" Consequence Severity for each Incident Outcome.

There are three approaches that may be used to categorize consequence severity for *human harm* in RAST.

- **Simplified Quantitative Estimate of Human Harm**: This method involves the use of mathematical models to estimate the release rate, the subsequent dispersion, and toxic or blast effects. The models used in RAST are described in the Chemical Hazards Engineering Fundamentals (CHEF) manual available for free download from CCPS. In addition to direct comparison with a company's risk tolerance criteria, quantitative methods provide better consistency between different analysts.

It must be recognized that the results of real-world events have been both significantly less and significantly greater than those calculated. A set of assumptions such as weather conditions, wind direction, and release orientation are used to determine a "worst" consequence that may not represent real-world events.

- **Severity without Direct Reference to Human Harm**: This method is based on results of simple dispersion or explosion models such as a release where the distance to ERPG-2 concentration exceeds 1000 m or where the distance to 1 psi blast overpressure exceeds 500 m. Each Incident Outcome utilizes a different correlation with either a Hazard Distance or Concentration divided by a Level of Concern. Administrative parameters for relating consequence severity to dispersion and explosion model estimates may be updated to reflect a company's specific criteria.

  This approach avoids directly estimating the number of potential injuries or fatalities which may appear to imply that injuries or fatalities are tolerable. This approach also recognizes the difficulty in estimating the number of people who may be harmed and how severe the harm might be. For example, a toxic release may result in one or more fatalities or no harm at all, depending on the proximity of people to the release location and capability they have to escape.

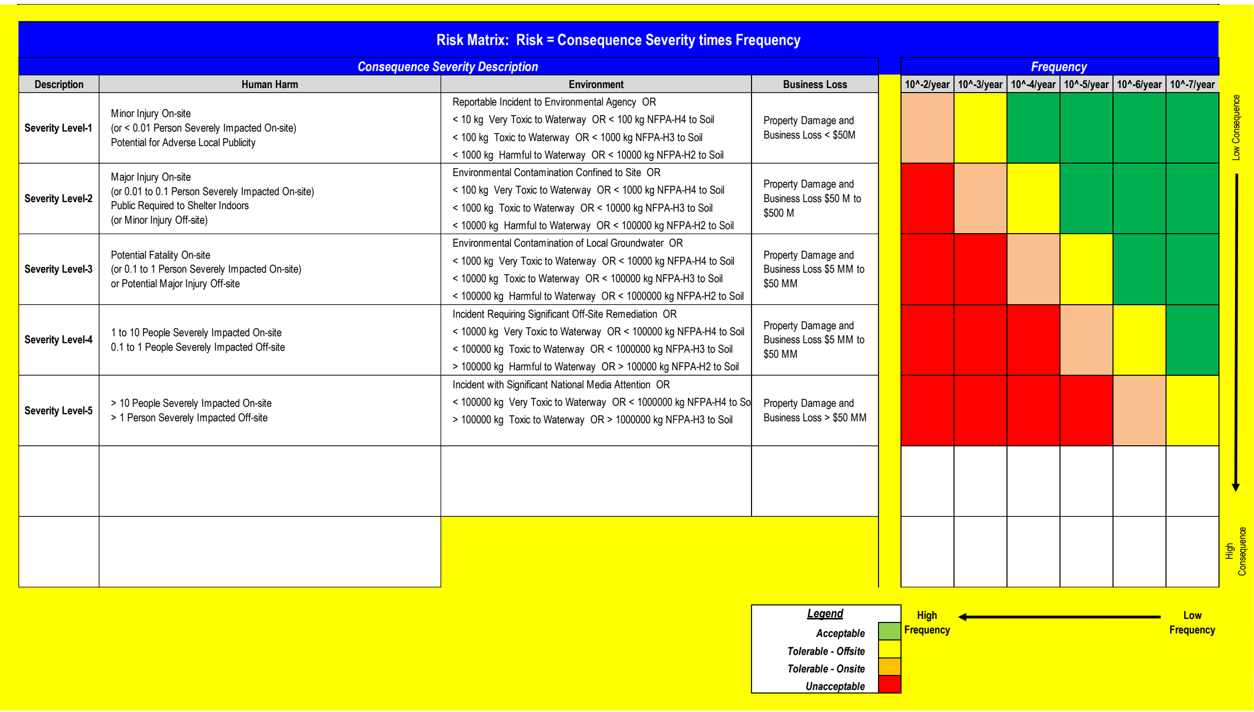
- **Estimates of Consequence Severity other than provided by RAST**: RAST allows the User to enter a severity level as agreed upon by the study team rather than utilize the estimates provided.

Consequence severity for **Environmental Damage** is based on liquid release quantity to the ground or to waterways with a specific NFPA Health Hazard Rating (or GHS Hazard Classification) for Environmental Damage severity. (For example, 1000 kg material with GHS Hazard Classification of "toxic to aquatic life" or "toxic if swallowed")

Consequence severity for **Business Loss** is based on User entered cost to repair damaged equipment plus cost of business interruption for Business Loss severity

Scenario Frequency in RAST is order-of-magnitude and based on independence of initiating events, enabling conditions/conditional modifiers and protective layers. Tables of initiating event frequencies, enabling condition or conditional modifier probabilities (such as probability of ignition), and probability of failure upon demand (PFD) for independent protective layers (IPL) are stored as administrative parameters. Residual failures (those leaks represented by chronic issues such as wear or fatigue rather than a process upset) are labeled Mechanical Integrity scenarios in RAST with frequency based on correlation on published leak frequency data. These tables and correlation coefficients may be updated to reflect a company's specific frequency values for use in risk analysis. The scenario frequency is simply the product of the initiating event frequency times the enabling condition or conditional modifier probability times the failure probability for each IPL appropriate for the scenario.

Risk Analysis within RAST involves converting the Consequence Severity and Scenario Frequency to graduated scales representing order-of-magnitude levels. A tabular Risk Matrix (Figure 1.5) is used to



Risk Matrix: Risk = Consequence Severity times Frequency

Consequence Severity Description				*Frequency*					
Description	**Human Harm**	**Environment**	**Business Loss**	**10^-2/year**	**10^-3/year**	**10^-4/year**	**10^-5/year**	**10^-6/year**	**10^-7/year**
Severity Level-1	Minor Injury On-site (or < 0.01 Person Severely Impacted On-site) Potential for Adverse Local Publicity	Reportable Incident to Environmental Agency OR < 10 kg Very Toxic to Waterway OR < 100 kg NFPA-H4 to Soil < 100 kg Toxic to Waterway OR < 1000 kg NFPA-H3 to Soil < 1000 kg Harmful to Waterway OR < 10000 kg NFPA-H2 to Soil	Property Damage and Business Loss < $50M	🟧	🟨	🟩	🟩	🟩	🟩
Severity Level-2	Major Injury On-site (or 0.01 to 0.1 Person Severely Impacted On-site) Public Required to Shelter Indoors (or Minor Injury Off-site)	Environmental Contamination Confined to Site OR < 100 kg Very Toxic to Waterway OR < 1000 kg NFPA-H4 to Soil < 1000 kg Toxic to Waterway OR < 10000 kg NFPA-H3 to Soil < 10000 kg Harmful to Waterway OR < 100000 kg NFPA-H2 to Soil	Property Damage and Business Loss $50 M to $500 M	🟥	🟧	🟨	🟩	🟩	🟩
Severity Level-3	Potential Fatality On-site (or 0.1 to 1 Person Severely Impacted On-site) or Potential Major Injury Off-site	Environmental Contamination of Local Groundwater OR < 1000 kg Very Toxic to Waterway OR < 10000 kg NFPA-H4 to Soil < 10000 kg Toxic to Waterway OR < 100000 kg NFPA-H3 to Soil < 100000 kg Harmful to Waterway OR < 1000000 kg NFPA-H2 to Soil	Property Damage and Business Loss $5 MM to $50 MM	🟥	🟥	🟧	🟨	🟩	🟩
Severity Level-4	1 to 10 People Severely Impacted On-site 0.1 to 1 People Severely Impacted Off-site	Incident Requiring Significant Off-Site Remediation OR < 10000 kg Very Toxic to Waterway OR < 100000 kg NFPA-H4 to Soil < 100000 kg Toxic to Waterway OR < 1000000 kg NFPA-H3 to Soil > 100000 kg Harmful to Waterway OR > 100000 kg NFPA-H2 to Soil	Property Damage and Business Loss $5 MM to $50 MM	🟥	🟥	🟥	🟧	🟨	🟩
Severity Level-5	> 10 People Severely Impacted On-site > 1 Person Severely Impacted Off-site	Incident with Significant National Media Attention OR < 100000 kg Very Toxic to Waterway OR < 1000000 kg NFPA-H4 to So > 100000 kg Toxic to Waterway OR > 1000000 kg NFPA-H3 to Soil	Property Damage and Business Loss > $50 MM	🟥	🟥	🟥	🟥	🟧	🟨

Legend	
Acceptable	🟩
Tolerable - Offsite	🟨
Tolerable - Onsite	🟧
Unacceptable	🟥

Figure 1.5 Example RAST Risk Matrix for Consequence Severity times Frequency

summarize results with each cell in the matrix (at intersecting values of Consequence Severity and Scenario Frequency) representing a specific value of scenario risk. Tolerable Risk may also be summarized in the same tabular Risk Matrix and compared to scenario risk in determining if further risk reduction is needed. The values of tolerable frequency for the various Consequence Severity levels are administrative parameters that should be updated to reflect a specific company’s risk tolerance criteria. The criteria for Human Harm in the above matrix may also be related to Hazard Distance if a company desires to not use number of severe impacts or fatalities as the reference. The default parameters provided in RAST should be considered “examples” as CCPS does not endorse any specific risk criteria.

RAST also provides a graph of cumulative frequency versus consequence severity level as an indicator of societal risk. For human harm consequences, this graph is similar to an F-N Curve for making risk decisions.

A Layers of Protection Analysis (LOPA) workbook within RAST is used to summarize the risk associated with each scenario to be analyzed. Scenarios are selected from a list of potential scenarios for risk analysis by the analysis team. Scenarios of relatively low risk may be screened out from LOPA consideration based on a company’s risk screening criteria which may be entered as administrative parameters. Those scenarios representing “worst cases” are noted (those requiring the greatest number of protective layers to meet a company’s risk tolerance criteria) to aid the analysis team in selecting which scenarios to include in the analysis.

During LOPA, the study team adds **additional cost effective IPLs** until each scenario is at or below the tolerable risk criteria. Once approved by company leadership, these additional IPLs would be implemented and entered into the company’s inspection, testing and maintenance programs to ensure that all safeguards are sustained for the life of the facility. RAST includes several reports to aid the study team in development of a design basis for effective IPLs (such as estimation of the maximum allowable response time for a protective layer to function).

RAST Documentation

RAST maintains datasets of new chemicals, suggested scenarios, consequence analysis results, and layers of protection analysis results for each equipment item evaluated. These datasets are compatible with and may be imported into newer versions of the RAST software to effectively manage the data and documentation associated with the study. Future HIRA studies for the facility are easily updated by importing previous studies into the latest version of RAST, review and update of inputs, and generation of updated reports.

All chemical, equipment, process conditions and location inputs are stored within RAST by the equipment item or unit operation name. A User may select any equipment item within the HIRA study to review inputs or results, make appropriate changes or additions, and save the updated information. All information related to risk analysis for a specific scenario is stored within RAST by the scenario number. A User may select any scenario number to review scenario details and identified protection layers, make changes, and save the updated information. All reports and analysis results may be viewed by selecting either the equipment item or scenario number depending on the specific report desired.

RAST Training Materials

There are three related training manuals (and workshops available) for RAST.

Chemical Hazard Engineering Fundamentals (CHEF) is intended for newer engineers or as a refresher for experienced personnel. It describes methodology for performing a Hazard Identification and Risk Analysis (HIRA) study. There are many simplifying assumptions used that may not be suitable for every situation. A RAST User should be familiar with CHEF materials to recognize when a simplifying assumption may not be appropriate within a specific HIRA study.

Risk Analysis Screening Tool (RAST User) focuses on how to utilize the software in helping HIRA study teams to improve productivity, consistency, and quality of the studies. Various inputs and reports are described in detail with examples.

RAST Technical Administrator is intended to show experienced Process Safety personnel how to incorporate a company's specific risk matrix and other screening criteria into the RAST software. It is intended for those filling a RAST Technical Administrator role rather than a RAST User.

2. GETTING STARTED

RAST is a collection of process safety and risk analysis screening tools used to perform Hazard Identification and Risk Analysis (HIRA). A simple study example will be used to illustrate some of the features of the RAST tool. The example presented in this manual covers simple identification of hazards and evaluation of risk associated with a single equipment item handling a single Chemical. Information input and Analysis details for more complex situations will be covered in the *Additional RAST Inputs and Reports* section. The tool is based on a Microsoft Excel platform.

Opening the RAST Tool

Open the RAST spreadsheet. The first tab is an “Introduction” worksheet that contains notes pertaining to recent changes and other communication is the first tab you will see. Save this “blank” copy of the tool to your desktop then select “Go to Main Menu” in the top right corner or use the worksheet tabs at the bottom of the page to go to “Main Menu”. You may also view the Instructions worksheet by selecting “Go to Instructions” in the top right corner or using the worksheet tabs at the bottom of the page.

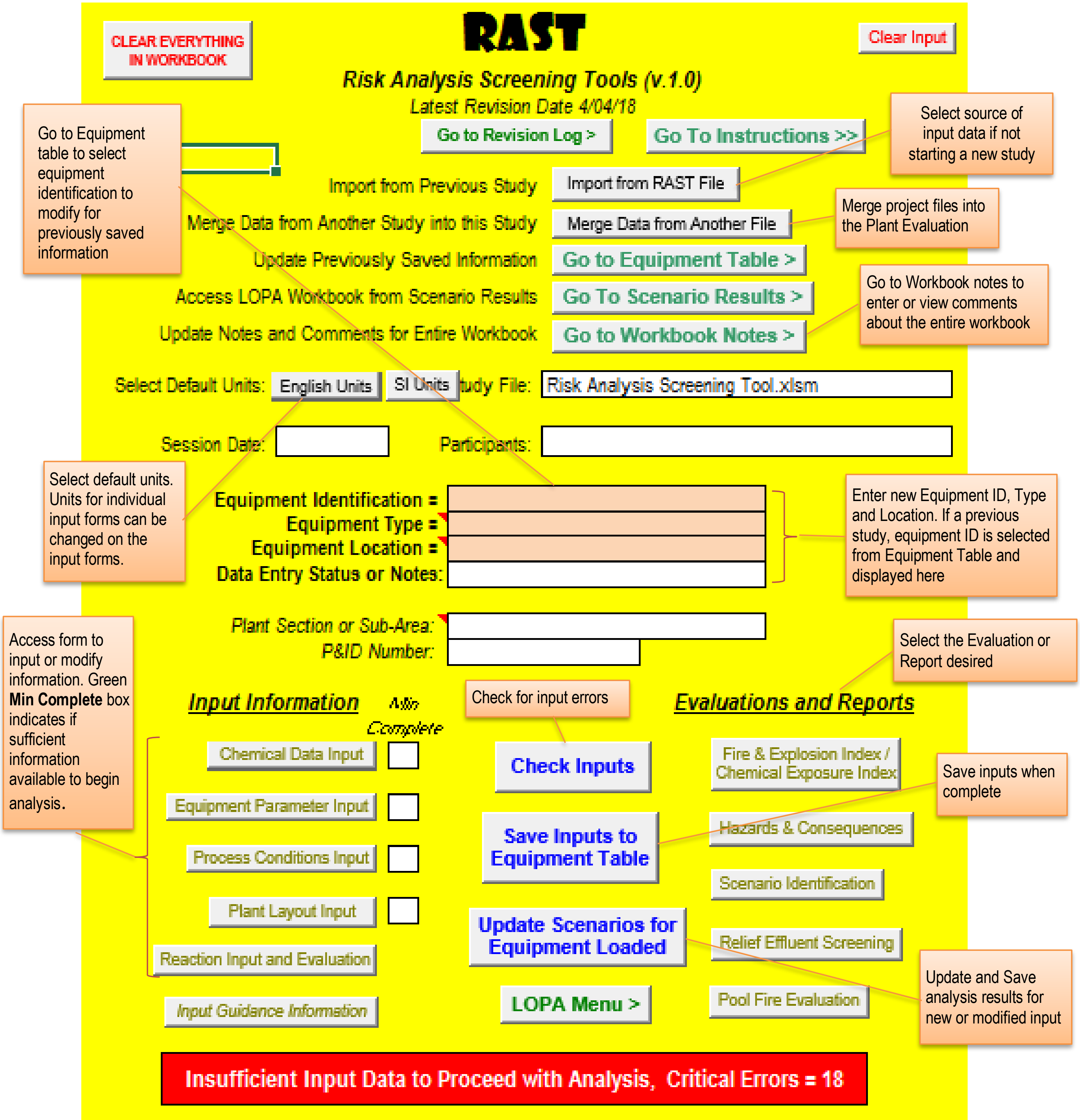
Main Menu

Equipment Identification, Equipment Type, and Location (Outdoors or Indoors) are entered on the Main Menu worksheet (Figure 2.1) On the Main Menu, one may also:

- Select the Source File for Input Information (prior LOPA or RAST workbook).
- Enter the Equipment Identification, Equipment Type and Location for analysis. (If updating a Previous Study, Equipment Identification, Equipment Type and Location is retrieved from the Equipment Table.)
- Access Workbook Notes for entering and viewing comments regarding the entire workbook and viewing selected parameters used in calculations (such as value of ambient temperature)
- Access Forms for Input Information such as Chemical Properties, Equipment Data, Operating Conditions, and Site or Facility Layout Information.
- Save all Input Information for the Equipment Identification selected
- Select the Evaluation or Report desired
- Update and Save Analysis Results for new or modified Equipment Items

Color Coding Guidance

Throughout the RAST workbook: “orange” colored cells represent the minimum required information while “yellow” colored cells represent other key information. In addition, “green” macro buttons at the top of each page are used for navigation to other worksheets, “black” for executing calculations, “red” to clear information, and “blue” for saving information.



Study File: Risk Analysis Screening Tool.xlsm

☐ ☐ ☐ ☐

Go to Equipment table to select equipment identification to modify for previously saved information

Select source of input data if not starting a new study

Merge project files into the Plant Evaluation

Go to Workbook notes to enter or view comments about the entire workbook

Select default units. Units for individual input forms can be changed on the input forms.

Enter new Equipment ID, Type and Location. If a previous study, equipment ID is selected from Equipment Table and displayed here

Access form to input or modify information. Green **Min Complete** box indicates if sufficient information available to begin analysis.

Check for input errors

Select the Evaluation or Report desired

Save inputs when complete

Update and Save analysis results for new or modified input

Insufficient Input Data to Proceed with Analysis, Critical Errors = 18

Figure 2.1: Main Menu

An Example Study

As an example, to illustrate the RAST tool, consider a simple Hazard Evaluation and Risk Analysis for the storage tank containing acrylonitrile at 25 C (77 F) and 0.01 barg (0.2 psig) depicted in Figure 2.2:

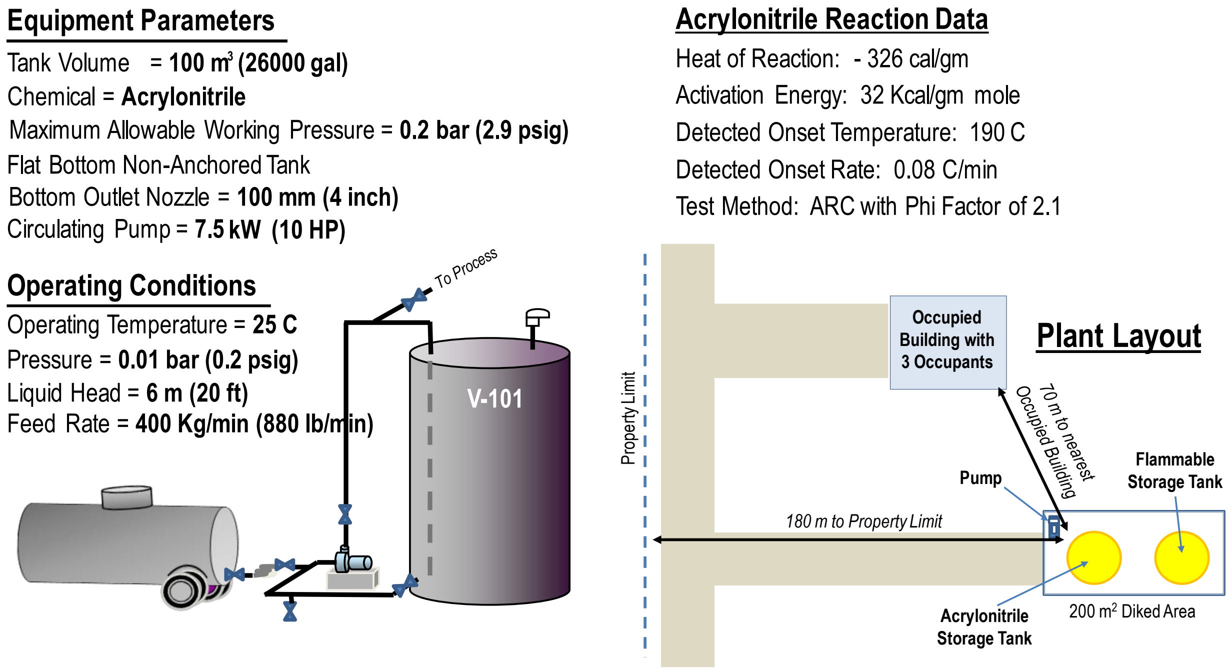


Figure 2.2: PFD for example (acrylonitrile storage tank)

Study Input Information

Let's begin by entering the *minimum necessary* Input Information to begin a new study.

STEP 1: *In the* ***Main Menu*** *worksheet:*

- Enter the **Equipment Identification, V-101**, select the **Equipment Type, Vessel/Tank** and **Location, Outdoors** from the drop-down lists.

  Location is assumed Outdoors if input is blank. If updating a previous study, the Equipment Identification would be selected from the Equipment Table and displaced on the Study Menu form.

- **Select Default Units** as **SI Units**

  If updating a previous study, DO NOT select Default Units as information has already been entered in previously defined units.

From the **Main Menu, Select** ***Chemical Data Input*** to enter Chemical information.

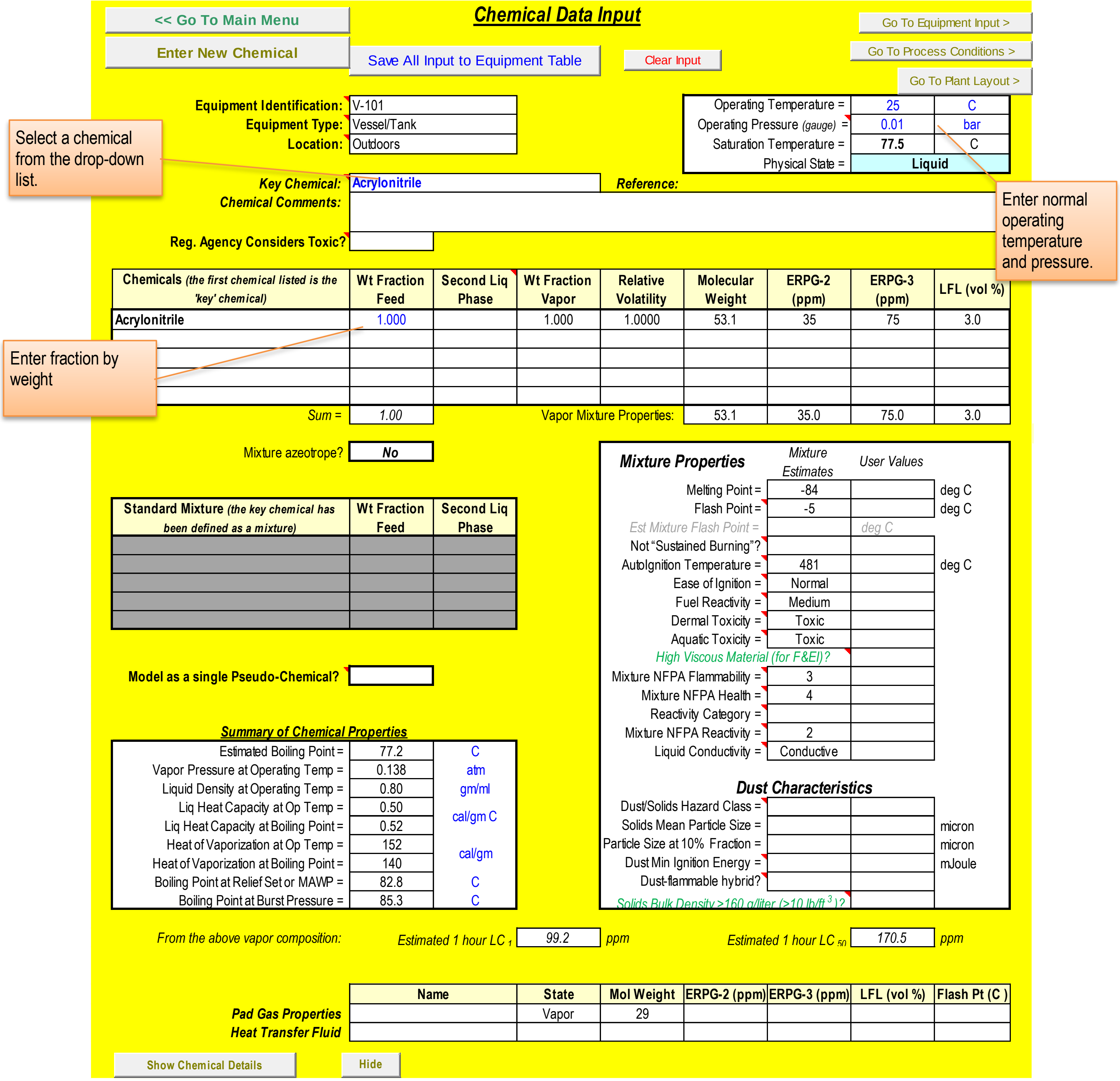
Chemical Information is entered on the Chemical Data worksheet (Figure 4). On this worksheet, one may:

- Select the Chemical (or Chemical Mixture) contained within the Equipment being analyzed.
- Access key Chemical Information from a Chemical Data Table.
- Estimate specific Chemical and Physical Properties at the Operating Temperature including the Physical State (vapor, liquid, or solid), Vapor Pressure, Vapor Composition, Liquid Density, Liquid Heat Capacity, and Heat of Vaporization. Other Chemical Information such as estimated mixture Boiling Point and Saturation Temperature (boiling point at the operating pressure) are also available.
- Enter additional Chemical Information not available or missing from the Chemical Data Table.

STEP 2*: In the* ***Chemical Data Input*** *worksheet:*

- **Select** the **Chemical Name**, ***Acrylonitrile,*** from the available list and **Enter Weight Fraction Feed** of **1.0**.
- **Enter** the **Operation Temperature** of **25 C** and **Operating Pressure** of **0.01 bar** gauge (near atmospheric pressure)**.**
- **Select Go to Main Menu** to continue with additional information input.

**Note that there are "orange" cells on the Chemical Data Input worksheet denoting minimum inputs. Once inputs are made in these cells, they are no longer "orange". Also, on the Main Menu the "Minimum Complete" box has turned green for Chemical Data Input once all the minimum required inputs have been entered.*



Select a chemical from the drop-down list.

Enter normal operating temperature and pressure.

Enter fraction by weight

Chemical Data Input

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

Operating Temperature =	25	C
Operating Pressure *(gauge)* =	0.01	bar
Saturation Temperature =	77.5	C
Physical State =	Liquid	

Key Chemical: Acrylonitrile
Reference:
Chemical Comments:
Reg. Agency Considers Toxic?

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 %)**
Acrylonitrile	1.000		1.000	1.0000	53.1	35	75	3.0
Sum =	*1.00*			Vapor Mixture Properties:	53.1	35.0	75.0	3.0

Mixture azeotrope? ***No***

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 =	77.2	C
Vapor Pressure at Operating Temp =	0.138	atm
Liquid Density at Operating Temp =	0.80	gm/ml
Liq Heat Capacity at Op Temp =	0.50	cal/gm C
Liq Heat Capacity at Boiling Point =	0.52	
Heat of Vaporization at Op Temp =	152	cal/gm
Heat of Vaporization at Boiling Point =	140	
Boiling Point at Relief Set or MAWP =	82.8	C
Boiling Point at Burst Pressure =	85.3	C

Mixture Properties	*Mixture Estimates*	*User Values*	
Melting Point =	-84		deg C
Flash Point =	-5		deg C
Est Mixture Flash Point =		*deg C*	
Not "Sustained Burning"?			
AutoIgnition Temperature =	481		deg C
Ease of Ignition =	Normal		
Fuel Reactivity =	Medium		
Dermal Toxicity =	Toxic		
Aquatic Toxicity =	Toxic		
High Viscous Material (for F&EI)?			
Mixture NFPA Flammability =	3		
Mixture NFPA Health =	4		
Reactivity Category =			
Mixture NFPA Reactivity =	2		
Liquid Conductivity =	Conductive		

Dust Characteristics

Dust/Solids Hazard Class =			
Solids Mean Particle Size =			micron
Particle Size at 10% Fraction =			micron
Dust Min Ignition Energy =			mJoule
Dust-flammable hybrid?			
Solids Bulk Density >160 g/liter (>10 lb/ft ^{3})?			

From the above vapor composition: *Estimated 1 hour LC $_1$* *99.2* *ppm* *Estimated 1 hour LC $_{50}$* *170.5* *ppm*

	Name	**State**	**Mol Weight**	**ERPG-2 (ppm)**	**ERPG-3 (ppm)**	**LFL (vol %)**	**Flash Pt (C)**
Pad Gas Properties		Vapor	29				
Heat Transfer Fluid							

Figure 2.3: Chemical Data Input

From the **Main Menu, Select *Equipment Parameter Input*** to enter Equipment Information.

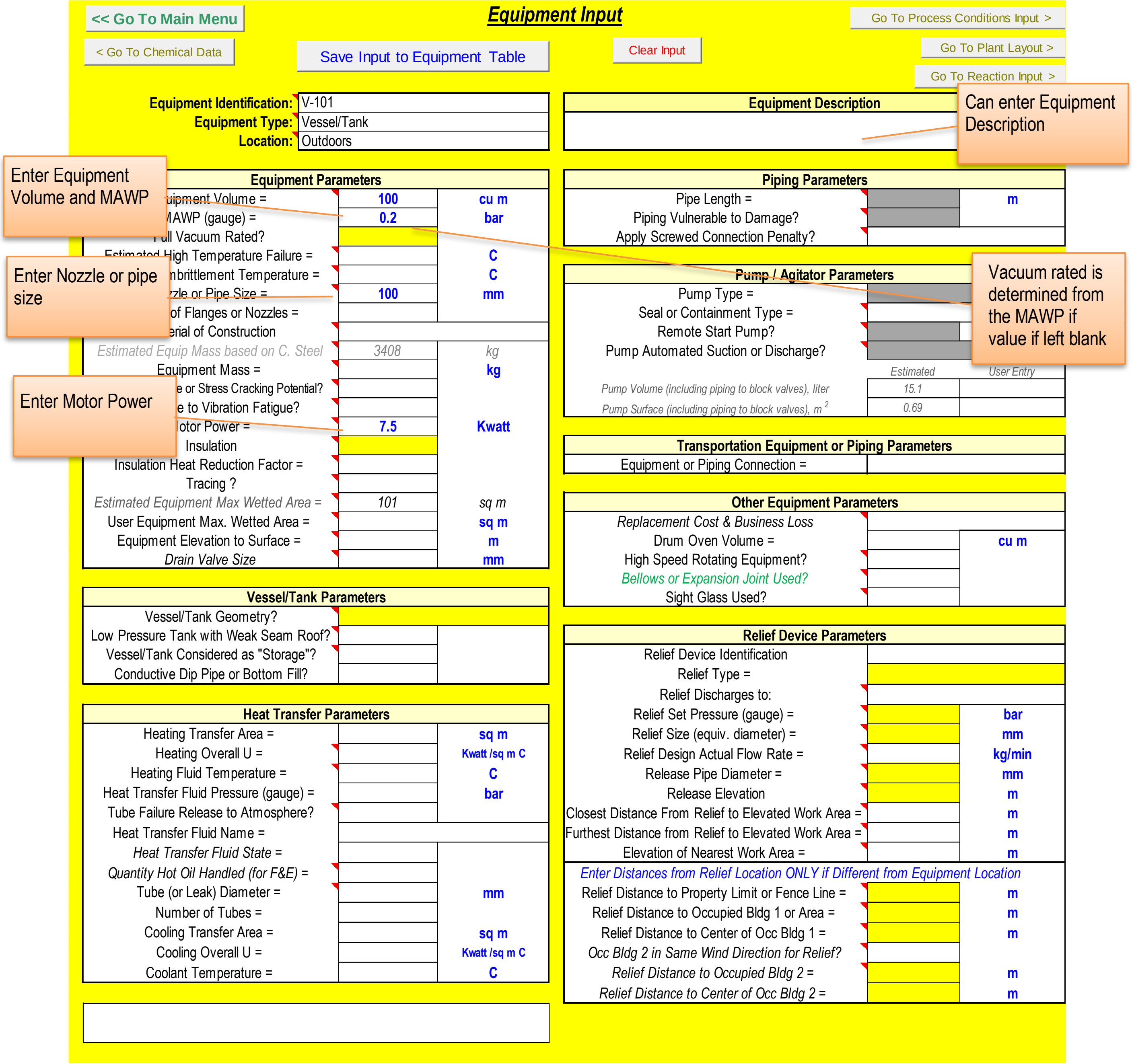
Equipment Parameters are input on the Equipment Input worksheet (Figure 2.4). On this worksheet one may:

- Enter key Equipment Information such as Volume, Maximum Allowable Working Pressure, Pipe or Nozzle Diameter, Material of Construction, Surface Area and Elevation.
- Enter Design Information for specialized equipment such as Heat Transfer Area, Heating Media Temperature, Coolant Temperature, Pipe Length, Pump Seal Type, etc.
- Enter information regarding Design Issues such as Corrosion or Stress Cracking Potential, Susceptible to Vibration Fatigue, Piping Vulnerable to Physical Damage, Use of Conductive Dip Pipe or Bottom Fill, etc.
- Enter Relief Device design information such as Relief Set Pressure, Relief Size (diameter), Relief Type, Tail Pipe Diameter, and Discharge Elevation.

***STEP 3**: In the **Equipment Input** worksheet:*

- **Enter** the **Equipment Volume** of **100 m^3, Maximum Allowable Working Pressure (MAWP)** of **0.2 bar** gauge and **Nozzle or Pipe Size** of **100 mm**. This represents the *minimum* input information
- Additional Equipment Parameters available that should be entered are **Motor Power** of **7.5 Kw** for the circulating pump (which is a mechanical energy input to the tank). You may also enter an ***Equipment Description*** if desired**.**
- **Select Go to Main Menu** to continue with additional information input.

**Note that there are no longer "orange" cells on the Equipment Input worksheet denoting that minimum input requirements have been met. Also note that on the Main Menu the "Minimum Complete" box has turned green for Equipment Parameter Input.*



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

Equipment Description

Equipment Parameters

uipment Volume =	100	cu m
AWP (gauge) =	0.2	bar
ull Vacuum Rated?		
Estimated High Temperature Failure =		C
nbrittlement Temperature =		C
zle or Pipe Size =	100	mm
of Flanges or Nozzles =		
erial of Construction		
Estimated Equip Mass based on C. Steel	*3408*	*kg*
Equipment Mass =		kg
e or Stress Cracking Potential?		
e to Vibration Fatigue?		
otor Power =	7.5	Kwatt
Insulation		
Insulation Heat Reduction Factor =		
Tracing ?		
Estimated Equipment Max Wetted Area =	*101*	*sq m*
User Equipment Max. Wetted Area =		sq m
Equipment Elevation to Surface =		m
Drain Valve Size		mm

Vessel/Tank Parameters

Vessel/Tank Geometry?	
Low Pressure Tank with Weak Seam Roof?	
Vessel/Tank Considered as "Storage"?	
Conductive Dip Pipe or Bottom Fill?	

Heat Transfer Parameters

Heating Transfer Area =		sq m
Heating Overall U =		Kwatt /sq m C
Heating Fluid Temperature =		C
Heat Transfer Fluid Pressure (gauge) =		bar
Tube Failure Release to Atmosphere?		
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 =		m
Piping Vulnerable to Damage?		
Apply Screwed Connection Penalty?		

Pump / Agitator Parameters

Pump Type =		
Seal or Containment Type =		
Remote Start Pump?		
Pump Automated Suction or Discharge?		
	Estimated	*User Entry*
Pump Volume (including piping to block valves), liter	*15.1*	
Pump Surface (including piping to block valves), m^2	*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 =		
Relief Discharges to:		
Relief Set Pressure (gauge) =		bar
Relief Size (equiv. diameter) =		mm
Relief Design Actual Flow Rate =		kg/min
Release Pipe Diameter =		mm
Release Elevation		m
Closest Distance From Relief to Elevated Work Area =		m
Furthest Distance from Relief to Elevated Work Area =		m
Elevation of Nearest Work Area =		m
Enter Distances from Relief Location ONLY if Different from Equipment Location		
Relief Distance to Property Limit or Fence Line =		m
Relief Distance to Occupied Bldg 1 or Area =		m
Relief Distance to Center of Occ Bldg 1 =		m
Occ Bldg 2 in Same Wind Direction for Relief?		
Relief Distance to Occupied Bldg 2 =		m
Relief Distance to Center of Occ Bldg 2 =		m

Figure 2.4: Equipment Input Worksheet

From the **Main Menu, Select *Process Conditions Input*** to enter Process and Operating Conditions Information

Process and Operating Information is entered on the Process Conditions worksheet (Figure 2.5). On this worksheet, one may:

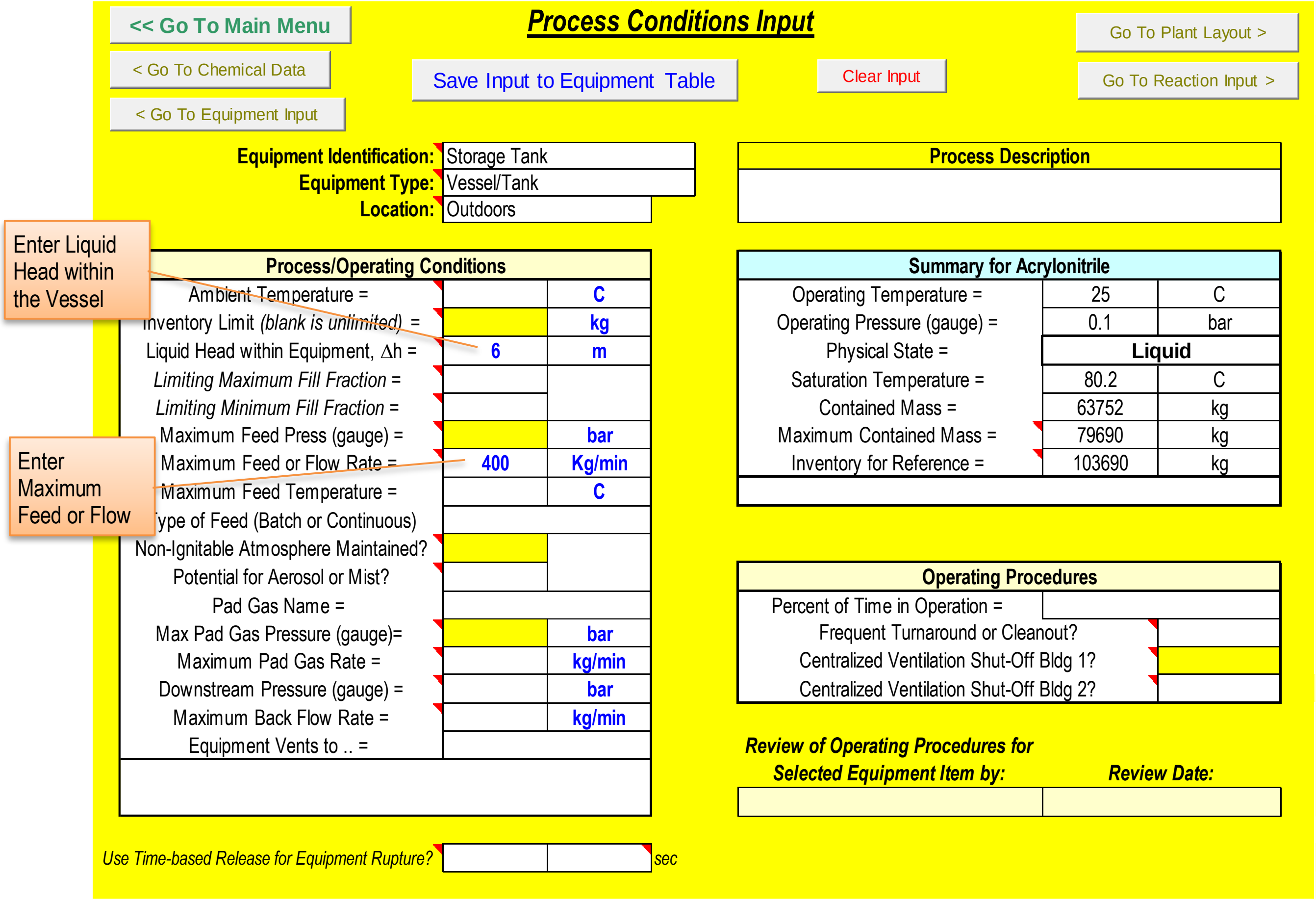
- Enter ambient temperature to be used in the analysis.
- Enter key process conditions such as the maximum fill or feed rate and the liquid head for equipment with low operating pressure.
- Enter additional feed information such as the total inventory, maximum feed pressure, and type of feed (continuous or batch).

- Enter information on use of Pad Gas such as Pad Gas Pressure, Maximum Pad Gas Flow Rate and if a Non-ignitable Atmosphere is Being Maintained in the equipment.

***STEP 4:** In the **Process Conditions** worksheet*:

- **Enter** the **Liquid Head within Equipment** of **6 m** and **Maximum Feed or Flow Rate** of **400 Kg/min**. Ensure input units are correct. Note that *Liquid Head* is entered since it has a significant impact on the pressure drop available for leaks in this case. (The tank is operating at << 1 atmosphere gauge). Also note that leaving the *Total Inventory* blank implies an unlimited inventory available for overflow or leak scenarios.
- **Select Go to Main Menu** to continue with additional information input.

**Note that there are no longer "orange" cells on the Process Conditions worksheet denoting that minimum input requirements have been met. Also note that on the Main Menu the "Minimum Complete" box has turned green for Process Conditions Input.*



Equipment Identification: Storage Tank
Equipment Type: Vessel/Tank
Location: Outdoors

Process Description

Process/Operating Conditions		
Ambient Temperature =		C
Inventory Limit *(blank is unlimited)* =		kg
Liquid Head within Equipment, Δh =	6	m
Limiting Maximum Fill Fraction =		
Limiting Minimum Fill Fraction =		
Maximum Feed Press (gauge) =		bar
Maximum Feed or Flow Rate =	400	Kg/min
Maximum Feed Temperature =		C
Type of Feed (Batch or Continuous)		
Non-Ignitable Atmosphere Maintained?		
Potential for Aerosol or Mist?		
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 Acrylonitrile		
Operating Temperature =	25	C
Operating Pressure (gauge) =	0.1	bar
Physical State =	Liquid	
Saturation Temperature =	80.2	C
Contained Mass =	63752	kg
Maximum Contained Mass =	79690	kg
Inventory for Reference =	103690	kg

Operating Procedures	
Percent of Time in Operation =	
Frequent Turnaround or Cleanout?	
Centralized Ventilation Shut-Off Bldg 1?	
Centralized Ventilation Shut-Off Bldg 2?	

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

Use Time-based Release for Equipment Rupture? *sec*

Figure 2.5: Process Conditions Worksheet

From the **Main Menu, Select *Plant Layout Input*** to enter Process and Operating Conditions Information

Site and Plant Layout Information is entered on the Plant Layout worksheet (Figure 2.6). On this worksheet, one may:

- Enter key location information such as minimum Distance to Property Limit or Fence Line, Furthest Distance to Property Limit, Distance to Occupied Building and Number of Building Occupants. One may also enter up to two offsite populated regions. If Equipment Location is "Indoors", key information includes the Enclosed Process Volume.

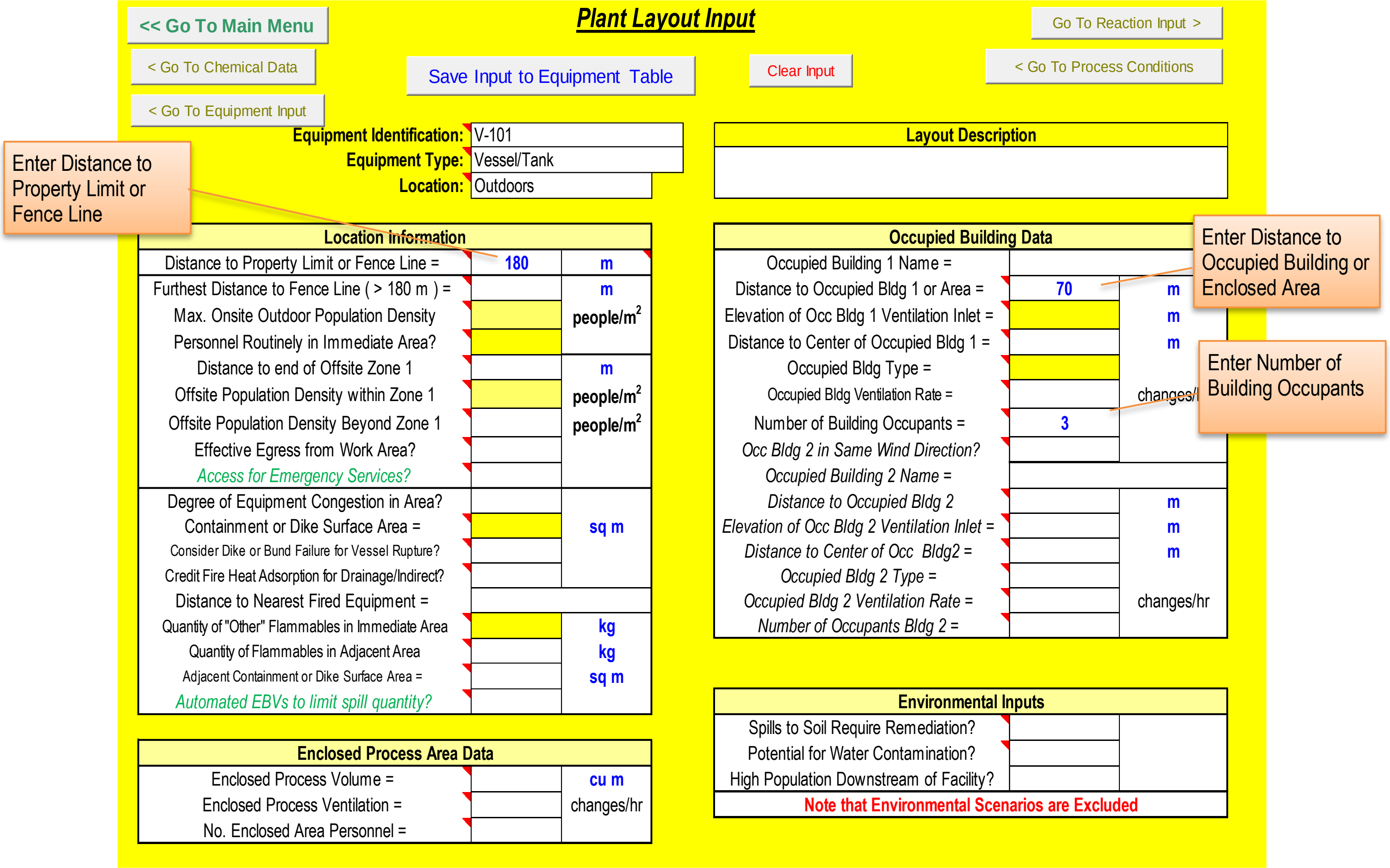
- Enter other location information such as: if Personnel are Routinely in the Immediate Area, Effective Egress from the Immediate Work Area, Degree of Equipment Congestion, Area of Containment Dike, Drainage to a Remote Location, and Distance from Fired Equipment.
- Enter the Number of Enclosed Area Personnel if the Equipment Location is Indoors.
- Enter Occupied Building Information including Name, Elevation of Ventilation Inlet, Ventilation Rate, and if there is Centralized Ventilation Shut-Off.

STEP 5: *In the **Plant Layout Input** worksheet*:

- **Enter** the **Distance to Property Limit or Fence Line** of **180 m**, the **Distance to Occupied Building or Enclosed Work Area** of **70 m** and **Maximum Number of Building Occupants** of **3**. Note that if equipment *Location* is *"Indoors", Enclosed Process Volume* becomes a required input.

Select Go to Main Menu to Check Inputs, Save Inputs to the Equipment Table, or view Evaluations or Reports.

**Note that there are no longer "orange" cells on the Plant Layout worksheet denoting that minimum input requirements have been met. Also note that on the Main Menu the "Min Complete" box has turned green for Plant Layout Input.*



Plant Layout Input

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

Layout Description

Enter Distance to Property Limit or Fence Line

Enter Distance to Occupied Building or Enclosed Area

Enter Number of Building Occupants

Location Information

Distance to Property Limit or Fence Line =	180	m
Furthest Distance to Fence Line (> 180 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 =		cu m
Enclosed Process Ventilation =		changes/hr
No. Enclosed Area Personnel =		

Occupied Building Data

Occupied Building 1 Name =		
Distance to Occupied Bldg 1 or Area =	70	m
Elevation of Occ Bldg 1 Ventilation Inlet =		m
Distance to Center of Occupied Bldg 1 =		m
Occupied Bldg Type =		
Occupied Bldg Ventilation Rate =		changes/
Number of Building Occupants =	3	
Occ Bldg 2 in Same Wind Direction?		
Occupied Building 2 Name =		
Distance to Occupied Bldg 2		m
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 =		

Environmental Inputs

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

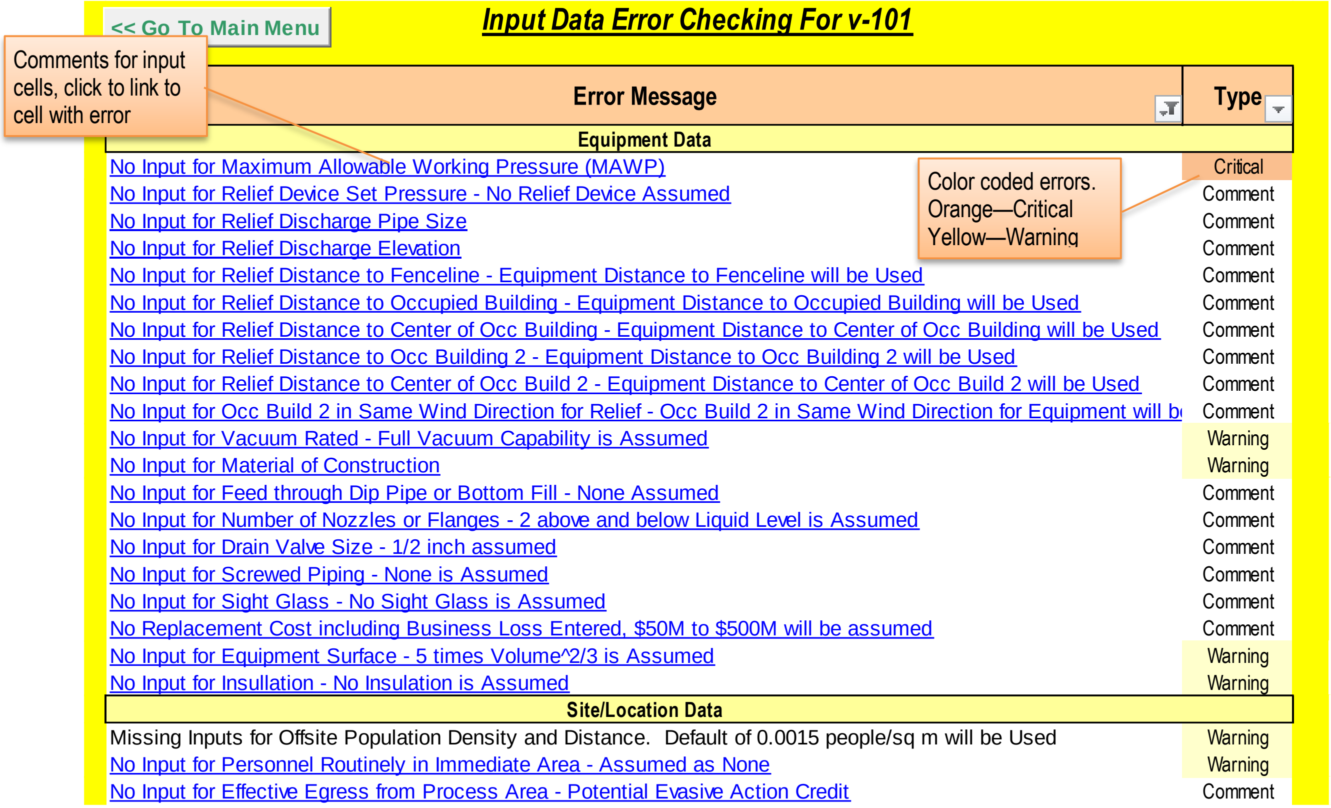
Note that Environmental Scenarios are Excluded

Figure 2.6: Plant Layout Worksheet

From the **Main Menu**, **Select <u>Check Inputs</u>** (blue macro button).

Inputs are checked for missing information, missing units, or values outside of a normal range. Errors are categorized as Comment, Warning, or Critical. Critical errors must be addressed before proceeding with preliminary evaluations. Any default values used for missing input information are described as comments.

See Figure 2.7 for error message examples.



Input Data Error Checking For v-101

Comments for input cells, click to link to cell with error

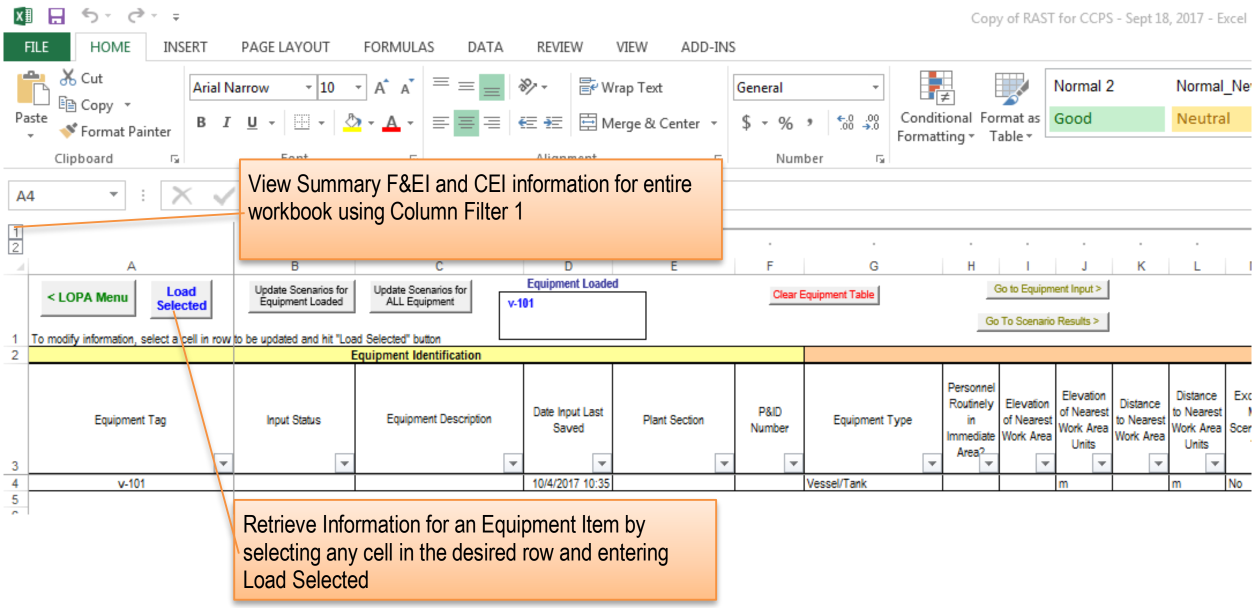
Color coded errors.
Orange—Critical
Yellow—Warning

Error Message	Type
Equipment Data	
No Input for Maximum Allowable Working Pressure (MAWP)	Critical
No Input for Relief Device Set Pressure - No Relief Device Assumed	Comment
No Input for Relief Discharge Pipe Size	Comment
No Input for Relief Discharge Elevation	Comment
No Input for Relief Distance to Fenceline - Equipment Distance to Fenceline will be Used	Comment
No Input for Relief Distance to Occupied Building - Equipment Distance to Occupied Building will be Used	Comment
No Input for Relief Distance to Center of Occ Building - Equipment Distance to Center of Occ Building will be Used	Comment
No Input for Relief Distance to Occ Building 2 - Equipment Distance to Occ Building 2 will be Used	Comment
No Input for Relief Distance to Center of Occ Build 2 - Equipment Distance to Center of Occ Build 2 will be Used	Comment
No Input for Occ Build 2 in Same Wind Direction for Relief - Occ Build 2 in Same Wind Direction for Equipment will b	Comment
No Input for Vacuum Rated - Full Vacuum Capability is Assumed	Warning
No Input for Material of Construction	Warning
No Input for Feed through Dip Pipe or Bottom Fill - None Assumed	Comment
No Input for Number of Nozzles or Flanges - 2 above and below Liquid Level is Assumed	Comment
No Input for Drain Valve Size - 1/2 inch assumed	Comment
No Input for Screwed Piping - None is Assumed	Comment
No Input for Sight Glass - No Sight Glass is Assumed	Comment
No Replacement Cost including Business Loss Entered, $50M to $500M will be assumed	Comment
No Input for Equipment Surface - 5 times Volume^2/3 is Assumed	Warning
No Input for Insullation - No Insulation is Assumed	Warning
Site/Location Data	
Missing Inputs for Offsite Population Density and Distance. Default of 0.0015 people/sq m will be Used	Warning
No Input for Personnel Routinely in Immediate Area - Assumed as None	Warning
No Input for Effective Egress from Process Area - Potential Evasive Action Credit	Comment

Figure 2.7: Error Messages from Check Inputs

Saving Input Information

From the Main Menu, or any of the Input worksheets (Equipment Input, Chemical Data, Process Conditions, Plant Layout, or Reaction Input), Select Save Inputs to Equipment Table (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 (Figure 2.8).



View Summary F&EI and CEI information for entire workbook using Column Filter 1

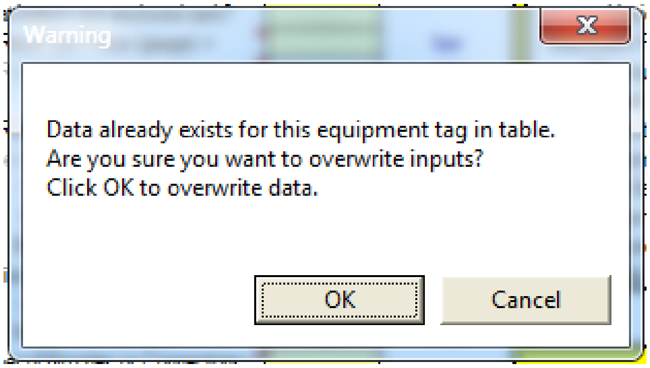
To modify information, select a cell in row to be updated and hit "Load Selected" button

Equipment Identification											
Equipment Tag	Input Status	Equipment Description	Date Input Last Saved	Plant Section	P&ID Number	Equipment Type	Personnel Routinely in Immediate Area?	Elevation of Nearest Work Area	Elevation of Nearest Work Area Units	Distance to Nearest Work Area	Distance to Nearest Work Area Units	Exc Scer
v-101			10/4/2017 10:35			Vessel/Tank			m		m	No

Retrieve Information for an Equipment Item by selecting any cell in the desired row and entering Load Selected

Figure 2.8: Example Equipment Table

Inputs for additional equipment items are stored in subsequent rows on the Equipment Table. To save time for creating inputs, information for a previously stored Equipment Identification or Tag may be retrieved, modified to reflect the desired new input and saved under another unique Equipment Identification or Tag. If Input information for a specific Equipment Tag already exists in the Equipment Table, a message will appear asking if the information is to be updated or overwritten (Figure 2.9).



Data already exists for this equipment tag in table.
Are you sure you want to overwrite inputs?
Click OK to overwrite data.

Figure 2.9: Warning notice

Evaluations and Reports

Once the minimum required inputs have been entered, the user or analysis team may begin evaluations and identification of hazard scenarios. As more information is input, more thorough evaluation may be performed. In this way, a project team may begin with little initial information. Additional hazard scenarios are added for consideration as greater information is input. Selected evaluations and summaries associated with Screening Level Hazard Evaluation will be discussed in the next sections of Getting Started.

Preliminary Fire and Explosion Index

Even with limited information, the Dow Fire and Explosion Index (F&EI) or Chemical Exposure Index (CEI) may be estimated. These represent "Relative Ranking" indices which may be used by a company to screen when qualitative versus quantitative HIRA methods should be used. An example criterion for requiring a quantitative versus qualitative HIRA study might be an F&EI Index of 128 or higher.

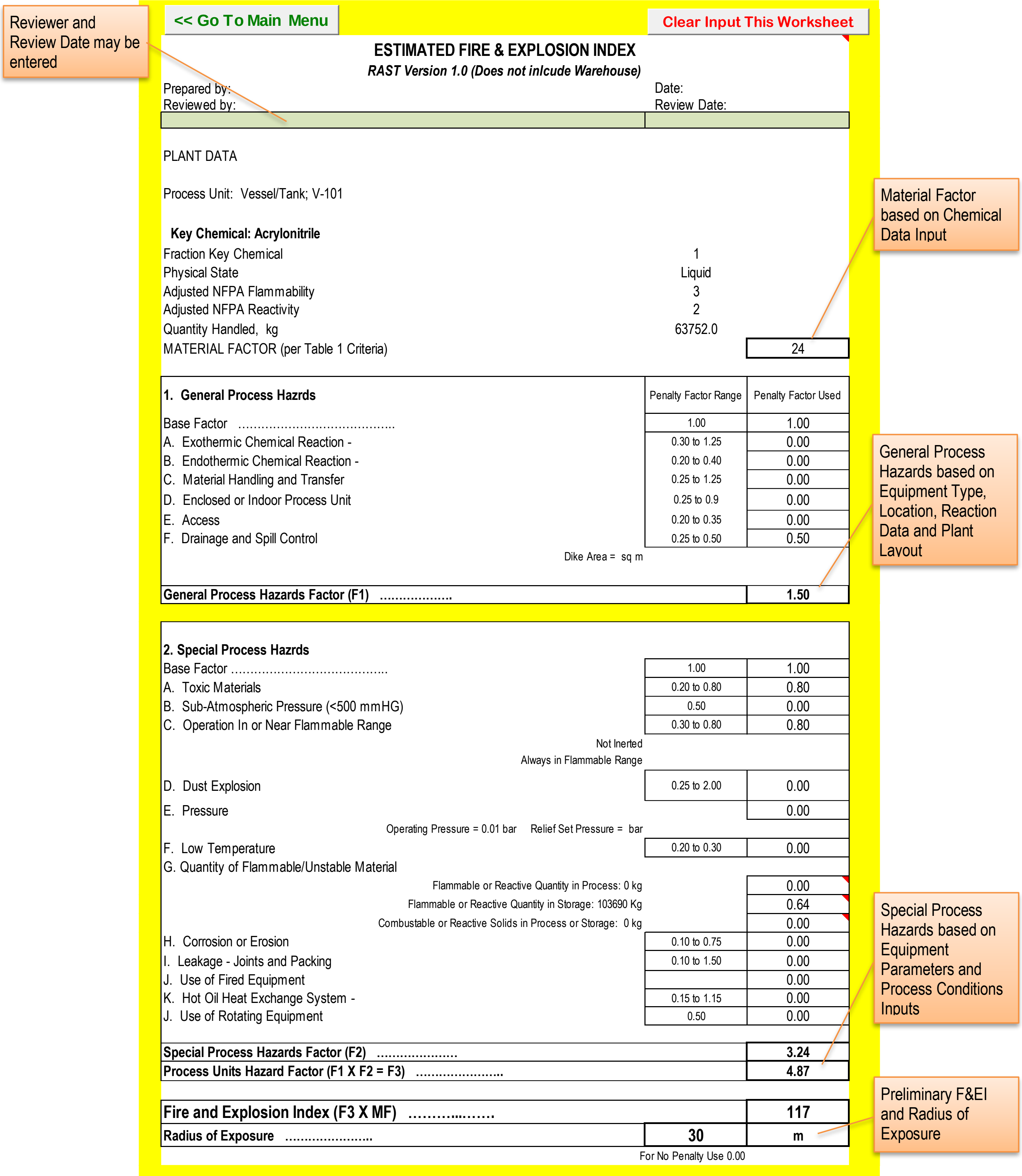
The Fire and Explosion Index categorizes process hazard as shown in Table 1.1:

Table 1.1: Fire & Explosion Index Degree of Hazard

F&EI Range	Degree of Hazard
1 – 60	Light
61 – 96	Moderate
97 – 127	Intermediate
128 – 158	Heavy
159 and higher	Severe

Note that Preliminary F&EI from the RAST tool is based on a ***single Equipment Item***. The Dow *Fire & Explosion Index Hazard Classification Guide* allows evaluation of larger "Process Units" (consisting of multiple equipment items) within a single analysis. The Dow *F&EI Hazard Classification Guide* notes that risk will be overstated for Process Units handling less than 5000 lb. (2269 kg.)). Careful consideration should be given to Preliminary Results for equipment items handling small quantities. Also note that answers to several F&EI questions are evaluated based on available Input information which may not exactly match the question criteria. As a result, the Index and Radius of Exposure may be slightly different that attained with the DOW F&EI but is typically within 5 to 10% of the numerical value.

To view the preliminary Fire and Explosion Index, *Select* Fire & Explosion Index / Chemical Exposure Index from the *Study Menu* worksheet (Figure 2.10).



Reviewer and Review Date may be entered

Material Factor based on Chemical Data Input

General Process Hazards based on Equipment Type, Location, Reaction Data and Plant Layout

Special Process Hazards based on Equipment Parameters and Process Conditions Inputs

Preliminary F&EI and Radius of Exposure

ESTIMATED FIRE & EXPLOSION INDEX

RAST Version 1.0 (Does not inlcude Warehouse)

Prepared by: Date:
Reviewed by: Review Date:

PLANT DATA

Process Unit: Vessel/Tank; V-101

Key Chemical: Acrylonitrile

Fraction Key Chemical	1	
Physical State	Liquid	
Adjusted NFPA Flammability	3	
Adjusted NFPA Reactivity	2	
Quantity Handled, kg	63752.0	
MATERIAL FACTOR (per Table 1 Criteria)		24

1. General Process Hazrds	Penalty Factor Range	Penalty Factor Used
Base Factor	1.00	1.00
A. Exothermic Chemical Reaction -	0.30 to 1.25	0.00
B. Endothermic Chemical Reaction -	0.20 to 0.40	0.00
C. Material Handling and Transfer	0.25 to 1.25	0.00
D. Enclosed or Indoor Process Unit	0.25 to 0.9	0.00
E. Access	0.20 to 0.35	0.00
F. Drainage and Spill Control	0.25 to 0.50	0.50
Dike Area = sq m		
General Process Hazards Factor (F1)		**1.50**

2. Special Process Hazrds		
Base Factor	1.00	1.00
A. Toxic Materials	0.20 to 0.80	0.80
B. Sub-Atmospheric Pressure (<500 mmHG)	0.50	0.00
C. Operation In or Near Flammable Range	0.30 to 0.80	0.80
Not Inerted		
Always in Flammable Range		
D. Dust Explosion	0.25 to 2.00	0.00
E. Pressure		0.00
Operating Pressure = 0.01 bar Relief Set Pressure = bar		
F. Low Temperature	0.20 to 0.30	0.00
G. Quantity of Flammable/Unstable Material		
Flammable or Reactive Quantity in Process: 0 kg		0.00
Flammable or Reactive Quantity in Storage: 103690 Kg		0.64
Combustable or Reactive Solids in Process or Storage: 0 kg		0.00
H. Corrosion or Erosion	0.10 to 0.75	0.00
I. Leakage - Joints and Packing	0.10 to 1.50	0.00
J. Use of Fired Equipment		0.00
K. Hot Oil Heat Exchange System -	0.15 to 1.15	0.00
J. Use of Rotating Equipment	0.50	0.00
Special Process Hazards Factor (F2)		**3.24**
Process Units Hazard Factor (F1 X F2 = F3)		**4.87**

Fire and Explosion Index (F3 X MF) ....……..		**117**
Radius of Exposure	**30**	**m**

For No Penalty Use 0.00

Figure 2.10: Fire & Explosion Index Preliminary Results

Preliminary Chemical Exposure Index

Chemical Exposure Index (CEI) may be estimated based on the ERPG-2 and ERPG-3 (Emergency Response Planning Guideline) concentrations from the Chemical Data worksheet. Calculation Units are selected as either SI or US/English based on the Input Units for Distance (meter or feet). Up to four standard cases are estimated:

Pipe or Nozzle Failure is based on the leak rate from hole size per the CEI guidance of:

- Diameter less than 2 inch (50 mm) – full bore failure
- Diameter between 2 and 4 inch (100 mm) – estimated as a 2 inch hole
- Diameter greater than 4 inch – estimated as a hole equivalent to 20% of cross-sectional area

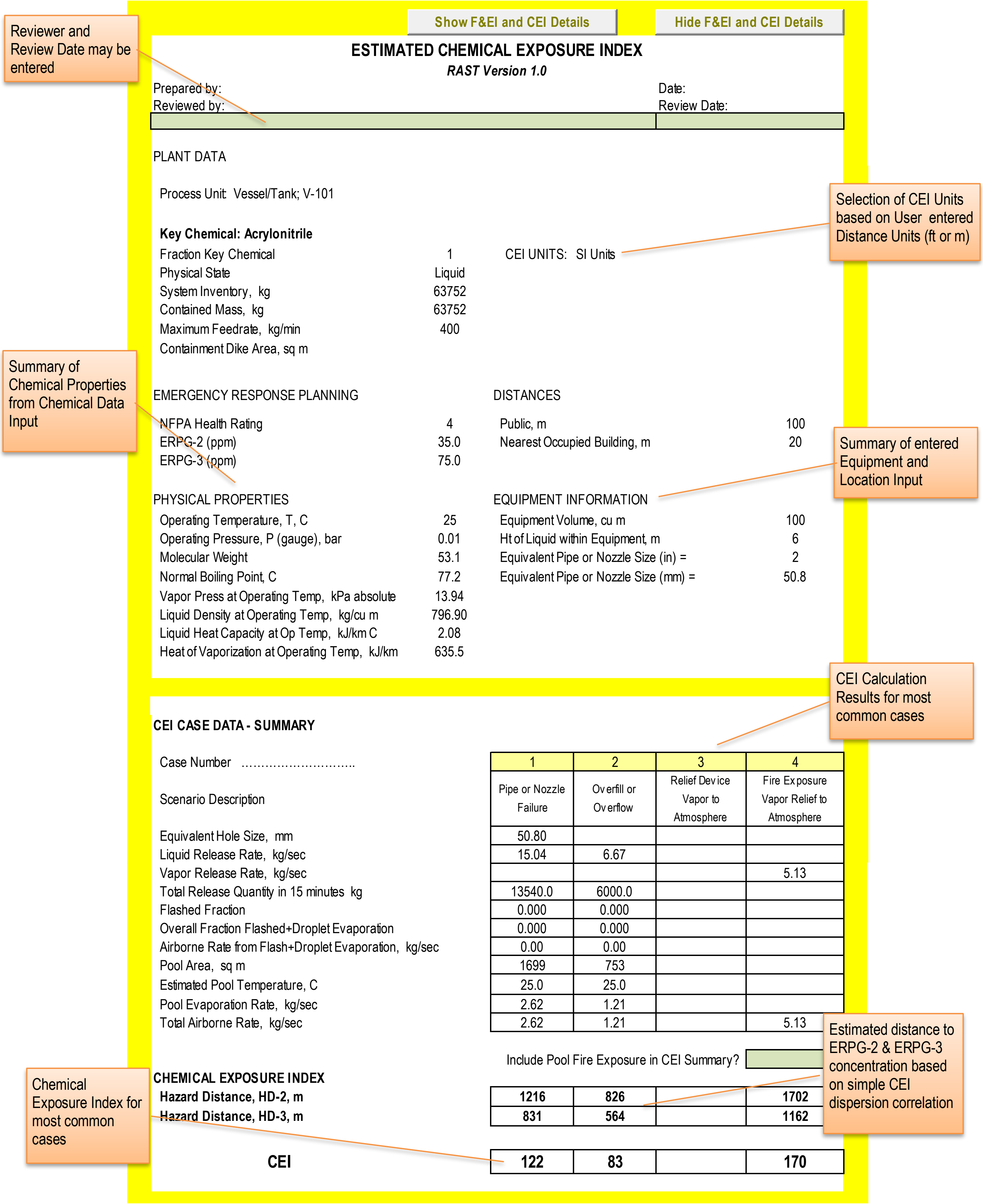
Equipment Overfill or Overflow is based on a leak rate equivalent to the entered feed rate.

Release from Pressure Relief Device is based on an entered Design Capacity or estimated from the Relief Diameter and Set Pressure. (Results for this case are blank if Relief Device information has not been entered.)

Fire Exposure Vapor Venting is based on NFPA-30 estimates of fire heat input divided by the heat of vaporization. (Results for this case are blank if a fire potential is not feasible based on Chemical Data input and "Quantity of Other Flammables in Area" is zero or blank.)

The Chemical Exposure Index and related Hazard Distance to ERPG-2 concentration (HD-2) or Hazard Distance to ERPG-3 concentration (HD-3) are based on "ground" elevation releases lasting at least 5 minutes in duration. An example criterion for requiring a quantitative versus qualitative HIRA study might be a CEI Index of 200 or greater.

To view the preliminary Chemical Exposure Index, *Select* Fire & Explosion Index / Chemical Exposure Index from the *Main Menu* worksheet (Figure 2.11).



ESTIMATED CHEMICAL EXPOSURE INDEX

RAST Version 1.0

Prepared by: Date:
Reviewed by: Review Date:

PLANT DATA

Process Unit: Vessel/Tank; V-101

Key Chemical: Acrylonitrile

Fraction Key Chemical	1	CEI UNITS: SI Units
Physical State	Liquid	
System Inventory, kg	63752	
Contained Mass, kg	63752	
Maximum Feedrate, kg/min	400	
Containment Dike Area, sq m		

EMERGENCY RESPONSE PLANNING		DISTANCES	
NFPA Health Rating	4	Public, m	100
ERPG-2 (ppm)	35.0	Nearest Occupied Building, m	20
ERPG-3 (ppm)	75.0		

PHYSICAL PROPERTIES		EQUIPMENT INFORMATION	
Operating Temperature, T, C	25	Equipment Volume, cu m	100
Operating Pressure, P (gauge), bar	0.01	Ht of Liquid within Equipment, m	6
Molecular Weight	53.1	Equivalent Pipe or Nozzle Size (in) =	2
Normal Boiling Point, C	77.2	Equivalent Pipe or Nozzle Size (mm) =	50.8
Vapor Press at Operating Temp, kPa absolute	13.94		
Liquid Density at Operating Temp, kg/cu m	796.90		
Liquid Heat Capacity at Op Temp, kJ/km C	2.08		
Heat of Vaporization at Operating Temp, kJ/km	635.5		

CEI CASE DATA - SUMMARY

Case Number ………………………	1	2	3	4
Scenario Description	Pipe or Nozzle Failure	Overfill or Overflow	Relief Device Vapor to Atmosphere	Fire Exposure Vapor Relief to Atmosphere
Equivalent Hole Size, mm	50.80			
Liquid Release Rate, kg/sec	15.04	6.67		
Vapor Release Rate, kg/sec				5.13
Total Release Quantity in 15 minutes kg	13540.0	6000.0		
Flashed Fraction	0.000	0.000		
Overall Fraction Flashed+Droplet Evaporation	0.000	0.000		
Airborne Rate from Flash+Droplet Evaporation, kg/sec	0.00	0.00		
Pool Area, sq m	1699	753		
Estimated Pool Temperature, C	25.0	25.0		
Pool Evaporation Rate, kg/sec	2.62	1.21		
Total Airborne Rate, kg/sec	2.62	1.21		5.13

Include Pool Fire Exposure in CEI Summary?

CHEMICAL EXPOSURE INDEX

Hazard Distance, HD-2, m	**1216**	**826**		**1702**
Hazard Distance, HD-3, m	**831**	**564**		**1162**
CEI	**122**	**83**		**170**

Reviewer and Review Date may be entered

Selection of CEI Units based on User entered Distance Units (ft or m)

Summary of Chemical Properties from Chemical Data Input

Summary of entered Equipment and Location Input

CEI Calculation Results for most common cases

Estimated distance to ERPG-2 & ERPG-3 concentration based on simple CEI dispersion correlation

Chemical Exposure Index for most common cases

Figure 2.11: Chemical Exposure Index Preliminary Results

Hazard Summary

A summary of Process Hazards is developed based on the input information is provided for "normal' and selected "upset" process conditions. Hazards associated with excessive pressure (potential for equipment rupture and/or relief device activation), chemical exposure (thermal and/or chemical burns, dermal toxicity), flammability (including pool fire potential), inhalation toxicity, and reactivity are included in this summary. If information beyond the minimum required is input, additional hazards are considered. *The evaluation team should also consider any other hazards not identified in this summary.*

Example Initial Hazard Screening Results are summarized as:

Flammable Hazard Sufficient for Further Consideration if:

- Flash Point less than a specified limit (such as 60 deg C) - ***or***
- The maximum process temperature (under normal or upset conditions) is greater than the flash point less a specified limit (such as 5 deg C) - ***or***
- The chemical is considered a combustible dust or dust-flammable liquid hybrid.

Toxicity Hazard Sufficient for Further Consideration if:

- ERPG-3 less than a specified limit (such as1000 ppm by volume) - ***or***
- Chemical is labeled as toxic in contact with skin, or toxic to the environment or considered by a regulatory agency to be toxic.

Reactivity Hazard Sufficient for Further Consideration if:[1]

- Heat of Reaction / Mass is more exothermic than specified limit (such as –50 J/gm) - ***or***
- There is evidence of highly volatile or gaseous products generated - ***or***
- There is evidence of a reaction with water or any other chemical which may be inadvertently added - ***or***
- The chemical is considered a potential Condensed-Phase Detonable (explosive)

Hazardous Service Sufficient for Further Consideration if:

- The maximum process temperature (under normal, upset, or reaction conditions) is greater than a specified limit for thermal burns (such 60 deg C for liquids, or 100 deg C for vapors) or temperature is less than a low temperature limit (such as -20 deg C) - ***or***
- The chemical handled is considered corrosive to human tissue - ***or***
- The estimated maximum process pressure or vapor pressure (under normal, upset, or reaction conditions) exceeds the equipment Maximum Allowable Working Pressure or relief device set pressure.

Note that the Hazard Screening Criteria found on hidden worksheets may be changed to reflect a company's specific criteria. It is suggested that a company representative proficient in chemical process risk analysis (filling a RAST Technical Administrator role) be responsible for updating study parameters rather than RAST

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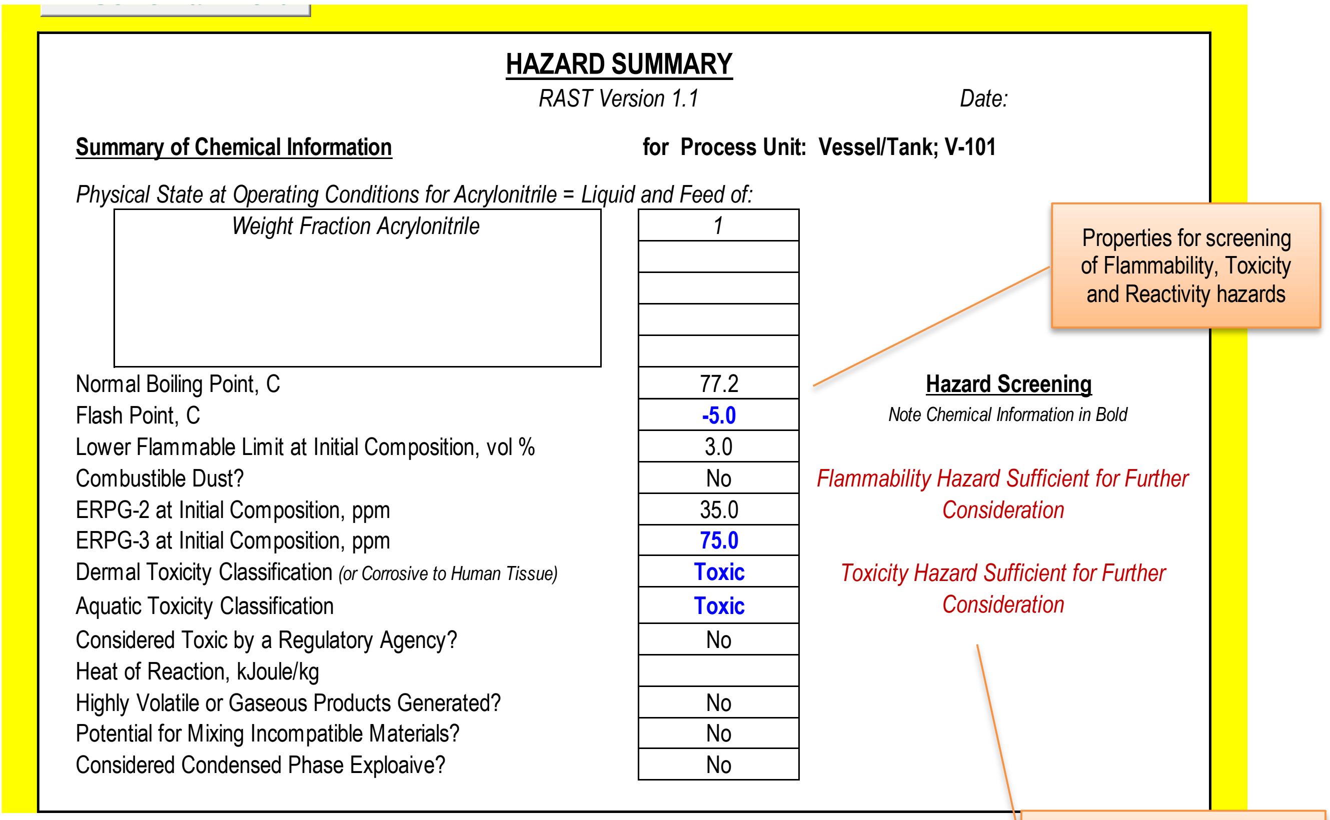
[1] The Chemical Reactivity Worksheet (Version 4.0) can be used to assist in identification of reactivity hazards. It is available free of charge at: https://www.aiche.org/ccps/resources/crw-overview

users or members of a specific study team. The default parameters provided in RAST should be considered "examples" as CCPS does not endorse any specific risk criteria.

Figures 2.12, 2.13 and 2.14 show the Hazard Summary for the Acrylonitrile example.



HAZARD SUMMARY

RAST Version 1.1 *Date:*

Summary of Chemical Information **for Process Unit: Vessel/Tank; V-101**

Physical State at Operating Conditions for Acrylonitrile = Liquid and Feed of:

Weight Fraction Acrylonitrile	*1*
Normal Boiling Point, C	77.2
Flash Point, C	**-5.0**
Lower Flammable Limit at Initial Composition, vol %	3.0
Combustible Dust?	No
ERPG-2 at Initial Composition, ppm	35.0
ERPG-3 at Initial Composition, ppm	**75.0**
Dermal Toxicity Classification *(or Corrosive to Human Tissue)*	**Toxic**
Aquatic Toxicity Classification	**Toxic**
Considered Toxic by a Regulatory Agency?	No
Heat of Reaction, kJoule/kg	
Highly Volatile or Gaseous Products Generated?	No
Potential for Mixing Incompatible Materials?	No
Considered Condensed Phase Exploaive?	No

Hazard Screening

Note Chemical Information in Bold

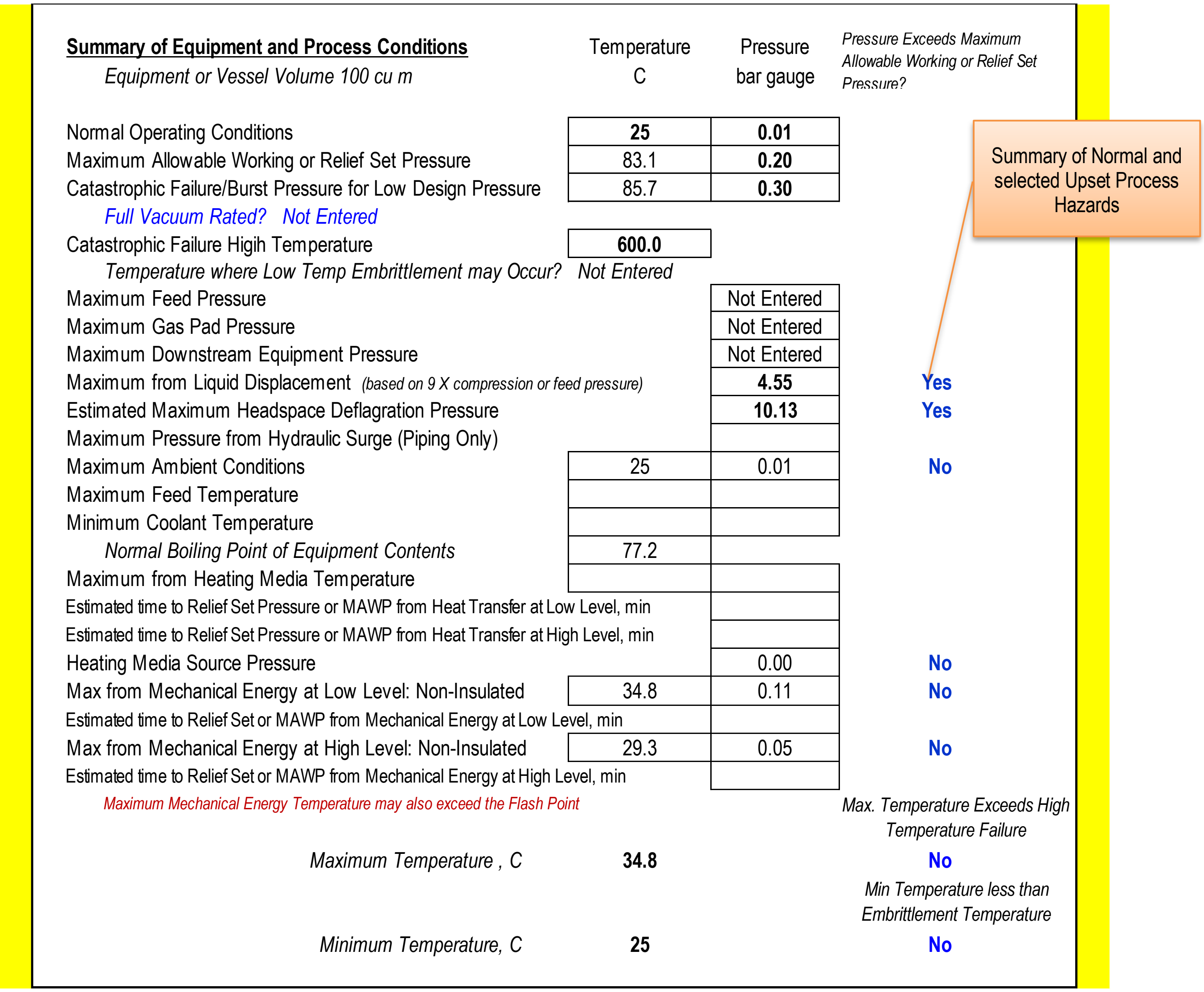
Flammability Hazard Sufficient for Further Consideration

Toxicity Hazard Sufficient for Further Consideration

Properties for screening of Flammability, Toxicity and Reactivity hazards

Hazard Screening results

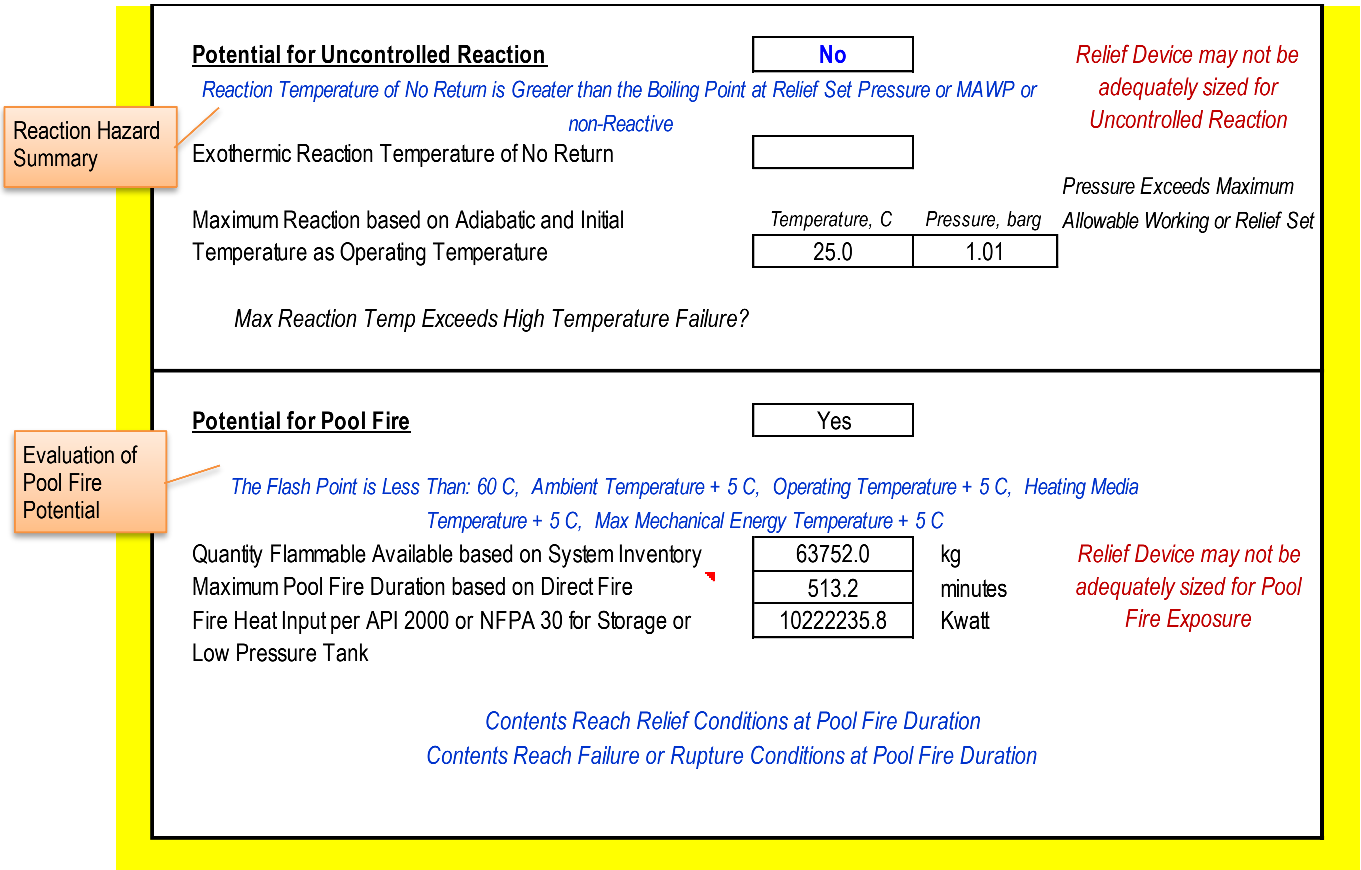
Figure 2.12. Hazard Summary Part 1 – Chemical Information



Summary of Equipment and Process Conditions *Equipment or Vessel Volume 100 cu m*	Temperature C	Pressure bar gauge	*Pressure Exceeds Maximum Allowable Working or Relief Set Pressure?*
Normal Operating Conditions	**25**	**0.01**	
Maximum Allowable Working or Relief Set Pressure	83.1	**0.20**	
Catastrophic Failure/Burst Pressure for Low Design Pressure	85.7	**0.30**	
Full Vacuum Rated? Not Entered			
Catastrophic Failure Higih Temperature	**600.0**		
Temperature where Low Temp Embrittlement may Occur?	*Not Entered*		
Maximum Feed Pressure		Not Entered	
Maximum Gas Pad Pressure		Not Entered	
Maximum Downstream Equipment Pressure		Not Entered	
Maximum from Liquid Displacement *(based on 9 X compression or feed pressure)*		**4.55**	**Yes**
Estimated Maximum Headspace Deflagration Pressure		**10.13**	**Yes**
Maximum Pressure from Hydraulic Surge (Piping Only)			
Maximum Ambient Conditions	25	0.01	**No**
Maximum Feed Temperature			
Minimum Coolant Temperature			
Normal Boiling Point of Equipment Contents	77.2		
Maximum from Heating Media Temperature			
Estimated time to Relief Set Pressure or MAWP from Heat Transfer at Low Level, min			
Estimated time to Relief Set Pressure or MAWP from Heat Transfer at High Level, min			
Heating Media Source Pressure		0.00	**No**
Max from Mechanical Energy at Low Level: Non-Insulated	34.8	0.11	**No**
Estimated time to Relief Set or MAWP from Mechanical Energy at Low Level, min			
Max from Mechanical Energy at High Level: Non-Insulated	29.3	0.05	**No**
Estimated time to Relief Set or MAWP from Mechanical Energy at High Level, min			
Maximum Mechanical Energy Temperature may also exceed the Flash Point			*Max. Temperature Exceeds High Temperature Failure*
Maximum Temperature , C	**34.8**		**No**
			Min Temperature less than Embrittlement Temperature
Minimum Temperature, C	**25**		**No**

Summary of Normal and selected Upset Process Hazards

Figure 2.13: Hazard Summary Part 2 – Equipment and Process Conditions



Reaction Hazard Summary

Potential for Uncontrolled Reaction **No**

Reaction Temperature of No Return is Greater than the Boiling Point at Relief Set Pressure or MAWP or non-Reactive

Relief Device may not be adequately sized for Uncontrolled Reaction

Exothermic Reaction Temperature of No Return

Pressure Exceeds Maximum Allowable Working or Relief Set

	Temperature, C	*Pressure, barg*
Maximum Reaction based on Adiabatic and Initial Temperature as Operating Temperature	25.0	1.01

Max Reaction Temp Exceeds High Temperature Failure?

Evaluation of Pool Fire Potential

Potential for Pool Fire Yes

The Flash Point is Less Than: 60 C, Ambient Temperature + 5 C, Operating Temperature + 5 C, Heating Media Temperature + 5 C, Max Mechanical Energy Temperature + 5 C

Quantity Flammable Available based on System Inventory	63752.0	kg
Maximum Pool Fire Duration based on Direct Fire	513.2	minutes
Fire Heat Input per API 2000 or NFPA 30 for Storage or Low Pressure Tank	10222235.8	Kwatt

Relief Device may not be adequately sized for Pool Fire Exposure

Contents Reach Relief Conditions at Pool Fire Duration

Contents Reach Failure or Rupture Conditions at Pool Fire Duration

Figure 2.14: Hazard Summary Part 3 – Reactivity and Fire Information

Consequence Summary

A summary of potential Consequences for a variety of Loss Events based on a single Equipment Item is provided in the Consequence Summary. The **Loss Event** is selected and estimation results for Airborne Quantity, Vapor Dispersion, Explosion, and Impact Assessment including ***LOPA Tolerable Frequency Factor*** and ***Occupied Building Impacts*** are displayed.

IMPORTANT: The Consequence Analysis in RAST is based on "steady state" rather than dynamic conditions at the chemical composition and flow rate entered on the Chemical Data and Process Conditions input worksheets. Several unit operations may require dynamic simulation to perform detailed hazard and risk evaluation rather than use of "average" composition or process conditions used by RAST. Units where composition changes over time or location within the equipment would be reactors or distillation columns. The liquid or vapor velocity within piping systems may also be time or location dependent. In these cases, the User needs to determine if RAST is capable of providing the accuracy and level of detail needed.

Loss Event Categories are aligned to specific discharge models including:

- Hole Size where release rate is determined by modeling the discharge from a hole of specified diameter, process pressure, and fluid density. A small hole (5 to 15 mm) may represent gasket failure or leaks from mechanical pump seals. A medium hole (25 mm) may represent significant equipment or piping leaks, while a large hole (100 mm to full bore) represents hose, pipe, or equipment nozzle failure.
- Overflow or Specified Rate where release rate is determined from the feed or other specified release rate.

- Excessive Heat where release rate is determined from the rate of heat input divided by the heat of vaporization.
- Equipment Rupture represents a sudden release of the entire contents and may apply to both energy and hazardous chemical releases.

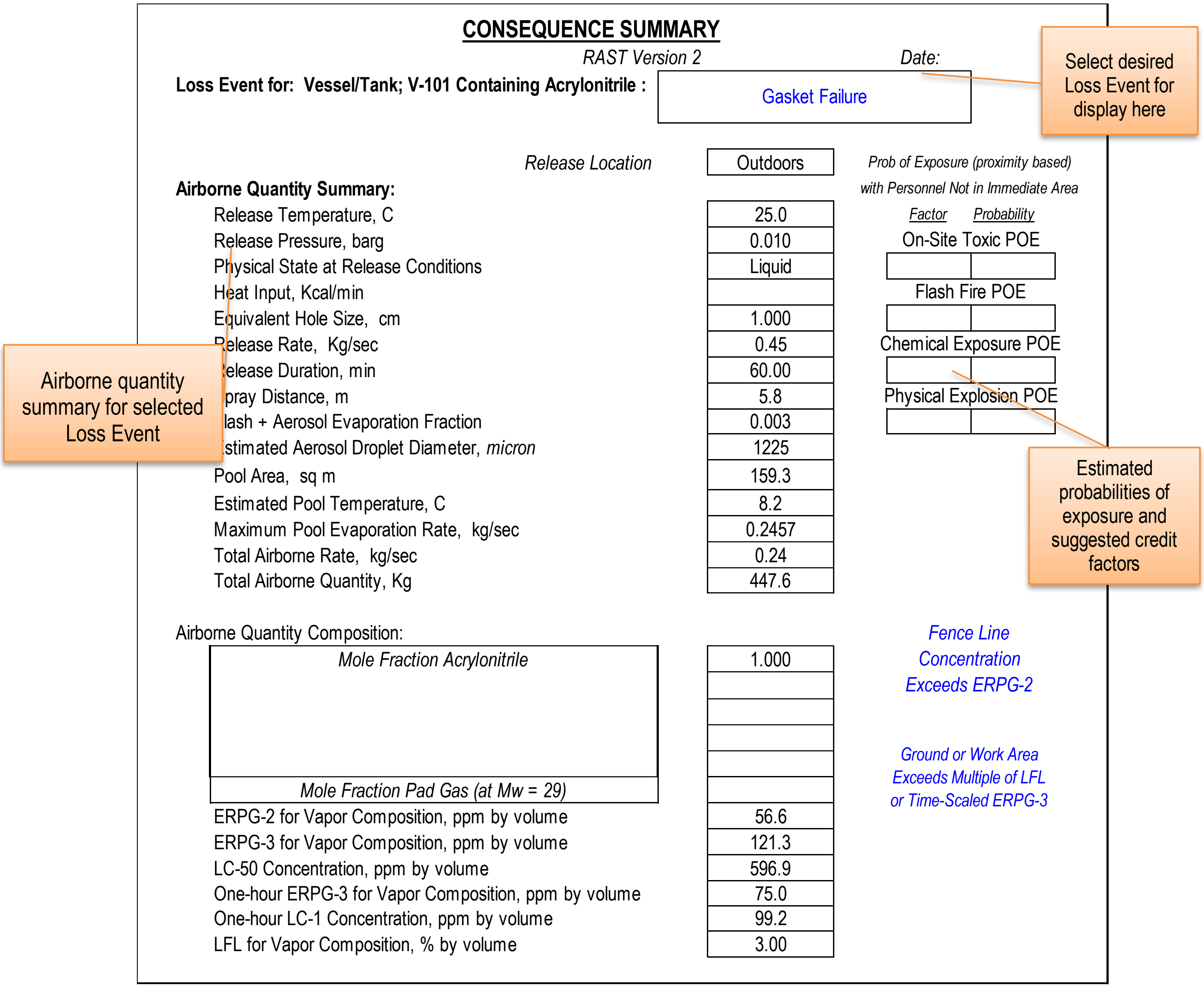
Airborne Quantity for liquid releases involves estimation of liquid release rate, flash fraction, aerosol evaporation fraction, and evaporation from liquid pools.

Vapor Dispersion involves estimation of concentration and distance by jet mixing or atmospheric dispersion for continuous or instantaneous releases. The effects of buoyancy, momentum, elevation, and ventilation for indoor releases are also considered.

Explosions include Physical Explosion (equipment rupture), outdoor Vapor Cloud Explosion, and indoor Building (or confined space) Explosion. Hazard and damage level are related to blast overpressure with distance from the explosion epicenter.

Impact Assessment involves estimation of the number of people potentially impacted by various Incident Outcomes including Flash Fire, Vapor Cloud Explosion, Building Explosion, Physical Explosion, Toxic Release and Chemical Exposure. Impacts to personnel outdoors, within enclosed process areas, and within occupied buildings are considered. If the Study Parameter option to represent consequence severity is set as “Hazard Distance”, the Impact Assessment, severity is estimated from Vapor Dispersion and Explosion estimates rather than number of people.

Figure 2.15, 2.16 & 2.17 show the Consequence summary for the Acrylonitrile example.



CONSEQUENCE SUMMARY

RAST Version 2 *Date:*

Loss Event for: Vessel/Tank; V-101 Containing Acrylonitrile : Gasket Failure

Select desired Loss Event for display here

Release Location Outdoors

Airborne Quantity Summary:

Release Temperature, C	25.0
Release Pressure, barg	0.010
Physical State at Release Conditions	Liquid
Heat Input, Kcal/min	
Equivalent Hole Size, cm	1.000
Release Rate, Kg/sec	0.45
elease Duration, min	60.00
pray Distance, m	5.8
lash + Aerosol Evaporation Fraction	0.003
stimated Aerosol Droplet Diameter, *micron*	1225
Pool Area, sq m	159.3
Estimated Pool Temperature, C	8.2
Maximum Pool Evaporation Rate, kg/sec	0.2457
Total Airborne Rate, kg/sec	0.24
Total Airborne Quantity, Kg	447.6

Airborne quantity summary for selected Loss Event

Prob of Exposure (proximity based)

with Personnel Not in Immediate Area

	Factor	*Probability*
On-Site Toxic POE		
Flash Fire POE		
Chemical Exposure POE		
Physical Explosion POE		

Estimated probabilities of exposure and suggested credit factors

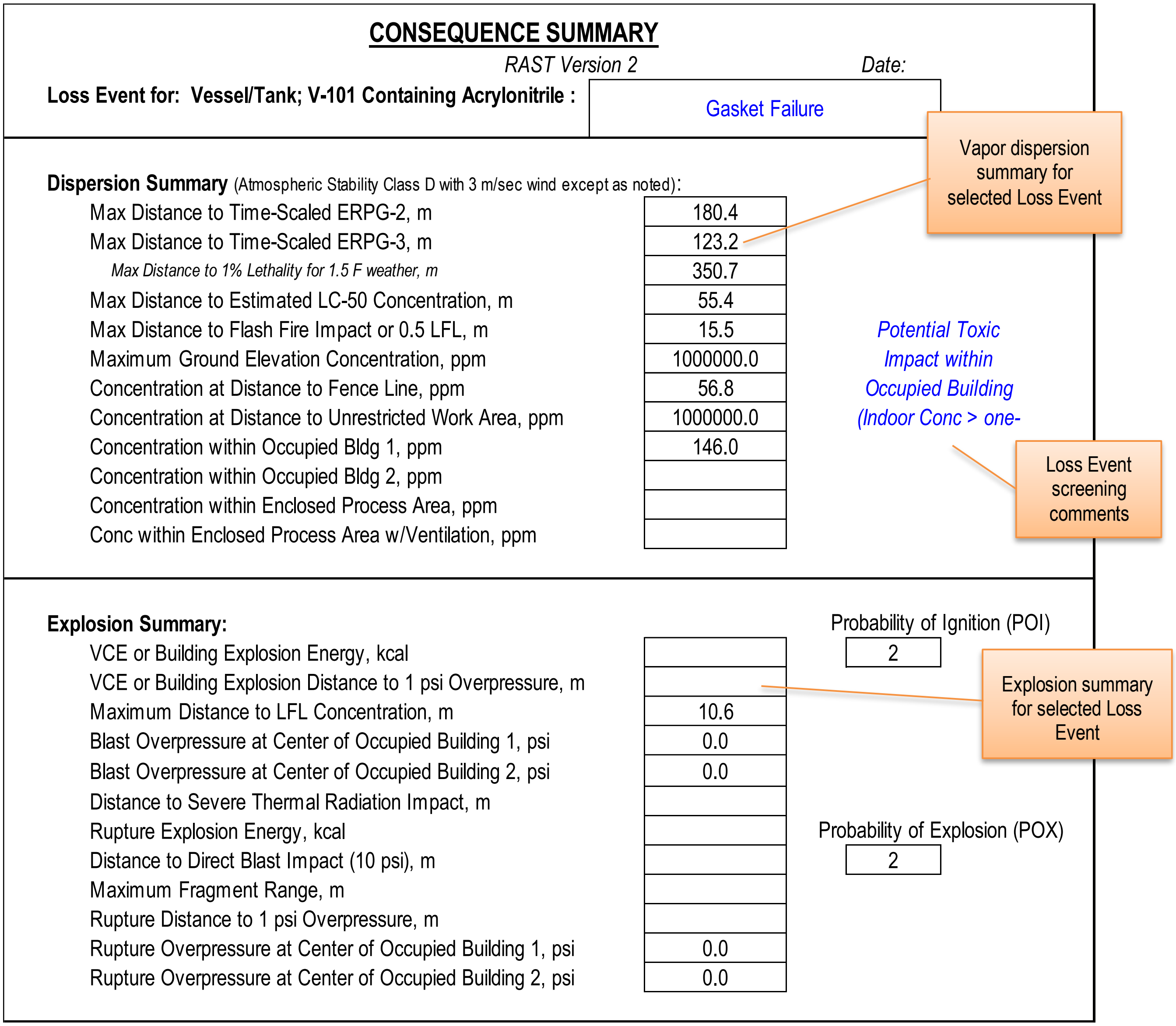
Airborne Quantity Composition:

Mole Fraction Acrylonitrile	1.000
Mole Fraction Pad Gas (at Mw = 29)	
ERPG-2 for Vapor Composition, ppm by volume	56.6
ERPG-3 for Vapor Composition, ppm by volume	121.3
LC-50 Concentration, ppm by volume	596.9
One-hour ERPG-3 for Vapor Composition, ppm by volume	75.0
One-hour LC-1 Concentration, ppm by volume	99.2
LFL for Vapor Composition, % by volume	3.00

Fence Line Concentration Exceeds ERPG-2

Ground or Work Area Exceeds Multiple of LFL or Time-Scaled ERPG-3

Figure 2.15: Consequence Summary for Acrylonitrile example part 1



CONSEQUENCE SUMMARY

RAST Version 2 *Date:*

Loss Event for: Vessel/Tank; V-101 Containing Acrylonitrile : Gasket Failure

Dispersion Summary (Atmospheric Stability Class D with 3 m/sec wind except as noted):

Max Distance to Time-Scaled ERPG-2, m	180.4
Max Distance to Time-Scaled ERPG-3, m	123.2
Max Distance to 1% Lethality for 1.5 F weather, m	350.7
Max Distance to Estimated LC-50 Concentration, m	55.4
Max Distance to Flash Fire Impact or 0.5 LFL, m	15.5
Maximum Ground Elevation Concentration, ppm	1000000.0
Concentration at Distance to Fence Line, ppm	56.8
Concentration at Distance to Unrestricted Work Area, ppm	1000000.0
Concentration within Occupied Bldg 1, ppm	146.0
Concentration within Occupied Bldg 2, ppm	
Concentration within Enclosed Process Area, ppm	
Conc within Enclosed Process Area w/Ventilation, ppm	

Potential Toxic Impact within Occupied Building (Indoor Conc > one-

Vapor dispersion summary for selected Loss Event

Loss Event screening comments

Explosion Summary:

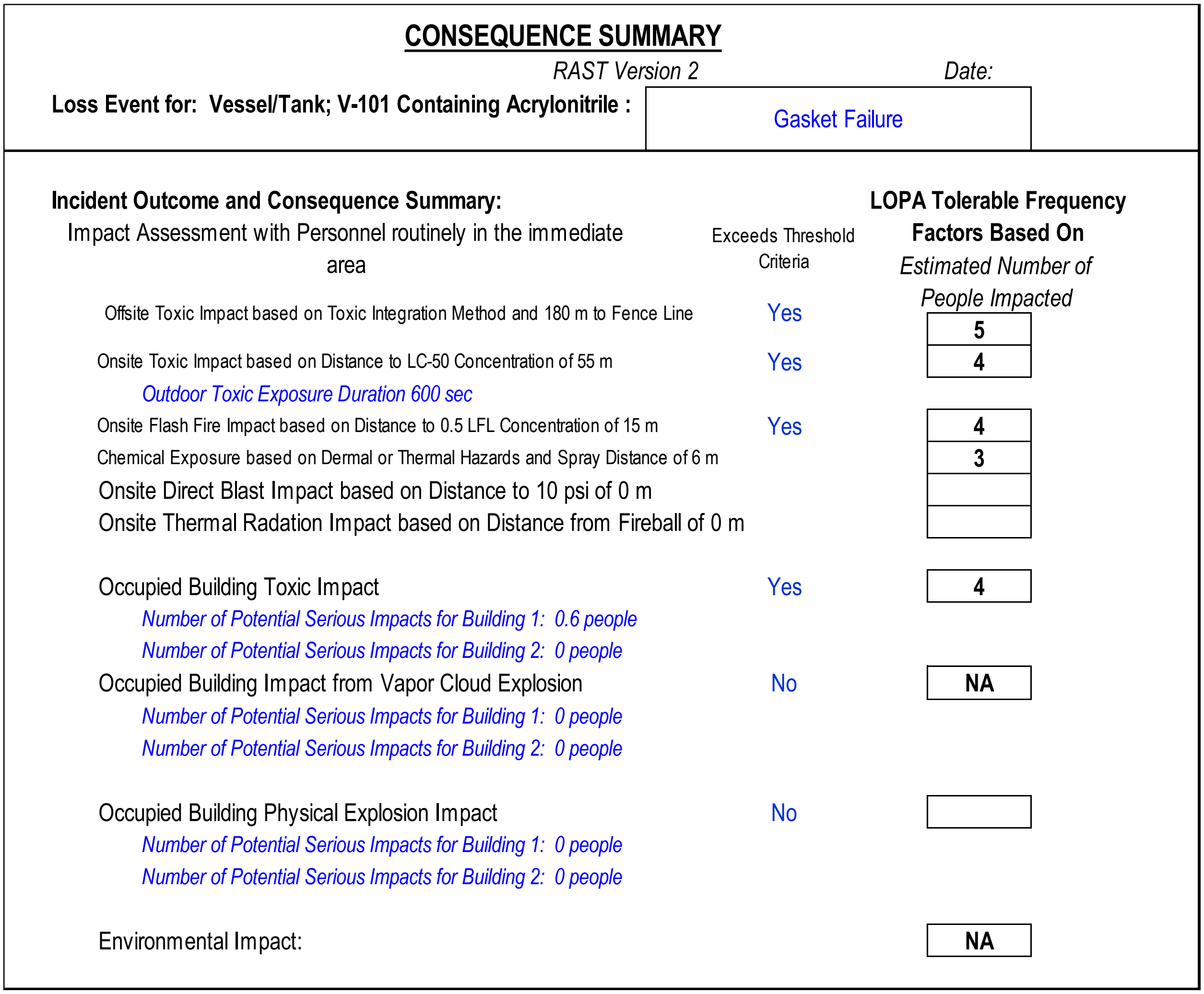
VCE or Building Explosion Energy, kcal	
VCE or Building Explosion Distance to 1 psi Overpressure, m	
Maximum Distance to LFL Concentration, m	10.6
Blast Overpressure at Center of Occupied Building 1, psi	0.0
Blast Overpressure at Center of Occupied Building 2, psi	0.0
Distance to Severe Thermal Radiation Impact, m	
Rupture Explosion Energy, kcal	
Distance to Direct Blast Impact (10 psi), m	
Maximum Fragment Range, m	
Rupture Distance to 1 psi Overpressure, m	
Rupture Overpressure at Center of Occupied Building 1, psi	0.0
Rupture Overpressure at Center of Occupied Building 2, psi	0.0

Probability of Ignition (POI): 2

Probability of Explosion (POX): 2

Explosion summary for selected Loss Event

Figure 2.16: Consequence Summary for Acrylonitrile example part 2 – Dispersion & Explosion Summary for Selected Loss Event



CONSEQUENCE SUMMARY

RAST Version 2 *Date:*

Loss Event for: Vessel/Tank; V-101 Containing Acrylonitrile : Gasket Failure

Incident Outcome and Consequence Summary:

Impact Assessment with Personnel routinely in the immediate area

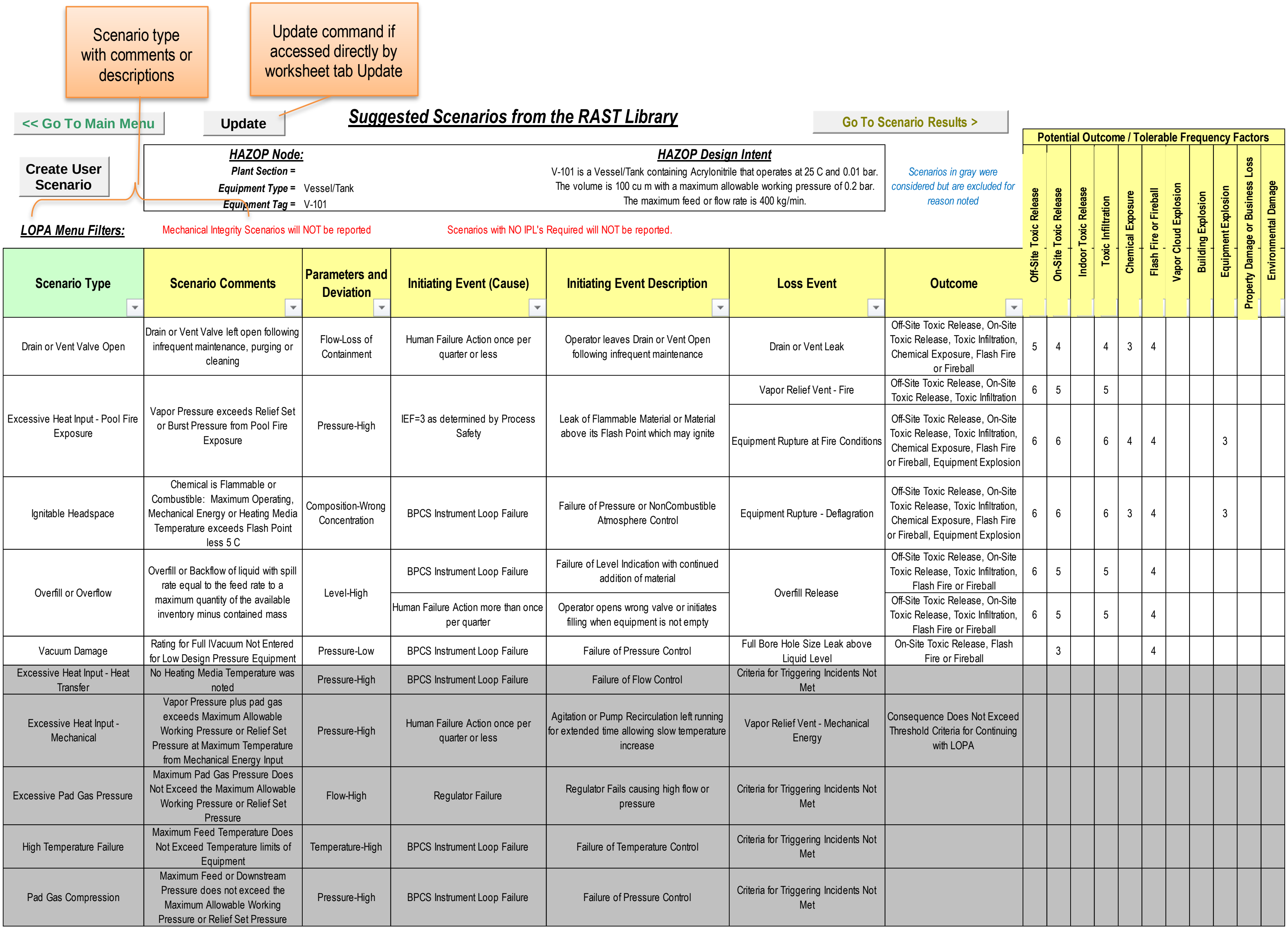
	Exceeds Threshold Criteria	**LOPA Tolerable Frequency Factors Based On** *Estimated Number of People Impacted*
Offsite Toxic Impact based on Toxic Integration Method and 180 m to Fence Line	Yes	**5**
Onsite Toxic Impact based on Distance to LC-50 Concentration of 55 m	Yes	**4**
Outdoor Toxic Exposure Duration 600 sec		
Onsite Flash Fire Impact based on Distance to 0.5 LFL Concentration of 15 m	Yes	**4**
Chemical Exposure based on Dermal or Thermal Hazards and Spray Distance of 6 m		**3**
Onsite Direct Blast Impact based on Distance to 10 psi of 0 m		
Onsite Thermal Radiation Impact based on Distance from Fireball of 0 m		
Occupied Building Toxic Impact	Yes	**4**
Number of Potential Serious Impacts for Building 1: 0.6 people		
Number of Potential Serious Impacts for Building 2: 0 people		
Occupied Building Impact from Vapor Cloud Explosion	No	**NA**
Number of Potential Serious Impacts for Building 1: 0 people		
Number of Potential Serious Impacts for Building 2: 0 people		
Occupied Building Physical Explosion Impact	No	
Number of Potential Serious Impacts for Building 1: 0 people		
Number of Potential Serious Impacts for Building 2: 0 people		
Environmental Impact:		**NA**

Figure 2.17: Consequence Summary for Acrylonitrile example part 3 – Impact Assessment Summary for Selected Loss Event including LOPA Tolerable Frequency Factor for Selected Loss Event

Scenario Identification

A library of scenarios has been developed from operational experience, incident history, and historical risk analysis studies. The scenario library in RAST is based on considering the entered Equipment Item as a study "node" for which common parameters and deviations are identified – a technique used in Hazard and Operability Studies (HAZOP). For simplified Process Risk Analysis, parameter deviations are primarily focused on those which could lead to an unintended release of hazardous material or energy (a Loss Event) impacting people or the environment. Few cases involving only Equipment Damage or Business Loss have been included.

Scenarios considered in the library not meeting a "feasibility" criterion are shown in gray and not included on the Scenario Results worksheet. The Scenario Identification list is intended to assist the Hazard Evaluation or Risk Analysis study team identify *what could go wrong* in the operation of the equipment item. This list is interactive: adding or modifying input information will update the list. If this worksheet is accessed directly by the worksheet tabs then the "Update" command should be used to ensure the information is current. Figure 2.18 shows the Suggested Scenario screen for some selected scenarios.



Scenario type with comments or descriptions

Update command if accessed directly by worksheet tab Update

Suggested Scenarios from the RAST Library

HAZOP Node:
Plant Section =
Equipment Type = Vessel/Tank
Equipment Tag = V-101

HAZOP Design Intent
V-101 is a Vessel/Tank containing Acrylonitrile that operates at 25 C and 0.01 bar.
The volume is 100 cu m with a maximum allowable working pressure of 0.2 bar.
The maximum feed or flow rate is 400 kg/min.

Scenarios in gray were considered but are excluded for reason noted

LOPA Menu Filters: Mechanical Integrity Scenarios will NOT be reported Scenarios with NO IPL's Required will NOT be reported.

							Potential Outcome / Tolerable Frequency Factors										
Scenario Type	**Scenario Comments**	**Parameters and Deviation**	**Initiating Event (Cause)**	**Initiating Event Description**	**Loss Event**	**Outcome**	**Off-Site Toxic Release**	**On-Site Toxic Release**	**Indoor Toxic Release**	**Toxic Infiltration**	**Chemical Exposure**	**Flash Fire or Fireball**	**Vapor Cloud Explosion**	**Building Explosion**	**Equipment Explosion**	**Property Damage or Business Loss**	**Environmental Damage**
Drain or Vent Valve Open	Drain or Vent Valve left open following infrequent maintenance, purging or cleaning	Flow-Loss of Containment	Human Failure Action once per quarter or less	Operator leaves Drain or Vent Open following infrequent maintenance	Drain or Vent Leak	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Chemical Exposure, Flash Fire or Fireball	5	4		4	3	4					
Excessive Heat Input - Pool Fire Exposure	Vapor Pressure exceeds Relief Set or Burst Pressure from Pool Fire Exposure	Pressure-High	IEF=3 as determined by Process Safety	Leak of Flammable Material or Material above its Flash Point which may ignite	Vapor Relief Vent - Fire	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration	6	5		5							
					Equipment Rupture at Fire Conditions	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Chemical Exposure, Flash Fire or Fireball, Equipment Explosion	6	6		6	4	4			3		
Ignitable Headspace	Chemical is Flammable or Combustible: Maximum Operating, Mechanical Energy or Heating Media Temperature exceeds Flash Point less 5 C	Composition-Wrong Concentration	BPCS Instrument Loop Failure	Failure of Pressure or NonCombustible Atmosphere Control	Equipment Rupture - Deflagration	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Chemical Exposure, Flash Fire or Fireball, Equipment Explosion	6	6		6	3	4			3		
Overfill or Overflow	Overfill or Backflow of liquid with spill rate equal to the feed rate to a maximum quantity of the available inventory minus contained mass	Level-High	BPCS Instrument Loop Failure	Failure of Level Indication with continued addition of material	Overfill Release	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Flash Fire or Fireball	6	5		5		4					
			Human Failure Action more than once per quarter	Operator opens wrong valve or initiates filling when equipment is not empty		Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Flash Fire or Fireball	6	5		5		4					
Vacuum Damage	Rating for Full IVacuum Not Entered for Low Design Pressure Equipment	Pressure-Low	BPCS Instrument Loop Failure	Failure of Pressure Control	Full Bore Hole Size Leak above Liquid Level	On-Site Toxic Release, Flash Fire or Fireball		3				4					
Excessive Heat Input - Heat Transfer	No Heating Media Temperature was noted	Pressure-High	BPCS Instrument Loop Failure	Failure of Flow Control	Criteria for Triggering Incidents Not Met												
Excessive Heat Input - Mechanical	Vapor Pressure plus pad gas exceeds Maximum Allowable Working Pressure or Relief Set Pressure at Maximum Temperature from Mechanical Energy Input	Pressure-High	Human Failure Action once per quarter or less	Agitation or Pump Recirculation left running for extended time allowing slow temperature increase	Vapor Relief Vent - Mechanical Energy	Consequence Does Not Exceed Threshold Criteria for Continuing with LOPA											
Excessive Pad Gas Pressure	Maximum Pad Gas Pressure Does Not Exceed the Maximum Allowable Working Pressure or Relief Set Pressure	Flow-High	Regulator Failure	Regulator Fails causing high flow or pressure	Criteria for Triggering Incidents Not Met												
High Temperature Failure	Maximum Feed Temperature Does Not Exceed Temperature limits of Equipment	Temperature-High	BPCS Instrument Loop Failure	Failure of Temperature Control	Criteria for Triggering Incidents Not Met												
Pad Gas Compression	Maximum Feed or Downstream Pressure does not exceed the Maximum Allowable Working Pressure or Relief Set Pressure	Pressure-High	BPCS Instrument Loop Failure	Failure of Pressure Control	Criteria for Triggering Incidents Not Met												

Figure 2.18: Portion of suggested Scenarios of Acrylonitrile example

Example Impact of Changes in Parameter Inputs

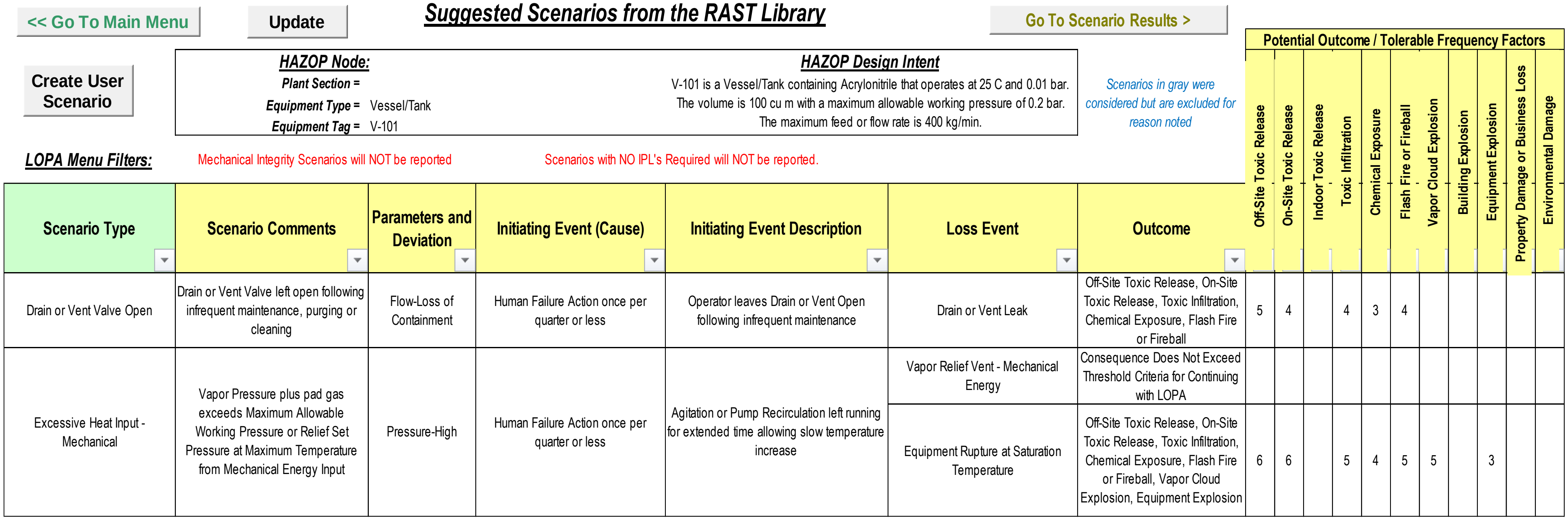
To demonstrate the impact of a Parameter Input change:

Select **Scenario Identification** from the Main Menu and view the Scenario List.

Return to the Main Menu and Select **Equipment Parameter Input**. Enter the input for **Insulation?** as **"Yes"**

Again, Select **Scenario Identification** from Main Menu.

Notice that a new scenario has been added (Figure 2.19):



Suggested Scenarios from the RAST Library

HAZOP Node:
Plant Section =
Equipment Type = Vessel/Tank
Equipment Tag = V-101

HAZOP Design Intent
V-101 is a Vessel/Tank containing Acrylonitrile that operates at 25 C and 0.01 bar. The volume is 100 cu m with a maximum allowable working pressure of 0.2 bar. The maximum feed or flow rate is 400 kg/min.

Scenarios in gray were considered but are excluded for reason noted

LOPA Menu Filters: Mechanical Integrity Scenarios will NOT be reported Scenarios with NO IPL's Required will NOT be reported.

Potential Outcome / Tolerable Frequency Factors

Scenario Type	Scenario Comments	Parameters and Deviation	Initiating Event (Cause)	Initiating Event Description	Loss Event	Outcome	Off-Site Toxic Release	On-Site Toxic Release	Indoor Toxic Release	Toxic Infiltration	Chemical Exposure	Flash Fire or Fireball	Vapor Cloud Explosion	Building Explosion	Equipment Explosion	Property Damage or Business Loss	Environmental Damage
Drain or Vent Valve Open	Drain or Vent Valve left open following infrequent maintenance, purging or cleaning	Flow-Loss of Containment	Human Failure Action once per quarter or less	Operator leaves Drain or Vent Open following infrequent maintenance	Drain or Vent Leak	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Chemical Exposure, Flash Fire or Fireball	5	4		4	3	4					
Excessive Heat Input - Mechanical	Vapor Pressure plus pad gas exceeds Maximum Allowable Working Pressure or Relief Set Pressure at Maximum Temperature from Mechanical Energy Input	Pressure-High	Human Failure Action once per quarter or less	Agitation or Pump Recirculation left running for extended time allowing slow temperature increase	Vapor Relief Vent - Mechanical Energy	Consequence Does Not Exceed Threshold Criteria for Continuing with LOPA											
					Equipment Rupture at Saturation Temperature	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Chemical Exposure, Flash Fire or Fireball, Vapor Cloud Explosion, Equipment Explosion	6	6		5	4	5	5		3		

Figure 2.19: New Scenario Added due to Adding Insulation

If the vessel is well insulated, then the small quantity of heat from the circulation may be able to slowly raise the maximum temperature to the point where vapor pressure of acrylonitrile exceeds the design limits of the equipment.

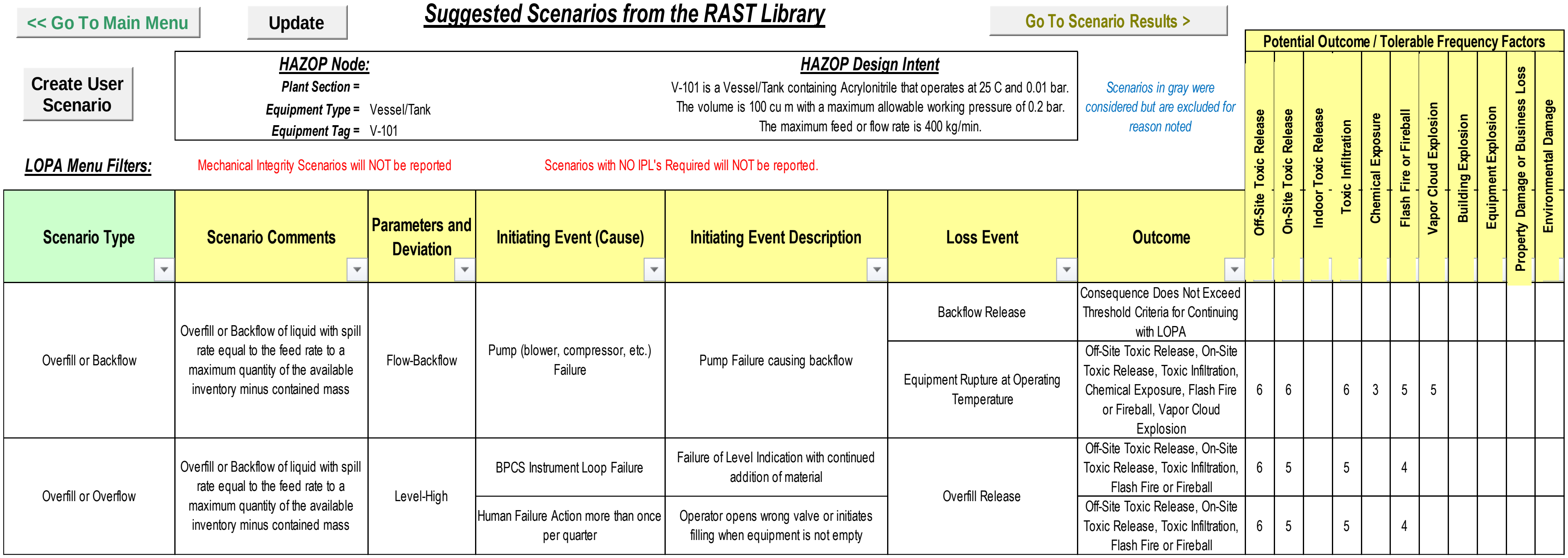
As another example:

Select **Process Conditions Input** from the Main Menu.

Enter for **Downstream Pressure** (gauge) **=** a value of **0.5 bar** to reflect the head of fluid downstream.

Return to the Main Menu and again select **Scenario Identification**.

Notice that the Overfill Scenario has been modified (Figure 2.20):



Suggested Scenarios from the RAST Library

HAZOP Node:
Plant Section =
Equipment Type = Vessel/Tank
Equipment Tag = V-101

HAZOP Design Intent
V-101 is a Vessel/Tank containing Acrylonitrile that operates at 25 C and 0.01 bar.
The volume is 100 cu m with a maximum allowable working pressure of 0.2 bar.
The maximum feed or flow rate is 400 kg/min.

Scenarios in gray were considered but are excluded for reason noted

LOPA Menu Filters: Mechanical Integrity Scenarios will NOT be reported Scenarios with NO IPL's Required will NOT be reported.

							Potential Outcome / Tolerable Frequency Factors										
Scenario Type	**Scenario Comments**	**Parameters and Deviation**	**Initiating Event (Cause)**	**Initiating Event Description**	**Loss Event**	**Outcome**	**Off-Site Toxic Release**	**On-Site Toxic Release**	**Indoor Toxic Release**	**Toxic Infiltration**	**Chemical Exposure**	**Flash Fire or Fireball**	**Vapor Cloud Explosion**	**Building Explosion**	**Equipment Explosion**	**Property Damage or Business Loss**	**Environmental Damage**
Overfill or Backflow	Overfill or Backflow of liquid with spill rate equal to the feed rate to a maximum quantity of the available inventory minus contained mass	Flow-Backflow	Pump (blower, compressor, etc.) Failure	Pump Failure causing backflow	Backflow Release	Consequence Does Not Exceed Threshold Criteria for Continuing with LOPA											
					Equipment Rupture at Operating Temperature	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Chemical Exposure, Flash Fire or Fireball, Vapor Cloud Explosion	6	6		6	3	5	5				
Overfill or Overflow	Overfill or Backflow of liquid with spill rate equal to the feed rate to a maximum quantity of the available inventory minus contained mass	Level-High	BPCS Instrument Loop Failure	Failure of Level Indication with continued addition of material	Overfill Release	Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Flash Fire or Fireball	6	5		5		4					
			Human Failure Action more than once per quarter	Operator opens wrong valve or initiates filling when equipment is not empty		Off-Site Toxic Release, On-Site Toxic Release, Toxic Infiltration, Flash Fire or Fireball	6	5		5		4					

Figure 2.20: Scenario Modification due to Adding Downstream Pressure

A second Loss Event has been added to reflect *backflow* as a means by which Overfill may occur. Also notice that additional Initiating Events may be added. Note that the backflow rate may also need to be entered for evaluation of Consequence. (The Outcome comments note that the Consequence Does Not Exceed Threshold Criteria for Continuing in LOPA".)

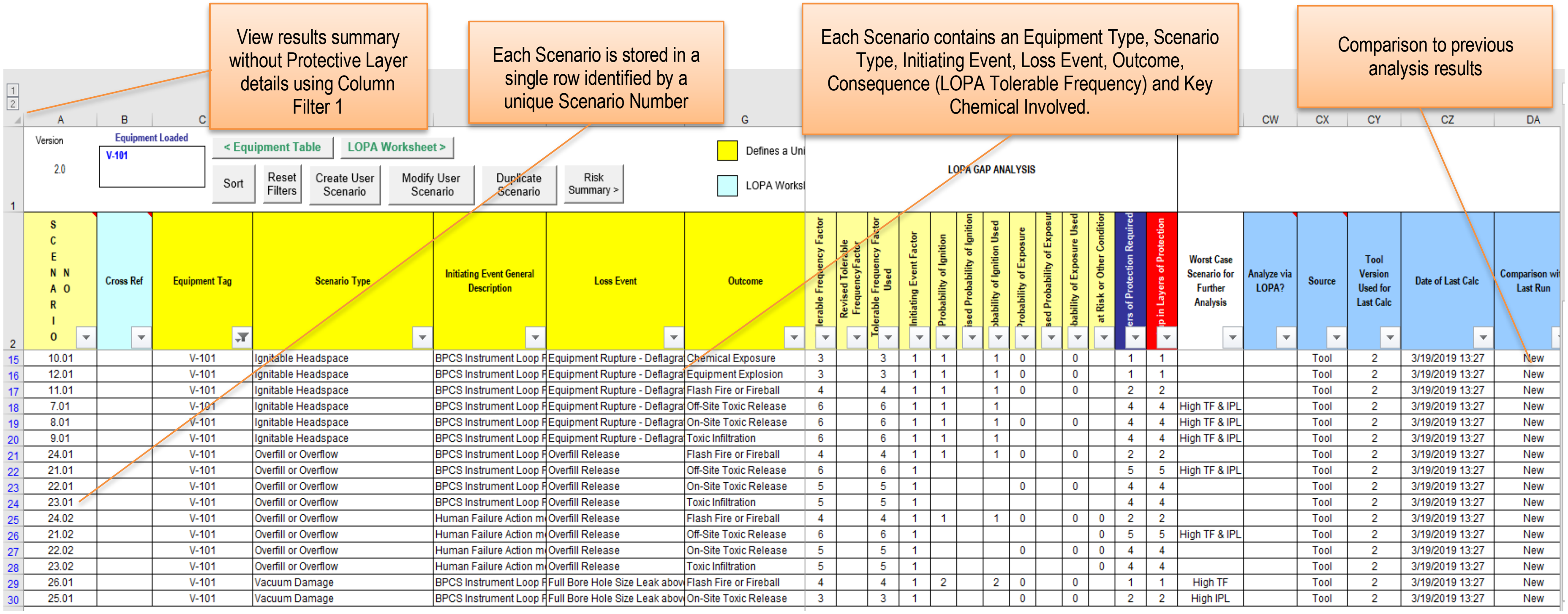
Saving Preliminary Analysis Results

From the Main Menu, Select **Go to Equipment Table**, select the cell containing V-101, and Select **Load Selected**. This will remove the changes in Insulation and Downstream Pressure inputs and return to the Main Menu. Select **Update Scenarios for Equipment Loaded** (black macro button). Results of the Preliminary Analysis will be stored on the Scenario Results worksheet in a single row identified by a unique Scenario Number. Results contain information regarding the type of equipment, scenario category, initiating event, loss event, incident outcome, consequence, a summary of release quantities and summary of hazard distance estimates.

The Scenario Results worksheet may be accessed from the LOPA Menu.

There is no "calculation" per se, but a capture of scenario information at a point in time based on the Input information available. If Inputs are changed and Update Scenarios for Equipment Loaded is initiated at a later time, estimates are compared to the previous values for each existing Scenario. When estimates do not match the previous estimate, the cell containing the changed results turns "green" and the prior values are stored in the cell comments. This allows the user to determine the impact of changes in the Input information.

An example of the Scenario Results worksheet is located in Figure 2.21



View results summary without Protective Layer details using Column Filter 1

Each Scenario is stored in a single row identified by a unique Scenario Number

Each Scenario contains an Equipment Type, Scenario Type, Initiating Event, Loss Event, Outcome, Consequence (LOPA Tolerable Frequency) and Key Chemical Involved.

Comparison to previous analysis results

	SCENARIO NO	Cross Ref	Equipment Tag	Scenario Type	Initiating Event General Description	Loss Event	Outcome	lerable Frequency Factor	Revised Tolerable FrequencyFactor	Tolerable Frequency Factor Used	Initiating Event Factor	Probability of Ignition	ised Probability of Ignition	obability of Ignition Used	Probability of Exposure	sed Probability of Exposur	bability of Exposure Used	at Risk or Other Conditior	ers of Protection Required	p in Layers of Protection	Worst Case Scenario for Further Analysis	Analyze via LOPA?	Source	Tool Version Used for Last Calc	Date of Last Calc	Comparison wi Last Run
15	10.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagra	Chemical Exposure	3		3	1	1		1	0		0		1	1			Tool	2	3/19/2019 13:27	New
16	12.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagra	Equipment Explosion	3		3	1	1		1	0		0		1	1			Tool	2	3/19/2019 13:27	New
17	11.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagra	Flash Fire or Fireball	4		4	1	1		1	0		0		2	2			Tool	2	3/19/2019 13:27	New
18	7.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagra	Off-Site Toxic Release	6		6	1	1		1					4	4	High TF & IPL		Tool	2	3/19/2019 13:27	New
19	8.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagra	On-Site Toxic Release	6		6	1	1		1	0		0		4	4	High TF & IPL		Tool	2	3/19/2019 13:27	New
20	9.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagra	Toxic Infiltration	6		6	1	1		1					4	4	High TF & IPL		Tool	2	3/19/2019 13:27	New
21	24.01		V-101	Overfill or Overflow	BPCS Instrument Loop F	Overfill Release	Flash Fire or Fireball	4		4	1	1		1	0		0		2	2			Tool	2	3/19/2019 13:27	New
22	21.01		V-101	Overfill or Overflow	BPCS Instrument Loop F	Overfill Release	Off-Site Toxic Release	6		6	1								5	5	High TF & IPL		Tool	2	3/19/2019 13:27	New
23	22.01		V-101	Overfill or Overflow	BPCS Instrument Loop F	Overfill Release	On-Site Toxic Release	5		5	1				0		0		4	4			Tool	2	3/19/2019 13:27	New
24	23.01		V-101	Overfill or Overflow	BPCS Instrument Loop F	Overfill Release	Toxic Infiltration	5		5	1								4	4			Tool	2	3/19/2019 13:27	New
25	24.02		V-101	Overfill or Overflow	Human Failure Action m	Overfill Release	Flash Fire or Fireball	4		4	1	1		1	0		0	0	2	2			Tool	2	3/19/2019 13:27	New
26	21.02		V-101	Overfill or Overflow	Human Failure Action m	Overfill Release	Off-Site Toxic Release	6		6	1							0	5	5	High TF & IPL		Tool	2	3/19/2019 13:27	New
27	22.02		V-101	Overfill or Overflow	Human Failure Action m	Overfill Release	On-Site Toxic Release	5		5	1				0		0	0	4	4			Tool	2	3/19/2019 13:27	New
28	23.02		V-101	Overfill or Overflow	Human Failure Action m	Overfill Release	Toxic Infiltration	5		5	1							0	4	4			Tool	2	3/19/2019 13:27	New
29	26.01		V-101	Vacuum Damage	BPCS Instrument Loop F	Full Bore Hole Size Leak abov	Flash Fire or Fireball	4		4	1	2		2	0		0		1	1	High TF		Tool	2	3/19/2019 13:27	New
30	25.01		V-101	Vacuum Damage	BPCS Instrument Loop F	Full Bore Hole Size Leak abov	On-Site Toxic Release	3		3	1				0		0		2	2	High IPL		Tool	2	3/19/2019 13:27	New

Figure 2.21: Preliminary Analysis Results

3. CHEMICAL DATA

The chemical and physical properties of materials handled are fundamental in Hazard Evaluation and Risk Analysis. RAST contains a small chemical database and allows modification or creation of key chemical parameters for single components and mixtures.

This section contains:

- The simple correlations used for common chemical properties as a function of temperature.
- How to enter chemical properties for a new chemical.
- How to create a mixture from listed chemicals.
- How vapor composition is estimated in RAST from liquid composition assuming an “ideal” mixture.

Chemical Property Correlations in RAST

Chemical Properties are needed at several temperatures to perform screening calculations. The following are simple correlations of key chemical properties used in RAST that require only two data points at different temperatures in the region of interest.

Vapor Pressure: $\ln (P^{sat}) = a - b / (T - c)$. *The “c” constant is 0 if only two data points are used with T in deg K*

Liquid Density: $\rho = a - b\,T$

Liquid Heat Capacity: $C_S = a + b\,T$

Heat of Vaporization: $\lambda = a - b\,T - c\,T^2$. *The “c” constant is zero if only two data points are used.*

Vapor density may be estimated as an ideal gas by:

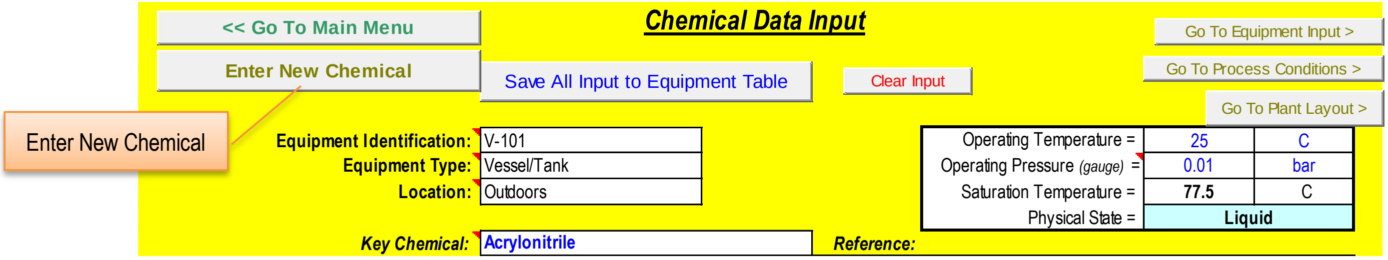
$\rho_V = 0.12\ P\ Mw / T$ *where P is pressure in kPa and T in deg K*

Note that values of the coefficients in the above correlations are typically positive numbers as the “sign” is part of the correlating equation.

The simple property correlations in RAST due not include an equation of state (vapor is estimated as an ideal gas). This **limitation will result in less accuracy for equipment operating with liquid at elevated temperature and pressure** (such as a liquefied gas operating near the critical temperature of the material). In some cases, it may be necessary to utilize more advanced software in estimation of thermodynamic properties for determination of material or energy release rate near the critical point.

Entering New Chemical Properties

A fairly comprehensive list of chemical properties is available within the RAST Chemical Data Table. However, if a chemical is not listed or the User wants to modify the available data, the **Enter New Chemical** option must be used. Note that to create a chemical mixture, the properties for *each* component must be available from the Chemical Table listing. Refer to Figure 3.1.



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

Operating Temperature = 25 C
Operating Pressure (gauge) = 0.01 bar
Saturation Temperature = 77.5 C
Physical State = Liquid

Key Chemical: Acrylonitrile
Reference:

Figure 3.1: Entering a New Chemical

From the Chemical Data worksheet, select **Enter New Chemical**. One may begin with properties from an existing chemical by selecting a Chemical Name under the column "Starting chemical that is similar" or merely enter values under the column "User Supplied Values". Note that if any chemical property is updated by the user, then the chemical needs to be saved using a different Chemical Name to be available on the chemical listing.

Select **Save Data to Chemical Table** to save information as a "user" chemical for use within the current RAST file. All "user" chemicals will be included in new RAST files that are "imported" from this file. Contact a RAST administrator for addition, update, or deletion of chemical information in the globally available list within the RAST tool.

Example Entry of New Chemical Properties

As an example, we will enter data for t-butyl amine (CAS 75-64-9) as a new chemical. The input information may come from a variety of sources, including various Physical Property Databases, Vendor NFPA Ratings, American Industrial Association ERPG values (or US Department of Transportation Protective Action Criteria), Material Safety Datasheets, or other literature references.

STEP 1: Enter initial data.

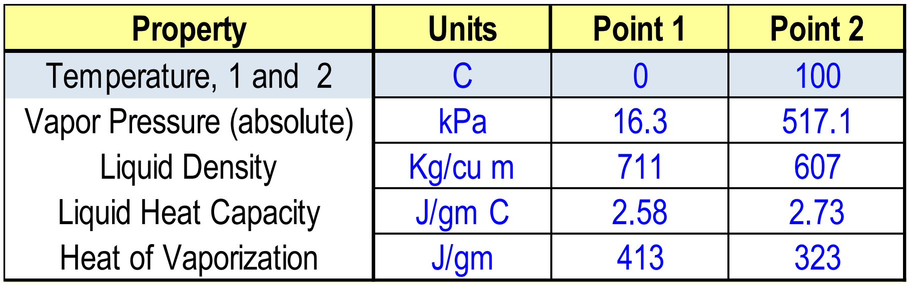
Molecular Weight: 73.14

Melting Point: -86.7 deg C

Boiling Point: 44.4 deg C

Select two temperatures to correlate vapor pressure, liquid density, liquid heat capacity and heat of vaporization. These temperatures should be selected to represent the region of interest (including operating temperature, ambient temperature, boiling point, etc.) and fall between the melting point to less than 0.8 of the critical temperature (if known) or roughly 1.2 times the boiling point in deg K. *(In this example, the critical temperature is listed as 211 deg C or 484 deg K such that 0.8 of the critical temperature is 387 deg K or 114 deg C.)* Temperatures of 0 deg C and 100 deg C are selected. Liquid properties values at "saturation" (pressure equals vapor pressure) are typically used.

***STEP 2: Enter chemical property data at the two selected temperatures*.** Using data from external sources in Figure 3.2:



Property	Units	Point 1	Point 2
Temperature, 1 and 2	C	0	100
Vapor Pressure (absolute)	kPa	16.3	517.1
Liquid Density	Kg/cu m	711	607
Liquid Heat Capacity	J/gm C	2.58	2.73
Heat of Vaporization	J/gm	413	323

Figure 3.2: Chemical Properties from External Sources

STEP 3: Enter remaining available chemical data from the supplier Material Safety Data Sheet (MSDS), ERPG Database, and other sources into the center (white) column.

Flash Point: -8 deg C
Lower Flammable Limit: 1.7 volume %
Upper Flammable Limit: 8.9 volume %
Autoignition Temperature: 380 deg C
ERPG-2: 0.38 ppm

ERPG-3: 56 ppm
NFPA-Health Rating: 3
NFPA-Flammability Rating: 3
NFPA-Stability Rating: 0

STEP 4: Enter Ease of Ignition category if there is sufficient information to indicate this hazard characteristic is outside of the default category of "Normal". Categories are Low, Normal, Elevated, and High Ignition based on heat of oxidation, Minimum Ignition Energy, Auto-Ignition Temperature, Fundamental Burning Velocity, and other rating systems such as Maximum Experimental Safe Gap. These categories are described in a report titled "Assessing Probability of Ignition (POI) of Gases and Vapors with Deflagration Potential", Larry G. Britton, Neolytica Inc, March 10th, 2005. Examples of materials in the different Ignition Probability categories:

- ***Low:*** ammonia, methylene chloride, and trichloroethylene
- ***Normal:*** n-butane, propylene, acetone, methane, and methanol
- ***Elevated:*** hydrogen, acetylene, ethylene oxide, propylene oxide, carbon disulfide, and ethylene
- ***High:*** silane and various alkyl aluminum compounds (normally described as pyrophoric)

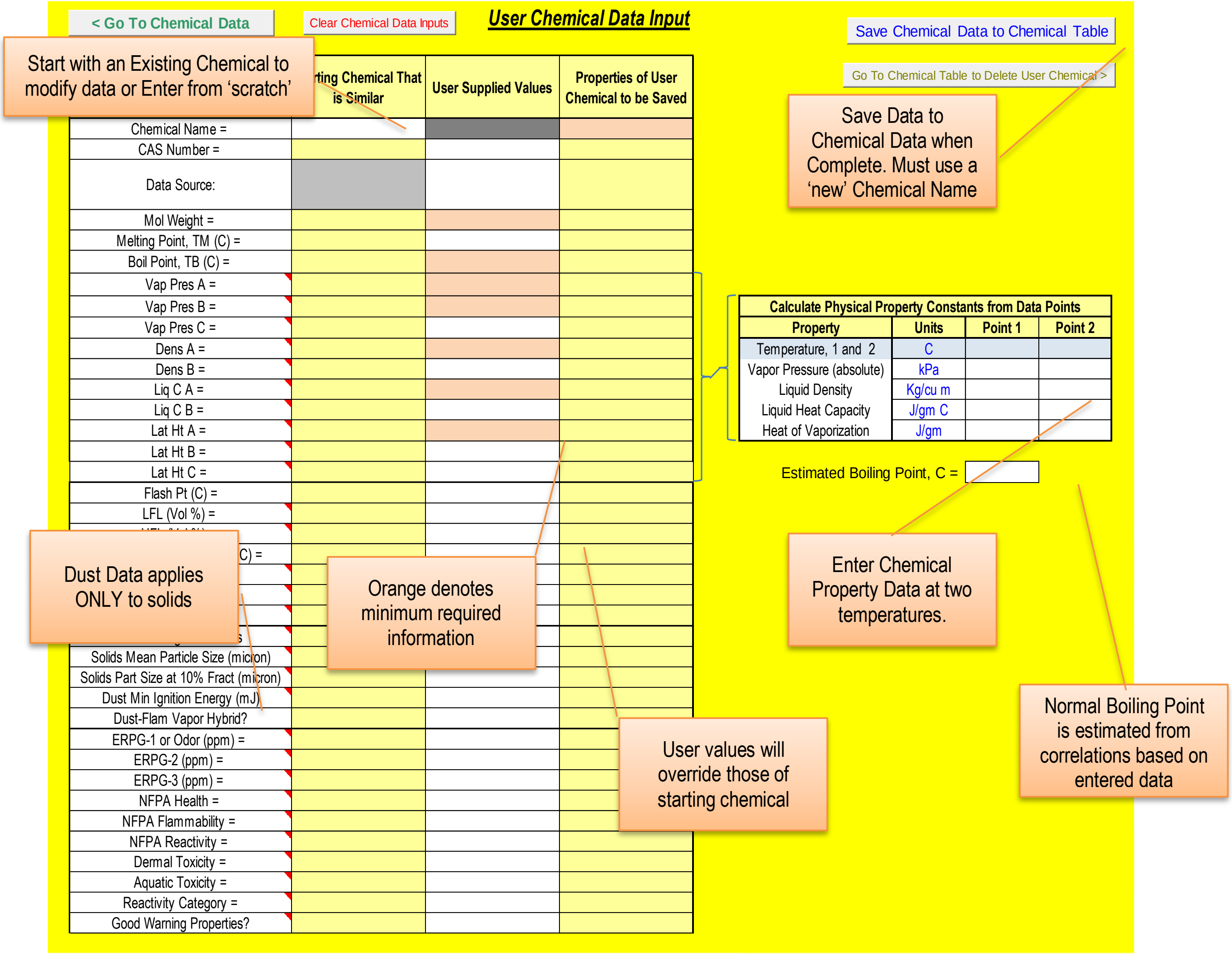
STEP 5: Enter Fuel Reactivity category if there is sufficient information to indicate this hazard characteristic is outside of the default category of "Medium". Categories are Low, Medium, and High based on Fundamental Burning Velocity of less than 45 cm/sec, between 45 and 75 cm/sec and greater than 75 cm/sec respectively.

STEP 6: Enter Conductivity category if there is sufficient information to indicate this hazard characteristic is outside of the default category of "Semi-Conductive". Categories are Non-Conductive, Semi-Conductive, and Conductive based on liquid electrical conductivity of less than 100 pico-siemen/meter (pS/m), between 100 and 10000 pS/m and greater than 10000 pS/m respectively.

STEP 7: Enter Dermal and Aquatic Toxicity category if there is sufficient information to indicate a toxicity hazard based on (United Nations) Globally Harmonized System or European Dangerous Substances Directive categories.

STEP 8: Enter Dust Hazard Classification if the material is a solid and there is sufficient information to indicate dust flammability hazard. Often this information is specific to the equipment in which the dust is handled and, therefore, not saved to the Chemical Table. In those cases, the dust classification information is entered and saved to the Equipment Table from the Chemical Data or Main Menu.

Refer to Figure 3.3 for the User Chemical Data Input screen.



User Chemical Data Input

	ting Chemical That is Similar	User Supplied Values	Properties of User Chemical to be Saved
Chemical Name =			
CAS Number =			
Data Source:			
Mol Weight =			
Melting Point, TM (C) =			
Boil Point, TB (C) =			
Vap Pres A =			
Vap Pres B =			
Vap Pres C =			
Dens A =			
Dens B =			
Liq C A =			
Liq C B =			
Lat Ht A =			
Lat Ht B =			
Lat Ht C =			
Flash Pt (C) =			
LFL (Vol %) =			
C) =			
s			
Solids Mean Particle Size (micron)			
Solids Part Size at 10% Fract (micron)			
Dust Min Ignition Energy (mJ)			
Dust-Flam Vapor Hybrid?			
ERPG-1 or Odor (ppm) =			
ERPG-2 (ppm) =			
ERPG-3 (ppm) =			
NFPA Health =			
NFPA Flammability =			
NFPA Reactivity =			
Dermal Toxicity =			
Aquatic Toxicity =			
Reactivity Category =			
Good Warning Properties?			

Calculate Physical Property Constants from Data Points

Property	Units	Point 1	Point 2
Temperature, 1 and 2	C		
Vapor Pressure (absolute)	kPa		
Liquid Density	Kg/cu m		
Liquid Heat Capacity	J/gm C		
Heat of Vaporization	J/gm		

Estimated Boiling Point, C =

Start with an Existing Chemical to modify data or Enter from 'scratch'

Save Data to Chemical Data when Complete. Must use a 'new' Chemical Name

Dust Data applies ONLY to solids

Orange denotes minimum required information

Enter Chemical Property Data at two temperatures.

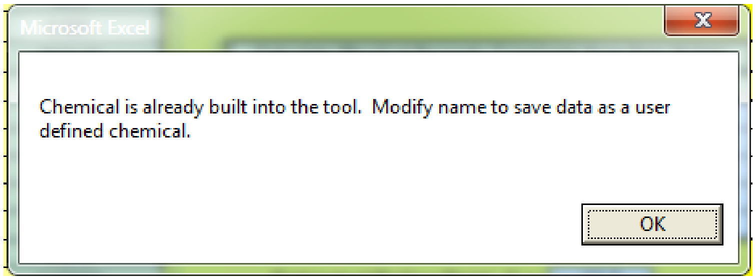
User values will override those of starting chemical

Normal Boiling Point is estimated from correlations based on entered data

Figure 3.3: New Chemical Data Input

STEP 9: Enter the Chemical Name under "Properties of New Chemical to be saved" and select Save Chemical Data to Chemical Table.

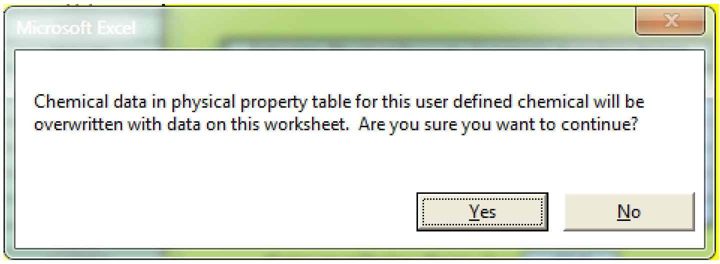
If a Chemical Name is selected that has already been used in the Chemical Table, a dialog box appears as a reminder that the data will not be saved under the selected name. Merely enter "OK" and select another Chemical Name. See Figure 3.4.



Chemical is already built into the tool. Modify name to save data as a user defined chemical.

Figure 3.4: Error if choose already existing name

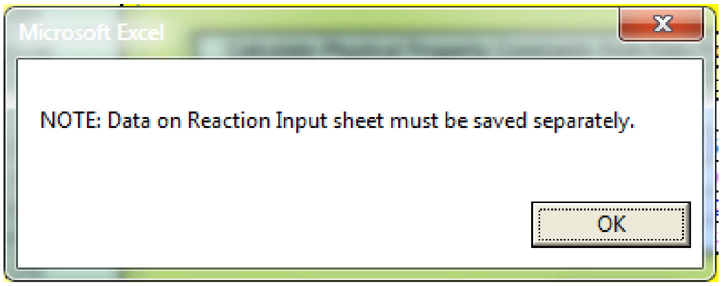
If a User specified Chemical Name is selected that already exists in the Chemical Table, a dialog box appears. If merely updating data for a User specified Chemical, enter "OK". See Figure 3.5.



Chemical data in physical property table for this user defined chemical will be overwritten with data on this worksheet. Are you sure you want to continue?

Figure 3.5: Dialog box to ensure you want to overwrite chemical data

Since Reaction Data may be saved to the Chemical Table for User specified Chemicals, a reminder that reaction information must be entered and saved from the Reaction Input worksheet appears, enter "OK". See Figure 3.6.



NOTE: Data on Reaction Input sheet must be saved separately.

Figure 3.6: Reminder to enter Reaction Data

Chemical Mixtures

Where it is necessary to consider mixtures, simple methods based on selection of one component as a Key Chemical are presented below. These methods are generally sufficient for hazard evaluation over a narrow temperature range which should include the operating temperature, ambient temperature and the normal boiling point. The following "Mixture Rules" provide a reasonable estimate for selected chemical properties. Either mass fraction with property per unit mass or mole fraction with property per mole may be used.

Mixture Liquid Density may be estimated by additive volumes:

$1/\rho$ mixture = sum of liquid fraction divided by density of each component.

> *Example: Estimate liquid density for a mixture of 50 wt% A at 1.0 gm/cc and 50 wt% B at .0.6 gm/cc. Mixture volume = 0.5 / 1 + 0.5 / 0.6 = 1.333 cc/gm, and mixture density = 1 /1.333 = 0.75 gm/cc*

Mixture Vapor Density may be estimated as an ideal gas as:

$\rho_V = 0.12\ P\ Mw_{avg} / T$

where ρ_V is vapor density (kg/m3), P is pressure (kPa), T is temperature (deg K), Mw is average molecular weight of the vapor mixture.

> Example: Estimate the vapor density for a mixture of 50 wt% A of molecular weight 30 and 50% wt% B of molecular weight 100 at 101.3 kPa pressure and 298 K. The average molecular weight is 1 / (0.5/30 + 0.5/100) = 46.2. $\rho_V = 0.12\ P\ Mw_{avg} / T = 0.12\ (101.2)\ 46.2 / 298 = 1.88$ kg/m^3.

Mixture Liquid Heat Capacity may be estimated as the sum of liquid fraction times Heat Capacity for each component.

> *Example: Estimate liquid heat capacity for a mixture of 50 wt% A at 1.5 joule/gm and 50 wt% B at 3 joule/gm. Mixture heat capacity = 0.5 (1.5) + 0.5 (3) = 2.25 joule/gm C*

Mixture Heat of Vaporization may be estimated as the sum of vapor fraction times Heat of Vaporization for each component.

> *Example: Estimate the heat of vaporization for a vapor mixture of 50 wt% A at 600 joule/gm and 50 wt% B at 400 joule/gm. Mixture heat of vaporization = 0.5 (600) + 0.5 (400) = 500 joule/gm*

Vapor-Liquid Equilibrium in RAST

Mixture Vapor Pressure requires an estimation of the equilibrium vapor composition from a known liquid composition. For simple Risk Analysis, an ideal mixture is assumed where the partial vapor pressure of each component is equal to the pure component vapor pressure times its mole fraction in the liquid (Raoult's Law).

A further simplification is assumption of constant relative volatility and/or a constant ratio of vapor pressures over a narrow temperature range. The vapor-liquid equilibrium ratio for each component is $k_i = y_i / x_i$ where y_i is the mole fraction vapor for component i and x_i is the liquid mole fraction of component i. Relative Volatility is the ratio of k_i values which may be estimated relative to a "key chemical" as:

$$\alpha_i = k_i / k_{key} = x_{Key}\ y_i / (\ x_i\ y_{key}\ )$$

For an "ideal" mixture, the relative volatility is also the ratio of vapor pressures.

Note: The ratio of vapor pressure typically decreases with increasing temperature. Selection of the appropriate temperature range is important to provide a reasonable or conservative estimate of vapor composition from liquid composition.

Two liquid phases (each of which is assumed ideal) is used for mixtures of immiscible liquids. In these cases, each component is assumed to be present in either liquid phase A or liquid phase B. The mixture partial pressure is the sum of the partial pressure for each liquid phase. An activity coefficient for each component is estimated at the feed composition and assumed constant in the region of interest as:

$$\gamma_i - x'_i + x''_i / x_i$$

where: x'_i and x''_i are the liquid mole fractions of component i in liquid phase A and B respectively and x_i is the overall liquid mole fraction of component i. For a single liquid phase $\gamma_i = 1$.

The partial pressure for each component is determined as:

$$P_i = P^{sat}_i x_i \gamma_i$$

where: P^{sat}_i is the vapor pressure of component i.

The total pressure, Π, is estimated as the sum of partial pressures or:

$$\Pi = \Sigma P^{sat}_i x_i \gamma_i \quad \text{and} \quad \Pi = x_{key} \gamma_{key} P^{sat}_{key} / y_{key}$$

where:

x_i is the overall liquid mole fraction of component i
y_i is the vapor mole fraction of component i
γ_i is activity coefficient for component i
P^{sat}_i is the vapor pressure of component i
P_i is the partial pressure of component i
Π is the total pressure

Note that aqueous mixtures containing acids or bases are highly complex and not easily correlated by this simple model.

Example Entry of a Liquid Mixture

As an example, enter data for a mixture of 0.5 weight fraction acrylonitrile and 0.5 weight fraction water at an Operating Temperature of 25 C and Operating Pressure of 0.01 barg.

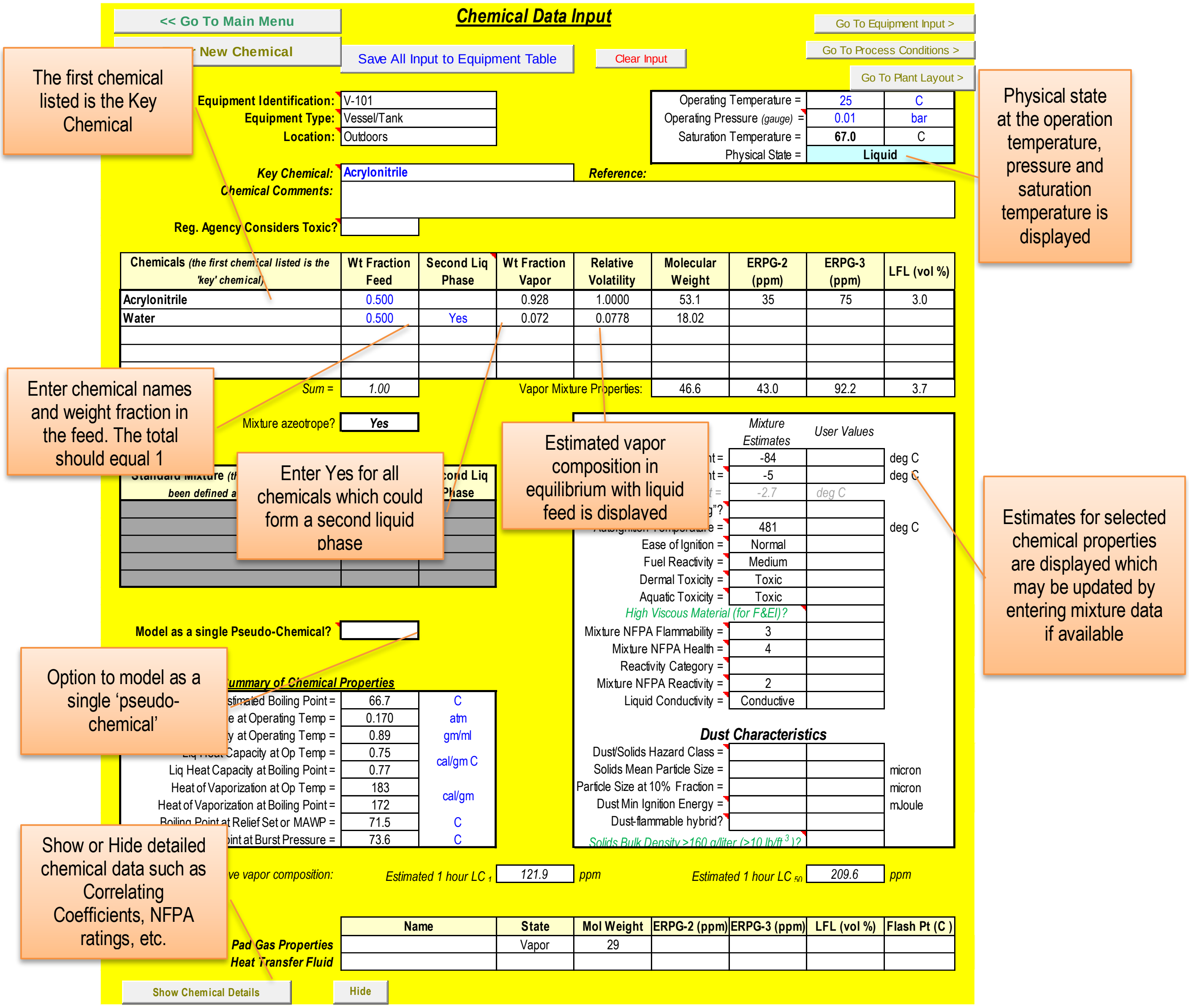
STEP 1: Enter liquid composition *on the Chemical Data worksheet. Enter 0.5 as the weight fraction for Acrylonitrile. Select "Water" as a second chemical from the chemical list and enter the weight fraction of 0.5.*

STEP 2: Enter which (if any) chemicals form a second liquid phase*. Enter "Yes" for Second Liquid Phase for Water. Note the change in vapor composition and estimated Saturation Temperature when "Yes" is entered. There is a significant difference in these estimates for two miscible versus immiscible liquids.*

STEP 3: Update mixture Flash Point, Melting Point, Autoignition Temperature, and categories for Ease of Ignition, Fuel Reactivity, Dermal Toxicity, Aquatic Toxicity, and Liquid Conductivity *as appropriate. These parameters are not accurately estimated for mixtures, such that values representing the "worst" chemical in the mixture are initially selected. An estimated mixture flash point is provided based on the temperature at which the equilibrium vapor composition at atmospheric pressure equals the estimated lower flammable limit. Experimentally determined values should always be entered if available.*

Observe the change in estimated boiling point between water as a second liquid phase or in solution*. Observe that changing the Operating Temperature to 80 C will change the Physical State to "Vapor".* See Figure 3.7.

Do Not Save this example. Clear Water inputs and change Weight Fraction Acrylonitrile in Feed to 1.0.



The first chemical listed is the Key Chemical

Physical state at the operation temperature, pressure and saturation temperature is displayed

Enter chemical names and weight fraction in the feed. The total should equal 1

Enter Yes for all chemicals which could form a second liquid phase

Estimated vapor composition in equilibrium with liquid feed is displayed

Estimates for selected chemical properties are displayed which may be updated by entering mixture data if available

Option to model as a single ‘pseudo-chemical’

Show or Hide detailed chemical data such as Correlating Coefficients, NFPA ratings, etc.

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

Operating Temperature =	25	C
Operating Pressure *(gauge)* =	0.01	bar
Saturation Temperature =	**67.0**	C
Physical State =	**Liquid**	

Key Chemical: Acrylonitrile
Reference:
Chemical Comments:
Reg. Agency Considers Toxic?

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 %)**
Acrylonitrile	0.500		0.928	1.0000	53.1	35	75	3.0
Water	0.500	Yes	0.072	0.0778	18.02			
Sum =	*1.00*		Vapor Mixture Properties:		46.6	43.0	92.2	3.7

Mixture azeotrope? ***Yes***

Model as a single Pseudo-Chemical?

ummary of Chemical Properties

stimated Boiling Point =	66.7	C
e at Operating Temp =	0.170	atm
y at Operating Temp =	0.89	gm/ml
Capacity at Op Temp =	0.75	cal/gm C
Liq Heat Capacity at Boiling Point =	0.77	
Heat of Vaporization at Op Temp =	183	cal/gm
Heat of Vaporization at Boiling Point =	172	
Boiling Point at Relief Set or MAWP =	71.5	C
int at Burst Pressure =	73.6	C

	Mixture Estimates	*User Values*	
nt =	-84		deg C
nt =	-5		deg C
t =	-2.7	deg C	
”?			
e =	481		deg C
Ease of Ignition =	Normal		
Fuel Reactivity =	Medium		
Dermal Toxicity =	Toxic		
Aquatic Toxicity =	Toxic		
High Viscous Material (for F&EI)?			
Mixture NFPA Flammability =	3		
Mixture NFPA Health =	4		
Reactivity Category =			
Mixture NFPA Reactivity =	2		
Liquid Conductivity =	Conductive		

Dust Characteristics

Dust/Solids Hazard Class =			
Solids Mean Particle Size =			micron
Particle Size at 10% Fraction =			micron
Dust Min Ignition Energy =			mJoule
Dust-flammable hybrid?			
Solids Bulk Density >160 g/liter (>10 lb/ft^3)?			

ve vapor composition: *Estimated 1 hour LC $_1$* *121.9* *ppm* *Estimated 1 hour LC $_{50}$* *209.6* *ppm*

	Name	**State**	**Mol Weight**	**ERPG-2 (ppm)**	**ERPG-3 (ppm)**	**LFL (vol %)**	**Flash Pt (C)**
Pad Gas Properties		Vapor	29				
Heat Transfer Fluid							

Figure 3.7: Chemical Mixture Data Input

Multi-component Flash and Evaporation in RAST

A single stage equilibrium flash is estimated in RAST assuming constant relative volatility. From a material balance:

$$F = V + L$$

$$F\, z_i = V\, y_i + L\, x_i$$

$$z_i = (V / F)\, y_i + (1 – V / F)\, x_i = F_V\, y_i + (1 – F_V)\, x_i$$

$$x_i = z_i / \{ F_V\, (y_i / x_i) + 1 – F_V \}$$

substituting $\alpha_i = k_i / k_{key} = x_{Key}\ y_i / (x_i\, y_{key})$ and $\Pi = x_{key}\, \gamma_{key}\, P^{sat}_{key} / y_{key}$ yields:

$$x_i = z_i / \{ F_V (\alpha_i \gamma_{key} P^{sat}_{key} / \Pi) + 1 - F_V \}$$

A heat balance of the system yields:

$$F_V = (T_0 - T) C_S / \lambda$$

A simple Rayleigh distillation (single equilibrium stage) is used in RAST for multi-component evaporation from a liquid pool once liquid feed to the pool has stopped. The material balance correlation is:

$$x_i = z_i \; e^{\alpha_i \ln [(1 - F_V) x_{key} / z_{key}]} / (1 - F_V)$$

where:

F *is molar flow rate of the feed stream*
L *is molar liquid flow rate following flash*
V *is molar vapor flow rate following flash*
z_i *is the feed mole fraction of component i*
x_i *is the liquid mole fraction of component I after flash or evaporation*
y_i *is the vapor mole fraction of component i after flash or evaporation*
x_{key} *is the liquid mole fraction of the key component after flash or evaporation*
y_{key} *is the vapor mole fraction of the key component after flash or evaporation*
z_{key} *is the overall feed mole fraction of the key component*
γ_{key} *is activity coefficient for the key component*
P^{sat}_{key} *is the vapor pressure of the key component at the final temperature*
F_V *is the flash fraction*
Π *is the total pressure after flash or evaporation*
T_0 *is the initial temperature*
T *is the final temperature after flash*
C_S *is the molar liquid heat capacity*
λ *is the molar heat of vaporization*

The above correlations are solved by trial-and-error for the temperature, T, at which both the material and energy balance is satisfied or $\Sigma x_i = 1$.

4. REACTIVITY DATA AND EVALUATION

Introduction

Evaluation of Reactivity Hazards is one of our most challenging activities. It often involves interpretation of Reactive Chemicals test data. RAST allows input of Reactive Chemicals testing data in addition to providing several screening analysis techniques.

This section covers:

- Reactivity Screening evaluation including: Estimation of Maximum Reaction Temperature and Pressure, Temperature of No Return (TNR), and Time to Maximum Rate (TMR).
- Check for Insulation or Packing Fire potential.
- Check for Potential Explosive
- Correlation of Reactive Chemicals test data to first-order kinetics
- Evaluation of potential process upsets on reaction rate such as: catalytic impurities, "pooling" of reactants, and mis-loading or wrong recipe.

Reaction Data and Evaluation

The Reaction Data worksheet is used both for input of Reactive Chemicals data and Screening Evaluation of Reactivity Hazards. Inputs include heat of reaction, activation energy, detected onset temperature, detected onset rate, test method, and quantity of volatile or gas generation per volume of material.

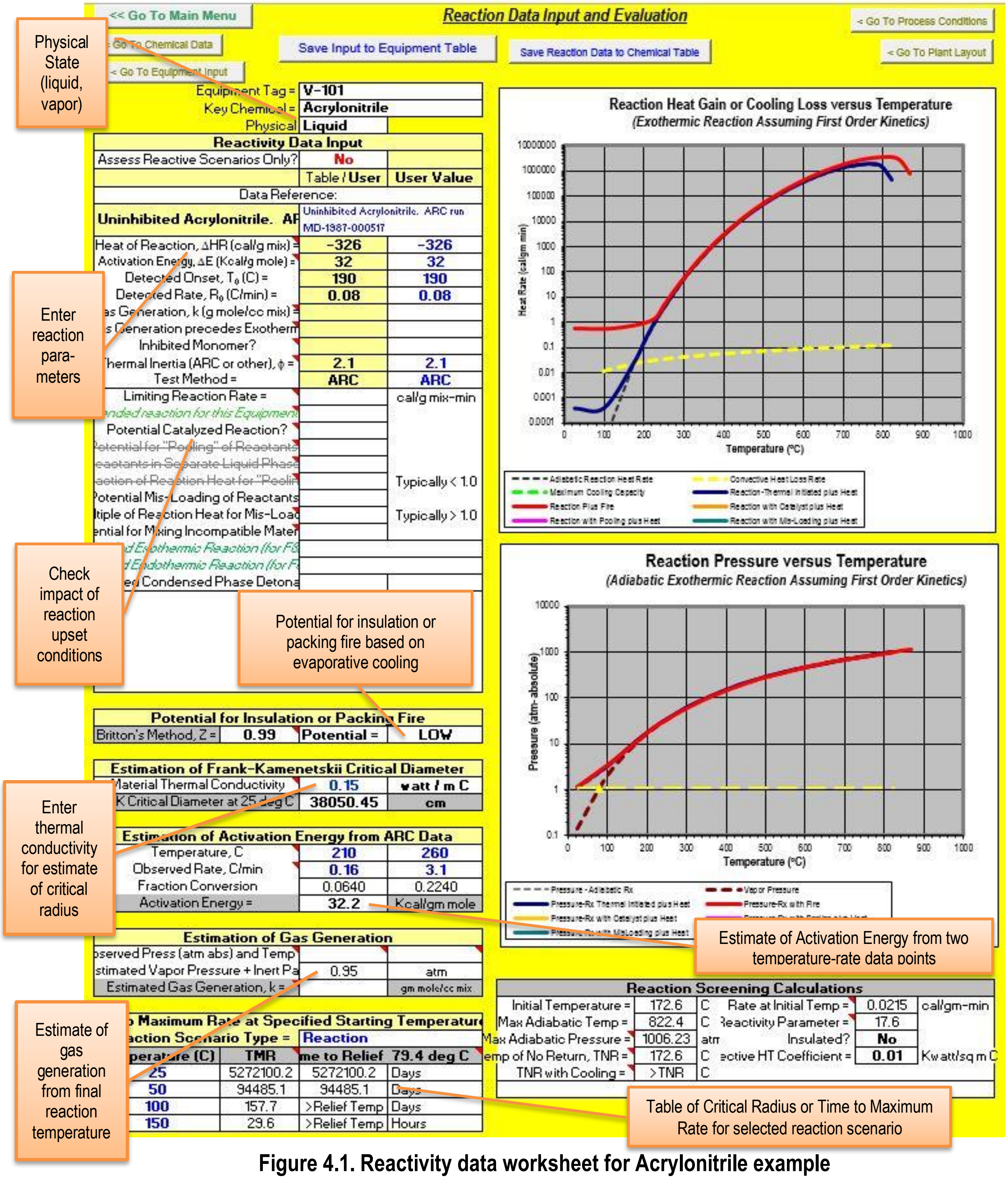
The detected onset temperature, detected onset rate, and Activation Energy represents a "best fit" of Reactive Chemicals data to a first-order kinetic model. For a test method of *Accelerating Rate Calorimetry* (ARC) or *Vent Sizing Package* (VSP), a *thermal inertia* or phi factor is also required. The phi factor represents the fraction of total reaction heat retained by the sample and is used to scale the data to large equipment. If the test method is *Differential Scanning Calorimetry* (DSC), the detected onset rate is not required as it is assumed to be the sensitivity of the instrument. For a test method of *Theoretical*, inputs are assumed to have been adjusted for large scale equipment.

Several screening evaluations are performed based on equipment, chemical, and reaction inputs. These include: Maximum Reaction Temperature and Pressure, Temperature of No Return (TNR) and Time to Maximum Rate (TMR) for up to 4 initial temperatures. A Reactivity Parameter provides an estimate for potential explosive material (Index > 20) similar to the Yoshida correlation noted in the Chemical Hazard Engineering Fundamentals (CHEF) workshop under Reactivity. Finally, the Frank-Kamenetskii critical diameter for "spontaneous reaction" of powders and solids is estimated at the operating temperature and up to 4 initial temperatures by providing a thermal conductivity input of the bulk material.

Example Reaction Data Input and Evaluation (See Figure 4.1)

As an example, enter Reactive Chemicals test data for uninhibited acrylonitrile. This data is based on Accelerating Rate Calorimetry MD-1987-000517.

STEP 1: Enter the heat of reaction*. The measured heat in this experiment was -1058 J/g or -253 cal/g. This is only 80% of the theoretically reported value of -17.3 kcal/mole or -326 cal/g. Enter -326 cal/g.*



Equipment Tag = V-101
Key Chemical = Acrylonitrile
Physical Liquid

Reactivity Data Input		
Assess Reactive Scenarios Only?	No	
	Table / User	User Value
Data Reference:		
Uninhibited Acrylonitrile. AR	Uninhibited Acrylonitrile. ARC run MD-1987-000517	
Heat of Reaction, ΔHR (cal/g mix) =	-326	-326
Activation Energy, ΔE (Kcal/g mole) =	32	32
Detected Onset, T_0 (C) =	190	190
Detected Rate, R_0 (C/min) =	0.08	0.08
as Generation, k (g mole/cc mix) =		
s Generation precedes Exotherm		
Inhibited Monomer?		
Thermal Inertia (ARC or other), ϕ =	2.1	2.1
Test Method =	ARC	ARC
Limiting Reaction Rate =		cal/g mix-min
nded reaction for this Equipment		
Potential Catalyzed Reaction?		
~~otential for "Pooling" of Reactants~~		
~~eactants in Separate Liquid Phase~~		
~~action of Reaction Heat for "Poolin~~		Typically < 1.0
Potential Mis-Loading of Reactants		
ltiple of Reaction Heat for Mis-Load		Typically > 1.0
ential for Mixing Incompatible Mater		
d Exothermic Reaction (for FS		
d Endothermic Reaction (for F		
ed Condensed Phase Detona		

Potential for Insulation or Packing Fire			
Britton's Method, Z =	0.99	Potential =	LOW

Estimation of Frank-Kamenetskii Critical Diameter		
Material Thermal Conductivity	0.15	watt / m C
K Critical Diameter at 25 deg C	38050.45	cm

Estimation of Activation Energy from ARC Data		
Temperature, C	210	260
Observed Rate, C/min	0.16	3.1
Fraction Conversion	0.0640	0.2240
Activation Energy =	32.2	Kcal/gm mole

Estimation of Gas Generation		
bserved Press (atm abs) and Temp		
stimated Vapor Pressure + Inert Pa	0.95	atm
Estimated Gas Generation, k =		gm mole/cc mix

Maximum Rate at Specified Starting Temperature			
action Scenario Type =	Reaction		
perature (C)	TMR	me to Relief	79.4 deg C
25	5272100.2	5272100.2	Days
50	94485.1	94485.1	Days
100	157.7	>Relief Temp	Days
150	29.6	>Relief Temp	Hours

Reaction Screening Calculations					
Initial Temperature =	172.6	C	Rate at Initial Temp =	0.0215	cal/gm-min
Max Adiabatic Temp =	822.4	C	Reactivity Parameter =	17.6	
Max Adiabatic Pressure =	1006.23	atm	Insulated?	No	
Temp of No Return, TNR =	172.6	C	ective HT Coefficient =	0.01	Kwatt/sq m C
TNR with Cooling =	>TNR	C			

Physical State (liquid, vapor)

Enter reaction para-meters

Check impact of reaction upset conditions

Potential for insulation or packing fire based on evaporative cooling

Enter thermal conductivity for estimate of critical radius

Estimate of Activation Energy from two temperature-rate data points

Estimate of gas generation from final reaction temperature

Table of Critical Radius or Time to Maximum Rate for selected reaction scenario

Figure 4.1. Reactivity data worksheet for Acrylonitrile example

Note that for Continuous Reactions, the Heat of Reaction per Mass in RAST could include heating of the feed to the maximum reaction temperature such that the apparent Reaction heat is $\Delta H_R/2$.

***STEP 2: Enter the Activation Energy**. The Activation Energy should be based on a "best fit" of Reactive Chemicals Data to a first-order model. <u>Enter 32 Kcal/gm mole.</u>*

If two temperature-rate data pair are available (two points on the "best fit" line), these may be entered under the section "Estimation of Activation Energy from ARC Data". The two data points should be selected within the lower ½ of the temperature rise and, in a region, where there is minimal scatter in the data. Enter 0.16 C/min at 210 C and 3.1 C/min at 260 C (data points from the ARC experiment, Figure 4.2). The estimated Activation Energy is 32.2 Kcal/gm mole (Figure 4.3). *(Note that the Estimated Activation Energy will change slightly with changes in the Detected Onset Temperature and Detected Onset Rate.)*

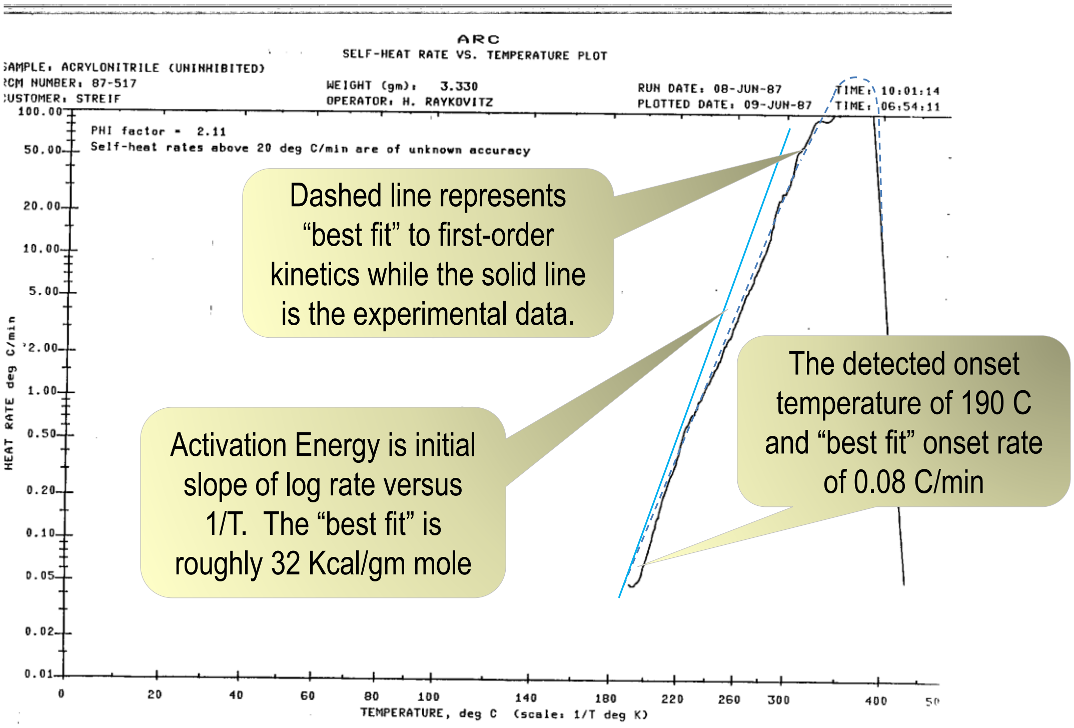
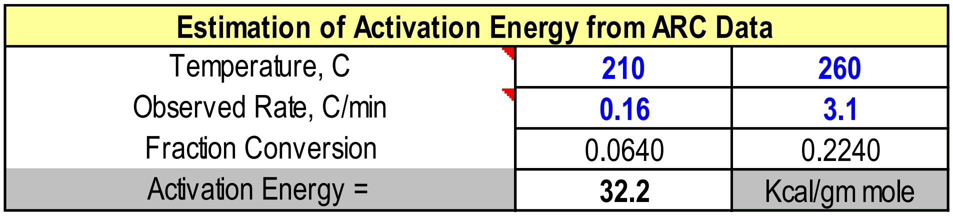


Figure 4.2 ARC data for example

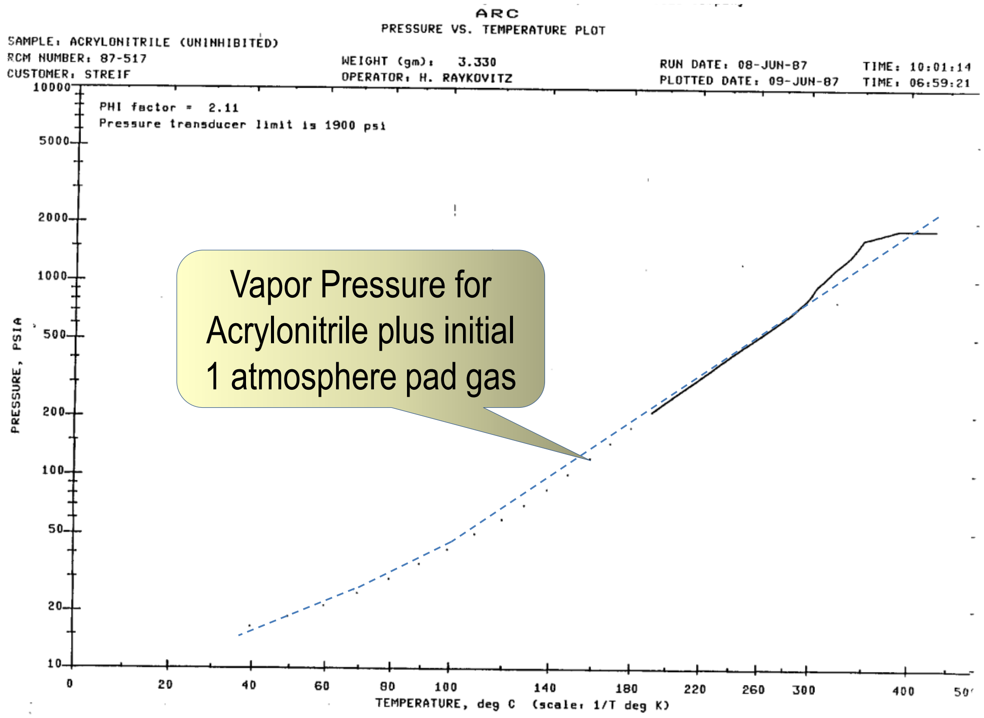


Estimation of Activation Energy from ARC Data		
Temperature, C	210	260
Observed Rate, C/min	0.16	3.1
Fraction Conversion	0.0640	0.2240
Activation Energy =	32.2	Kcal/gm mole

Figure 4.3 Results from Reactivity Data worksheet

***STEP 3: Enter the Detected Onset Temperature and Detected Onset Rate**. The Detected Onset Temperature in Figure 4.2 represents the detection limit of the test instrument. If inputs are based on a theoretical model rather than test data, a detected onset temperature corresponding to a detected onset rate of 0.01 cal/min (roughly 0.02 deg C/min) is suggested. If the test method is ARC or VSP, the thermal inertia or phi factor also needs to be input. Enter 190 C for the detected onset temperature, 0.08 C/min as a first-order "best fit" for the detected onset rate, a phi factor of 2.1 and "ARC" as the test method. This represents the "best fit" rate at the detected onset temperature of the experiment.*

STEP 4: Enter the Gas Generation. From the vapor pressure versus temperature data (Figure 4.4), there is no evidence of volatile or gaseous products of reaction. Enter 0 or leave blank.

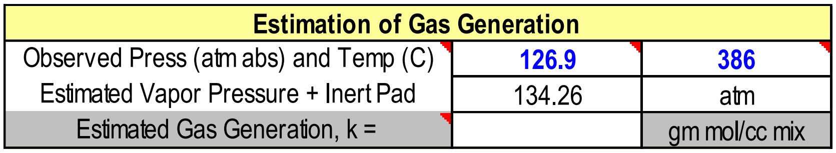


Vapor Pressure for Acrylonitrile plus initial 1 atmosphere pad gas

Figure 4.4 Vapor pressure vs. Temperature for example

A single pressure-temperature at the end of the experiment may be used to estimate the quantity of Gas Generation. A pressure of 1865 psia (126.9 atm) at 386 C was reported from the experimental near the end of the experiment. Enter this data point and the estimated vapor pressure + inert pad (from the Chemical Data entered) is 134 atm which is slightly higher than the observed pressure indicating zero (or blank) gaseous products formed. The typical range for gm mole gas generated per cc reaction liquid is zero to 0.01.

For vapor-phase reactions, the gas generation term represents the moles products divided by moles reactants with values in the typical range of 0.5 to 2.



Estimation of Gas Generation		
Observed Press (atm abs) and Temp (C)	126.9	386
Estimated Vapor Pressure + Inert Pad	134.26	atm
Estimated Gas Generation, k =		gm mol/cc mix

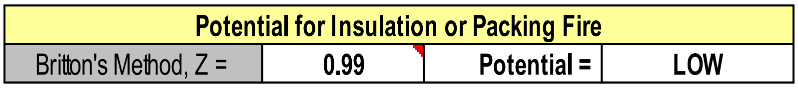
Figure 4.5 Gas generation results for example

STEP 5: Enter the Questions: "Gas Generation precedes Exotherm?" and "Inhibited Monomer?" The answers to these questions do not impact the preliminary Reactivity Evaluation but may be important in understanding upset process conditions that could lead to runaway reaction or generation of excessive pressure.

Note that any reaction that generates volatile or gaseous products will slowly pressurize a "closed" system, even a normal operating temperature.

STEP 6: Potential for Insulation or Packing Fire. The potential for insulation or packing fires is categorized as high, medium, or low (Figure 4.6). This index is based on Britton's method which compares

Flash Point and Autoignition Temperature. If the chemical *cannot* undergo an oxidation reaction, this Index should be ignored. Results do not reflect other exothermic reactions (such a polymerization) that may occur.

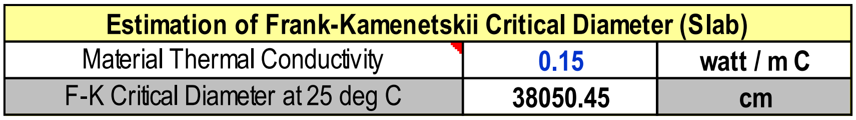


Potential for Insulation or Packing Fire			
Britton's Method, Z =	0.99	Potential =	LOW

Figure 4.6 Potential for Insulation or Packing Fire

STEP 7: Estimation of Frank-Kamenetskii Critical Diameter. Frank-Kamenetskii theory allows for a temperature gradient to be taken into account for a reacting system. This is particularly important where there could be a considerable resistance to convective heat transfer such as for solids or highly viscous fluids. This Critical Diameter is shape dependent and that reported in RAST is based on an "infinite slab". The F-K Critical Diameter represents the "depth" of solid or fluid at which "hot spots" can occur which, after a long enough induction time, may lead to runaway reaction.

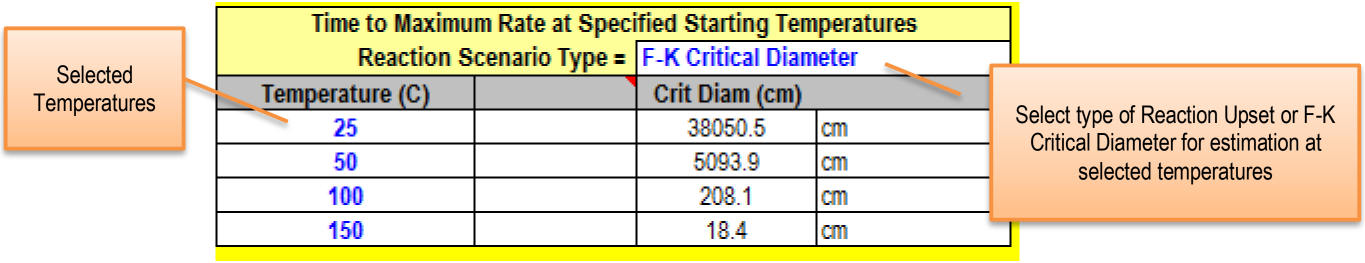
<u>Enter Thermal Conductivity</u> for Acrylonitrile of <u>0.15 watt / m C</u> at the operating temperature of 25 C. The F-K Critical Diameter is estimated at 38050 cm indicating that thermal gradients within the fluid are not likely to be sufficient for runaway reaction from the normal operating temperature (Figure 4.7).



Estimation of Frank-Kamenetskii Critical Diameter (Slab)		
Material Thermal Conductivity	0.15	watt / m C
F-K Critical Diameter at 25 deg C	38050.45	cm

Figure 4.7 F-K Critical Diameter

The F-K Critical Diameter may be estimated at a several temperatures from the table at the lower left-hand side of the Reaction Input worksheet. <u>Select F-K Critical Diameter and Enter Desired Temperatures (Figure 4.8).</u> The Critical Diameter does not become sufficiently small to indicate a runaway hazard below the Temperature of No Return (which is based on convective heat loss assuming a *uniform temperature* within the reacting medium or Semenov theory).



Time to Maximum Rate at Specified Starting Temperatures

Reaction Scenario Type = F-K Critical Diameter

Temperature (C)		Crit Diam (cm)	
25		38050.5	cm
50		5093.9	cm
100		208.1	cm
150		18.4	cm

Selected Temperatures

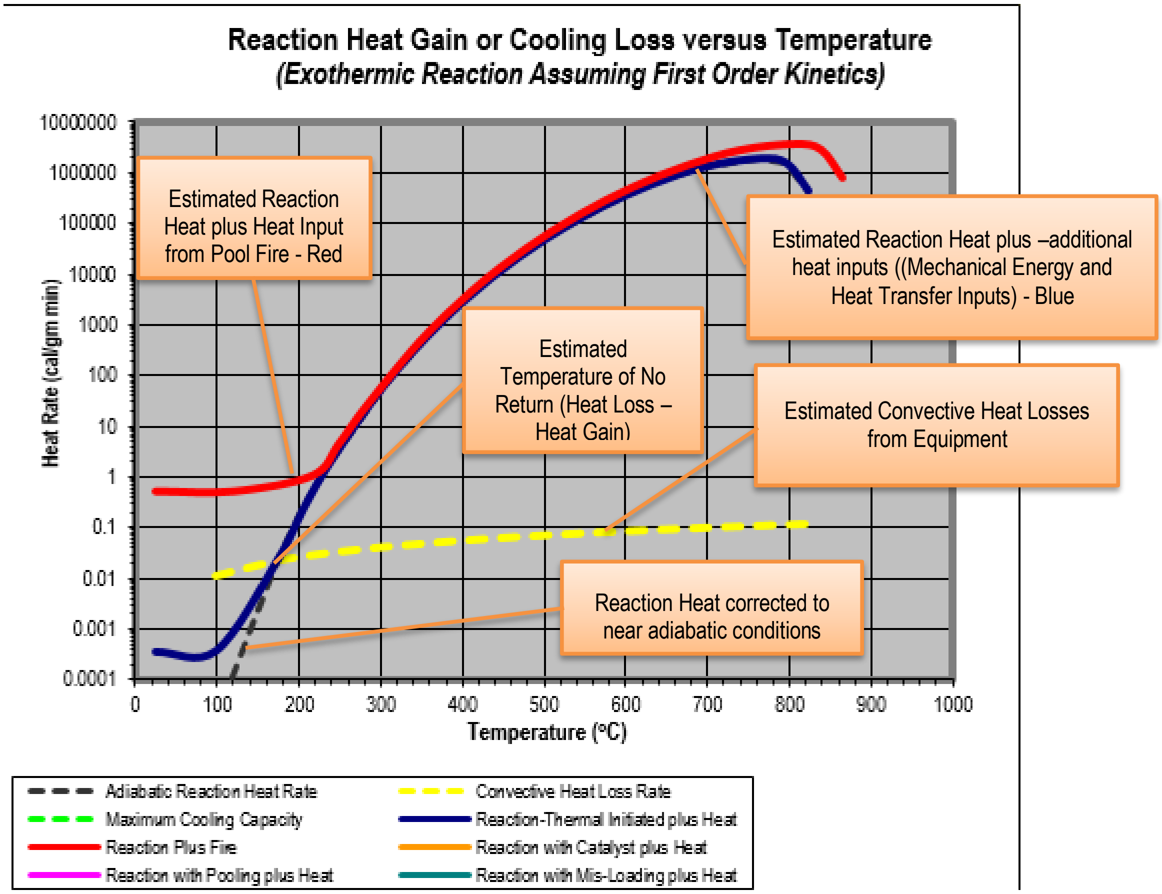
Select type of Reaction Upset or F-K Critical Diameter for estimation at selected temperatures

Figure 4.8 F-K Critical Diameter vs. Temperature

STEP 8: Preliminary Reactivity Evaluation. Upon entry of the reaction inputs, a graph of heat rate versus temperature will be shown corrected to near "adiabatic" conditions (dashed black line). A yellow dashed line representing the estimated convective heat losses from the equipment (based on outer surface area and insulation inputs from the Equipment Input worksheet) is also shown. The intersection of the yellow dashed line representing heat losses and the reaction heat rate represents the Temperature of No Return – the temperature above which runaway reaction occurs based on convective heat losses.

STEP 9: Save Inputs to the Equipment Table.

If mechanical energy or heat transfer inputs have been entered in the Equipment Input, a second line is shown on the graph representing reaction heat plus these additional heat inputs (dark blue line). If the potential for pool fire exists, then a third line is shown representing reaction heat plus pool fire heat input (red line) (Figure 4.9).



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

Estimated Reaction Heat plus Heat Input from Pool Fire - Red

Estimated Reaction Heat plus –additional heat inputs ((Mechanical Energy and Heat Transfer Inputs) - Blue

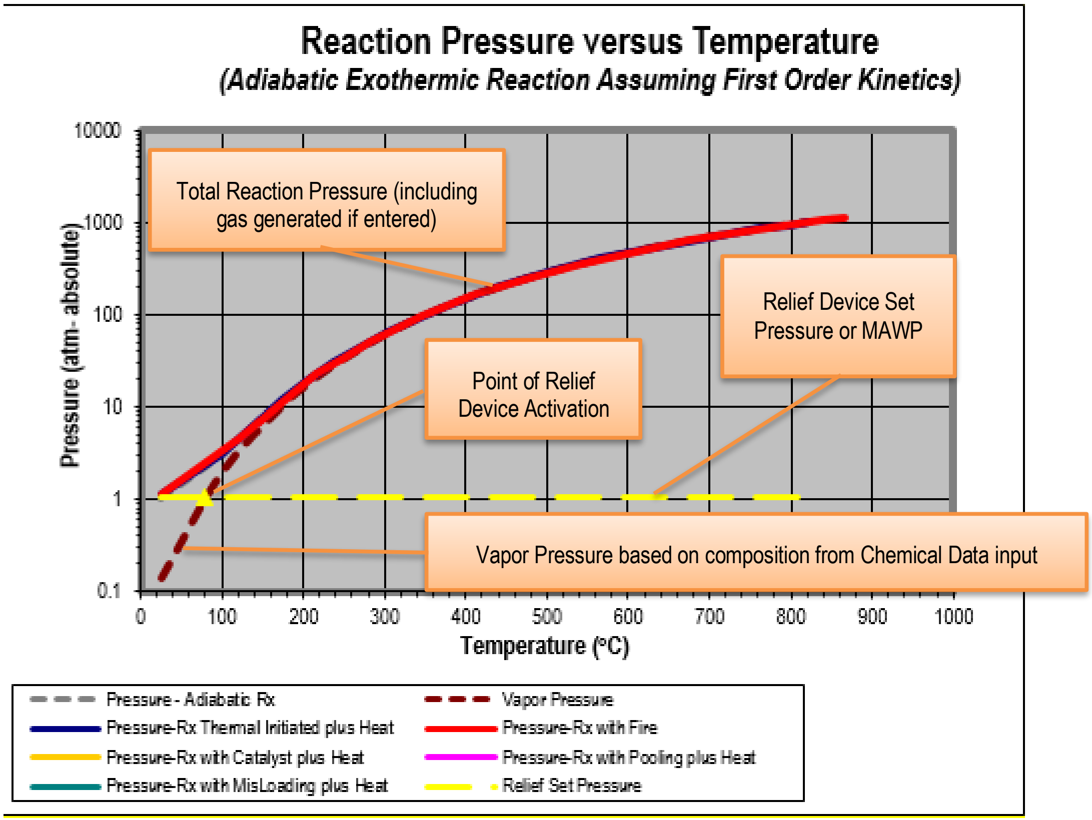
Estimated Temperature of No Return (Heat Loss – Heat Gain)

Estimated Convective Heat Losses from Equipment

Reaction Heat corrected to near adiabatic conditions

Figure 4.9 Reaction Heat Gain or Cooling Loss Chart

A second graph of pressure versus temperature is also provided. The dashed black line represents the vapor pressure per the composition input from the Chemical Data worksheet. *Note that the effect of changes in composition with reaction conversion is not considered*. The total pressure (including initial gas pad and any gas generation input) for reaction heat plus additional heat inputs is shown as a dark blue line. If the potential for pool fire exists, then a third line is shown representing reaction heat plus pool fire heat input (red line). A dashed yellow line represents the Relief Device Set Pressure or Maximum Allowable Working Pressure (MAWP) if relief device information is not available. A yellow triangle is shown at the intersection of the reaction pressure and Relief Device Set Pressure (or MAWP) and represents the reaction conditions where relief device activation may occur (Figure 4.10).



Total Reaction Pressure (including gas generated if entered)

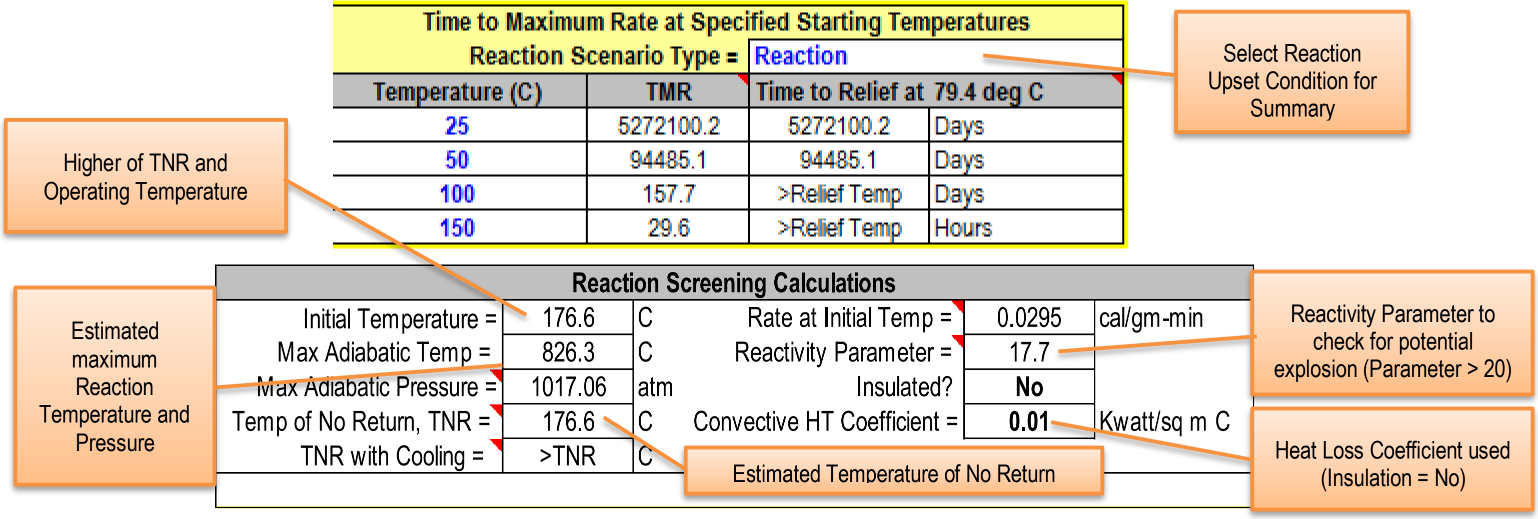
Relief Device Set Pressure or MAWP

Point of Relief Device Activation

Vapor Pressure based on composition from Chemical Data input

Figure 4.10 Reaction Pressure versus Temperature

A table summarizing maximum reaction temperature and pressure, temperature of no return, and Reactivity Parameter for potential explosive is shown at the bottom left of the Reaction Input worksheet. The Reaction Scenario Type is selected to determine which values are presented. (Figure 4.11)



Time to Maximum Rate at Specified Starting Temperatures

Reaction Scenario Type = Reaction

Temperature (C)	TMR	Time to Relief at 79.4 deg C	
25	5272100.2	5272100.2	Days
50	94485.1	94485.1	Days
100	157.7	>Relief Temp	Days
150	29.6	>Relief Temp	Hours

Reaction Screening Calculations

Initial Temperature =	176.6	C	Rate at Initial Temp =	0.0295	cal/gm-min
Max Adiabatic Temp =	826.3	C	Reactivity Parameter =	17.7	
Max Adiabatic Pressure =	1017.06	atm	Insulated?	**No**	
Temp of No Return, TNR =	176.6	C	Convective HT Coefficient =	**0.01**	Kwatt/sq m C
TNR with Cooling =	>TNR	C			

Select Reaction Upset Condition for Summary

Higher of TNR and Operating Temperature

Estimated maximum Reaction Temperature and Pressure

Reactivity Parameter to check for potential explosion (Parameter > 20)

Heat Loss Coefficient used (Insulation = No)

Estimated Temperature of No Return

Figure 4.11 Reaction Summary

Reaction Scenario Type as "Reaction". Values shown represent no additional heat input. Try other Reaction Scenario Types to view appropriate hazard screening values.

Evaluation of Potential Process Upsets

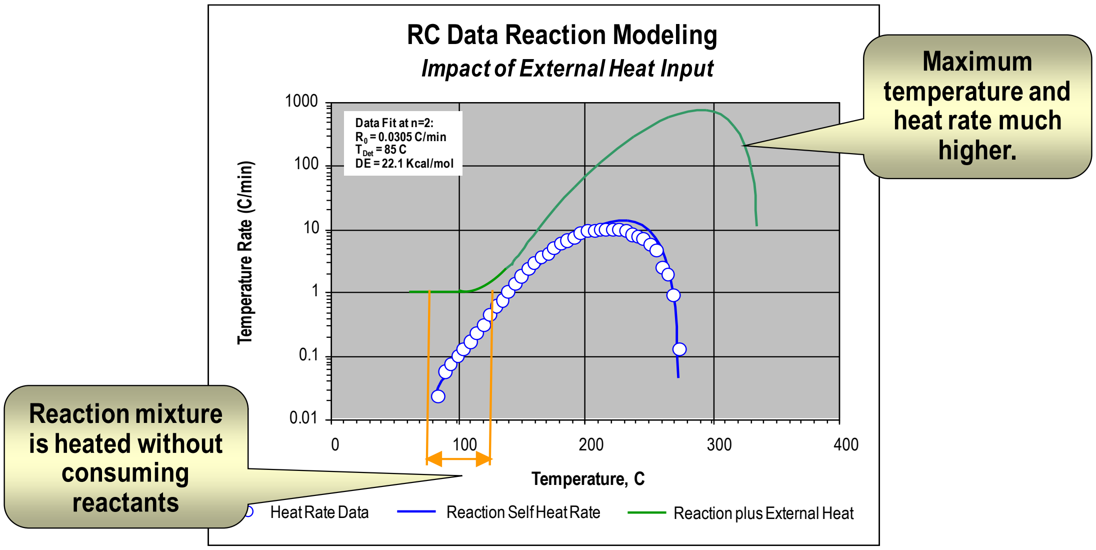
In some cases, screening evaluation for the impact of a process upset to a reaction may be obtained by adjustment of appropriate kinetic parameters. Common process upsets of interest are:

- ☐ External heat plus reaction
- ☐ Change in heat of reaction per mass (mis-loading or scale-up)
- ☐ Introduction of a catalytic impurity
- ☐ "Pooling" of reactants

It is important to recognize the evaluation of process upsets in RAST is based on a "steady state" approach with an "average" composition entered in the Chemical Data worksheet and simple first-order reaction kinetics. A dynamic simulation for a runaway reaction may be needed to address more detailed issues such as relief design for reactive systems.

Impact of External Heat: External heat may result from a heat transfer surface, mechanical energy such as an agitator or circulating pump, or fire. The primary impact of external heat is an increase in temperature without consuming reactants. At temperatures where reaction heat rate is much less than the external heat input, reaction conversion is essentially zero and total heat rate is only attributed to the external source. RAST uses a simple first-order kinetic model to determine reaction heat rate and either a constant external heat rate (such as for fire or mechanical energy) or an external heat rate which depends on temperature difference with a heating media (such as a heat exchanges). The total heat rate is the sum of both reaction and the external heat source.

Consider the impact of external heat on our acrylonitrile storage tank example. The maximum reaction temperature, pressure, and heat rate are much higher with external heat input. The reaction heat versus temperature with external fire (red line) exhibits a peak rate at nearly 80 C higher than the adiabatic reaction (dashed black line). This results in a higher peak heat rate and higher pressure (Figure 4.12).



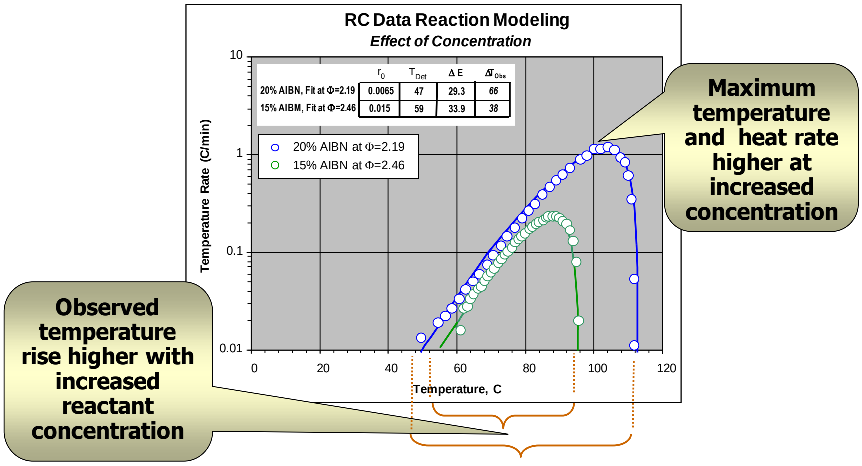
Maximum temperature and heat rate much higher.

Reaction mixture is heated without consuming reactants

Figure 4.12 Example Simple Kinetic Model with 1 C/min External Heat

Change in Heat of Reaction per Mass: A change in heat of reaction per mass affects the maximum temperature, the conversion per temperature increment, and the initial heat rate. This change may be the result of scale-up since Thermal Inertia (loss of reaction heat to equipment or sample container) is less for larger scale equipment. A change in the heat of reaction per mass may also be the result of mis-loading or a change in reactant concentration. More dilute exothermic reactions generate less total heat per mass.

The temperature rise for the reaction below (Figure 4.13) is roughly 0.2 divided by 0.15 or 1.33 times higher for 20 weight % reactant versus 15 %. The corresponding maximum reaction rate is significantly (nearly one order of magnitude) higher for the more concentration reaction.

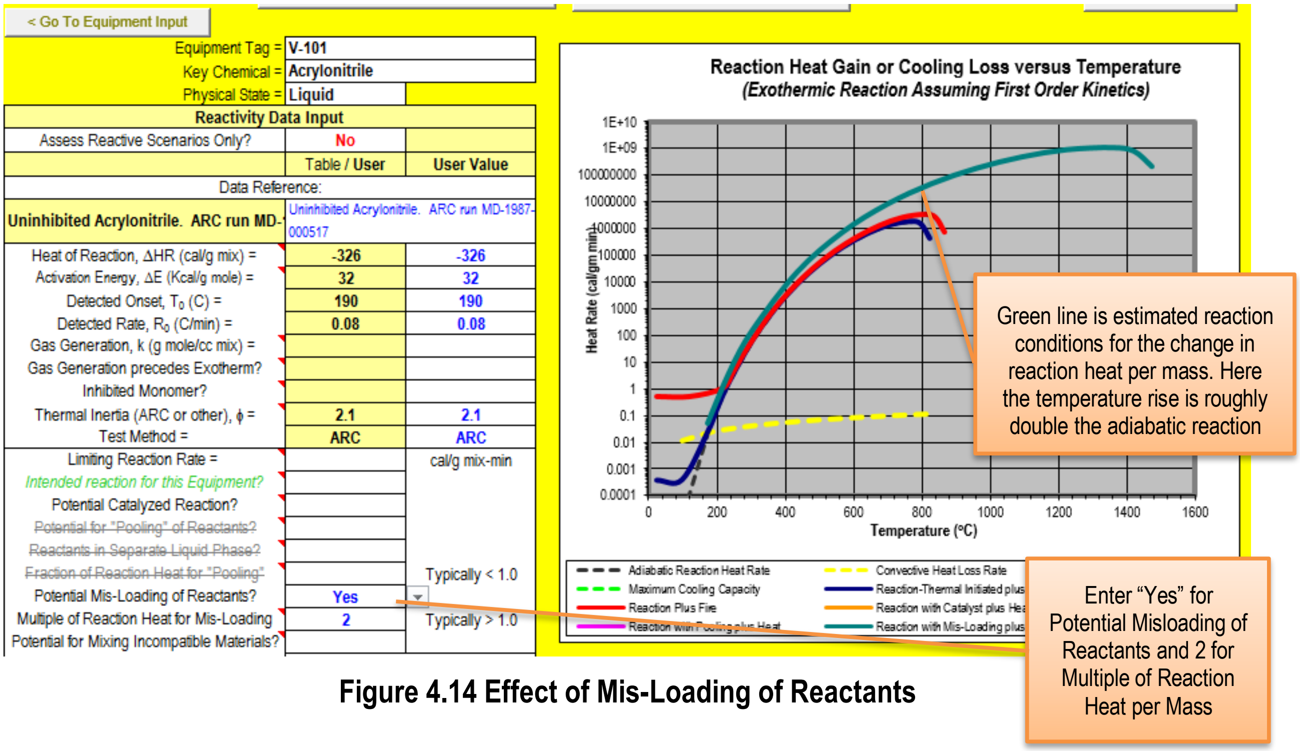


Maximum temperature and heat rate higher at increased concentration

Observed temperature rise higher with increased reactant concentration

Figure 4.13 Example Simple Kinetic Model for Change in Reactant Concentration

The Reaction Input worksheet may be used to estimate the impact of changes in heat of reaction per mass. Assume that the reaction is run in 50% solvent (with a liquid heat capacity similar to the reactant) and a possible upset condition is failure to add solvent. Enter "Yes" for the question "Potential Mis-Loading of Reactants?" Enter "Multiple of Reaction Heat for Mis-Loading" of 2. This corresponds to the same heat of reaction but only ½ the total mass. Note that the temperature rise is essentially double the adiabatic temperature rise. This change results in an estimated peak reaction rate more than two orders of magnitude higher (Figure 4.14).



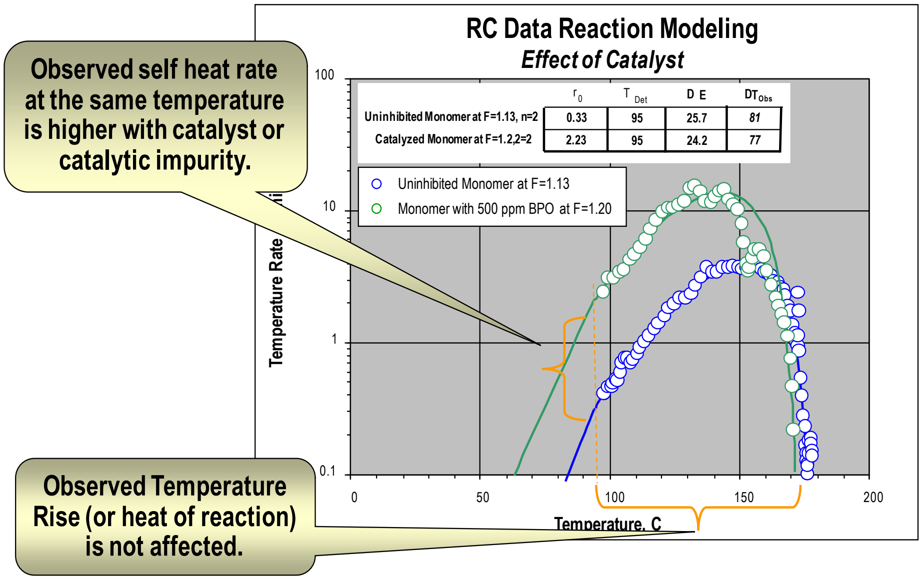
Equipment Tag =	V-101	
Key Chemical =	Acrylonitrile	
Physical State =	Liquid	
Reactivity Data Input		
Assess Reactive Scenarios Only?	No	
	Table / User	User Value
Data Reference:		
Uninhibited Acrylonitrile. ARC run MD-	Uninhibited Acrylonitrile. ARC run MD-1987-000517	
Heat of Reaction, ΔHR (cal/g mix) =	-326	-326
Activation Energy, ΔE (Kcal/g mole) =	32	32
Detected Onset, T_0 (C) =	190	190
Detected Rate, R_0 (C/min) =	0.08	0.08
Gas Generation, k (g mole/cc mix) =		
Gas Generation precedes Exotherm?		
Inhibited Monomer?		
Thermal Inertia (ARC or other), ϕ =	2.1	2.1
Test Method =	ARC	ARC
Limiting Reaction Rate =		cal/g mix-min
Intended reaction for this Equipment?		
Potential Catalyzed Reaction?		
~~Potential for "Pooling" of Reactants?~~		
~~Reactants in Separate Liquid Phase?~~		
~~Fraction of Reaction Heat for "Pooling"~~		Typically < 1.0
Potential Mis-Loading of Reactants?	Yes	
Multiple of Reaction Heat for Mis-Loading	2	Typically > 1.0
Potential for Mixing Incompatible Materials?		

Green line is estimated reaction conditions for the change in reaction heat per mass. Here the temperature rise is roughly double the adiabatic reaction

Enter "Yes" for Potential Misloading of Reactants and 2 for Multiple of Reaction Heat per Mass

Figure 4.14 Effect of Mis-Loading of Reactants

Introduction of a Catalyst or Catalytic Impurity: Introduction of a small amount of catalytic material may significantly increase the overall self-heat rate for exothermic reactions. Chemicals normally maintained within safe operating limits may quickly progress to potential runaway conditions at the operating temperature. The reaction rate for the polymerization in Figure 4.15 is significantly higher (nearly one order of magnitude) with the addition of 500 ppm of BFO catalyst. Note that only reaction rate and not temperature rise (or heat of reaction) is affected by catalyst addition.



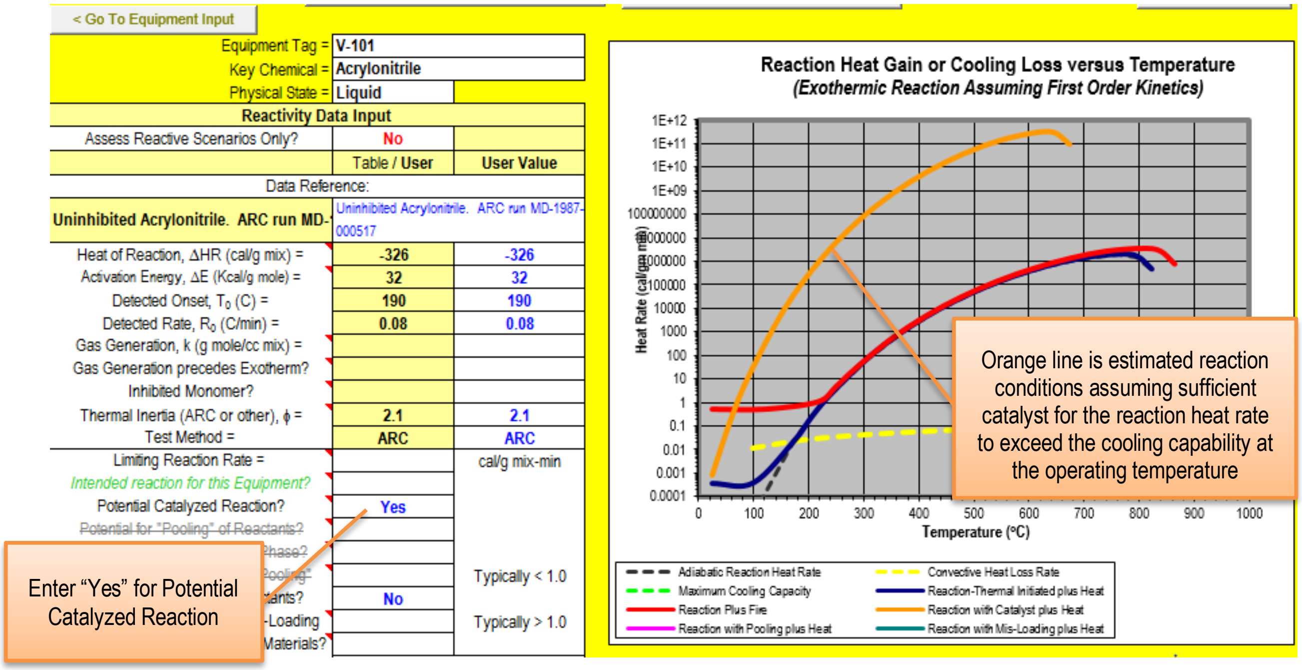
Observed self heat rate at the same temperature is higher with catalyst or catalytic impurity.

Observed Temperature Rise (or heat of reaction) is not affected.

Figure 4.15 Example Simple Kinetic Model for Addition of Catalyst

The Reaction Input worksheet may be used to estimate the impact of a catalyst. Enter "Yes" for the question "Potential Catalyzed Reaction". An estimate is made within RAST by increasing the first-order rate constant until reaction heat rate exceeds the cooling capability at the normal operating temperature (orange line, Figure 4.16). This is a *hypothetical* situation and may not reflect what could actually occur. It is merely to address the question "if a sufficiently effective catalyst exists for uncontrolled reaction to occur at the normal operating temperature, what might be the effect to reaction parameters?"

Should the potential impact of a catalyst significantly affect analysis results, it is highly recommended that experimental data be obtained.



< Go To Equipment Input

Equipment Tag = V-101
Key Chemical = Acrylonitrile
Physical State = Liquid

Reactivity Data Input

Assess Reactive Scenarios Only?	No	
	Table / User	User Value
Data Reference:		
Uninhibited Acrylonitrile. ARC run MD-	Uninhibited Acrylonitrile. ARC run MD-1987-000517	
Heat of Reaction, ΔHR (cal/g mix) =	-326	-326
Activation Energy, ΔE (Kcal/g mole) =	32	32
Detected Onset, T_0 (C) =	190	190
Detected Rate, R_0 (C/min) =	0.08	0.08
Gas Generation, k (g mole/cc mix) =		
Gas Generation precedes Exotherm?		
Inhibited Monomer?		
Thermal Inertia (ARC or other), ϕ =	2.1	2.1
Test Method =	ARC	ARC
Limiting Reaction Rate =		cal/g mix-min
Intended reaction for this Equipment?		
Potential Catalyzed Reaction?	Yes	
~~Potential for "Pooling" of Reactants?~~		
~~Phase?~~		
~~Pooling"~~		Typically < 1.0
ants?	No	
-Loading		Typically > 1.0
Materials?		

Enter "Yes" for Potential Catalyzed Reaction

Orange line is estimated reaction conditions assuming sufficient catalyst for the reaction heat rate to exceed the cooling capability at the operating temperature

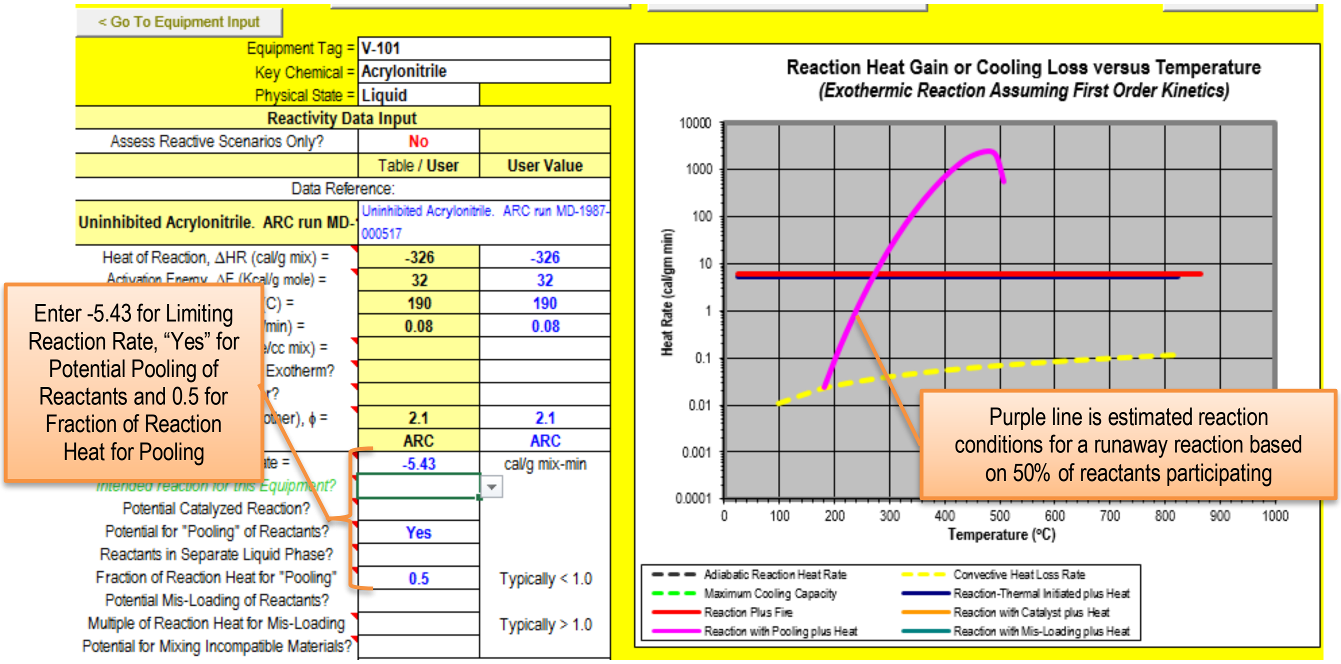
Figure 4.16 Effect of Potential Catalyzed Reaction

Note that for our acrylonitrile example, polymerization does not occur at an appreciable rate unless the temperature is well above the normal boiling point of 77 C (TNR = 140 C) even for uninhibited material. Since the equipment cannot operate at a pressure corresponding to the vapor pressure of acrylonitrile at 140 C (roughly 76 psia or 5.2 bar), the equipment would likely fail and contents vaporize prior to reaching the Temperature of No Return. However, if a catalyst is inadvertently added, a potentially explosive reaction rate could occur. The "catalyst" might be a strong acid or base such that if this vessel were vented to a scrubber, a potential reactive scenario might be contamination by the scrubber fluid.

Pooling of Reactants: A common means for controlling an exothermic reaction is by slow addition of a limiting reagent such that the overall reaction heat rate is proportional to the addition rate. "Pooling" occurs if the concentration of limiting reagent is allowed to increase - typically by loss of mixing or low temperature. Following accumulation of un-reacted material, batch reaction kinetics occurs potentially leading to runaway reaction.

For a batch reaction, a limiting reaction rate is estimated as the Heat of Reaction divided by the *Addition Time*. For a continuous reaction, a limiting reaction rate is estimated as the Heat of Reaction per mass divided by the *Residence Time*. Residence Time is estimated as the total reactor mass divided by the mass feed rate.

Assume that the reaction is controlled by the addition of monomer over 60 minutes. Enter a Limiting Reaction Rate of -326 / 60 minutes or -5.43 cal / g-min. To estimate reaction conditions if 50% of the feed were added without reacting, enter "Yes" for "Potential for Pooling" of Reactants?" and 0.5 for Fraction of Reaction Heat for "Pooling". [Note – these lines are "greyed out" until the values are entered.] An estimate is made within RAST for this condition denoted by a purple line on the heat rate versus temperature plot (Figure 4.17).



< Go To Equipment Input

Equipment Tag =	V-101	
Key Chemical =	Acrylonitrile	
Physical State =	Liquid	
Reactivity Data Input		
Assess Reactive Scenarios Only?	No	
	Table / User	User Value
Data Reference:		
Uninhibited Acrylonitrile. ARC run MD-	Uninhibited Acrylonitrile. ARC run MD-1987-000517	
Heat of Reaction, ΔHR (cal/g mix) =	-326	-326
Activation Energy, ΔE (Kcal/g mole) =	32	32
C) =	190	190
min) =	0.08	0.08
/cc mix) =		
Exotherm?		
r?		
other), ϕ =	2.1	2.1
	ARC	ARC
te =	-5.43	cal/g mix-min
Intended reaction for this Equipment?		
Potential Catalyzed Reaction?		
Potential for "Pooling" of Reactants?	Yes	
Reactants in Separate Liquid Phase?		
Fraction of Reaction Heat for "Pooling"	0.5	Typically < 1.0
Potential Mis-Loading of Reactants?		
Multiple of Reaction Heat for Mis-Loading		Typically > 1.0
Potential for Mixing Incompatible Materials?		

Enter -5.43 for Limiting Reaction Rate, "Yes" for Potential Pooling of Reactants and 0.5 for Fraction of Reaction Heat for Pooling

Purple line is estimated reaction conditions for a runaway reaction based on 50% of reactants participating

Figure 4.17 Effect of Reactant Pooling

In some cases, two liquid phases may be present. If, for example, the reaction mixture were 25 % acrylonitrile and 75% water, the Heat of Reaction per Mass would be 0.25 (-326) or -81.5 cal/g mixture. By selecting "Yes" to "Reactants in Separate Liquid Phase", an estimate of reaction conditions is made within RAST based conservatively on no heat loss to the second liquid. Note that "pooling of reactants" does not apply to vapor-phase reactions.

Do not save the entries for Potential Mis-Loading of Reactants, Potential Catalyzed Reaction, and Potential for "Pooling" of Reactants.

5. ADDITIONAL RAST INPUTS AND REPORTS

Introduction

RAST allows input of detailed information for Equipment, Process Conditions and Plant Layout. This additional information is used to support identification of hazard scenarios and improved quantification of risk.

This section covers:

- How additional Equipment Parameter information is used to identify scenarios and evaluate hazards.
- How additional Process Conditions information is used to identify scenarios and evaluate hazards.
- How additional Plant Layout information is used to identify scenarios and evaluate hazards.

Equipment Parameters

In addition to the minimum required inputs, other information may be needed for various evaluations and reports. The more information available, the more thorough the evaluation. However, only those inputs for the specific equipment being evaluating needs to be entered. See Figure 5.1 for further examples.

General Equipment Information

General Equipment information applies to most types of equipment. The minimum required inputs are **Volume** and **Maximum Allowable Working Pressure** (MAWP). Other inputs include:

Full Vacuum Rated? – should be answered "No" if vacuum failure is *feasible*. If the MAWP is less than 1 atmosphere gauge (101 kPag or 14.7 psig), this input is highlighted "yellow" as a recommended input. If blank, the default assumption is that the equipment is vacuum rated

Estimated High Temperature Failure – is the temperature where equipment failure may be possible at the normal operating pressure due to weakened material strength.

Estimated Embrittlement Temperature – is the temperature where equipment may fail under stress of shock due to transition from ductile to brittle.

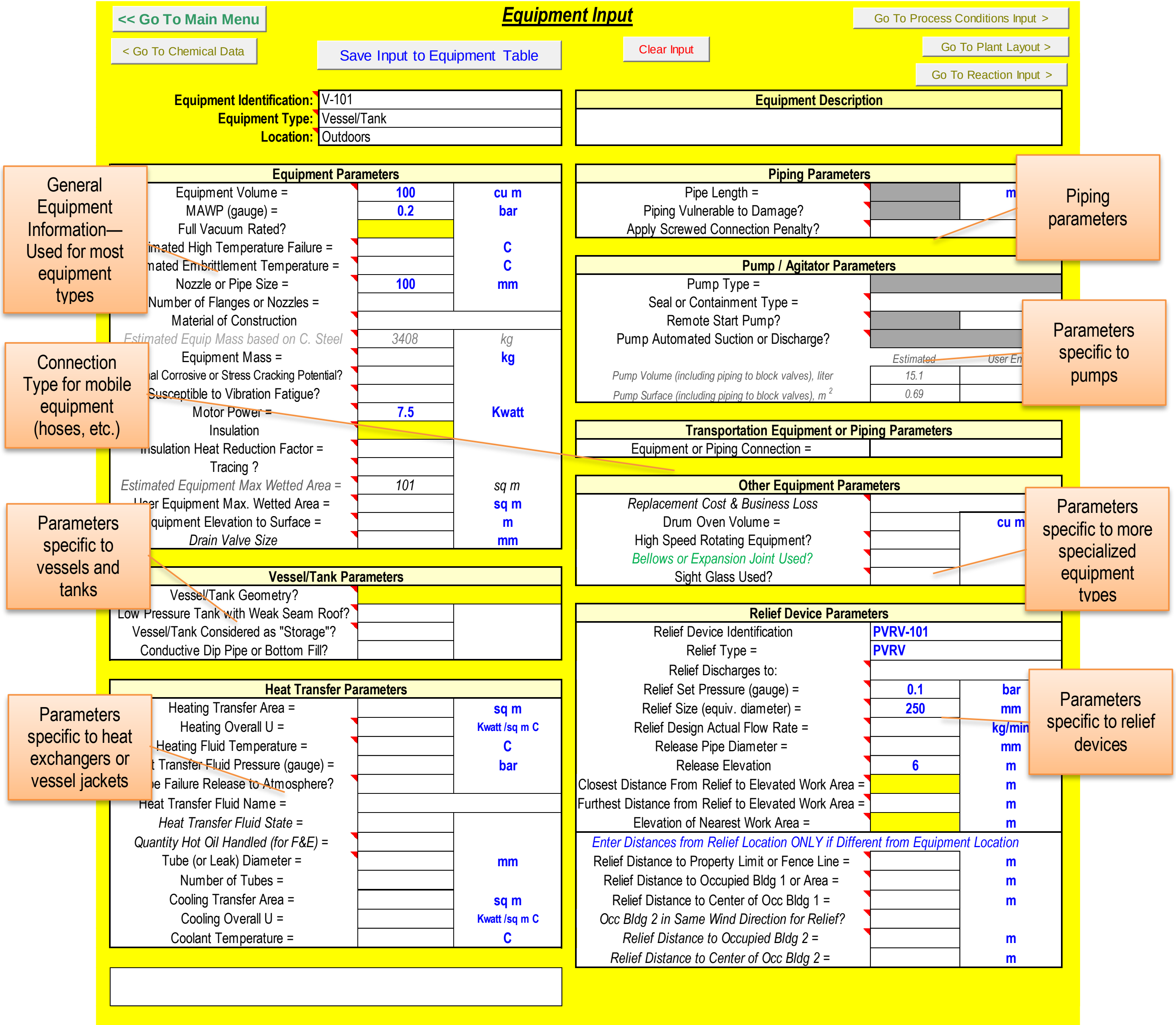
Nozzle or Pipe Diameter – represents the largest practical hole size for nozzle, pipe, or hose failure scenarios. This is *a minimum input requirement* for all but solids containing equipment.

Number of Flanges or Nozzles – input is used in evaluation of Mechanical Integrity scenarios for smaller hole sizes (5 mm and 25 mm) typically associated with flange or gasket failures.

Material of Construction – is a list of common construction materials. This input is used to determine if the equipment is "brittle" (likely to result in many fragments upon overpressure failure or rupture), susceptible to corrosion under insulation (external corrosion), and in determining the failure frequency for Mechanical Integrity scenarios.

Equipment Mass – is used in providing a better estimate for "time to failure" for overheating cases. If blank, the default is zero such that only the mass of equipment contents is used in the estimate. For pumps, a default estimate of equipment mass based on data from centrifugal pumps is used if this input is blank.

Internal Corrosion or Stress Cracking Potential? – should be answered "Yes" if the equipment contents represent an internal corrosion or stress cracking potential for the Material of Construction. This input is used in determining the failure frequency for Mechanical Integrity scenarios. If blank, the default assumption is that the Material of Construction is compatible with the equipment contents.



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

Equipment Description

Equipment Parameters

Equipment Volume =	100	cu m
MAWP (gauge) =	0.2	bar
Full Vacuum Rated?		
imated High Temperature Failure =		C
nated Embrittlement Temperature =		C
Nozzle or Pipe Size =	100	mm
Number of Flanges or Nozzles =		
Material of Construction		
Estimated Equip Mass based on C. Steel	3408	kg
Equipment Mass =		kg
al Corrosive or Stress Cracking Potential?		
Susceptible to Vibration Fatigue?		
Motor Power =	7.5	Kwatt
Insulation		
nsulation Heat Reduction Factor =		
Tracing ?		
Estimated Equipment Max Wetted Area =	101	sq m
er Equipment Max. Wetted Area =		sq m
quipment Elevation to Surface =		m
Drain Valve Size		mm

Vessel/Tank Parameters

Vessel/Tank Geometry?	
Low Pressure Tank with Weak Seam Roof?	
Vessel/Tank Considered as "Storage"?	
Conductive Dip Pipe or Bottom Fill?	

Heat Transfer Parameters

Heating Transfer Area =		sq m
Heating Overall U =		Kwatt /sq m C
Heating Fluid Temperature =		C
t Transfer Fluid Pressure (gauge) =		bar
e Failure Release to Atmosphere?		
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 =		m
Piping Vulnerable to Damage?		
Apply Screwed Connection Penalty?		

Pump / Agitator Parameters

Pump Type =		
Seal or Containment Type =		
Remote Start Pump?		
Pump Automated Suction or Discharge?		
	Estimated	User En
Pump Volume (including piping to block valves), liter	15.1	
Pump Surface (including piping to block valves), m^2	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	PVRV-101	
Relief Type =	PVRV	
Relief Discharges to:		
Relief Set Pressure (gauge) =	0.1	bar
Relief Size (equiv. diameter) =	250	mm
Relief Design Actual Flow Rate =		kg/min
Release Pipe Diameter =		mm
Release Elevation	6	m
Closest Distance From Relief to Elevated Work Area =		m
Furthest Distance from Relief to Elevated Work Area =		m
Elevation of Nearest Work Area =		m
Enter Distances from Relief Location ONLY if Different from Equipment Location		
Relief Distance to Property Limit or Fence Line =		m
Relief Distance to Occupied Bldg 1 or Area =		m
Relief Distance to Center of Occ Bldg 1 =		m
Occ Bldg 2 in Same Wind Direction for Relief?		
Relief Distance to Occupied Bldg 2 =		m
Relief Distance to Center of Occ Bldg 2 =		m

Figure 5.1: Additional Equipment Input Parameters

Susceptible to Vibration Fatigue? – should be answered "Yes" if vibration fatigue could cause a small hole size leak representing a "crack" in larger piping or failure of small piping branches.

Motor Power – represents mechanical energy input for the equipment such as a vessel agitator or mixer, circulating pump, etc. It may also represent an electric heater or tracing. An overall "inefficiency" of 50% (power resulting in heat) is assumed which is conservative for pumps and agitators but optimistic for electric heaters. For pumps, with a hydraulic efficiency of 0.6 and a 0.9 efficient electric motor exactly matched to the required hydraulic power, the thermal inefficiency would be roughly (1-0.6) (1-0.9) = 0.36 rather than 0.5. The user may need to adjust the power input to for improved estimates of maximum mechanical energy temperature.

Insulation – is used to determine a heat loss coefficient in energy balance estimations. Choices are "Yes", "No", and "Fireproof". The option, "Fireproof" will reduce the estimated heat input from external fire. If the equipment operating temperature is within the Corrosion Under Insulation temperature range, the Input will be labeled "Insulation with Potential Corrosion (CUI)".

Insulation Heat Reduction Factor - This is a reduction factor which will be multiplied by the heat transfer coefficient to account for insulation. It will default to a value of 0.05 if not entered.

User Equipment Wetted Surface Area – is the wetted surface area of the equipment used for fire heat input or convective heat losses. If blank an estimated Wetted Surface Area will be used based on equipment volume and tank/vessel geometry

Tracing? – entered as "Yes" if equipment is heat traced.

Equipment Elevation to Surface – represents the elevation or height of a leak above a liquid pool. This input is used to determine fire heat input (fire heat is zero for greater than 30 feet or 9.1 m elevation), distance for liquid spray and duration of aerosol droplets for estimation of Airborne Quantity. A default value of 1 m is used if this input is blank.

Drain Valve Size – is the "hole size" equivalent that will be used for estimation of leak rate for a drain valve inadvertently opened scenario. A default of ½ inch is used (representing a standard ¾ inch plug valve equivalent to a ½ inch hole) if this input is blank.

Parameters Specific to Vessels or Tanks

In addition to the General Equipment Parameters, additional inputs specific to **Vessels or Tanks** include:

Vessel/Tank Geometry? – Geometry is noted as horizontal, vertical, flat bottom" and/or "anchored" to improve estimation of surface area and Rupture Pressure.

Low Pressure Tank with Weak Seam Roof? – Used to determine is vessel is anchored to credit a Weak Seam Roof.

Vessel/Tank Considered as "Storage"? – To determine if the tank is considered as Storage per API 521. This is an Input for F&EI and used in determining fire heat input.

Conductive Dip Pipe or Bottom Fill? – should be answered "Yes" if appropriate. A "Yes" answer will suggest this design feature as a potential Safety Related Protective System for preventing electrostatic discharge for tanks or vessels containing flammable materials.

Parameters Specific to Heat Exchangers or Vessel Jackets

In addition to the General Equipment Parameters, additional inputs specific to **Heat Exchangers or Vessel Jackets** include:

Heat Transfer Area – is the area, A, used in estimation of heat input rate, $q = U A \Delta T$ where ΔT is the temperature difference between the Heat Transfer Fluid Temperature and Operating Temperature.

Heating Overall U – is the heat transfer coefficient, U, used in estimation of heat input rate. If either Heat Transfer Area or Heating Overall U is blank, no estimation of heat input rate is performed.

Heat Transfer Fluid Temperature – is used to determine if the maximum operating vapor pressure exceeds design limits, if the maximum operating temperature can exceed the Reaction Temperature of No Return, and in estimation of the heat input rate.

Heat Transfer Fluid Pressure – is used to determine if tube or heat exchanger failure will leak heat transfer fluid into the process or if process fluid would leak into the heat transfer system.

Tube Failure Release to Atmosphere? - Should be answered "Yes" if tube failure will result in a release of process fluid to atmosphere.

Heat Transfer Fluid Name – is used to look up chemical properties of the heat transfer fluid for estimation of tube leak hazards. **Heat Transfer Fluid State** is not an input but estimated from the fluid properties, temperature and pressure.

Tube or Leak Diameter – is used to estimate the leak rate and potential consequences for tube failure.

Number of Tubes – is entered either as "< 100" or "> 100" to determine the Initiating Event factor in LOPA.

Cooling Transfer Area, **Cooling Overall U**, and **Coolant Temperature** – are inputs to estimate the Temperature of No Return with cool for reaction scenarios.

Parameters Specific to Piping

In addition to the General Equipment Parameters, additional inputs specific to Equipment or Piping include:

Pipe Length – is the length of piping associated with an entire piping loop in the same Chemical Service.

Piping Vulnerable to Damage? – is used to determine if a pipe damage scenario should be added to the list of scenarios for consideration.

Apply Screwed Connection Penalty? – this input has options for: No Penalty, Through Very Small, Through Medium, Through Very Large and Through Extremely Large. A penalty will be taken for Mechanical Integrity scenarios through the hole size noted.

Note that Piping inputs are only used if the Equipment Type is Piping, Pump, Compressor or Blower, or Turbine or Gas Expander.

Parameters Specific to Pumps

In addition to the General Equipment Parameters of Volume, Maximum Allowable Working Pressure (MAWP) and Motor Power, additional inputs specific to **Pumps** include:

Equipment Volume – represents the volume of the pump plus piping system. The volume of the pump cavity is estimated for a pump based on data for centrifugal pumps.

Pump Type – is used in determining the suggested type of Pump Deadhead scenario for evaluation. Options are: *Centrifugal, Positive Displacement, or Diaphragm with Limited Source Pressure*. The default is assumed Centrifugal if the input is blank.

Seal or Containment Type – is used to determine the Initiating Event for a Seal or Casing Leak scenario. Options are: *Single Mechanical, Double Mechanical, Magnetic Drive or Canned, or Double Containment.*

Remote Start Pump? – should be answered "Yes" if an "off, jog, auto" field switch is used (could not be in a manual "on" position) and the switch location is beyond the severe hazard impact zone associated with pump failure. The default is "No" if the input is blank.

Automated Suction or Discharge? – should be answered "Discharge Only" or "Both Suction and Discharge" if a failure of instrument air or Basic Process Control could result in the inadvertent closing of the discharge and/or suction values creating a pump deadhead scenario.

Parameters Specific to Relief Devices

Relief Device information may be entered for all types of equipment. Entry of a Relief Set Pressure indicates that a Relief Device exists (or is planned) for the equipment item being evaluated. The additional Relief Device Parameters are used for evaluation of Relief Device Effluent or in estimating the release rate within Layers of Protection Analysis.

Relief Device Identification – is the identification number of the Relief Device for reference.

Relief Type – is the type of Relief Device including: *Rupture Disk*, *Graphite Disk*, *Safety Valve*, *Pilot Operated Valve*, *ERV*, *PVRV*, *Pressure Relief Line*, *Combination PSV*, *and Combination Disks*.

Relief Discharges to: - provides information relative to the release location and orientation. Options include: Indoors, Outdoors-Upwards, Outdoors-Horizontal, Outdoors to Ground, Pump or Compressor Suction, Vent Header to Blow-down Tank, and Scrubber or Containment.

Relief Set Press (gauge) - is the set pressure of the Relief Device. If blank, it is assumed that no Relief Device has been used for overpressure protection of the equipment being evaluated.

Relief Size (equivalent diameter) – is the orifice diameter for Safety Values or diameter for other types of devices. It is used in estimation of the Actual Flow Rate for relief device activation.

Relief Design Actual Flow Rate – is the actual flow capacity from Relief Design calculations and must be matched to the composition on the Chemical Input worksheet. If the actual flow rate is based on a relief vent design program which only compares worst case chemical within a mixture, the input should be left blank and an estimate based on the device diameter and set pressure will be used.

Relief Tail Pipe Diameter – is the diameter of the Tail Pipe and used to determine the exit velocity from the relief system. This velocity is an important parameter in determining dilution of the relief effluent by "jet mixing". A low velocity is assumed if the input is blank.

Relief Discharge Elevation – is the elevation of the relief discharge and used in the dispersion modeling for estimation of ground level concentration versus distance. A worst case "ground" elevation release is assumed if the input is blank.

Closest Distance to Nearest Elevated Work Area – is used to determine the concentration of toxic or flammable material at the closest edge of the nearest elevated work area from the release location, most typically a relief device.

Furthest Distance to Nearest Elevated Work Area – is used to determine the concentration of toxic or flammable material at the furthest edge (for large areas) of the nearest elevated work area from the release location, most typically a relief device

Elevation of Nearest Work Area - is used to determine the concentration of toxic or flammable material within the nearest work area.

Locations Specific to Relief Device – ***Entered ONLY if Different from Equipment Location, includes:***

Relief Distance to Property Limit or Fence Line

Relief Distance to Occupied Building 1 or Area

Relief Distance to Center of Occupied Building 1

Occupied Building 2 in Same Wind Direction for Relief?

Relief Distance to Occupied Building 2

Relief Distance to Center of Occupied Building 2

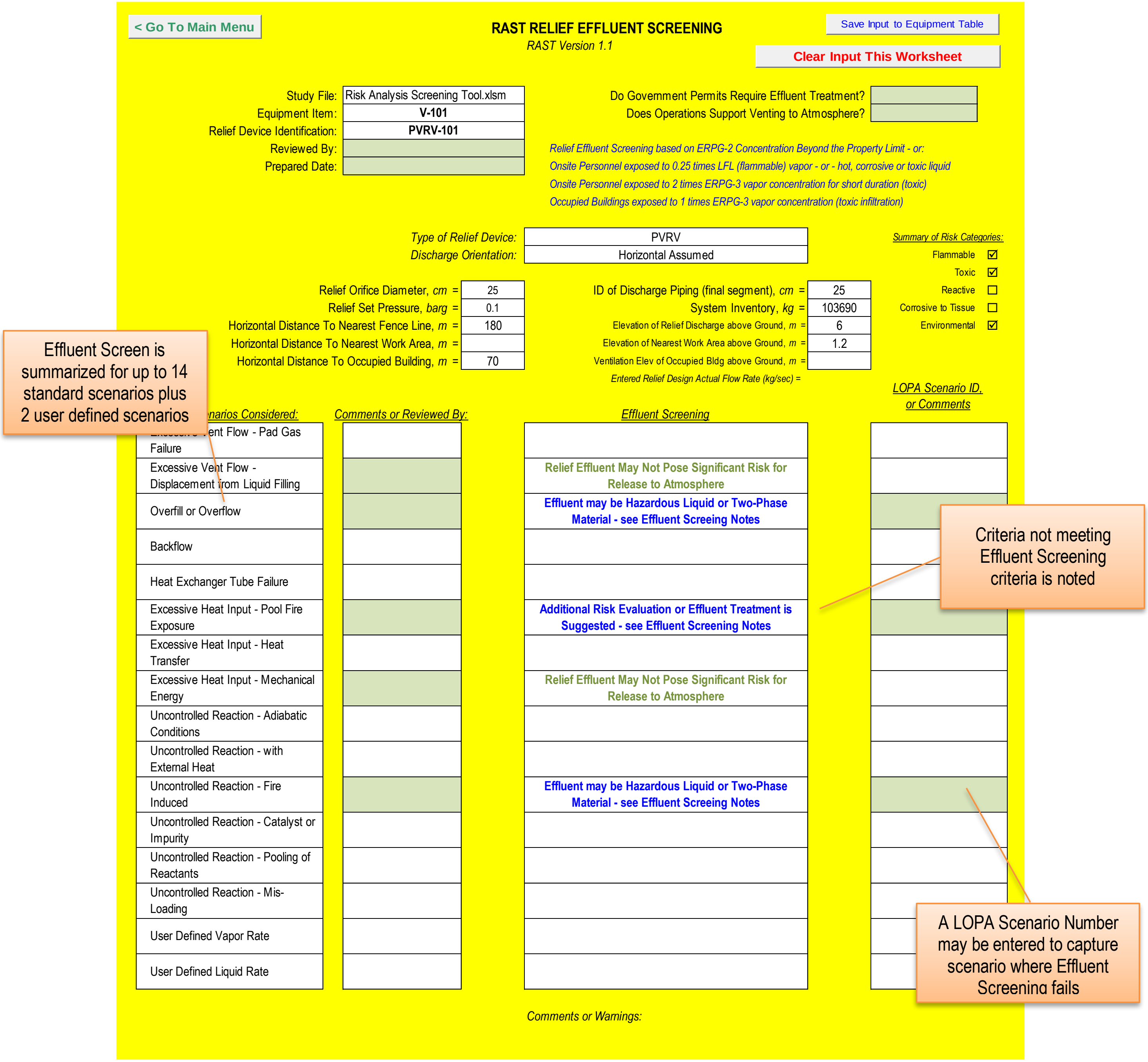
Example Relief Device Effluent Screening Evaluation

As an example, for a Relief Device Effluent Evaluation, continue with the "Getting Started" Study Example. *(Note that Inputs on the Plant Layout worksheet will also impact Relief Effluent Screening.)*

STEP 1: Go to the ***Equipment Table*** and select a cell in the row representing Inputs for **V-101**. Use the ***Load Selected*** command. Information for **V-101** should now be "active" on the ***Equipment Input*** worksheet.

STEP 2: Go to ***Equipment Input*** and enter the **Relief Device Identification** as PVRV-101. Select **PVRV** for **the Relief Type**. Also enter **Relief Size** of **250 mm** (10 inch), a **Relief Set Pressure** of 0.**07 barg** (1 psig), and **Relief Discharge Elevation** of **6 m** (20 ft). Select ***Save Input to Equipment Table.***

STEP 3: Select ***Go to the Main Menu***, then Select ***Relief Effluent Screening Report*** from the Main Menu (Figure 5.2).



RAST RELIEF EFFLUENT SCREENING

RAST Version 1.1

Study File: Risk Analysis Screening Tool.xlsm
Equipment Item: V-101
Relief Device Identification: PVRV-101
Reviewed By:
Prepared Date:

Do Government Permits Require Effluent Treatment?
Does Operations Support Venting to Atmosphere?

Relief Effluent Screening based on ERPG-2 Concentration Beyond the Property Limit - or:
Onsite Personnel exposed to 0.25 times LFL (flammable) vapor - or - hot, corrosive or toxic liquid
Onsite Personnel exposed to 2 times ERPG-3 vapor concentration for short duration (toxic)
Occupied Buildings exposed to 1 times ERPG-3 vapor concentration (toxic infiltration)

Type of Relief Device: PVRV
Discharge Orientation: Horizontal Assumed

Relief Orifice Diameter, *cm* = 25
Relief Set Pressure, *barg* = 0.1
Horizontal Distance To Nearest Fence Line, *m* = 180
Horizontal Distance To Nearest Work Area, *m* =
Horizontal Distance To Occupied Building, *m* = 70

ID of Discharge Piping (final segment), *cm* = 25
System Inventory, *kg* = 103690
Elevation of Relief Discharge above Ground, *m* = 6
Elevation of Nearest Work Area above Ground, *m* = 1.2
Ventilation Elev of Occupied Bldg above Ground, *m* =
Entered Relief Design Actual Flow Rate (kg/sec) =

Summary of Risk Categories:
Flammable ☑
Toxic ☑
Reactive ☐
Corrosive to Tissue ☐
Environmental ☑

narios Considered:	*Comments or Reviewed By:*	*Effluent Screening*	*LOPA Scenario ID, or Comments*
ent Flow - Pad Gas Failure			
Excessive Vent Flow - Displacement from Liquid Filling		Relief Effluent May Not Pose Significant Risk for Release to Atmosphere	
Overfill or Overflow		**Effluent may be Hazardous Liquid or Two-Phase Material - see Effluent Screeing Notes**	
Backflow			
Heat Exchanger Tube Failure			
Excessive Heat Input - Pool Fire Exposure		**Additional Risk Evaluation or Effluent Treatment is Suggested - see Effluent Screening Notes**	
Excessive Heat Input - Heat Transfer			
Excessive Heat Input - Mechanical Energy		Relief Effluent May Not Pose Significant Risk for Release to Atmosphere	
Uncontrolled Reaction - Adiabatic Conditions			
Uncontrolled Reaction - with External Heat			
Uncontrolled Reaction - Fire Induced		**Effluent may be Hazardous Liquid or Two-Phase Material - see Effluent Screeing Notes**	
Uncontrolled Reaction - Catalyst or Impurity			
Uncontrolled Reaction - Pooling of Reactants			
Uncontrolled Reaction - Mis-Loading			
User Defined Vapor Rate			
User Defined Liquid Rate			

Comments or Warnings:

Effluent Screen is summarized for up to 14 standard scenarios plus 2 user defined scenarios

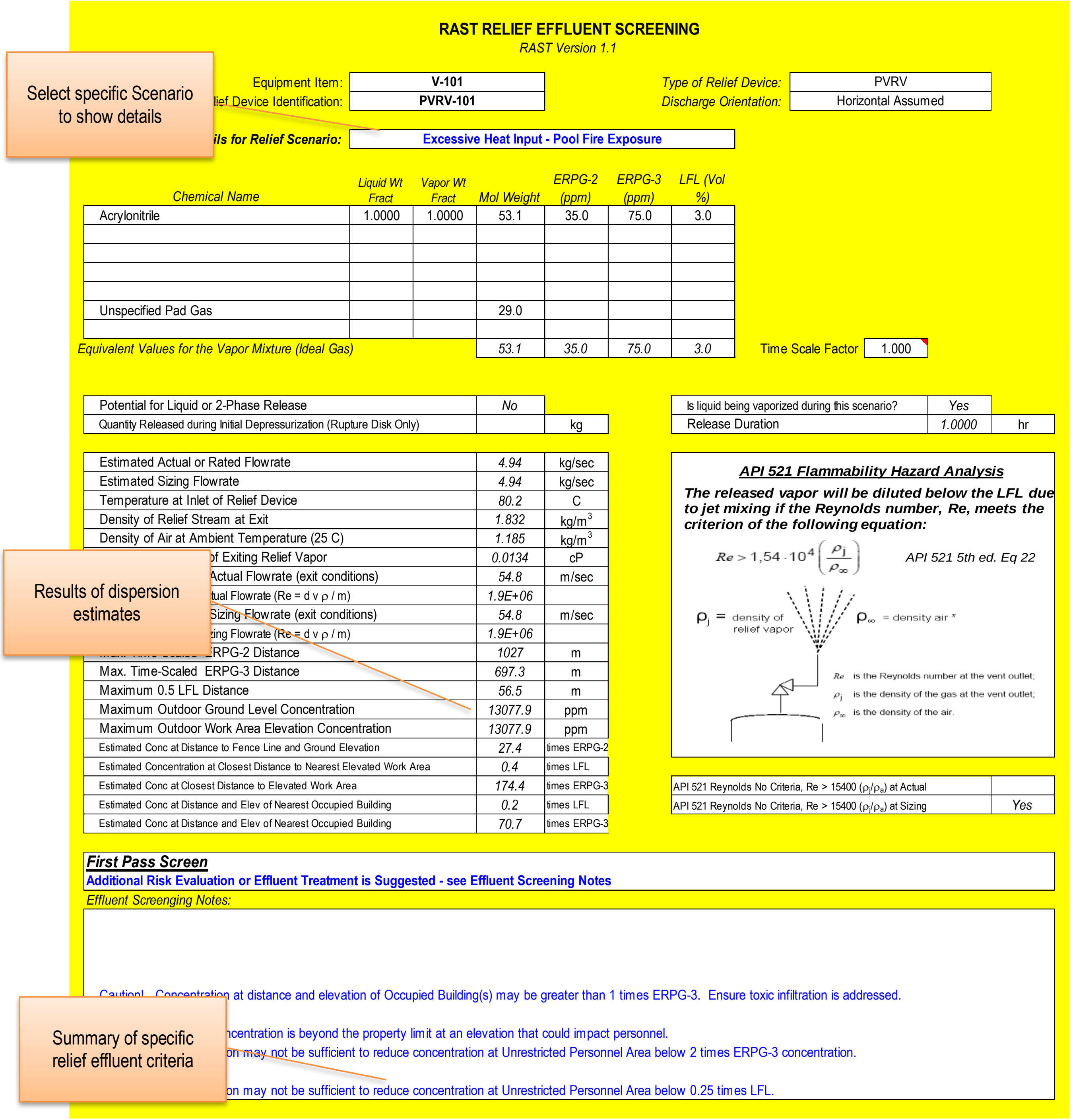
Criteria not meeting Effluent Screening criteria is noted

A LOPA Scenario Number may be entered to capture scenario where Effluent Screening fails

Figure 5.2: Relief Effluent Screening Report

Relief Effluent Screening for up to 14 standard scenarios and 2 User Defined scenarios are summarized. Input for the LOPA Scenario Number that demonstrates adequate Risk Management for these cases may be entered to complete the documentation requirements. Details are summarized by selecting the specific Scenario.

STEP 4: Select ***<u>Overfill or Overflow</u>*** from the available listing. A report, consistent with the Relief Effluent Screening Tool, is shown with details of the specific case selected. Refer to Figure 5.3.



RAST RELIEF EFFLUENT SCREENING

RAST Version 1.1

Equipment Item:	V-101	*Type of Relief Device:*	PVRV
lief Device Identification:	PVRV-101	*Discharge Orientation:*	Horizontal Assumed

ils for Relief Scenario: **Excessive Heat Input - Pool Fire Exposure**

Chemical Name	*Liquid Wt Fract*	*Vapor Wt Fract*	*Mol Weight*	*ERPG-2 (ppm)*	*ERPG-3 (ppm)*	*LFL (Vol %)*
Acrylonitrile	1.0000	1.0000	53.1	35.0	75.0	3.0
Unspecified Pad Gas			29.0			
Equivalent Values for the Vapor Mixture (Ideal Gas)			*53.1*	*35.0*	*75.0*	*3.0*

Time Scale Factor 1.000

Potential for Liquid or 2-Phase Release	*No*	
Quantity Released during Initial Depressurization (Rupture Disk Only)		kg

Is liquid being vaporized during this scenario?	*Yes*	
Release Duration	*1.0000*	hr

Estimated Actual or Rated Flowrate	*4.94*	kg/sec
Estimated Sizing Flowrate	*4.94*	kg/sec
Temperature at Inlet of Relief Device	*80.2*	C
Density of Relief Stream at Exit	*1.832*	kg/m^3
Density of Air at Ambient Temperature (25 C)	*1.185*	kg/m^3
of Exiting Relief Vapor	*0.0134*	cP
Actual Flowrate (exit conditions)	*54.8*	m/sec
tual Flowrate (Re = d v ρ / m)	*1.9E+06*	
Sizing Flowrate (exit conditions)	*54.8*	m/sec
zing Flowrate (Re = d v ρ / m)	*1.9E+06*	
RPG-2 Distance	*1027*	m
Max. Time-Scaled ERPG-3 Distance	*697.3*	m
Maximum 0.5 LFL Distance	*56.5*	m
Maximum Outdoor Ground Level Concentration	*13077.9*	ppm
Maximum Outdoor Work Area Elevation Concentration	*13077.9*	ppm
Estimated Conc at Distance to Fence Line and Ground Elevation	*27.4*	times ERPG-2
Estimated Concentration at Closest Distance to Nearest Elevated Work Area	*0.4*	times LFL
Estimated Conc at Closest Distance to Elevated Work Area	*174.4*	times ERPG-3
Estimated Conc at Distance and Elev of Nearest Occupied Building	*0.2*	times LFL
Estimated Conc at Distance and Elev of Nearest Occupied Building	*70.7*	times ERPG-3

<u>API 521 Flammability Hazard Analysis</u>

The released vapor will be diluted below the LFL due to jet mixing if the Reynolds number, Re, meets the criterion of the following equation:

$$Re > 1{,}54 \cdot 10^4 \left(\frac{\rho_j}{\rho_\infty} \right)$$

API 521 5th ed. Eq 22

API 521 Reynolds No Criteria, Re > 15400 (ρ_j/ρ_a) at Actual	
API 521 Reynolds No Criteria, Re > 15400 (ρ_j/ρ_a) at Sizing	*Yes*

<u>First Pass Screen</u>

Additional Risk Evaluation or Effluent Treatment is Suggested - see Effluent Screening Notes

Effluent Screenging Notes:

Caution! Concentration at distance and elevation of Occupied Building(s) may be greater than 1 times ERPG-3. Ensure toxic infiltration is addressed.

ncentration is beyond the property limit at an elevation that could impact personnel.

on may not be sufficient to reduce concentration at Unrestricted Personnel Area below 2 times ERPG-3 concentration.

on may not be sufficient to reduce concentration at Unrestricted Personnel Area below 0.25 times LFL.

Select specific Scenario to show details

Results of dispersion estimates

Summary of specific relief effluent criteria

Figure 5.3: Example of Specific Case Relief Effluent Report

Parameters Specific to Specialized Equipment

Other Equipment Parameters include Replacement Cost & Business Loss in addition to highly specialized parameter such as:

Replacement Cost & Business Loss – Used for determining the Business Loss Consequence.

Drum Oven Volume – is the volume of an oven rather than volume of equipment being evaluated (typically a drum).

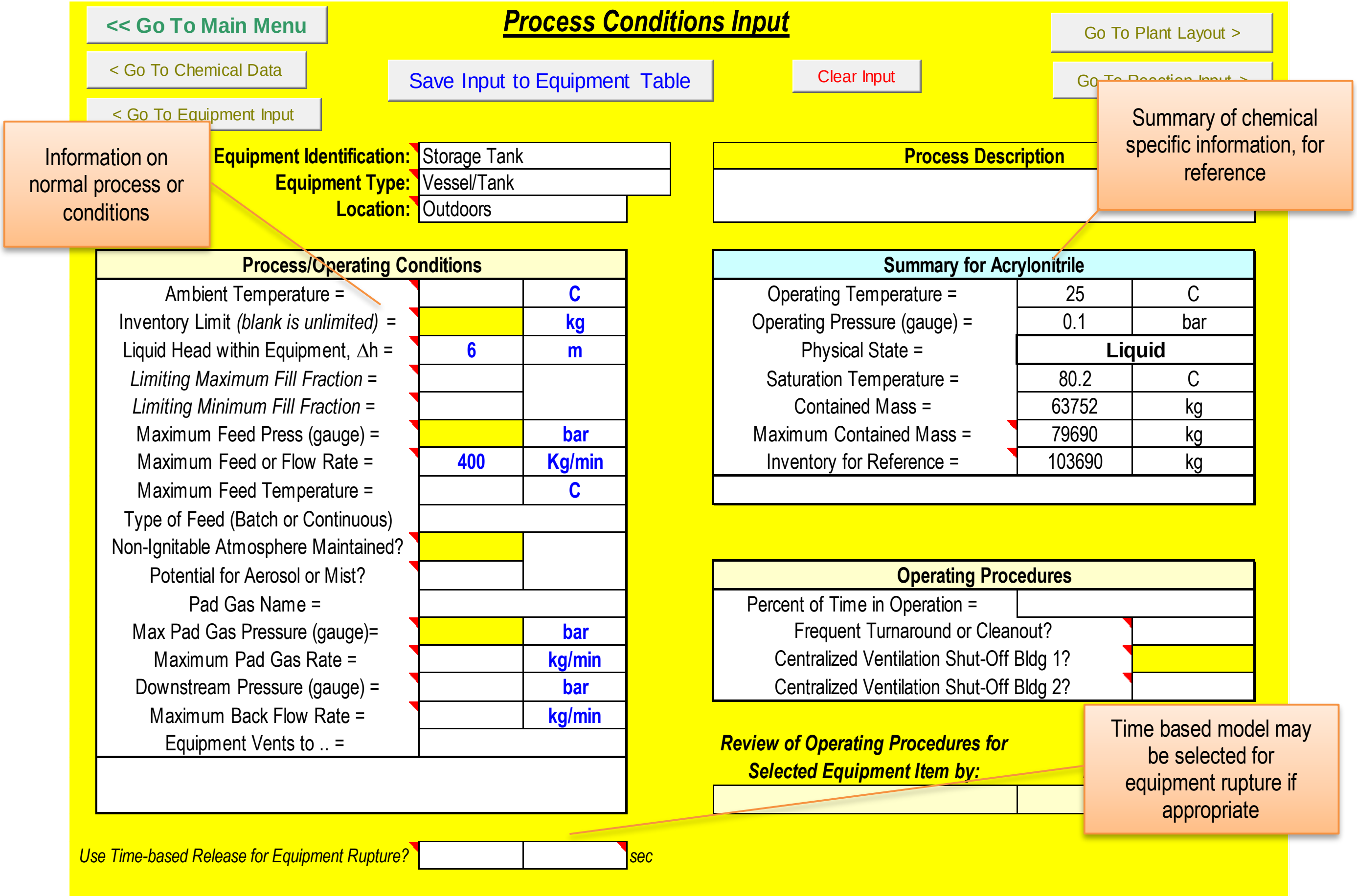
High Speed Rotation Equipment? – is used in determining the Probability of Ignition for Solids Handling Equipment. "Yes" implies a Maximum Tip Speed > 9.5 m/sec.

Bellows or Expansion Joint Used? – should be answered "Yes" if appropriate. A "Yes" answer will add the appropriate leakage penalty to the Fire and Explosion Index.

Sight Glass Used? – should be answered "Yes" if appropriate. A "Yes" answer will suggest a potential scenario involving failure of the sight glass and add the appropriate leakage penalty to the Fire and Explosion Index.

Process and Operating Conditions

In addition to the minimum required inputs of **Maximum Feed or Flow Rate** and **Liquid Head within Equipment** (for low Operating Pressure), other Process and Operating Information may be needed for various evaluations or reports. Refer to Figure 5.4.



Process Conditions Input

Information on normal process or conditions

Summary of chemical specific information, for reference

Equipment Identification: Storage Tank
Equipment Type: Vessel/Tank
Location: Outdoors

Process Description

Process/Operating Conditions		
Ambient Temperature =		C
Inventory Limit *(blank is unlimited)* =		kg
Liquid Head within Equipment, Δh =	6	m
Limiting Maximum Fill Fraction =		
Limiting Minimum Fill Fraction =		
Maximum Feed Press (gauge) =		bar
Maximum Feed or Flow Rate =	400	Kg/min
Maximum Feed Temperature =		C
Type of Feed (Batch or Continuous)		
Non-Ignitable Atmosphere Maintained?		
Potential for Aerosol or Mist?		
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 Acrylonitrile		
Operating Temperature =	25	C
Operating Pressure (gauge) =	0.1	bar
Physical State =	**Liquid**	
Saturation Temperature =	80.2	C
Contained Mass =	63752	kg
Maximum Contained Mass =	79690	kg
Inventory for Reference =	103690	kg

Operating Procedures	
Percent of Time in Operation =	
Frequent Turnaround or Cleanout?	
Centralized Ventilation Shut-Off Bldg 1?	
Centralized Ventilation Shut-Off Bldg 2?	

Review of Operating Procedures for Selected Equipment Item by:

Time based model may be selected for equipment rupture if appropriate

Use Time-based Release for Equipment Rupture? sec

Figure 5.4: Additional Process Condition Parameters

Total Inventory –the total quantity of chemical in the process which may be added to the equipment being evaluated. For storage tanks, it would represent a "full" tank plus the quantity within any tank truck, railcar, etc. that could be unloaded into the tank. The difference between Total Inventory and the estimated Maximum Contained Mass is the maximum amount that can be released for an overfill scenario.

Limiting Maximum Fill Fraction –the maximum fill fraction for the equipment used for estimating heat-up time, etc. If blank is assumed 0.9 or 90%.

Limiting Minimum Fill Fraction –the minimum fill fraction for the equipment used for estimating heat-up time, etc. If blank is assumed 0.1 or 10%.

Maximum Feed Pressure (gauge) –the source pressure of material feeding the equipment being evaluated. If the maximum feed pressure is less than the relief device set pressure, an overfill or hydraulic overpressure scenario is not feasible.

Maximum Feed Temperature –the maximum temperature of material feeding the equipment being evaluated.

Type of Feed (Batch or Continuous) –used in determining the most likely Initiating Event for some scenario cases.

Non-Ignitable Atmosphere Maintained? – answer "Yes" if a scenario case for "Loss of Inert or Air Ingress" should be included in the list of potential scenario cases.

Potential for Aerosol or Mist? –the potential for aerosol or mist from splash filling or vigorous agitation/mixing which may increase the probability of ignition for internal deflagration.

Pad Gas Name - used to look up chemical properties of the pad gas. If blank, a molecular weight of 29 is assumed for the pad gas.

Maximum Pad Pressure (gauge) - the source pressure of the pad gas feeding the equipment being evaluated. If the maximum pad gas pressure is greater than the relief device set pressure, an overpressure scenario is considered.

Maximum Pad Gas Rate –the maximum rate of pad gas into the equipment being evaluated. This input is used to estimate the rate of pressure rise for pad gas system failure.

Downstream Pressure (gauge) –the maximum pressure of downstream equipment and should include pressure due to change in elevation if appropriate. If this pressure is greater than the operating pressure, a backflow scenario is considered.

Maximum Back Flow Rate –the maximum back flow rate that could occur and used to estimate release rate for back flow scenarios.

Equipment Vents to… –used in identification of scenario cases. Options include: Immediate Area, Source/Vapor Balance, Scrubber System, Fired Equip (TOX- Flare), Does Not Vent, or Floating Roof Tank.

Operating Procedures

Information relative to selected common Operating Procedures may be input for use in Layers of Protection Analysis (LOPA). Included is:

Percent Time in Operation –used to determine if a Time at Risk Enabling Factor may be used in LOPA.

Frequent Turnaround or Cleanout? – answer "Yes" if frequent cleanout of equipment is needed for batch operations.

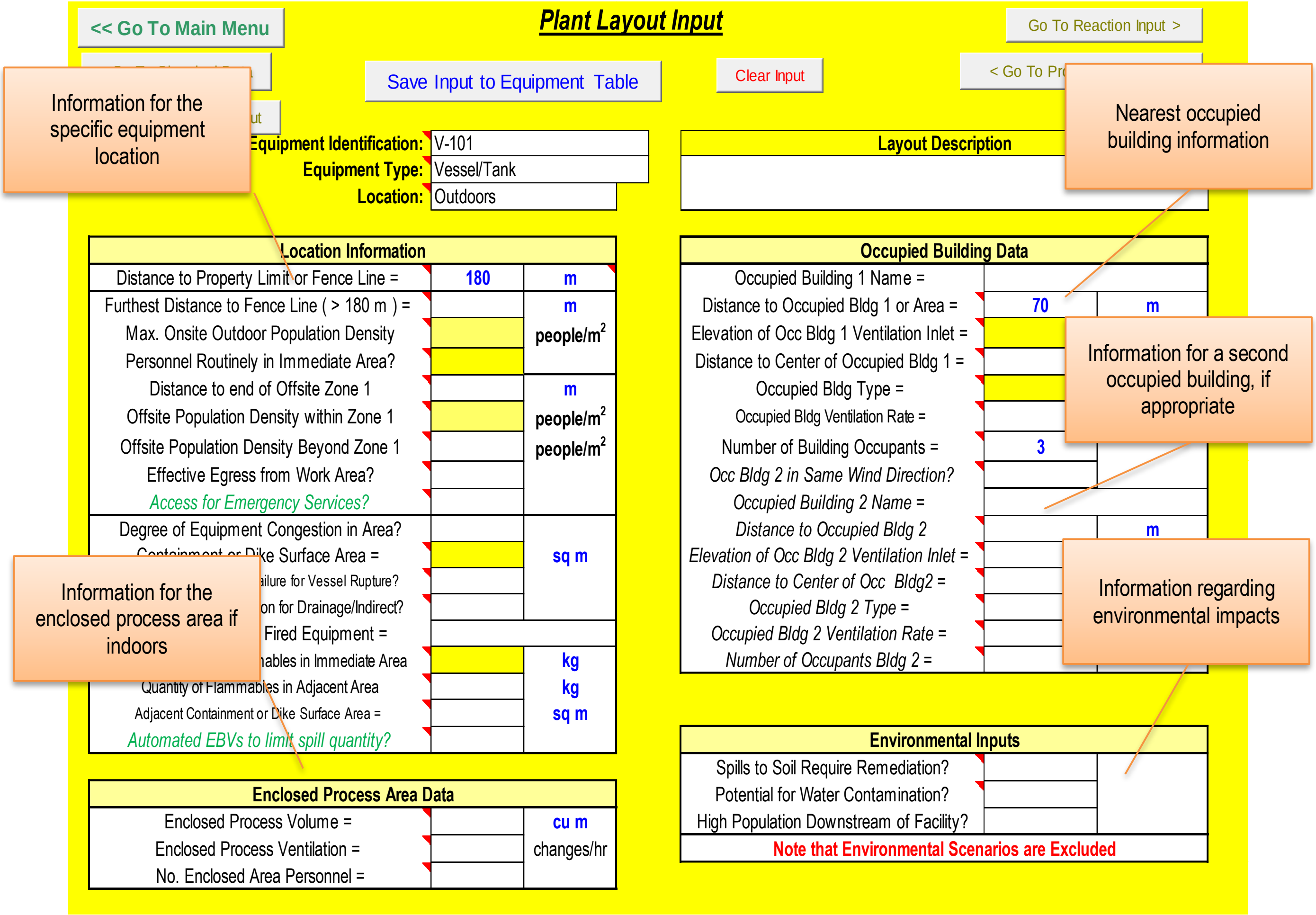
Effective Ventilation Shut-Off Building 1? - answer "Yes" if appropriate which will suggest a potential LOPA credit for toxic infiltration scenarios.

Effective Ventilation Shut-Off Building 2? - answer "Yes" if appropriate which will suggest a potential LOPA credit for toxic infiltration scenarios.

Use Time-based Release for Equipment Rupture? - answer "Yes" if a time-based model is to be used for Equipment Rupture outcome. The release duration in seconds also needs to be entered (to a maximum of 600 seconds). If left "blank" or "No" is entered, a Rupture (or Instantaneous) Release model will be used. For very rapid events such as explosions in pressure vessels, detonations, or very rapid runaway reactions, the Rupture Release model should be used. For slower events such as the rupture of a week seam roof or the base of a low-pressure vessel lifting from its foundations, a time-based model over an "appropriate" length of time may be more accurate.

Plant Layout Information

In addition to the minimum required inputs of **Distance to Property Limit of Fence Line**, **Distance to Occupied Building** and **Number of Building Occupants**, other Plant Layout Information may be needed for various evaluations or reports. Refer to Figure 5.5.



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

Layout Description

Location Information

Distance to Property Limit or Fence Line =	180	m
Furthest Distance to Fence Line (> 180 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
ailure for Vessel Rupture?		
on for Drainage/Indirect?		
Fired Equipment =		
ables 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 =		cu m
Enclosed Process Ventilation =		changes/hr
No. Enclosed Area Personnel =		

Occupied Building Data

Occupied Building 1 Name =		
Distance to Occupied Bldg 1 or Area =	70	m
Elevation of Occ Bldg 1 Ventilation Inlet =		
Distance to Center of Occupied Bldg 1 =		
Occupied Bldg Type =		
Occupied Bldg Ventilation Rate =		
Number of Building Occupants =	3	
Occ Bldg 2 in Same Wind Direction?		
Occupied Building 2 Name =		
Distance to Occupied Bldg 2		m
Elevation of Occ Bldg 2 Ventilation Inlet =		
Distance to Center of Occ Bldg2 =		
Occupied Bldg 2 Type =		
Occupied Bldg 2 Ventilation Rate =		
Number of Occupants Bldg 2 =		

Environmental Inputs

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

Note that Environmental Scenarios are Excluded

Information for the specific equipment location

Nearest occupied building information

Information for a second occupied building, if appropriate

Information for the enclosed process area if indoors

Information regarding environmental impacts

Figure 5.5: Additional Plant Layout Parameters

Specific Equipment Location Information

Furthest Distance to Fence Line or Effect Zone - used in estimating the maximum area of the effect zone to be used with the entered population density for outdoor toxic or flammable releases. Few people would be on-site beyond this distance.

Maximum Onsite Outdoor Population Density – represents the number of people who could be outdoors divided by the outdoor process area. A default of 0.0002 people/m^2 is used if this input is blank (which is an average value for many industrial facilities).

Personnel Routinely in Immediate Area? answer "Yes" if operator attendance is required, equipment location is near a walkway, etc. The default is "Yes" if the input is blank.

Distance to end of Offsite Zone 1 - two offsite population densities may be used in the analysis: beyond the Property Limit distance to the end of Zone 1 distance, and beyond Zone 1 distance.

Offsite Population Density within Zone 1 – offsite population density immediately beyond the Property Limit distance to the Zone 1 distance. If blank, the default offsite population density will be used. Typically, "Sparsely" populated is 0.0002 to 0.0005 people/m^2, "Moderately" populated is 0.001 to 0.002 people/m^2 and "Densely" populated is 0.003 to 0.005 people/m^2.

Offsite Population Density Beyond Zone 1 - offsite population density immediately beyond the Zone 1 distance. If blank, the default offsite population density will be used.

Effective Egress from Work Area? - answer"Yes" if personnel would not be trapped on an elevated work platform and have an unobstructed path for escape purposes.

Access for Emergency Services? – is used an input for Fire and Explosion Index. Options include: Adequate, Inadequate, and Partially Adequate.

Degree of Equipment Congestion in Area? – is used in determination of explosion energy. Options include: Low, Medium, and High.

Containment or Dike Area - is the surface area a spill would be confined to. If this input is blank, spills are assumed as not confined.

Consider Dike or Bund Failure for Vessel Rupture? – answer "Yes" to assume a "wave" of liquid spills over the dike wall or the dike wall fails for rupture cases.

Credit Fire Heat Adsorption for Drainage/Indirect? - answer "Yes" if drainage is such that fire heat is not directly under the equipment. "Yes" will reduce the NFPA fire heat (with remote impoundment) input by 50% or use a lower correlating coefficient in API fire heat input.

Distance to Nearest Fired Equipment – is used in determining factors with the Fire and Explosion Index and probability of explosion with LOPA. Options include: No, within 10 m (33 ft), within 20 m (65 ft), within 30 m (100 ft), and greater than 30 m (100 ft).

Quantity of "Other" Flammable Liquids in Area – is the mass of flammable material in nearby equipment that provide fuel for a pool fire. This quantity does not include the contents of the equipment being evaluated.

Quantity of "Other" Flammable Liquids in Adjacent Area – is the mass of flammable material in equipment or vessels in an adjacent area that provide fuel for a pool fire.

Adjacent Containment Surface Area - is the surface area a spill would be confined to within the adjacent area.

Automated EBV to limit spill quantity? - answer "Yes" if appropriate. This input is used within the Fire and Explosion Index.

Enclosed Process Area Information

Enclosed Process Volume – is the volume of the enclosed process area in which the equipment is located. If the equipment is located in a room that is isolated from the other areas of the process building, only the room volume should be entered.

Enclosed Process Ventilation –represents the mechanical ventilation rate of the Process Area. This input is used to estimate concentration within the enclosed process area to determine if mechanical ventilation may represent a possible "credit" in LOPA. This input does not impact LOPA Consequence.

Number of Enclosed Area Personnel – represents the number of people who could be within the enclosed process area who may be impacted. A default of two people is assumed if this input is blank.

Occupied Building Information

Identical inputs for up to two Occupied Buildings may be used. If a second building is to be included in the evaluation, the question: **Occupied Building 2 in Same Wind Direction?** should be answered either "Yes" or "No" as appropriate. Refer to Figure 5.6 for an example.

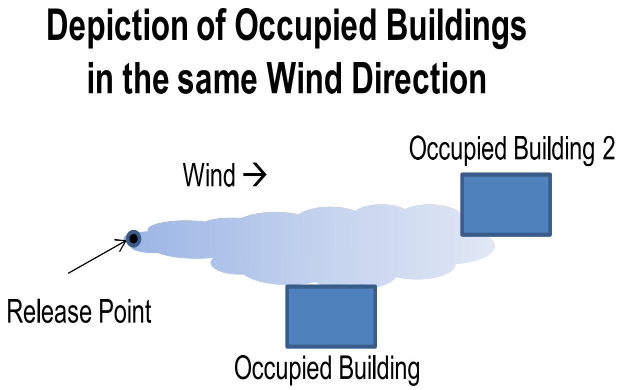


Figure 5.6: Depiction of 2 Occupied Buildings Downwind

Occupied Building Name – is a text field used for reference by the evaluation team.

Distance to Occupied Building or Area? – is a minimum required input and represents the distance to the nearest edge of the Occupied Building or Occupied Area within an Enclosed Process Building.

Elevation of Occupied Building Ventilation – is the elevation of the ventilation inlet and often corresponds to the roof elevation.

Distance to Center of Occupied Building – is used in estimation of explosion damage to the building. This value should always be greater than the Distance to Occupied Building. A default of Distance to Occupied Building is used if this input is blank.

Occupied Building Type – is used to determine explosion damage to the Occupied Building. Options include: "Low Strength" which represents a low strength portable building, or "Typical Construction" representing typical residential or industry construction. Impacts to high strength or blast resistant buildings are not considered in RAST screening evaluation.

Occupied Building Ventilation Rate – is used in estimation of indoor concentration resulting from toxic infiltration. This input does not impact LOPA Consequence.

Centralized Ventilation Shut-Off? - answer "Yes" if appropriate which will suggest a potential LOPA credit.

Number of Building Occupants – is a minimum required input and should represent a daytime maximum building occupancy

Environmental Inputs

RAST contains a very approximate table for estimating Environmental Consequences. Both spills to soil and spills to a waterway are considered.

Spills to Soil Require Remediation? – answer "Yes" if using this Environmental Consequence Table for estimating the Tolerable Frequency for spills to soil. The consequence will be based on the NFPA Health ranking in addition to the quantity spilled.

Potential for Water Contamination - answer "Yes" if using this Environmental Consequence Table for estimating the Tolerable Frequency for spills to a waterway. The consequence will be estimated based on the entered Aquatic toxicity (harmful, toxic, and very toxic) in addition to the quantity spilled.

High Population Downstream of Facility? – answer "Yes" if a city or other highly populated area is immediately downstream of the spill. "Yes" will increase the consequence category (or Tolerable Frequency) by 1 for water contamination.

Estimation of Number of People Impacted from Plant Layout Information within RAST

It must be noted that **estimating the number of people impacted for a scenario is extremely inaccurate**. Often consequence severity is predicted significantly higher or significantly less than actual historical incidents. It is the intent of RAST to provide estimates primarily for consistency among Hazard Identification and Risk Analysis studies and for comparison.

When using the option for *Consequence Severity without Direct Reference to Human Harm*, inherent to the correlation of hazard distance or concentration divided by Level of Concern is a population density or number of building occupants. For situations where the population density is significantly greater or less than inherent to the correlation, or where the number of building occupants is significantly greater or less than inherent to the correlation; adjustments or Conditional Modifiers may be needed in Risk Analysis.

The location references of the various RAST inputs are depicted in Figure 5.7 below.

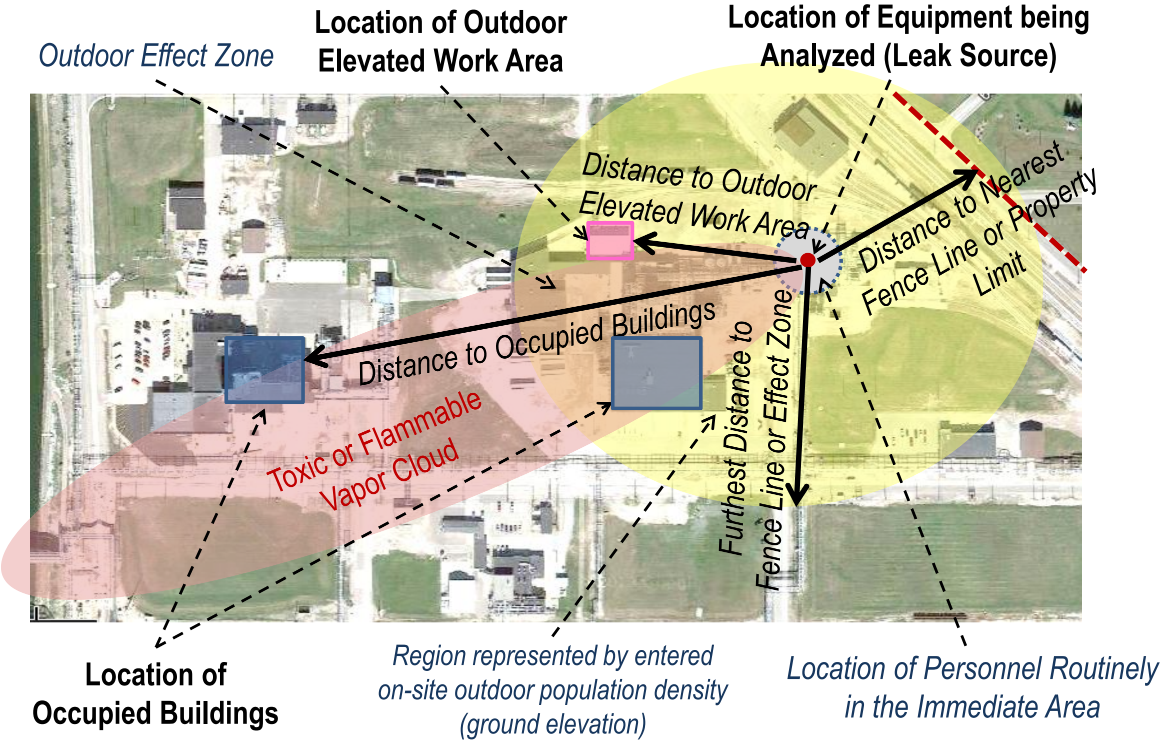


Figure 5.7: RAST Input Referenced Locations

The Maximum Number of On-Site Outdoor Personnel Impacted is estimated as:

Person Routinely in the Immediate Area

+ Person at Elevated Work Location

+ Effect Zone "Footprint" Area times Maximum Population Density

Note that the area of the Effect Zone is estimated as a "pie shaped" circle segment of 0.3 times Distance^2. The Vapor Cloud distance to a concentration of ½ the Lower Flammable Limit (flammable cloud) OR a multiple of ERPG-3 concentration (toxic cloud) at ground elevation will be used unless limited by entering a maximum "Distance to Furthest Fence Line or On-Site Personnel".

The number of people impacted within Occupied Buildings is estimated as the sum of "Vulnerability" (or fraction of building occupants impacted) times Maximum Number of Occupants for each building. For outdoor release scenarios, the number of outdoor on-site personnel impacted is added to those impacted within occupied building to obtain a total number of people impacted.

For example: Consider a flammable release with an estimated distance to ½ LFL concentration of 250 m, a maximum population density of 0.0002 people/m^2 within the effect zone, personnel noted as "routinely in the immediate area", concentration at the location of the elevated work area exceeding ½ LFL, and one building with 10 occupants within the blast wave of the resulting vapor cloud explosion such that the occupant vulnerability is 50%. The total number of people impacted for this scenario would be estimated as:

1 person within the immediate area

+ 1 person within the elevated work area

+ $0.3\ (250\ \text{m})^2\ (0.0002\ \text{people}/\text{m}^2) = 3.8$ people within the effect zone

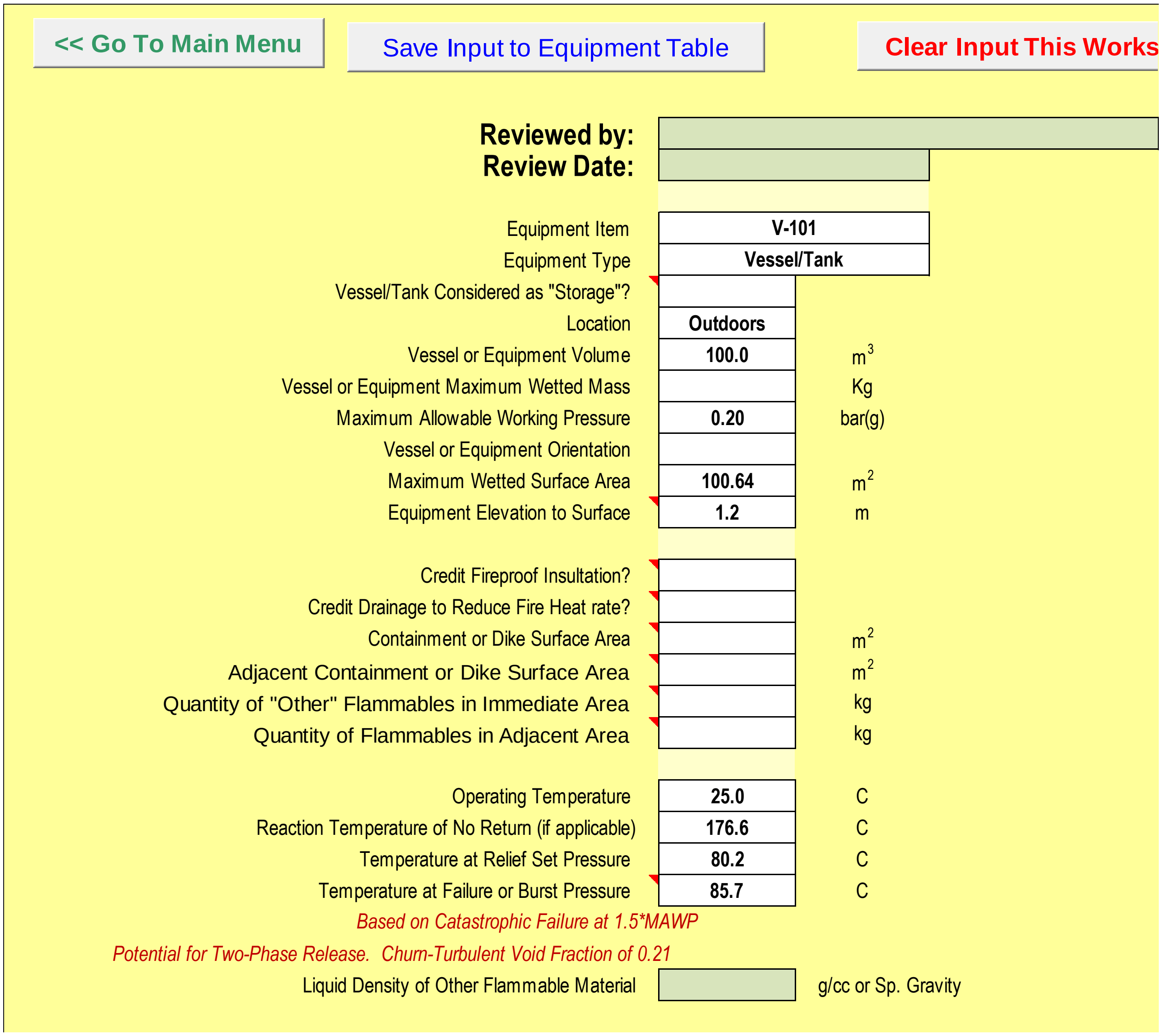
<u>+ 10 (0.5) = 5 people within the occupied building</u>

= 10.8 total people impacted

Additional information for estimation of effect zones and toxic or explosion damage vulnerability of building occupants is found in the training materials for Chemical Hazard Engineering Fundamentals (CHEF).

Pool Fire Evaluation Worksheet

Excessive Heat from Pool Fire is a common scenario case for Hazard Evaluation and Pressure Relief Design. The Pool Fire Evaluation worksheet provides a summary of key pool fire information for any Equipment Item. This summary contains an estimate of the fire heat adsorption rate and the pool fire duration. In addition, the times for heating to the saturation temperature at the relief device set pressure, heating to the saturation temperature at the rupture or catastrophic failure pressure, heating to the reaction temperature of no return are estimated. Figures 5.8, 5.9 & 5.10 depict the Pool Fire Evaluation worksheet.



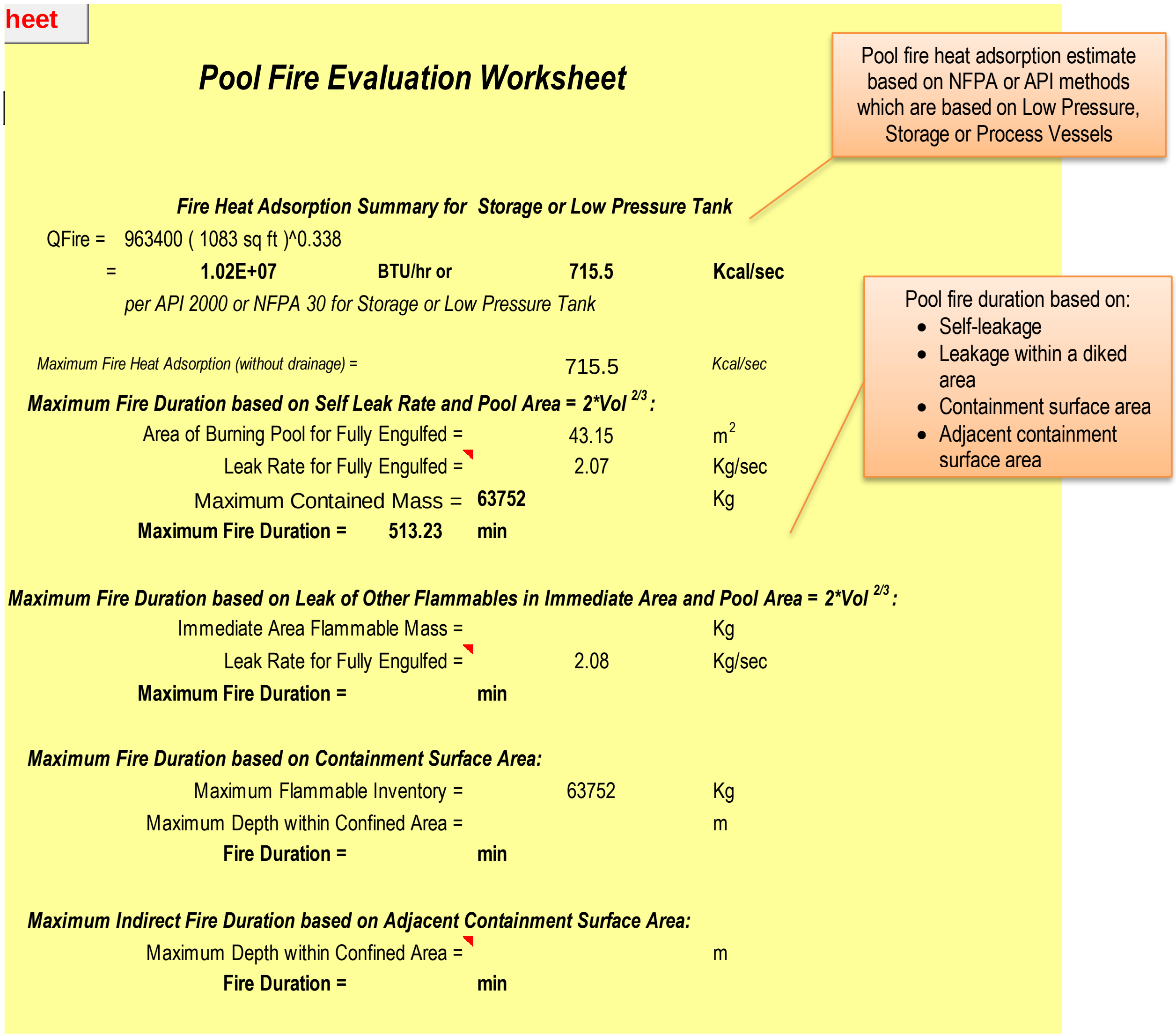
Reviewed by:		
Review Date:		
Equipment Item	V-101	
Equipment Type	Vessel/Tank	
Vessel/Tank Considered as "Storage"?		
Location	Outdoors	
Vessel or Equipment Volume	100.0	m^3
Vessel or Equipment Maximum Wetted Mass		Kg
Maximum Allowable Working Pressure	0.20	bar(g)
Vessel or Equipment Orientation		
Maximum Wetted Surface Area	100.64	m^2
Equipment Elevation to Surface	1.2	m
Credit Fireproof Insultation?		
Credit Drainage to Reduce Fire Heat rate?		
Containment or Dike Surface Area		m^2
Adjacent Containment or Dike Surface Area		m^2
Quantity of "Other" Flammables in Immediate Area		kg
Quantity of Flammables in Adjacent Area		kg
Operating Temperature	25.0	C
Reaction Temperature of No Return (if applicable)	176.6	C
Temperature at Relief Set Pressure	80.2	C
Temperature at Failure or Burst Pressure	85.7	C

*Based on Catastrophic Failure at 1.5*MAWP*

Potential for Two-Phase Release. Churn-Turbulent Void Fraction of 0.21

Liquid Density of Other Flammable Material		g/cc or Sp. Gravity

Figure 5.8: Pool Fire Evaluation Worksheet Part 1



heet

Pool Fire Evaluation Worksheet

Pool fire heat adsorption estimate based on NFPA or API methods which are based on Low Pressure, Storage or Process Vessels

Fire Heat Adsorption Summary for Storage or Low Pressure Tank

QFire = 963400 (1083 sq ft)^0.338

= **1.02E+07** **BTU/hr or** **715.5** **Kcal/sec**

per API 2000 or NFPA 30 for Storage or Low Pressure Tank

Maximum Fire Heat Adsorption (without drainage) = 715.5 *Kcal/sec*

Maximum Fire Duration based on Self Leak Rate and Pool Area = 2*Vol $^{2/3}$:

Area of Burning Pool for Fully Engulfed = 43.15 m^2

Leak Rate for Fully Engulfed = 2.07 Kg/sec

Maximum Contained Mass = **63752** Kg

Maximum Fire Duration = 513.23 min

Pool fire duration based on:

- Self-leakage
- Leakage within a diked area
- Containment surface area
- Adjacent containment surface area

Maximum Fire Duration based on Leak of Other Flammables in Immediate Area and Pool Area = 2*Vol $^{2/3}$:

Immediate Area Flammable Mass = Kg

Leak Rate for Fully Engulfed = 2.08 Kg/sec

Maximum Fire Duration = min

Maximum Fire Duration based on Containment Surface Area:

Maximum Flammable Inventory = 63752 Kg

Maximum Depth within Confined Area = m

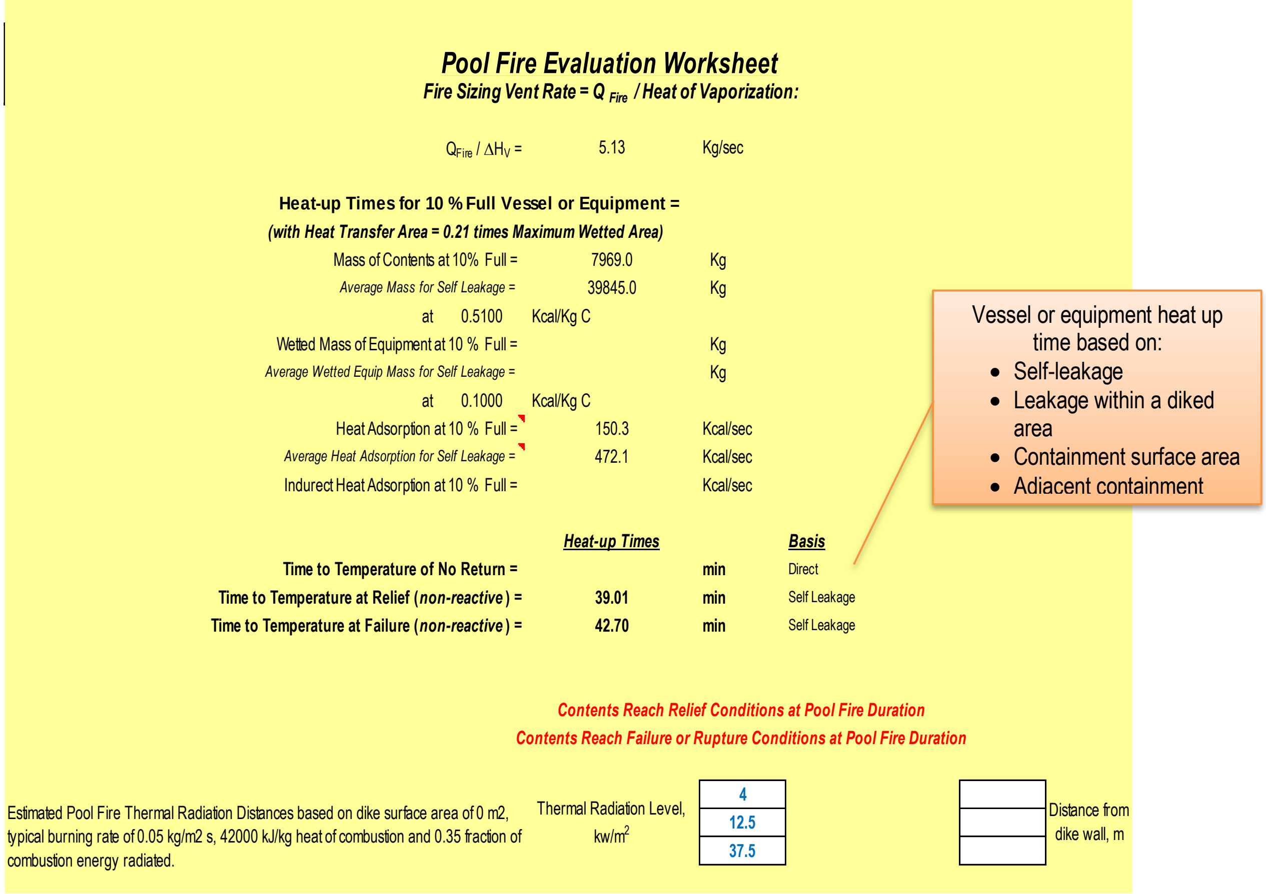
Fire Duration = min

Maximum Indirect Fire Duration based on Adjacent Containment Surface Area:

Maximum Depth within Confined Area = m

Fire Duration = min

Figure 5.9: Pool Fire Evaluation Worksheet Part 2



Pool Fire Evaluation Worksheet

Fire Sizing Vent Rate = Q $_{Fire}$ / Heat of Vaporization:

$Q_{Fire} / \Delta H_V$ = 5.13 Kg/sec

Heat-up Times for 10 % Full Vessel or Equipment =

(with Heat Transfer Area = 0.21 times Maximum Wetted Area)

Mass of Contents at 10% Full =	7969.0	Kg
Average Mass for Self Leakage =	39845.0	Kg
at 0.5100	Kcal/Kg C	
Wetted Mass of Equipment at 10 % Full =		Kg
Average Wetted Equip Mass for Self Leakage =		Kg
at 0.1000	Kcal/Kg C	
Heat Adsorption at 10 % Full =	150.3	Kcal/sec
Average Heat Adsorption for Self Leakage =	472.1	Kcal/sec
Indurect Heat Adsorption at 10 % Full =		Kcal/sec

	Heat-up Times		**Basis**
Time to Temperature of No Return =		**min**	Direct
Time to Temperature at Relief (*non-reactive*) =	**39.01**	**min**	Self Leakage
Time to Temperature at Failure (*non-reactive*) =	**42.70**	**min**	Self Leakage

Contents Reach Relief Conditions at Pool Fire Duration

Contents Reach Failure or Rupture Conditions at Pool Fire Duration

Estimated Pool Fire Thermal Radiation Distances based on dike surface area of 0 m2, typical burning rate of 0.05 kg/m2 s, 42000 kJ/kg heat of combustion and 0.35 fraction of combustion energy radiated.

Thermal Radiation Level, kw/m^2	Distance from dike wall, m
4	
12.5	
37.5	

Vessel or equipment heat up time based on:

- Self-leakage
- Leakage within a diked area
- Containment surface area
- Adiacent containment

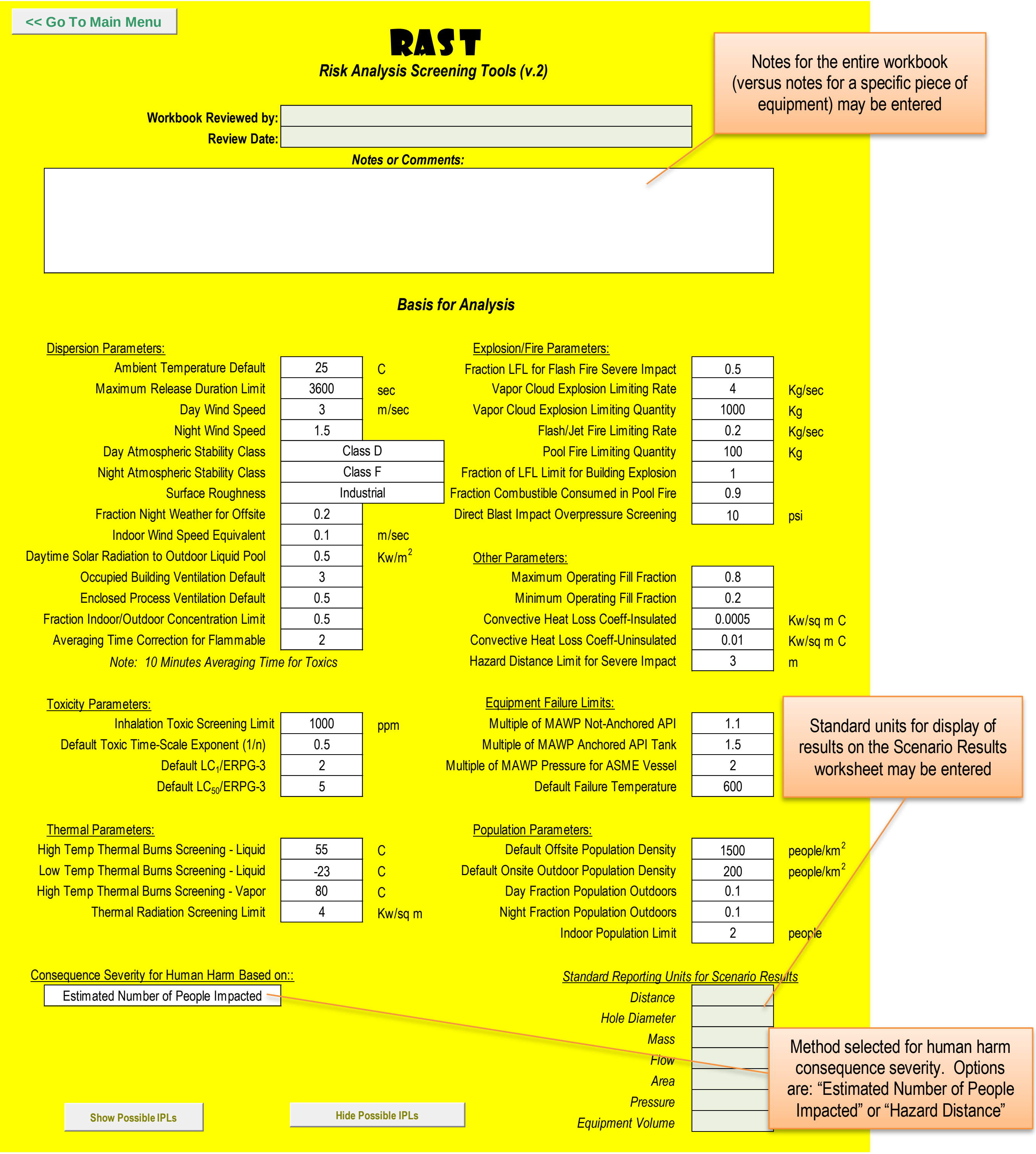
Figure 5.10: Pool Fire Evaluation Worksheet Part 3

Additional information associated with Pool Fire Evaluation is covered in the Layers of Protection Analysis section of this document under Pool Fire Frequency Evaluation.

Workbook Notes and Setting Units to be Displayed on the Scenario Results worksheet

A Workbook Notes tab is available to capture notes from the LOPA team that apply to the entire workbook. The Basis for Analysis is also summarized on the worksheet including the values for Ambient Temperature, Wind Speed, and Onsite Population Density.

Standard Units to be displayed for all scenarios in the Scenario Results worksheet may also be entered at the bottom right of this worksheet. If not entered, units will be displayed as those entered by the User for the various inputs. For example, the units for distance will be that entered by the user for "Distance to Property Limit or Fence Line" on the Plant Layout Worksheet (which may be different for each equipment entry). Entering Standard Reporting Units on the Workbook Notes worksheet will ensure that the units for *all* scenarios in the Scenario Results worksheet are the same. Refer to Figure 5.11.



Risk Analysis Screening Tools (v.2)

Workbook Reviewed by:

Review Date:

Notes or Comments:

Basis for Analysis

Dispersion Parameters:

Ambient Temperature Default	25	C
Maximum Release Duration Limit	3600	sec
Day Wind Speed	3	m/sec
Night Wind Speed	1.5	
Day Atmospheric Stability Class	Class D	
Night Atmospheric Stability Class	Class F	
Surface Roughness	Industrial	
Fraction Night Weather for Offsite	0.2	
Indoor Wind Speed Equivalent	0.1	m/sec
Daytime Solar Radiation to Outdoor Liquid Pool	0.5	Kw/m^2
Occupied Building Ventilation Default	3	
Enclosed Process Ventilation Default	0.5	
Fraction Indoor/Outdoor Concentration Limit	0.5	
Averaging Time Correction for Flammable	2	

Note: 10 Minutes Averaging Time for Toxics

Explosion/Fire Parameters:

Fraction LFL for Flash Fire Severe Impact	0.5	
Vapor Cloud Explosion Limiting Rate	4	Kg/sec
Vapor Cloud Explosion Limiting Quantity	1000	Kg
Flash/Jet Fire Limiting Rate	0.2	Kg/sec
Pool Fire Limiting Quantity	100	Kg
Fraction of LFL Limit for Building Explosion	1	
Fraction Combustible Consumed in Pool Fire	0.9	
Direct Blast Impact Overpressure Screening	10	psi

Other Parameters:

Maximum Operating Fill Fraction	0.8	
Minimum Operating Fill Fraction	0.2	
Convective Heat Loss Coeff-Insulated	0.0005	Kw/sq m C
Convective Heat Loss Coeff-Uninsulated	0.01	Kw/sq m C
Hazard Distance Limit for Severe Impact	3	m

Toxicity Parameters:

Inhalation Toxic Screening Limit	1000	ppm
Default Toxic Time-Scale Exponent (1/n)	0.5	
Default LC$_1$/ERPG-3	2	
Default LC$_{50}$/ERPG-3	5	

Equipment Failure Limits:

Multiple of MAWP Not-Anchored API	1.1
Multiple of MAWP Anchored API Tank	1.5
Multiple of MAWP Pressure for ASME Vessel	2
Default Failure Temperature	600

Thermal Parameters:

High Temp Thermal Burns Screening - Liquid	55	C
Low Temp Thermal Burns Screening - Liquid	-23	C
High Temp Thermal Burns Screening - Vapor	80	C
Thermal Radiation Screening Limit	4	Kw/sq m

Population Parameters:

Default Offsite Population Density	1500	people/km^2
Default Onsite Outdoor Population Density	200	people/km^2
Day Fraction Population Outdoors	0.1	
Night Fraction Population Outdoors	0.1	
Indoor Population Limit	2	people

Consequence Severity for Human Harm Based on::

Estimated Number of People Impacted

Standard Reporting Units for Scenario Results

Distance
Hole Diameter
Mass
Flow
Area
Pressure
Equipment Volume

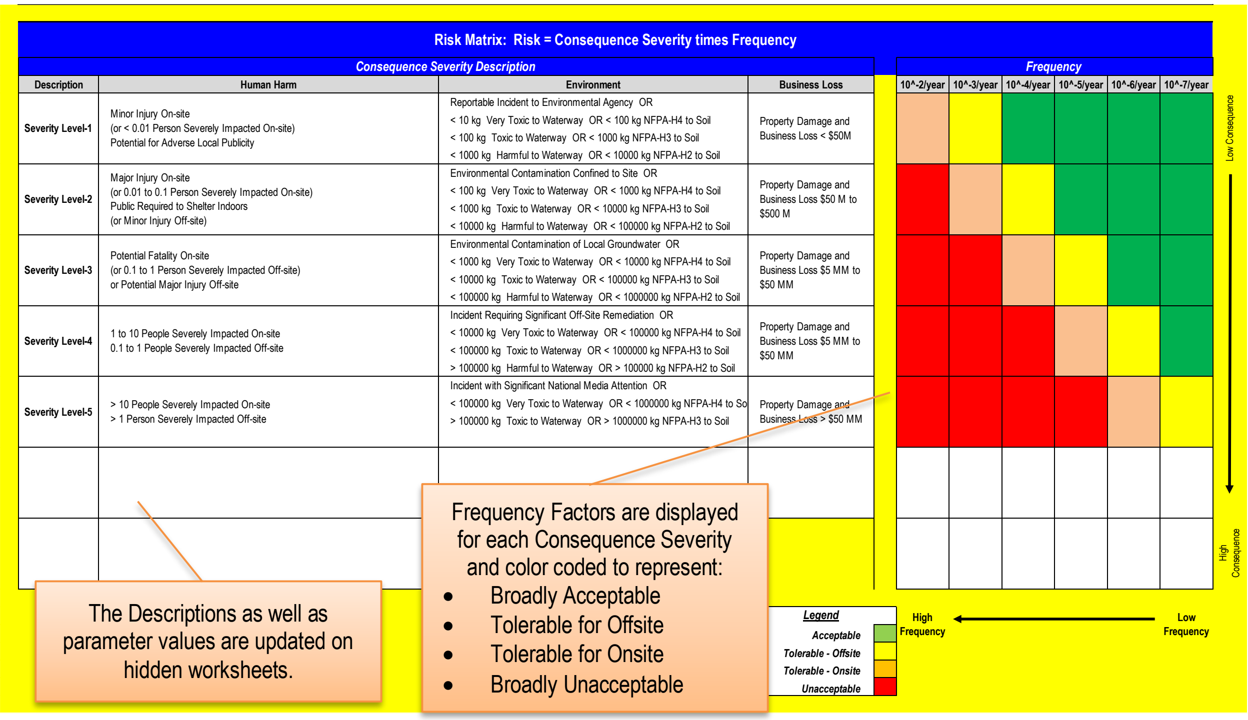
Notes for the entire workbook (versus notes for a specific piece of equipment) may be entered

Standard units for display of results on the Scenario Results worksheet may be entered

Method selected for human harm consequence severity. Options are: "Estimated Number of People Impacted" or "Hazard Distance"

Figure 5.11: Workbook Notes Worksheet

On the right-hand side of the Workbook Notes worksheet is a display of the specific Risk Matrix for use in RAST Hazard Analysis. It is suggested that a representative of the company (referred as a RAST "Technical Administrator") update the risk criteria and risk matrix to reflect the company's risk tolerance criteria. The Technical Administrator should also update the number of severity and frequency levels for consistency of users of the RAST within the company. The human harm criteria may be expressed as number of people severely impacted (the current default) or by the characteristics of the chemical release such as distance from the release point to a hazardous concentration. The default parameters provided in RAST should be considered "examples" as CCPS does not endorse any specific risk criteria.



Risk Matrix: Risk = Consequence Severity times Frequency

Consequence Severity Description				Frequency					
Description	Human Harm	Environment	Business Loss	10^-2/year	10^-3/year	10^-4/year	10^-5/year	10^-6/year	10^-7/year
Severity Level-1	Minor Injury On-site (or < 0.01 Person Severely Impacted On-site) Potential for Adverse Local Publicity	Reportable Incident to Environmental Agency OR < 10 kg Very Toxic to Waterway OR < 100 kg NFPA-H4 to Soil < 100 kg Toxic to Waterway OR < 1000 kg NFPA-H3 to Soil < 1000 kg Harmful to Waterway OR < 10000 kg NFPA-H2 to Soil	Property Damage and Business Loss < $50M	🟧	🟨	🟩	🟩	🟩	🟩
Severity Level-2	Major Injury On-site (or 0.01 to 0.1 Person Severely Impacted On-site) Public Required to Shelter Indoors (or Minor Injury Off-site)	Environmental Contamination Confined to Site OR < 100 kg Very Toxic to Waterway OR < 1000 kg NFPA-H4 to Soil < 1000 kg Toxic to Waterway OR < 10000 kg NFPA-H3 to Soil < 10000 kg Harmful to Waterway OR < 100000 kg NFPA-H2 to Soil	Property Damage and Business Loss $50 M to $500 M	🟥	🟧	🟨	🟩	🟩	🟩
Severity Level-3	Potential Fatality On-site (or 0.1 to 1 Person Severely Impacted Off-site) or Potential Major Injury Off-site	Environmental Contamination of Local Groundwater OR < 1000 kg Very Toxic to Waterway OR < 10000 kg NFPA-H4 to Soil < 10000 kg Toxic to Waterway OR < 100000 kg NFPA-H3 to Soil < 100000 kg Harmful to Waterway OR < 1000000 kg NFPA-H2 to Soil	Property Damage and Business Loss $5 MM to $50 MM	🟥	🟥	🟧	🟨	🟩	🟩
Severity Level-4	1 to 10 People Severely Impacted On-site 0.1 to 1 People Severely Impacted Off-site	Incident Requiring Significant Off-Site Remediation OR < 10000 kg Very Toxic to Waterway OR < 100000 kg NFPA-H4 to Soil < 100000 kg Toxic to Waterway OR < 1000000 kg NFPA-H3 to Soil > 100000 kg Harmful to Waterway OR > 100000 kg NFPA-H2 to Soil	Property Damage and Business Loss $5 MM to $50 MM	🟥	🟥	🟥	🟧	🟨	🟩
Severity Level-5	> 10 People Severely Impacted On-site > 1 Person Severely Impacted Off-site	Incident with Significant National Media Attention OR < 100000 kg Very Toxic to Waterway OR < 1000000 kg NFPA-H4 to So > 100000 kg Toxic to Waterway OR > 1000000 kg NFPA-H3 to Soil	Property Damage and Business Loss > $50 MM	🟥	🟥	🟥	🟥	🟧	🟨

Legend

- *Acceptable* 🟩
- *Tolerable - Offsite* 🟨
- *Tolerable - Onsite* 🟧
- *Unacceptable* 🟥

The Descriptions as well as parameter values are updated on hidden worksheets.

Frequency Factors are displayed for each Consequence Severity and color coded to represent:

- Broadly Acceptable
- Tolerable for Offsite
- Tolerable for Onsite
- Broadly Unacceptable

Figure 5.12: Workbook Notes Worksheet – Risk Matrix

6. SCENARIO DEVELOPMENT

Fortunately, the number of catastrophic incidents is small relative to the total number of incidents or near misses each year. Those incidents with extreme consequences are usually associated with a low frequency or probability.

Some of us will not personally experience a catastrophic incident during our career. This may present a challenge in appreciating which potential scenarios are credible. This section covers:

- How Scenarios are developed
- Understanding of RAST Library of common Scenarios
- How to enter User Defined Scenarios

Scenario Definition

A Scenario represents an unplanned sequence of events leading to a loss event with undesired consequence (Figure 6.1).

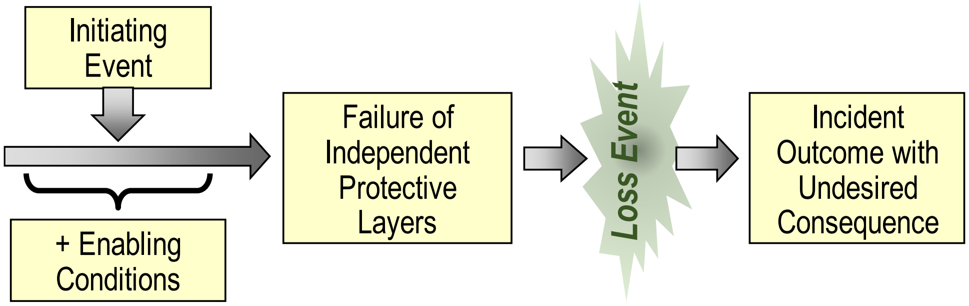


Figure 6.1 Schematic of a scenario

- **Event** – An occurrence involving a process that is caused by equipment performance or human action or by an occurrence external to the process.
- **Event Sequence** – A specific, unplanned series of events composed of an initiating event and intermediate events that may lead to an incident.
- **Loss Event** – Point in time in an abnormal situation when an irreversible physical event occurs that has the potential for loss and harm impacts. Examples include release of a hazardous material, ignition of flammable vapors or ignitable dust cloud, and over-pressurization rupture of a tank or vessel. An incident might involve more than one loss event, such as a flammable liquid spill (first loss event) followed by ignition of a flash fire and pool fire (second loss event) that heats up an adjacent vessel and its contents to the point of rupture (third loss event). Generally synonymous with hazardous event.
- **Initiating Event (Initiating Cause)** – The operational error, mechanical failure, or external event or agency that is the first event in an incident sequence and marks the transition from a normal situation to an abnormal situation.
- **Incident Outcome -** The physical manifestation of the incident: for toxic materials, the incident outcome is a toxic release, while for flammable materials; the incident outcome could be a boiling liquid expanding vapor explosion (BLEVE), flash fire, vapor cloud explosion (VCE), etc. For example, the incident outcome for a leak of chlorine from a railcar is a toxic release.

- **Consequence** - The undesirable result of a loss event, usually measured in health and safety effects, environmental impacts, loss of property, and business interruption costs.
- **Enabling Condition -** A condition that is not a failure, error or a protection layer but makes it possible for an event sequence to proceed to a consequence of concern. It consists of a condition or operating phase that does not directly cause the scenario, but that must be present or active in order for the scenario to proceed to a loss event; expressed as a dimensionless probability.

Scenario Development in RAST

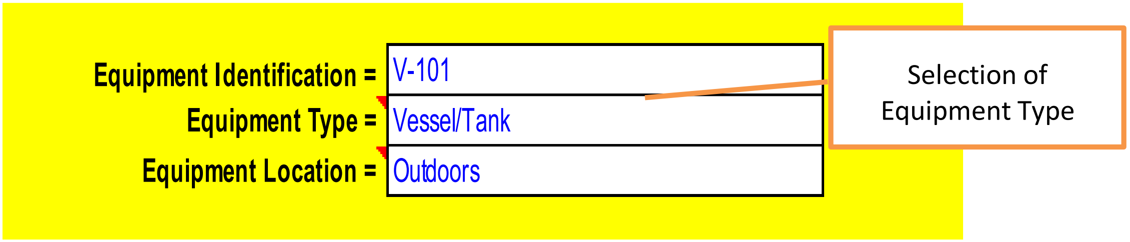
Scenarios are developed within RAST based on common process upsets (or deviations of a process parameter from the design intent) for a specific ***Type of Equipment*** and ***Chemical*** service***.*** Scenario Cases contain an Initiating Event, a single Loss Event and an Incident Outcome. A Scenario Type may also be used to provide a key phrase to describe the overall event sequence.

Initiating Event + Loss Event + Incident Outcome

For example, **Equipment Rupture** (Loss Event) caused by a **Process Control Failure** (Initiating Event) resulting in a **potential Off-Site Toxic Release** (Incident Outcome) represents a Scenario that might occur if the maximum pressure exceeds the design limits of the equipment. *We may also choose to describe this event sequence or Scenario Type as **Pressure Damage** to indicate a deviation of pressure from the design intent.*

Equipment Types in RAST

Within RAST, scenarios are developed for common process upsets for a specific equipment item Figure 6.2



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

Figure 6.2 Equipment Type Selection

_.

The general Equipment Types include:

Chemical Processing Equipment

- Absorber/Scrubber
- Compressor or Blower
- Distillation
- Drum/IBC Handling
- Extraction
- Filter/Centrifuge
- Heat Exchanger
- Piping
- Pump
- Stirred Reactor/Crystallizer
- Tank Truck/Rail Car/Tote

- Turbine or Gas Expander
- Vessel/Tank

Fired Equipment (shown in green text)

- Fired Equipment - Combustion Unit
- Fired Equipment - Fire Tube Combustion Unit
- Fired Equipment - Incinerator or TTU
- Fired Equipment – Flare
- Fired Equipment - Vapor Quench
- Fired Equipment - Process Heater

Solids Handling Equipment (shown in red text)

- Bag/Pak Dumping (Solids)
- Blender/Mixer (Solids)
- Conveyor-Mechanical (Solids)
- Conveyor-Pneumatic (Solids)
- Dryer-Mechanical (Solids)
- Dryer-Spray or Fluid Bed (Solids)
- Dust Filter or Bag house (Solids)
- Hopper Storage (Solids)
- Mill/Grinder (Solids)
- Screener or Sieve (Solids

Specialized Equipment

- Drum Oven
- USER DEFINED - EQUIPMENT

Initiating Events in RAST

Initially, the most likely Initiating Events are identified at a very high level. These will be defined in more detail ("how could this happen in my plant") after completing the Consequence Analysis. These are broadly categorized as: Control System Failures, Human Error, or Mechanical Failures. These broad categories are broken into greater detail for *Initiating Events* listed in RAST as:

Control System Failures

- BPCS Instrument Loop Failure

Human Error

- Human Failure Action more than once per quarter
- Human Failure Action once per quarter or less
- 3rd Party Intervention

Mechanical Failures

- Mechanical Failure (e.g. leading to spark or hot spot within equipment)
- Heat Exchanger Tube Leak < 100 tubes

- Heat Exchanger Tube Leak > 100 tubes
- Unloading/Loading Hose Failure
- Mechanical Loading Arm Failure
- Sight Glass Failure
- Pump (blower, compressor, etc.) Failure Loss of Flow
- Regulator Failure
- Single Mechanical Seal Failure
- Double Mechanical Seal Failure
- Canned/Magnetic Drive Pump Failure
- General Utility Failure
- Natural Disaster (Storm, Earthquake, etc.)

Other Initiating Events categorized by Failure Frequency Factors (Initialing Event Factors (IEF))

- IEF=0 (1/year) as determined by Fault Tree or Detailed Analysis
- IEF=1 (1/10 or 10^{-1}/year) as determined by Fault Tree or Detailed Analysis
- IEF=2 (1/100 or 10^{-2}/year) as determined by Fault Tree or Detailed Analysis
- IEF=3 (1/1,000 or 10^{-3}/year) as determined by Fault Tree or Detailed Analysis
- IEF=4 (1/10,000 or 10^{-4}/year) as determined by Fault Tree or Detailed Analysis
- IEF=5 4 (1/100,000 or 10^{-5}/year) as determined by Fault Tree or Detailed Analysis

Loss Event Categories in RAST

Loss Events are typically associated with "unintended release of a hazardous material or energy". Loss Event in RAST are categorized by the type of estimate used to determine release rate.

☐ **Hole Size** release.

Standardized hole sizes simplify the screening analysis, for example:

- 5 to 15 mm to represent gasket failure.

- 100 mm to full bore diameter to represent pipe or equipment nozzle failure.

☐ **Overflow** or other Material Balance released such that rate estimated from feed or fill rate.

☐ **Excessive Heat** such that vapor release rate estimated from rate of heat input divided by heat of vaporization.

☐ **Equipment Rupture** as a sudden release of entire equipment contents and reaction or pressure-volume energy.

☐ **Equipment Damage** represents a loss event requiring repair or replacement of equipment without loss of containment.

These broad categories are broken into greater detail for *Loss Events* listed in RAST as:

Hole Size Categories

- **Very Small Hole Size** leak represents a 5 mm (3/16 inch) hole leak which may be typical for a valve stem packing small gasket failure.

- **Small Hole Size** leak represents a standard size which can be used in process upset scenarios. The default setting is ½ inch hole (12.7 mm).
- **Mechanical Seal Hole Size** leak represents a maximum hole size for pump seal failure. The default setting is ½ inch hole (12.7 mm).
- **Gasket Hole Size** leak represents a typical hole size for gasket failure. The default setting is a ½ inch hole (12.7 mm).
- **Gasket Hole Size Leak (top)** represents a gasket leak from the vapor space of a liquid filled vessel by depressurization of the pad gas saturated with the liquid contents
- **Medium Hole Size** leak is used for Mechanical Integrity scenarios. The default setting is a 25 mm (1 inch) hole.
- **Medium Hole Size Leak (top)** represents a leak from the vapor space of a liquid filled vessel by depressurization of the pad gas saturated with the liquid contents.
- **Full Bore Hole Size** leak represents a full-bore pipe or nozzle hole which is common for nozzle failure and pipe rupture.
- **Large Hole Size Leak (top)** represents a leak from the vapor space of a liquid filled vessel by depressurization of the pad gas saturated with the liquid contents
- **Very Large and Extremely Large Hole Size** is used for Mechanical Integrity scenarios. The default setting is a 100 mm (4 inch) or 250 mm (10 inch) hole respectively and.
- **Very Large and Extremely Large Hole Size (top)** represents a leak from the vapor space of a liquid filled vessel by depressurization of the pad gas saturated with the liquid contents.
- **Drain or Vent Hole Size** represents a hole size entered by the User representing an open drain or vent valve.
- **Drain or Vent Hole Size (top)** represents a leak from the vapor space of a liquid filled vessel by depressurization of the pad gas saturated with the liquid contents
- **Tube Hole Size (Process)** represents a hole size entered by the User representing a "full bore" failure of a heat exchanger tube.
- **Tube Hole Size (Heat Transfer Fluid)** represents a leak of heat transfer fluid for a "full bore" heat exchanges tube failure.
- **User Hole Size** represents a hole size entered by the User.
- **User Hole Size (top)** represents a leak from the vapor space of a liquid filled vessel by depressurization of the pad gas saturated with the liquid contents

Overflow and other Material Balance Related Loss Events

- **Vent Release** is based on a User entered feed rate primarily used for scenarios associated with vent treatment systems such as a scrubber, flare, or thermal oxidizer.
- **Pad Gas Release** represents a release rate equivalent to the maximum pad gas feed rate.
- **Overfill Release** represents a release rate equal to the input feed rate, pad gas, or back flow rate. The release is assumed to flow out the relief system if the input feed pressure is greater than the relief set pressure.
- **Vapor Displacement from Liquid Filling** represents a vapor release rate equal to displacement of the entered liquid feed rate.
- **Solids Spill** represents a spill of solids equal to the feed rate. The release is assumed to occur from failed nozzle or flexible connection.
- **User Defined Release** is a release rate entered by the User.

Excessive Heat or other Heat Balance Loss Events

- **Vapor Relief Vent - Fire** represents a release rate estimated from fire exposure heat rate divided by the heat of vaporization released through the Relief System.
- **Vapor Relief Vent – Heat Transfer** represents all vapor venting and the rate is calculated as U A ΔT divided by the heat of vaporization which depends on the temperature difference between the heating media and saturation at relief pressure.
- **Vapor Relief Vent – Mechanical Energy** represents all vapor venting and the rate is calculated as the heat from mechanical energy divided by the heat of vaporization.
- **Vapor Relief Vent - Reaction** represents all vapor venting and is the reaction heat rate at relief temperature divided by the heat of vaporization. A check for two-phase flow is used for Reaction cases and vapor created from flash or evaporation of ejected liquid is added to the vapor generated from reaction heat. Venting is assumed to be through the Relief System if the maximum Reaction Pressure exceeds the Relief Set Pressure. Vapor Relief Vent may occur for any of the five primary reaction types: *Adiabatic*, *External Heat, Fire, Catalytic, Pooling of Reactants, or Mis-Loading of Reactants.*

Equipment Rupture Loss Events

- **Equipment Rupture at Operation Temperature** represents a release of energy at the burst pressure and normal operating temperature. In addition to the blast wave from the sudden release of pressure, the entire contents of the equipment are assumed to be released "instantaneously" at normal process temperature.
- **Equipment Rupture at Peak Pressure** represents a release of energy at the burst pressure and temperature corresponding to the sum of vapor pressure plus thermal expansion of pad gas. In addition to the blast wave from the sudden release of pressure, the entire contents of the equipment are assumed to be released "instantaneously" at burst pressure saturation temperature.
- **Equipment Rupture at Saturation Temperature** represents a release of energy at the burst pressure and saturation temperature (boiling point at burst pressure). In addition to the blast wave from the sudden release of pressure, the entire contents of the equipment are assumed to be released "instantaneously" at burst pressure saturation temperature.
- **Equipment Rupture at Fire Conditions** represents a release of energy at the burst pressure and saturation temperature. In addition to the blast wave from the sudden release of pressure, the entire contents of the equipment are assumed to be released "instantaneously" at the fire burst pressure saturation temperature.
- **Equipment Rupture – Internal Deflagration** represents a release of energy at a deflagration pressure of roughly 10 atmospheres. In addition to the blast wave from the sudden release of pressure, the entire contents of the equipment are assumed to be released "instantaneously" at normal process temperature.
- **Equipment Rupture – Detonation/Deflagration** represents a release of energy with fragmentation assuming a condensed phase explosive material. In addition to the blast wave from the sudden release of pressure, the entire contents of the equipment are assumed to be released "instantaneously" at burst pressure saturation temperature.

Other Loss Events

- **Equipment Damage** represents an overpressure or high temperature event exceeding the design limits that does not lead to rupture. Equipment Damage may be associated with economic loss or loss of business scenario.

- **Equipment Failure above Design Temperature** represents failure of equipment due to high temperature rather than overpressure. It is analyzed similar to a full-bore hole size leak.
- **Secondary Dust Release** represents the release of dust that could accumulate on beams, rafters, or other surfaces and be later displaced to for a combustible or flammable dust cloud.
- **Flaming Liquid Release** represents a special case used for scenarios associated with Fired Equipment.

Incident Outcome in RAST

Incident Outcome in RAST is based on a generalized Event Tree (Figure 6.3). A single loss event may have several potential outcomes including:

Flammable Outcome:

☐ Flash Fire or Fireball
☐ Vapor Cloud Explosion
☐ Building or Confined Space Explosion

Toxic Outcome:

☐ Off-site toxic exposure
☐ On-site toxic exposure
☐ Toxic infiltration of occupied buildings
☐ Chemical Exposure

Other Outcome:

☐ Physical Explosion
☐ Environmental Incident
☐ Equipment Damage or Business Loss

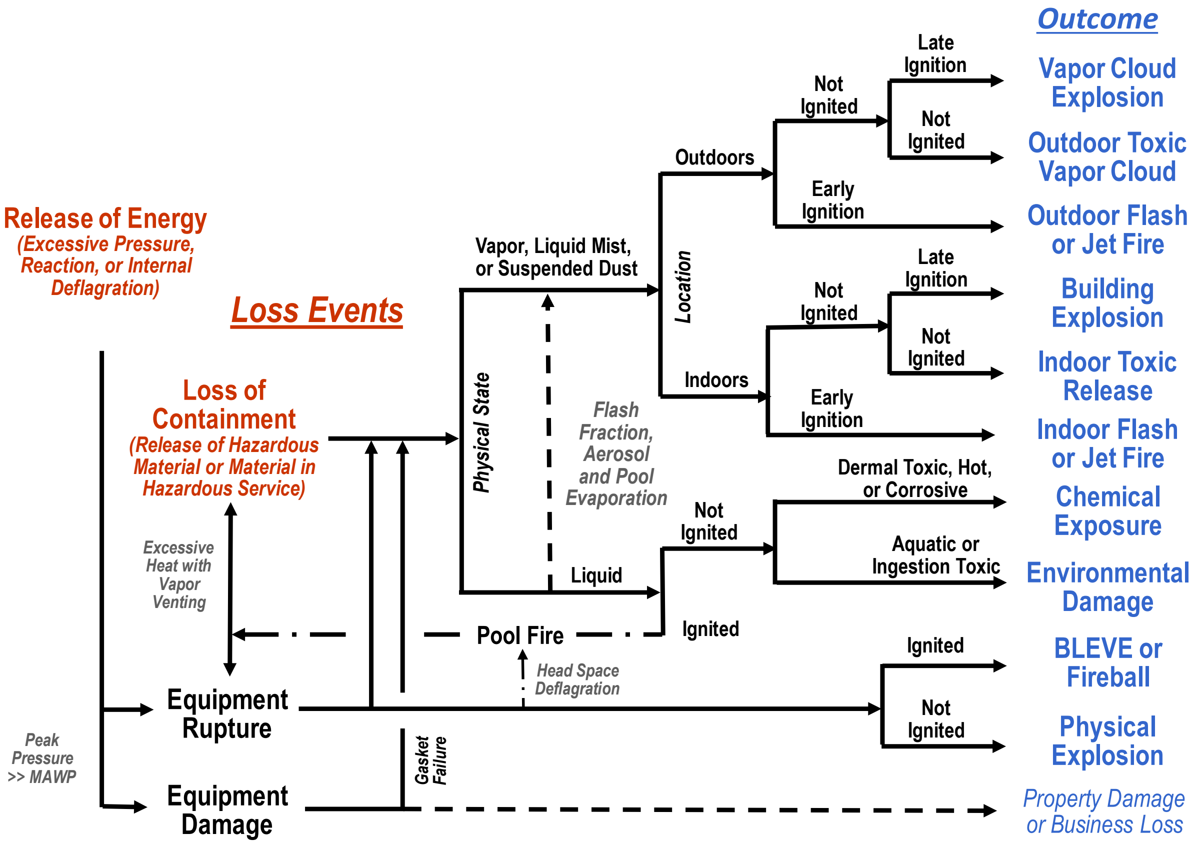


Figure 6.3 Generalized Event Tree for RAST

Example criteria for screening of various Incident Outcome is covered in Chemical Hazards Engineering Fundamentals training. In summary:

- ☐ **Flash (or Jet) Fire**

  Personnel exposure to flammable cloud of a multiple of LFL concentration

- ☐ **Vapor Cloud Explosion**

  1000 Kg flammable (100 Kg for high flame speed) released within 5 minutes

- ☐ **Building Explosion**

  Indoor average concentration exceeds LFL

- ☐ **Physical Explosion**

  1 psi overpressure (0.3 psi for fragmentation) distance exceed a threshold distance

- ☐ **Toxic Vapor Release (Indoor, Outdoor)**

  - Off-site exposure to > ERPG-2 concentration (60 min. basis)

  - On-site exposure to > LC-50 concentration for short duration outdoors (5-10 minutes)

  - On-site exposure to > ERPG-3 concentration based on 60 min. exposure within an occupied building.

These criteria are managed by the RAST Technical Administrator within hidden worksheets of the RAST spreadsheet.

Development of a Scenario Library

A library of Scenario Cases is available within the RAST tool. The intent of the Library is to provide analysis teams with initial ideas to build upon and not a substitute for performing Hazard Evaluation. Development of scenarios is roughly based on deviations of key process parameters similar to that used for Hazard and Operability Studies (HAZOP) (Figure 6.4).

Guidewords ⇒ Parameter ⇓	More	Less	None	Reverse	Part Of	As Well As	Other Than
Flow	High flow	Low flow	No flow	Back flow			Loss of containment
Pressure	High pressure	Low pressure	Vacuum		Partial pressure		
Temperature	High temperature	Low temperature				Cryogenic	
Level	High level	Low level	No level				Loss of containment
Composition State	Additional phase	Loss of phase		Change of state	Wrong concentration	Contaminants	Wrong material
Reaction	High reaction rate	Low reaction rate	No reaction	Reverse action	Incomplete reaction	Side reaction	Wrong reaction

Figure 6.4 Example HAZOP Deviations

Beware of changing inputs such as the Chemical composition or properties, Equipment Type, Maximum Allowable Working Pressure, etc. as the suggested Scenario Type and Scenario Feasibility are dependent on Chemical Data, Equipment and Process Conditions inputs.

Also recognize that the Scenario Library in RAST only identifies the MOST LIKELY Initiating Events. In Layers of Protection Analysis, it is important for the Analysis Team to determine if other Initiating Events are feasible and either Modify the suggested Initiating Event as appropriate or Create additional scenario cases for analysis based on their knowledge of the process.

Scenario Types

Scenario types are used to categorize common parameter deviations and are often related to a specific Type of Equipment. The common parameter deviations help to define the most common Initiating Events for the scenario. Examples include:

Example RAST Scenario Type	HAZOP Parameters with Deviation		
Accumulation of Untreated Vent or Waste	*Composition-Wrong Concentration*		*Flow-High*
Blocked-In with Thermal Expansion	*Temperature-High*	*Flow-No*	
Excessive Heat Input - Heat Transfer	*Energy-High*	*Pressure-High*	*Temperature-High*
Pad Gas or Vapor Flow	*Flow-High*		
Ignitable Headspace	*Composition-Wrong Concentration*		
Overfill, Overflow, or Backflow	*Level-High*	*Flow-Backflow*	
Pressure Damage	*Pressure-High*		
Vacuum Damage	*Pressure-Low*		
Pump Deadhead	*Pressure-High*	*Flow-No*	*Temperature-High*
Hose or Loading Arm Damage from Movement	*Flow-Loss of Containment*		
Drain or Vent Valve Open	*Flow-Loss of Containment*		
Seal Leak	*Flow-Loss of Containment*		

In addition, a "feasibility" check of process conditions which allow the event sequences to occur, is also used. Those Scenario Cases where the likelihood of the event sequence is extremely low based on process limitations are not included in the suggested list within RAST.

Flammability	**Fire and Explosion**
Flash Point	Process Temperature > Flash Point
Lower Flammability Limit	Max Concentration > Lower Flammable Limit
Minimum Ignition Energy	Ignition Source > Minimum Ignition Energy
Toxicity	**Toxicity**
Inhalation Toxicity	Max Vapor Concentration > ER Value
Dermal Toxicity	Potential For Dermal Exposure
Aquatic Toxicity	Potential for Environmental Damage
Reactivity	**Reactivity**
Heat of Reaction	Max Pressure > MAWP or Relief Set
Detected Onset Temperature	Max Process or Heating Temp > Temp of No Return
Gas Generation	

RAST Scenario Group and Scenario

A **RAST Scenario Group** is also similar to a "Bow Tie Diagram". It represents a single Loss Event with the related Initiating Events and Incident Outcomes. Figure 6.5 represent the generic Bow-Tie utilized in RAST. RAST evaluates essentially all Incident Outcome of interest but initially includes only the most common one or two Initiating Events. If needed, the study team would add additional scenarios representing other Initiating Events of interest prior to selecting scenarios for Layers of Protection Analysis.

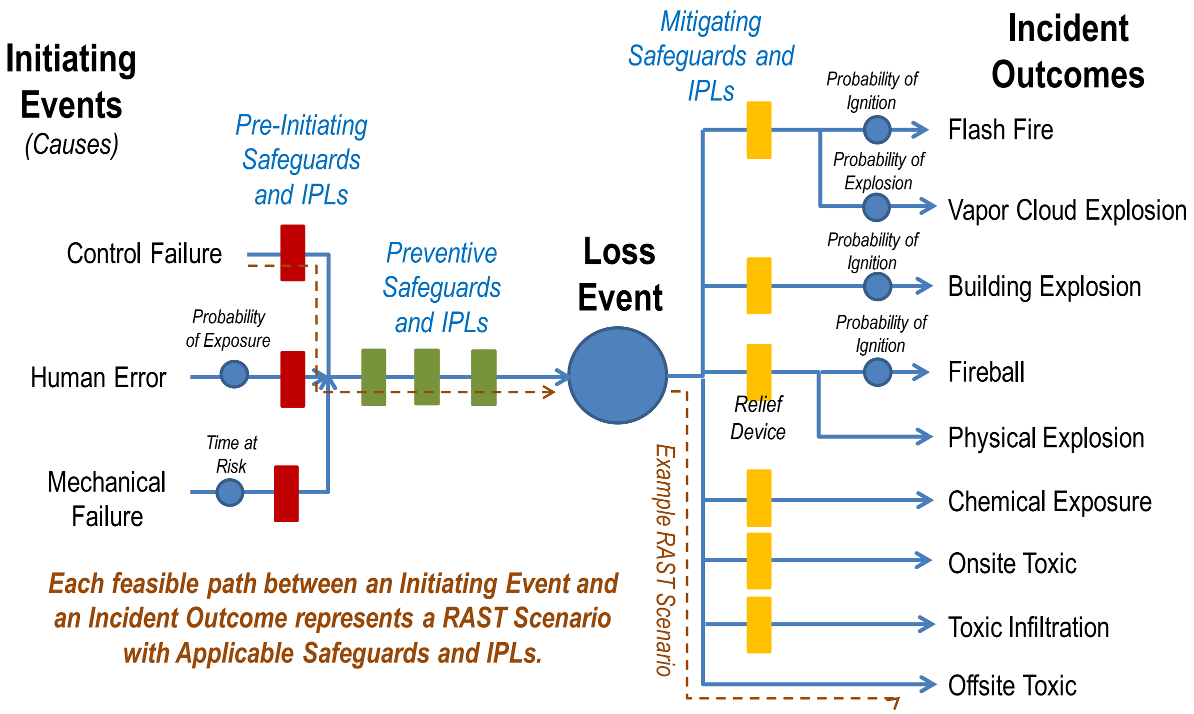


Figure 6.5 Generic Bow Tie diagram used in RAST

RAST Scenario Types

The *Scenario Type* is also used to "link" Loss Event for a specific Equipment Type and Chemical Service in the Scenario Library. A *Scenario* in RAST represents a specific combination of Equipment Type, Chemical Handled and Loss Event with one of several possible Initiating Events and one of several possible Incident Outcome. Examples of Scenario Type include:

Accumulation of Untreated Vent or Waste is used for Fired Equipment - Incinerator or TTU to represent scenarios where vents are not adequately destroyed with *a Vent Release* to the atmosphere. The most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

Blocked-In with Thermal Expansion may occur within piping or equipment handling refrigerated liquids, high melting point material that would require tracing, or very long un-insulated pipelines (>100 m) that could be heated by solar radiation. It is assumed that pressure build-up causes a gasket failure of a liquid full system which is not discovered until the subsequent transfer of material through this piping or equipment.

Casing or Containment Failure represents failure of a canned or magnetic drive pump casing caused by an upset, wear, or fatigue.

Connection Failure represents failure of a flexible connection to solids handling equipment resulting in a *Solids Spill*. The typical Initiating Event is *General Mechanical Failure*.

Drain or Vent Valve Open may occur following maintenance activities or during connection or disconnection of transportation equipment (drums, totes, tank trucks, rail cars, etc.). It is assumed that a *Drain Size leak* is most commonly initiated by *Operator Action Failure.*

Excessive Heat Input causes an overpressure event due to high vapor pressure at elevated temperature. It is assumed that this pressure may result in all vapor venting *Release thru Relief System* (if the relief device is adequately sized) or *Equipment Rupture at Saturation* conditions (if the maximum pressure exceeds the burst pressure). Excluding reactive scenarios, there are three specific types that match to a specific Vapor Relief Loss Event:

> <u>*Excessive Heat Input – Heat Transfer*</u> is triggered if vapor pressure at the maximum heating media temperature exceeds the relief set pressure.
>
> <u>*Excessive Heat Input – Mechanical Energy*</u> is triggered if vapor pressure at a maximum temperature evaluated by a simple equipment heat balance exceeds the relief set pressure.
>
> <u>*Excessive Heat Input – Fire*</u> is triggered if the chemical handled is flammable or there are other flammable materials in the area. It is assumed that the fire will persist long enough for relief set and equipment burst pressures to be achieved.

Excessive Pad Gas Flow represents a scenario where the release rate equals the feed rate of pad gas or air saturated with process chemicals. It is assumed that a *Release thru Relief System* occurs if the Maximum Inert Pressure exceeds the Relief Set Pressure.

Exhaustion of Scrubbing Media represents a scenario where the scrubbing media become depleted resulting in a Vent Release normally caused by Loss of Composition Control (BPCS Failure).

Flash Back of High Energy Feed is used for Fired Equipment – Incinerator, Thermal Oxidizer or Flare to represent propagation of combustion to upstream equipment resulting in *Equipment Damage*. It is assumed that the most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

Fuel Accumulation during Light Off is used for Fired Equipment representing a process upset during start-up of the unit resulting in Equipment Damage or Equipment Rupture - Deflagration. It is assumed that the most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

Fuel Accumulation during Operation is used for Fired Equipment representing a process upset during operation resulting in Equipment Damage or Equipment Rupture - Deflagration. It is assumed that the most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

Fuel Accumulation while Down is used for Fired Equipment representing leakage of fuel when not in operation resulting in Equipment Damage or Equipment Rupture - Deflagration. It is assumed that the most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

High Fuel Flow or Energy Content is used for Fired Equipment representing a process upset during normal operation resulting in Equipment Damage or Equipment Rupture - Deflagration. It is assumed that the most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

High Temperature Failure is used the maximum Feed Temperature exceeds the Design Temperature of the equipment resulting in Equipment Failure above Design Temperature. It is assumed that the most likely Initiating Event is loss of temperature or flow control (BSCS Failure).

Hose or Loading Arm Connection failure may occur during connection or disconnection of transportation equipment (totes, tank trucks, rail cars, etc.). It is assumed that a *Small Hole Size Leak* (gasket failure) is most commonly initiated by Operator Action Failure.

Hose or Loading Arm Damage from Movement represents leakage from piping caused by movement of a transport vehicle while connected. The potential for a Large Hole Size Leak is assumed to be most commonly initiated by Third Party Intervention.

Hydraulic Surge may occur due to the sudden change in fluid momentum in long pipelines if valves are closed too quickly (or during start-up of a pump).

Ignitable Headspace may potentially result in an internal deflagration and *Equipment Rupture – Deflagration* if the chemical handled is greater than 5 °C above the flash point. It is assumed that the peak deflagration pressure reaches 10 atmospheres which in turn assumes ignition at atmospheric pressure and may exceed the burst pressure for some equipment.

Liquid in Vapor Feed represents a process upset associated with the feed to a Flare resulting in Flaming Liquid hazards or Equipment Damage. It is assumed that the most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

Loss of Flow – Absorber or Scrubber represents a scenario where vapor feed is not treated but assumed a *Release thru Vent System* at the feed rate. It is triggered if the physical state of the feed stream is "vapor" for *Equipment* that is Absorber or Scrubber. It is assumed that the most likely Initiating Event is *Basic Process Control System* (BPCS) Failure.

Loss of Flow or Level - Fired Equipment represents a process upset where quench equipment or a process heater may see excessively high temperature with Equipment Damage or Rupture at Saturation Conditions. It is assumed that the most likely Initiating Events include *Pump Failure* or *Basic Process Control System* (BPCS) Failure.

Loss of Pilot or Ignition is used for Fired Equipment – Flare to represent loss of flame during operation with *Release through Vent System* of untreated material.

Loss of Vacuum - Thermal Oxidizer used for Fired Equipment – Incinerator or TTU to represent loss of vacuum during operation with *Release through Vent System* of untreated material.

Low Temperature Embrittlement represents the potential for material of construction to become brittle at low temperature resulting in fracture upon stress or thermal shock. It is assumed that the most likely Initiating Event is Human Error allowing evaporative cooling of low boiling chemicals in preparation for maintenance with subsequent full-bore pipe or equipment nozzle failure (Large Hole Size Leak).

Mechanical Integrity Failure represents a piping or equipment leak caused by corrosion, wear or fatigue. Hole sizes include *Very Small, Medium, Very Large* and *Extremely Large* with failure frequency dependent on the length of piping.

Movement of Flammable Liquid or Mist represents the potential for electrostatic build-up during movement of flammable liquids such as transport or mixing resulting in *Equipment Rupture – Deflagration*. It is assumed that the peak deflagration pressure reaches 10 atmospheres which assumes ignition at atmospheric pressure and may exceed the burst pressure for some equipment.

Overflow or Overfill, and ***Overflow or Backflow*** represents a release equal to the feed rate (or back flow rate) of process chemical <u>if sufficient Inventory is available</u>*.* It is assumed a *Release thru Relief System* if the peak pressure exceeds the relief set pressure.

> <u>*Overflow - Foam or Entrainment*</u> is a type of Overflow or Backflow scenario for equipment handling vapor/liquid mixtures such as Distillation.
>
> <u>*Overflow - Plugging or Freezing*</u> is a type of Overflow or Backflow scenario for equipment containing material that may easily plug or freeze.

Physical Damage or Puncture represents leakage from piping caused by impact from lifts or vehicle collisions. The potential for a Large Hole Size Leak is assumed to be most commonly initiated by Third Party Intervention.

Piping or Equipment Leak - Small is a general scenario type for leaks of mechanical loading arm, sight glass or other small equipment. A Small Hole size is used as the Loss Event.

Piping or Equipment LOPC – Large is a *Full-Bore Hole Size Leak* loss event resulting from a *Hose Failure, Sight Glass Failure or Mechanical Failure due to vibration.*

Plugged or Frozen Vent Line is used for Fired Equipment – Flare resulting in *Equipment Damage*. The most likely Initiating Event is assumed to be *Loss of Utilities*.

Pressure Damage is a broad category of scenario for solids handling equipment that assumes a *Solids Spill* if the peak pressure exceeds MAWP. If the peak pressure exceeds the burst pressure, *Rupture at Operating Temperature* is the loss event selected.

Propagation of Flame or Burning Ember is used in Solids Handling scenarios to represent an upset in an upstream equipment item that could ignite dust downstream.

Pump Deadhead is an event where one or both of the suction and discharge valves are closed while the pump or compressor is running. It is assumed that heat and pressure build-up result in *Equipment Rupture at Saturation* conditions or may result in an *Uncontrolled Reaction – Thermal Initiation*.

Relief Device Failure is failure of a rupture disk at the normal operating pressure due to pressure cycling or fatigue.

Rotating Equipment Damage is a failure or *Rupture at Operating Temperature* due primarily High Speed (Turbines) or Vibration (other Rotating Equipment).

Seal Leak is a leak of a mechanical pump or other rotating equipment seal caused by an upset, wear, or fatigue. The frequency of failure is determined by the type of seal arrangement – *Single Mechanical Seal, Double Mechanical Seal, Magnetic Drive*, or *Canned Pump*.

Tube Failure LOPC is associated with a Heat Exchanger. If the Process source pressure is higher than the Heat Transfer Fluid pressure and the Relief Set Pressure, the leak is assumed to be Process Fluid. If the Heat Transfer Fluid source pressure is higher than the Relief Set Pressure and Operating Pressure, the leak is assumed to be Heat Transfer Fluid.

Uncontrolled Reaction is a group of overpressure scenarios resulting from gas generation or high vapor pressure at elevated temperature. This pressure may result in vapor venting as a *Release thru Relief System* (if the relief device is adequately sized), *Equipment Rupture at Saturation* conditions if the maximum pressure exceeds the burst pressure, or *Equipment Rupture – Detonation* for highly reactive systems. Types of Reaction include:

> *Uncontrolled Reaction – Thermal Initiation* is used if the process, maximum heating media, or mechanical energy temperature exceeds the Temperature of No Return
>
> *Uncontrolled Reaction - Fire Induced* assumes that the fire will proceed long enough for the system to exceed the Temperature of No Return.
>
> *Uncontrolled Reaction – Catalyst or Impurity* denotes a reaction that may initiated by catalysts or impurities at normal operating temperature.

Uncontrolled Reaction – Pooling of Reactants denotes a reaction that is typically limited by feed rate but may build up reactants which then react like a batch reaction.

Uncontrolled Reaction - Mis-Loading denotes greater than normal reactant or less than normal solvent such that the heat of reaction per mass of mixture increases.

Uncontrolled Reaction – Incompatible Material is triggered by the user or if the NFPA reactivity rating is 2 or greater.

Vacuum Damage represents the potential for *Equipment Damage* or a *Nozzle Failure – top of Vessel* for equipment that is not full vacuum rated.

User Defined Scenarios

The User may enter additional Scenario Cases by selecting a Scenario Type, Initiating Event, Loss Event and Incident Outcome for the equipment item being evaluated. If one of the standard Scenario Types does not adequately describe the process upset, a **User Defined Scenario Type** may be selected and details entered under the Initiating Event description.

A **Loss Event** may be selected from the standard *List of Loss Events* which will allow estimation of Consequences by calculation methods within the RAST tool. Selecting User Defined Loss Event allows input of various Hazard Parameters such as Release Rate, Total Release Quantity, Distance to ERPG-3 Concentration, etc. from other software tools.

Consequences are estimated by Impact Analysis using the RAST estimates for various Hazard Parameters. If User Defined Loss Event is selected, Hazard Parameters evaluated in other software tools may be input to continue with Impact Analysis. Alternately, a Tolerable Frequency Factor may be selected without using a quantitative estimate.

Example User Defined Scenario Case

To enter a User Scenario: (Refer to Figure 6.5 for Steps 2-5)

STEP 1: Select Create User Scenario from either the Scenario List or Scenario Results worksheets.

STEP 2: Select the Scenario Type or User Defined Scenario Type from the listing. The Scenario Type is only used in the Scenario Description or to relate Loss Events with Initiating Events and Outcome in the Scenario Library. Select *Pressure Damage* from the listing.

STEP 3: Select the Initiating Event from the listing or based on the Initiating Event Factor. Enter a Description of the Initiating Event that will be used in scenario documentation. The Initiating Event Description may be also be entered or updated from the LOPA workbook. Select *Regulator Failure* from the listing. Enter a description of the failure such as "Pad Gas Pressure Regulator failure".

STEP 4: Select the Loss Event or User Defined Loss Event. A summary of RAST estimations for various Hazard Parameters will be displayed. If User Defined Loss Event is selected, an additional column appears for input of Hazard Parameters if desired. Select *Equipment Rupture at Operating Temperature* from the listing.

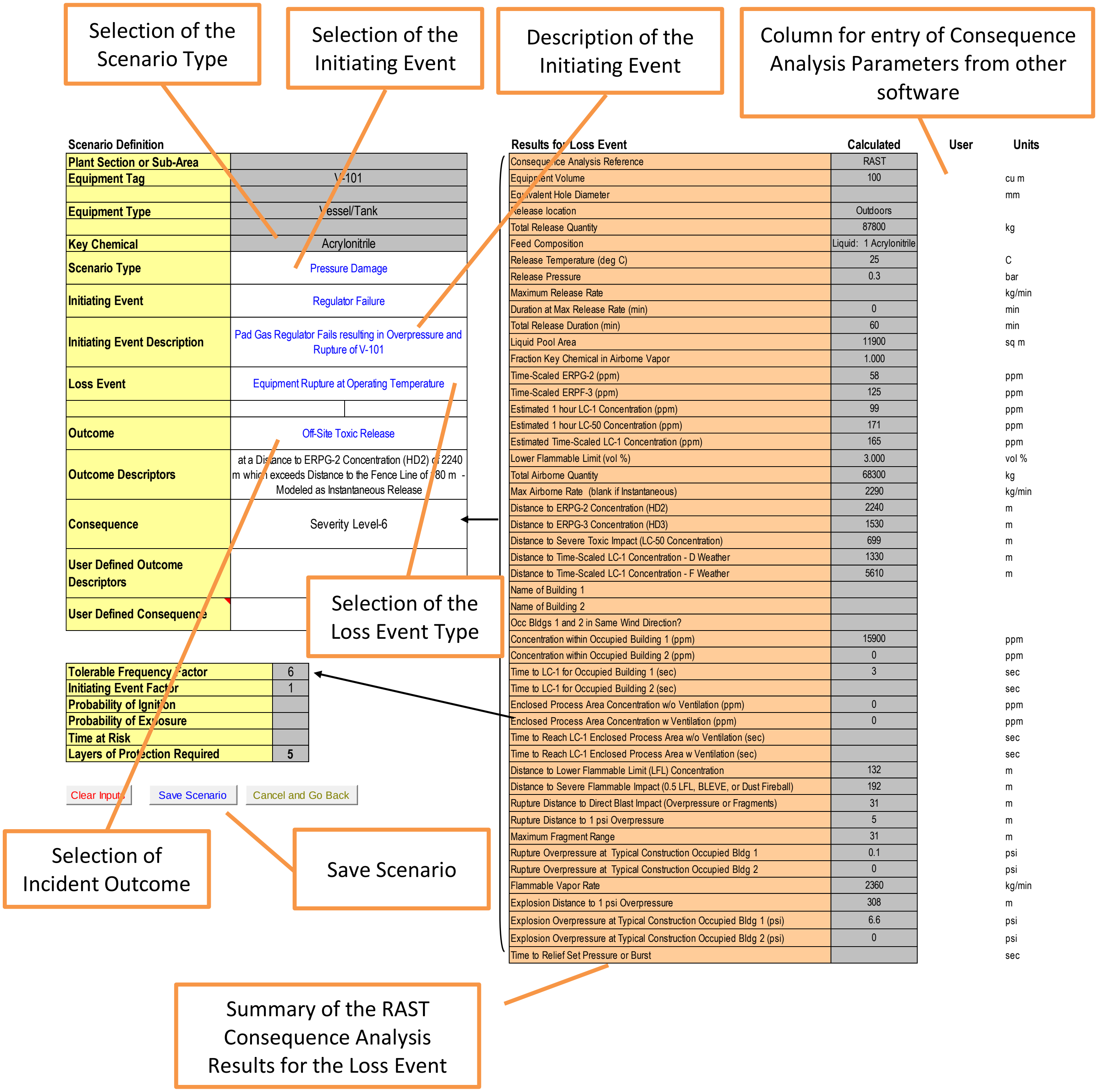
STEP 5: Select an Outcome from the listed options.

- A Table of Consequences or Tolerable Frequency Factors for each Outcome is displayed based on the Impact Analysis performed within RAST to aide in selection.

- If User Defined Loss Event was selected, a Tolerable Frequency Factor may be entered directly under User Defined Consequence using a standard LOPA Tolerable Frequency Description list.
- The numerical values for Tolerable Frequency Factor, Initiating Event Factor, Probability of Ignition (based on estimated cloud volume and flammable mass), Probability of Exposure (where sufficient input information is available), and Number of Protective Layers needed are displayed.

Select *Off-Site Toxic Release* from the listing. See Figure 6.6

STEP 6: Select Save Scenario to add this User Scenario to the Scenario Listing and Scenario Results. Select Cancel and Go Back to return to other RAST worksheets without saving the User Scenario. Select Clear Inputs to start over with entry of a User Scenario.



Selection of the Scenario Type

Selection of the Initiating Event

Description of the Initiating Event

Column for entry of Consequence Analysis Parameters from other software

Selection of the Loss Event Type

Selection of Incident Outcome

Save Scenario

Summary of the RAST Consequence Analysis Results for the Loss Event

Scenario Definition

Plant Section or Sub-Area	
Equipment Tag	V-101
Equipment Type	Vessel/Tank
Key Chemical	Acrylonitrile
Scenario Type	Pressure Damage
Initiating Event	Regulator Failure
Initiating Event Description	Pad Gas Regulator Fails resulting in Overpressure and Rupture of V-101
Loss Event	Equipment Rupture at Operating Temperature
Outcome	Off-Site Toxic Release
Outcome Descriptors	at a Distance to ERPG-2 Concentration (HD2) of 2240 m which exceeds Distance to the Fence Line of [illegible]80 m - Modeled as Instantaneous Release
Consequence	Severity Level-6
User Defined Outcome Descriptors	
User Defined Consequence	

Tolerable Frequency Factor	6
Initiating Event Factor	1
Probability of Ignition	
Probability of Exposure	
Time at Risk	
Layers of Protection Required	**5**

Clear Inputs | Save Scenario | Cancel and Go Back

Results for Loss Event	Calculated	User	Units
Consequence Analysis Reference	RAST		
Equipment Volume	100		cu m
Equivalent Hole Diameter			mm
Release location	Outdoors		
Total Release Quantity	87800		kg
Feed Composition	Liquid: 1 Acrylonitrile		
Release Temperature (deg C)	25		C
Release Pressure	0.3		bar
Maximum Release Rate			kg/min
Duration at Max Release Rate (min)	0		min
Total Release Duration (min)	60		min
Liquid Pool Area	11900		sq m
Fraction Key Chemical in Airborne Vapor	1.000		
Time-Scaled ERPG-2 (ppm)	58		ppm
Time-Scaled ERPF-3 (ppm)	125		ppm
Estimated 1 hour LC-1 Concentration (ppm)	99		ppm
Estimated 1 hour LC-50 Concentration (ppm)	171		ppm
Estimated Time-Scaled LC-1 Concentration (ppm)	165		ppm
Lower Flammable Limit (vol %)	3.000		vol %
Total Airborne Quantity	68300		kg
Max Airborne Rate (blank if Instantaneous)	2290		kg/min
Distance to ERPG-2 Concentration (HD2)	2240		m
Distance to ERPG-3 Concentration (HD3)	1530		m
Distance to Severe Toxic Impact (LC-50 Concentration)	699		m
Distance to Time-Scaled LC-1 Concentration - D Weather	1330		m
Distance to Time-Scaled LC-1 Concentration - F Weather	5610		m
Name of Building 1			
Name of Building 2			
Occ Bldgs 1 and 2 in Same Wind Direction?			
Concentration within Occupied Building 1 (ppm)	15900		ppm
Concentration within Occupied Building 2 (ppm)	0		ppm
Time to LC-1 for Occupied Building 1 (sec)	3		sec
Time to LC-1 for Occupied Building 2 (sec)			sec
Enclosed Process Area Concentration w/o Ventilation (ppm)	0		ppm
Enclosed Process Area Concentration w Ventilation (ppm)	0		ppm
Time to Reach LC-1 Enclosed Process Area w/o Ventilation (sec)			sec
Time to Reach LC-1 Enclosed Process Area w Ventilation (sec)			sec
Distance to Lower Flammable Limit (LFL) Concentration	132		m
Distance to Severe Flammable Impact (0.5 LFL, BLEVE, or Dust Fireball)	192		m
Rupture Distance to Direct Blast Impact (Overpressure or Fragments)	31		m
Rupture Distance to 1 psi Overpressure	5		m
Maximum Fragment Range	31		m
Rupture Overpressure at Typical Construction Occupied Bldg 1	0.1		psi
Rupture Overpressure at Typical Construction Occupied Bldg 2	0		psi
Flammable Vapor Rate	2360		kg/min
Explosion Distance to 1 psi Overpressure	308		m
Explosion Overpressure at Typical Construction Occupied Bldg 1 (psi)	6.6		psi
Explosion Overpressure at Typical Construction Occupied Bldg 2 (psi)	0		psi
Time to Relief Set Pressure or Burst			sec

Figure 6.6 User Defined Scenario Example

7. LAYERS OF PROTECTION ANALYSIS

Layers of Protection Analysis (LOPA) is a method for evaluating the effectiveness of Independent Protection Layers (IPLs) in reducing the likelihood or severity of an undesirable event. LOPA builds on information and Scenarios developed during Hazard Screening and Evaluation. The analysis uses a simplified "order of magnitude" approach for analysis of Process Risk.

This section covers:

- How Layers of Protection Analysis is addressed in RAST
- How to enter and update LOPA Unmitigated Risk information (such as Tolerable Frequency Factor, Initiating Event, and Enabling Conditions).
- How to enter Protective Layer information
- How to use worksheets that provide supporting evaluations for LOPA Analysis.

LOPA Menu

On the LOPA Menu worksheet (Figure 7.1); the Equipment Identification, Equipment Type, and Location (Outdoors or Indoors) are displayed. With the LOPA Menu, one may:

- Return to the Main Menu
- Update Scenario Analysis for cases associated with the Equipment Item being analyzed.
- Update Scenario Analysis for cases associated with all Equipment Items within the Equipment Table.
- Set controls for the cases that will be created in Scenario Analysis
- Access the Scenario Results worksheet for Selection of LOPA Scenario Cases.
- Set filter criteria for Scenario Results worksheet upon return from the LOPA Worksheet
- Access special LOPA worksheets including Pool Fire Evaluation, Protective Layer (IPL) Summary, Estimation of Maximum Allowable Response Time (MART) and Estimation of Maximum Allowable Leak Rate (MALR).
- View a Risk Summary

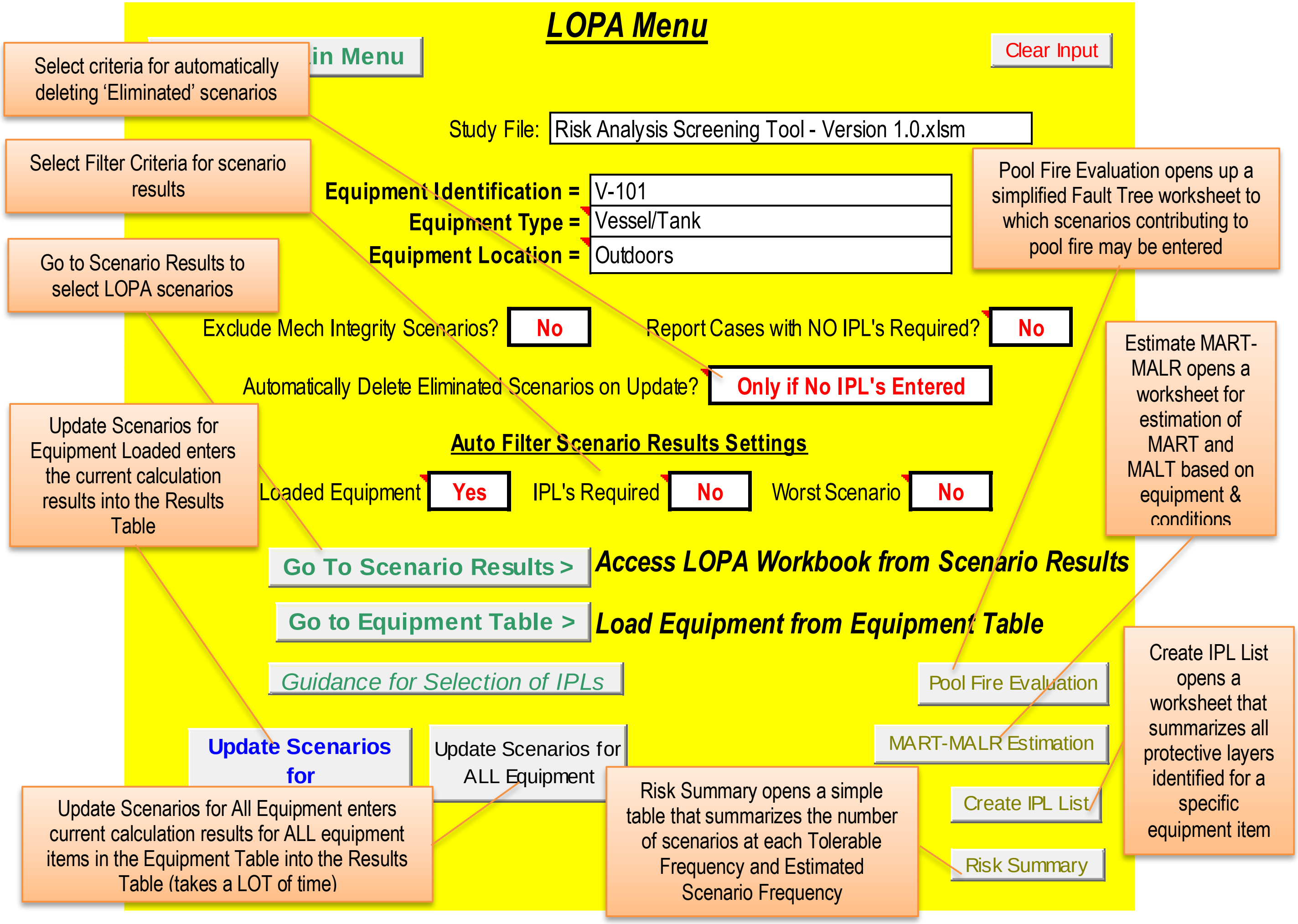
Update Scenario Analysis

This command updates the Scenario Results worksheet with the current estimations. Upon completion of the update, the Scenario Results worksheet will be displayed.

All calculations within the RAST Excel workbook are "live" or current with the input values displayed on the various Input worksheets. **Update Scenario Analysis** allows a "snapshot" of the current evaluation results to be saved as potential LOPA scenario cases. A comparison is made to the previous values in the Scenario Results worksheet allowing the User to track changes to the previous evaluation.

Update All Scenario Cases performs the *Update Scenario Analysis* for all Equipment Items in the Equipment Table. Note that for a large file this update may require more than one hour for completion.

(Additional information may be found under the *Scenario Results* workbook section below.)



Study File: Risk Analysis Screening Tool - Version 1.0.xlsm

Equipment Identification = V-101

Equipment Type = Vessel/Tank

Equipment Location = Outdoors

Exclude Mech Integrity Scenarios? No

Report Cases with NO IPL's Required? No

Automatically Delete Eliminated Scenarios on Update? Only if No IPL's Entered

Loaded Equipment Yes

IPL's Required No

Worst Scenario No

Select criteria for automatically deleting 'Eliminated' scenarios

Select Filter Criteria for scenario results

Go to Scenario Results to select LOPA scenarios

Update Scenarios for Equipment Loaded enters the current calculation results into the Results Table

Update Scenarios for All Equipment enters current calculation results for ALL equipment items in the Equipment Table into the Results Table (takes a LOT of time)

Pool Fire Evaluation opens up a simplified Fault Tree worksheet to which scenarios contributing to pool fire may be entered

Estimate MART-MALR opens a worksheet for estimation of MART and MALT based on equipment & conditions

Create IPL List opens a worksheet that summarizes all protective layers identified for a specific equipment item

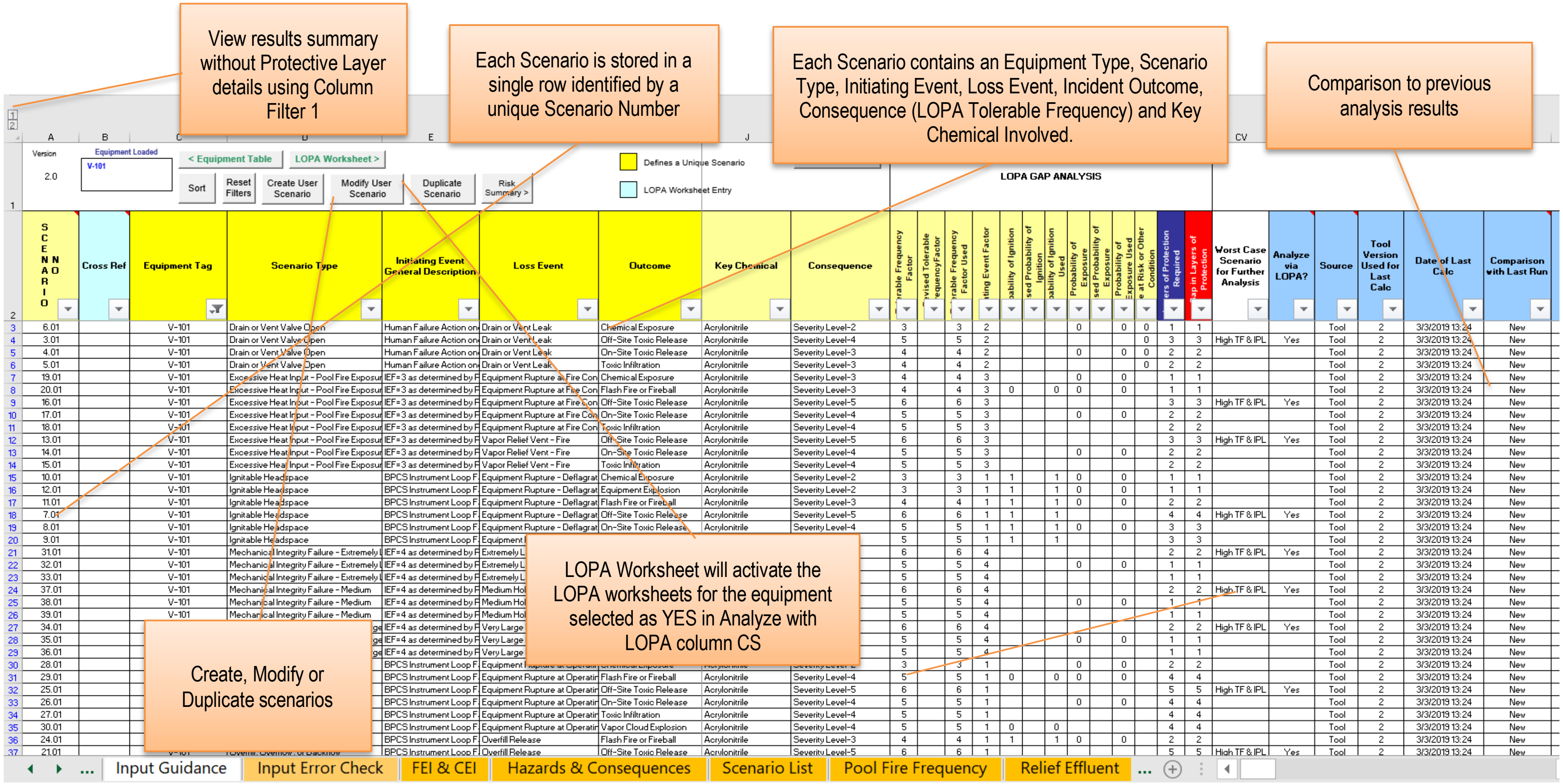
Risk Summary opens a simple table that summarizes the number of scenarios at each Tolerable Frequency and Estimated Scenario Frequency

Figure 7.1: LOPA Menu

Scenario Results Worksheet

The Scenario Results worksheet (Figure 7.2) contains a summary of the evaluation for all Scenario Cases that have been identified either from the Scenario Library or User entered. The summary for each Scenario Cases is stored under a unique Scenario Number which is assigned by the RAST tool. A "filter" button at the top left of this worksheet allows excluding the Protective Layer details from this view.

From the Scenario Results Worksheet one may access the LOPA Worksheet.



View results summary without Protective Layer details using Column Filter 1

Each Scenario is stored in a single row identified by a unique Scenario Number

Each Scenario contains an Equipment Type, Scenario Type, Initiating Event, Loss Event, Incident Outcome, Consequence (LOPA Tolerable Frequency) and Key Chemical Involved.

Comparison to previous analysis results

LOPA Worksheet will activate the LOPA worksheets for the equipment selected as YES in Analyze with LOPA column CS

Create, Modify or Duplicate scenarios

Version 2.0

Equipment Loaded: V-101

2	SCENARIO NO	Cross Ref	Equipment Tag	Scenario Type	Initiating Event General Description	Loss Event	Outcome	Key Chemical	Consequence	rable Frequency Factor	vised Tolerable requencyFactor	rable Frequency Factor Used	ating Event Factor	ability of Ignition	sed Probability of Ignition	ability of Ignition Used	Probability of Exposure	sed Probability of Exposure	Probability of Exposure Used	e at Risk or Other Condition	ers of Protection Required	ap in Layers of Protection	Worst Case Scenario for Further Analysis	Analyze via LOPA?	Source	Tool Version Used for Last Calc	Date of Last Calc	Comparison with Last Run
3	6.01		V-101	Drain or Vent Valve Open	Human Failure Action on	Drain or Vent Leak	Chemical Exposure	Acrylonitrile	Severity Level-2	3		3	2				0		0	0	1	1			Tool	2	3/3/2019 13:24	New
4	3.01		V-101	Drain or Vent Valve Open	Human Failure Action on	Drain or Vent Leak	Off-Site Toxic Release	Acrylonitrile	Severity Level-4	5		5	2							0	3	3	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
5	4.01		V-101	Drain or Vent Valve Open	Human Failure Action on	Drain or Vent Leak	On-Site Toxic Release	Acrylonitrile	Severity Level-3	4		4	2				0		0	0	2	2			Tool	2	3/3/2019 13:24	New
6	5.01		V-101	Drain or Vent Valve Open	Human Failure Action on	Drain or Vent Leak	Toxic Infiltration	Acrylonitrile	Severity Level-3	4		4	2							0	2	2			Tool	2	3/3/2019 13:24	New
7	19.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Equipment Rupture at Fire Con	Chemical Exposure	Acrylonitrile	Severity Level-3	4		4	3				0		0		1	1			Tool	2	3/3/2019 13:24	New
8	20.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Equipment Rupture at Fire Con	Flash Fire or Fireball	Acrylonitrile	Severity Level-3	4		4	3	0		0	0		0		1	1			Tool	2	3/3/2019 13:24	New
9	16.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Equipment Rupture at Fire Con	Off-Site Toxic Release	Acrylonitrile	Severity Level-5	6		6	3								3	3	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
10	17.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Equipment Rupture at Fire Con	On-Site Toxic Release	Acrylonitrile	Severity Level-4	5		5	3				0		0		2	2			Tool	2	3/3/2019 13:24	New
11	18.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Equipment Rupture at Fire Con	Toxic Infiltration	Acrylonitrile	Severity Level-4	5		5	3								2	2			Tool	2	3/3/2019 13:24	New
12	13.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Vapor Relief Vent - Fire	Off-Site Toxic Release	Acrylonitrile	Severity Level-5	6		6	3								3	3	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
13	14.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Vapor Relief Vent - Fire	On-Site Toxic Release	Acrylonitrile	Severity Level-4	5		5	3				0		0		2	2			Tool	2	3/3/2019 13:24	New
14	15.01		V-101	Excessive Heat Input - Pool Fire Exposur	IEF=3 as determined by F	Vapor Relief Vent - Fire	Toxic Infiltration	Acrylonitrile	Severity Level-4	5		5	3								2	2			Tool	2	3/3/2019 13:24	New
15	10.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagrat	Chemical Exposure	Acrylonitrile	Severity Level-2	3		3	1	1		1	0		0		1	1			Tool	2	3/3/2019 13:24	New
16	12.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagrat	Equipment Explosion	Acrylonitrile	Severity Level-2	3		3	1	1		1	0		0		1	1			Tool	2	3/3/2019 13:24	New
17	11.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagrat	Flash Fire or Fireball	Acrylonitrile	Severity Level-3	4		4	1	1		1	0		0		2	2			Tool	2	3/3/2019 13:24	New
18	7.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagrat	Off-Site Toxic Release	Acrylonitrile	Severity Level-5	6		6	1	1		1					4	4	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
19	8.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment Rupture - Deflagrat	On-Site Toxic Release	Acrylonitrile	Severity Level-4	5		5	1	1		1	0		0		3	3			Tool	2	3/3/2019 13:24	New
20	9.01		V-101	Ignitable Headspace	BPCS Instrument Loop F	Equipment				5		5	1	1		1					3	3			Tool	2	3/3/2019 13:24	New
21	31.01		V-101	Mechanical Integrity Failure - Extremely L	IEF=4 as determined by F	Extremely L				6		6	4								2	2	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
22	32.01		V-101	Mechanical Integrity Failure - Extremely L	IEF=4 as determined by F	Extremely L				5		5	4				0		0		1	1			Tool	2	3/3/2019 13:24	New
23	33.01		V-101	Mechanical Integrity Failure - Extremely L	IEF=4 as determined by F	Extremely L				5		5	4								1	1			Tool	2	3/3/2019 13:24	New
24	37.01		V-101	Mechanical Integrity Failure - Medium	IEF=4 as determined by F	Medium Hol				6		6	4								2	2	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
25	38.01		V-101	Mechanical Integrity Failure - Medium	IEF=4 as determined by F	Medium Hol				5		5	4				0		0		1	1			Tool	2	3/3/2019 13:24	New
26	39.01		V-101	Mechanical Integrity Failure - Medium	IEF=4 as determined by F	Medium Hol				5		5	4								1	1			Tool	2	3/3/2019 13:24	New
27	34.01			ge	IEF=4 as determined by F	Very Large				6		6	4								2	2	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
28	35.01			ge	IEF=4 as determined by F	Very Large				5		5	4				0		0		1	1			Tool	2	3/3/2019 13:24	New
29	36.01			ge	IEF=4 as determined by F	Very Large				5		5	4								1	1			Tool	2	3/3/2019 13:24	New
30	28.01				BPCS Instrument Loop F	Equipment Rupture at Operatir	Chemical Exposure	Acrylonitrile	Severity Level-2	3		3	1				0		0		2	2			Tool	2	3/3/2019 13:24	New
31	29.01				BPCS Instrument Loop F	Equipment Rupture at Operatir	Flash Fire or Fireball	Acrylonitrile	Severity Level-4	5		5	1	0		0	0		0		4	4			Tool	2	3/3/2019 13:24	New
32	25.01				BPCS Instrument Loop F	Equipment Rupture at Operatir	Off-Site Toxic Release	Acrylonitrile	Severity Level-5	6		6	1								5	5	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New
33	26.01				BPCS Instrument Loop F	Equipment Rupture at Operatir	On-Site Toxic Release	Acrylonitrile	Severity Level-4	5		5	1				0		0		4	4			Tool	2	3/3/2019 13:24	New
34	27.01				BPCS Instrument Loop F	Equipment Rupture at Operatir	Toxic Infiltration	Acrylonitrile	Severity Level-4	5		5	1								4	4			Tool	2	3/3/2019 13:24	New
35	30.01				BPCS Instrument Loop F	Equipment Rupture at Operatir	Vapor Cloud Explosion	Acrylonitrile	Severity Level-4	5		5	1	0		0					4	4			Tool	2	3/3/2019 13:24	New
36	24.01				BPCS Instrument Loop F	Overfill Release	Flash Fire or Fireball	Acrylonitrile	Severity Level-3	4		4	1	1		1	0		0		2	2			Tool	2	3/3/2019 13:24	New
37	21.01		V-101	Overfill, Overflow, or Backflow	BPCS Instrument Loop F	Overfill Release	Off-Site Toxic Release	Acrylonitrile	Severity Level-5	6		6	1								5	5	High TF & IPL	Yes	Tool	2	3/3/2019 13:24	New

Figure 7.2: Scenario Results Worksheet

Description of Scenario Results Worksheet

Columns at the left side of this worksheet identify the *Equipment Item*, *Equipment Type*, *Scenario Type*, *Initiating Event*, *Initiating Event Description*, *Loss Event*, *Incident Outcome,* and *Key Chemical* for the **Scenario Case**. These columns are denoted by "yellow" headings.

The next column is to notify the user of ***Flash Convergence Errors*** (column K with a pink header). If you are displaying entries in this column, see options below:

A. If the convergence is a scenario that will not be part of the risk analysis – merely ignore.
B. If the failure is the condensation routine such that routine returns zero condensed, that is likely OK since very few chemicals or mixture will condense following release. (Note that only low vapor pressure material released at a very high temperature, i.e. > 200 C, will become supersaturated in ambient air and condense.)
C. If a diked or bunded area exists and has not been entered, that may correct the issue. (A very large pool area is difficult to converge to a good average pool temperature.)
D. Adjust the composition slightly. The biggest issue appears to be a small quantity of dissolved gas in the liquid. In these cases, a very small fraction evaporated causes a significant change in the pool vapor pressure.
E. Select "pseudo" single chemical for the mixture which will generally be a more conservative result but less likely to fail to converge as there is no composition portion to the trial and error calculations (only flash fraction or temperature as being trialed).

The next series of columns represent a ***Summary of Evaluation Results***. These columns are denoted by "orange" headings. Included are:

Total Release Quantity

Maximum Release Rate

Total Airborne Quantity

Maximum Airborne Rate

Maximum Distance to Time-Scaled ERPG-2

Maximum Distance to Time Scaled ERPG-3

Distance to Severe Toxic Impact (LC-50 Concentration)

Concentration within Occupied Building

Enclosed Process Area Concentration

Distance to Severe Flammable Impact (Multiple of LFL, BLEVE, or Dust Fireball)

Rupture Distance to Direct Blast Impact (Overpressure or Fragments)

Rupture Distance to 1 psi Overpressure

Rupture Overpressure at Distance to Occupied Bldg.

Basis for Probability of Ignition (Airborne Rate or LFL Distance)

Explosion Distance to 1 psi Overpressure

Explosion Overpressure at Distance to Occupied Bldg.

Time to Relief Set Pressure or Burst Pressure

The next series of Columns represent a ***Summary of Unmitigated Risk*** for each Scenario Cases. The summary is based on analysis within the RAST workbook unless the User selects an alternate analysis. Included are:

Outcome Description

Consequence Description – based on RAST analysis of the Scenario Case

LOPA Tolerable Frequency Factor

Alternate Tolerable Frequency Factor – may be entered if other than RAST analysis is used

Initiating Event Factor

Probability of Ignition

Alternate POI – may be entered if other than RAST analysis is used

Probability of Exposure

Alternate POE – may be entered if other than RAST analysis is used

Time at Risk or Other Condition

Layers of Protection Required

Gap in Layers of Protection

The next columns capture information specific to ***Selection and Review of LOPA Scenario Cases***. Included are:

Worst Case Scenario for Further Analysis – provides guidance for selection of "worst" Scenario Cases. The Scenario Case (or cases) with the Highest *Tolerable Frequency* Factor (denoted ***High TF***), Largest Number of Protective Layers Required (denoted ***High IPL***), or both (denoted ***High TF & IPL***) are noted for each Scenario group. Scenario Group are those scenarios with the same *Equipment Item*, *Chemical service*, *Scenario Type*, and *Loss Event* but with a different *Initiating Event* or *Incident Outcome*.

Analysis of "worst case" scenarios represents the starting point.

- *If only "Preventive" Protective Layers are used (stops the Event Sequence such as a shutting off the feed pump upon high level or shutting off the heating media supply upon high temperature), then all other cases will be adequately managed (no additional scenario cases will need analysis).*
- *If more than one "Mitigating" Protective Layer is used (reduces the magnitude of the consequence such as a sprinkler system for pool fire scenarios, than additional scenario cases representing other than the "worst case" Outcome may need to be analyzed.*
- *If more than one "Pre-Initiating" Protective Layer is used (reduces the likelihood of the Initiating Event such as a checklist to prevent leaving drain valves open), than additional scenario cases representing other than the "worst case" Initiating Event may need to be analyzed.*

Analyze via LOPA? – "Yes" is entered to select the Scenario Case for LOPA analysis. Only Scenario Cases denoted "Yes" are transferred to the LOPA worksheet for further analysis.

Source Tool Version Used for Last Calculation – captures the Version Number of RAST used for the Results currently captured in the Scenario Results worksheet.

Source – indicates which Scenario Cases were entered from the RAST Library ("Tool" or "User" entered.

Comparison with Last Run – denotes each Scenario Case as:

- ***Same*** – no difference in any of the captured results
- ***Revised*** – differences were found in one or more stored values
- ***New*** – a new case was added that did not previously exist
- ***Eliminated*** – the case no longer meets screening criteria. *(Note that if the LOPA Team wants to retain an Eliminated Scenario Case, the Source column may be changed from "Tool" to "User" and the Modify User Scenario command used to update scenario information. Results are not updated for "Eliminated" Cases upon execution of the Update Scenario command.)*
- ***Orphaned*** – the equipment item for which the scenario was created no longer exists in the Equipment Table.

Notes – may be used to capture scenario details not related to a specific LOPA factor.

"Comments /Issues to Resolve"- may be used to capture action items

Manufacturing Name, Manufacturing Date – used to capture the Manufacturing approval of the LOPA Scenario Cases analysis.

Process Safety Name, Process Safety Date - used to capture the Process Safety approval of the LOPA Scenario Cases analysis.

Process Control Name, Process Control Date- used to capture the Process Control approval of the LOPA Scenario Cases analysis.

The remaining columns of the Scenario Results worksheet are used to store all ***Protective Layer*** information from the LOPA analysis including descriptions, factors, Instrument Identification numbers, etc. As discussed under RAST – Getting Started, changes are tracked from the previous saved results as any cell that contains a value which has changed turns "green" and the prior values stored in the cell comments.

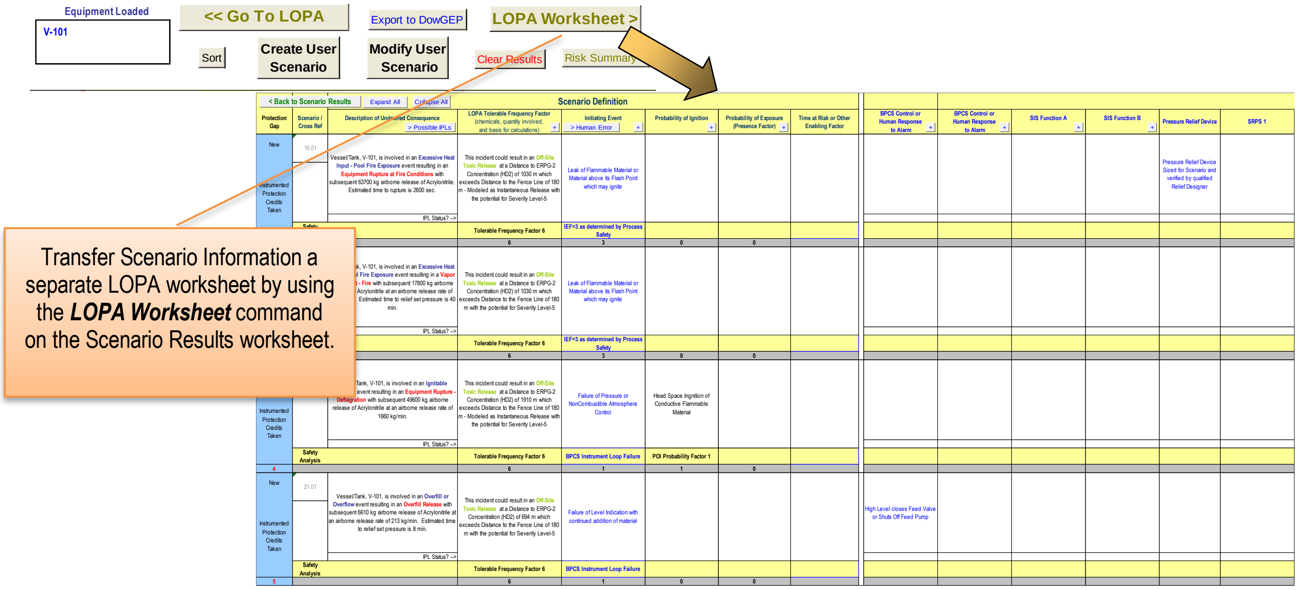
Existing Scenario Cases on the Scenario Results Worksheet may be modified by:

A scenario case may be *duplicated* by selecting any cell within the row representing the scenario may be copied and using the **Duplicate Scenario** command. A unique scenario number will be assigned by the tool.

A User Scenario may be *modified* by selecting any cell within the user scenario row and using the **Modify User Scenario** command which opens the User Scenario worksheet for editing.

The LOPA Worksheet

When activating the LOPA Worksheet from the Scenario Results worksheet, only Scenario Cases that are "filtered" on the Scenario Results worksheet will be viewed in the LOPA Workbook. For example, if the Equipment Tag (or Equipment Identification) is filtered to only one Equipment Item, only Scenario Cases for the specific Equipment Item where "Yes" has been entered under "Analyze by LOPA?" will be shown. This allows specific sections of the LOPA Worksheet to be active rather than the entire worksheet.



Protection Gap	Scenario / Cross Ref	Description of Undesired Consequence	LOPA Tolerable Frequency Factor (chemicals, quantity involved, and basis for calculations)	Initiating Event	Probability of Ignition	Probability of Exposure (Presence Factor)	Time at Risk or Other Enabling Factor	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
New Instrumented Protection Credits Taken	16.01	Vessel/Tank, V-101, is involved in an Excessive Heat Input - Pool Fire Exposure event resulting in an Equipment Rupture at Fire Conditions with subsequent 63700 kg airborne release of Acrylonitrile. Estimated time to rupture is 2600 sec. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 1030 m which exceeds Distance to the Fence Line of 180 m - Modeled as Instantaneous Release with the potential for Severity Level-5	Leak of Flammable Material or Material above its Flash Point which may ignite								Pressure Relief Device Sized for Scenario and verified by qualified Relief Designer	
	Safety		Tolerable Frequency Factor 6	IEF=3 as determined by Process Safety									
			6	3	0	0							
		k, V-101, is involved in an Excessive Heat l Fire Exposure event resulting in a Vapor t - Fire with subsequent 17800 kg airborne Acrylonitrile at an airborne release rate of Estimated time to relief set pressure is 40 min. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 1030 m which exceeds Distance to the Fence Line of 180 m with the potential for Severity Level-5	Leak of Flammable Material or Material above its Flash Point which may ignite									
			Tolerable Frequency Factor 6	IEF=3 as determined by Process Safety									
			6	3	0	0							
Instrumented Protection Credits Taken		Tank, V-101, is involved in an Ignitable event resulting in an Equipment Rupture - Deflagration with subsequent 49600 kg airborne release of Acrylonitrile at an airborne release rate of 1660 kg/min. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 1910 m which exceeds Distance to the Fence Line of 180 m - Modeled as Instantaneous Release with the potential for Severity Level-5	Failure of Pressure or NonCombustible Atmosphere Control	Head Space Ingnition of Conductive Flammable Material								
	Safety Analysis		Tolerable Frequency Factor 6	BPCS Instrument Loop Failure	POI Probability Factor 1								
4			6	1	1	0							
New Instrumented Protection Credits Taken	21.01	Vessel/Tank, V-101, is involved in an Overfill or Overflow event resulting in an Overfill Release with subsequent 6610 kg airborne release of Acrylonitrile at an airborne release rate of 213 kg/min. Estimated time to relief set pressure is 8 min. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 694 m which exceeds Distance to the Fence Line of 180 m with the potential for Severity Level-5	Failure of Level Indication with continued addition of material				High Level closes Feed Valve or Shuts Off Feed Pump					
	Safety Analysis		Tolerable Frequency Factor 6	BPCS Instrument Loop Failure									
5			6	1	0	0							

Transfer Scenario Information a separate LOPA worksheet by using the ***LOPA Worksheet*** command on the Scenario Results worksheet.

Figure 7.3: Accessing the LOPA Worksheet

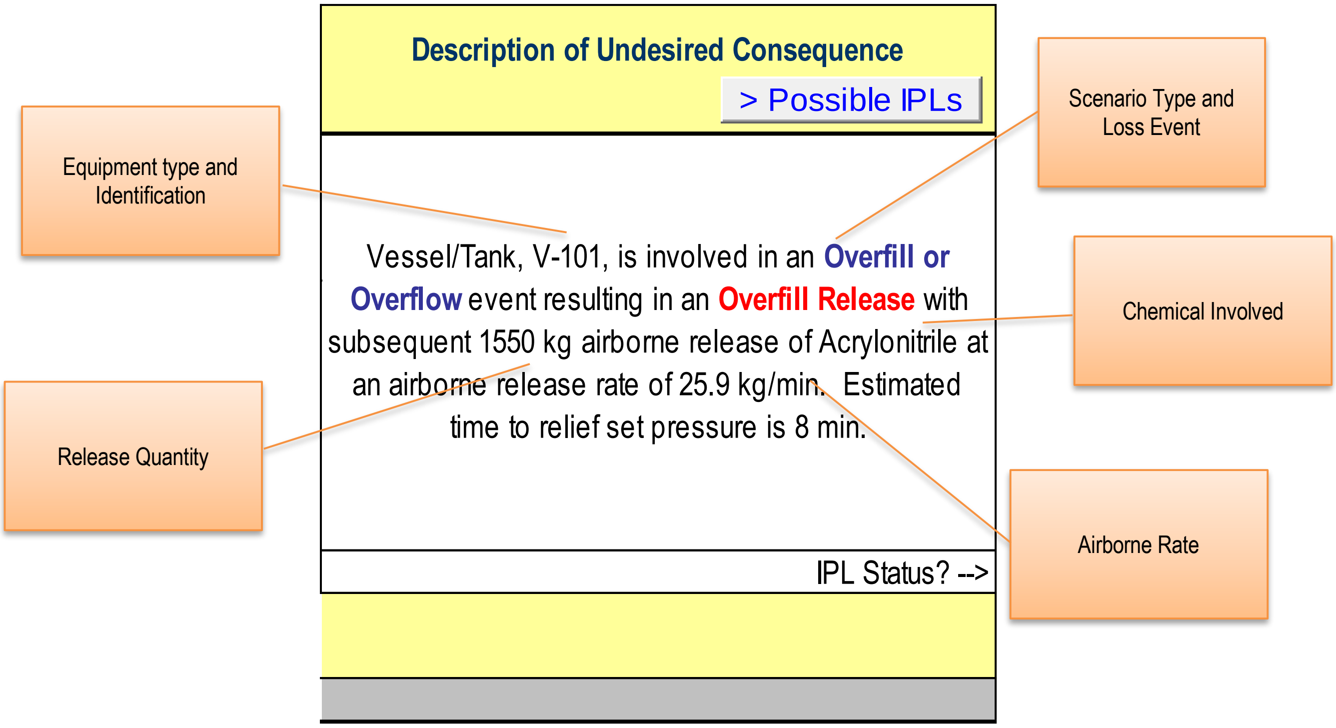
Unmitigated Risk – "Left" Side of LOPA Workbook

The "Left" Side of the LOPA Worksheet represents Unmitigated Risk and includes inputs for Tolerable Frequency Factor (or TFF), Initiating Event, Probability of Ignition (or Alternate POI), Probability of Exposure (or Alternate POE), Time at Risk or Other Enabling Factors.

Results from the RAST Consequence Analysis and Frequency Evaluation may be used or an Alternate method provided by the User. Additional Details for the Initiating Event (such as Sensor and Final Element Identification for Basic Process Control Failure, Procedure Reliability for Human Error, etc.) needs to be entered by the User.

Description of the Undesired Consequences

The description provided in RAST includes the Scenario Type, Type of Equipment, Chemical involved, Loss Event, Release Quantity, Airborne Rate and (if available) an estimate of the Process Safety Time. For User Defined scenarios, the Quantities reported are those entered by the User. See Figure 7.4.

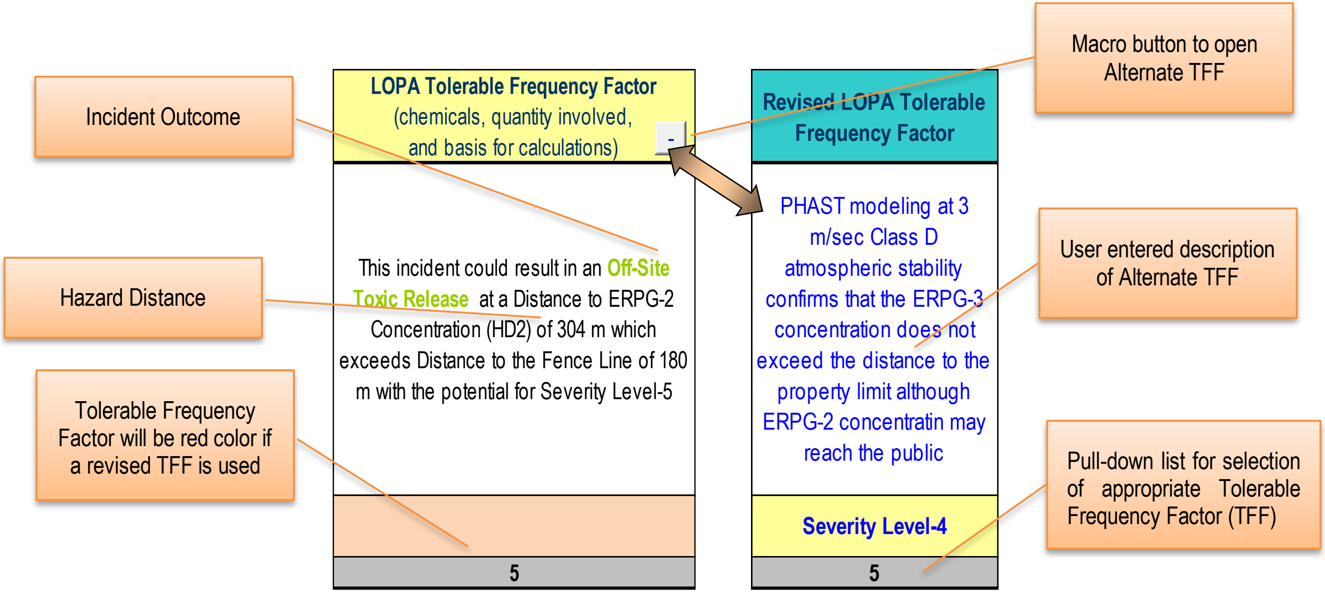


Vessel/Tank, V-101, is involved in an Overfill or Overflow event resulting in an Overfill Release with subsequent 1550 kg airborne release of Acrylonitrile at an airborne release rate of 25.9 kg/min. Estimated time to relief set pressure is 8 min.

Figure 7.4: Description of Consequence

Tolerable Frequency Factor Description

The Tolerable Frequency Factor description explains how the Tolerable Frequency was determined by the RAST tool. Included in the description is the selected Incident Outcome, a Hazard Distance (such as Distance to ERPG-2 Concentration), personnel location reference (such as distance to the Fence Line), and specifics on the Consequence Analysis method. A User may select an ***Alternate Tolerable Frequency Factor*** method by using the "+" macro button within the Tolerable Frequency Factor Description and a blank column will be available to enter a User Description and Select the Tolerable Frequency Factor from a "pull down" list. Refer to Figure 7.5.



This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 304 m which exceeds Distance to the Fence Line of 180 m with the potential for Severity Level-5

PHAST modeling at 3 m/sec Class D atmospheric stability confirms that the ERPG-3 concentration does not exceed the distance to the property limit although ERPG-2 concentratin may reach the public

Figure 7.5: Tolerable Frequency Factor Description

Initiating Event Factor (IEF)

The IEF is determined initially within RAST based on a most common Initiating Event but may be changed by the User from the available "pull down" list. The initial description (in blue text) should also be updated by the User to better reflect "how this could happen in my plant". *The Initial Description is only available until it is updated. RAST will not return to the initial description once it has been updated.*

If the Initiating Event is Human Error, the reliability of the procedure and frequency of execution may be entered by selecting the "Human Error" macro button to cross check the Initiating Event Factor. If the Initiating Event is Basic Process Control System Failure, Sensor and Final Element Information may be entered by selecting the "+" macro button. Refer to Figure 7.6.

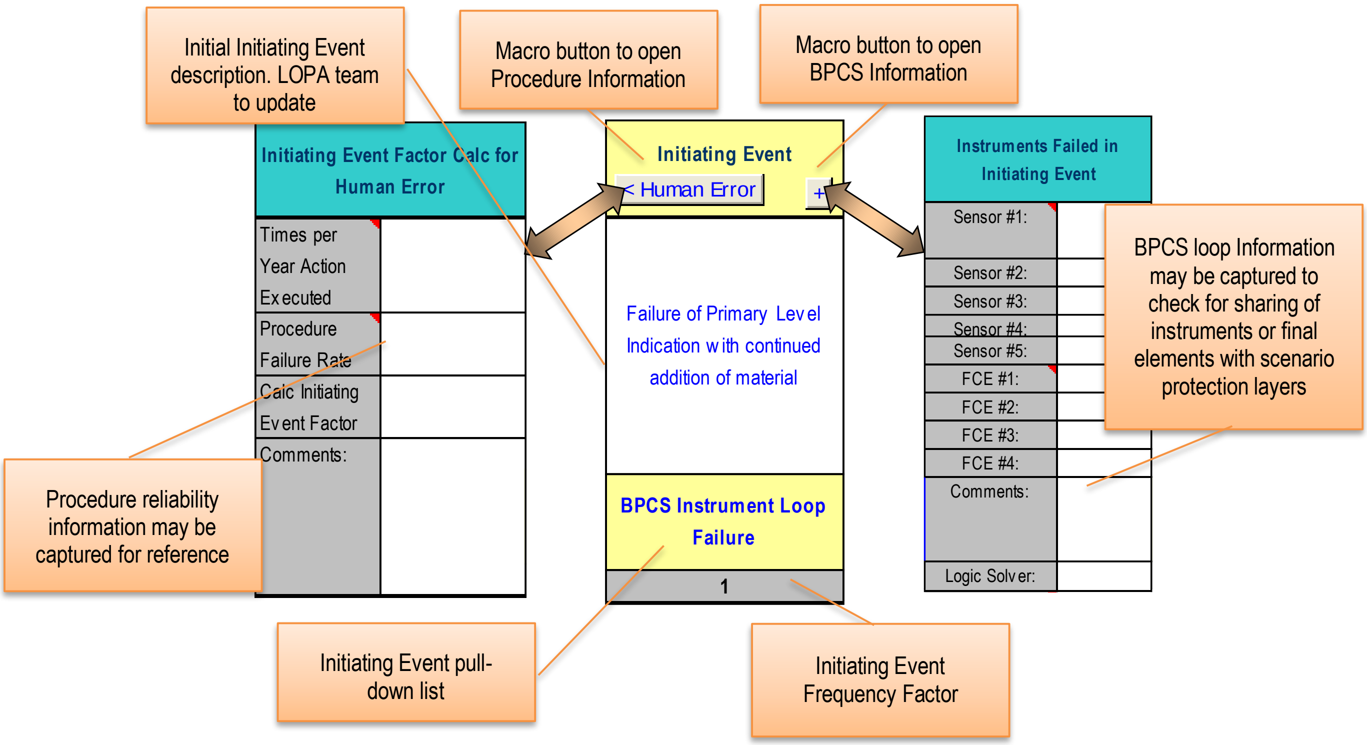
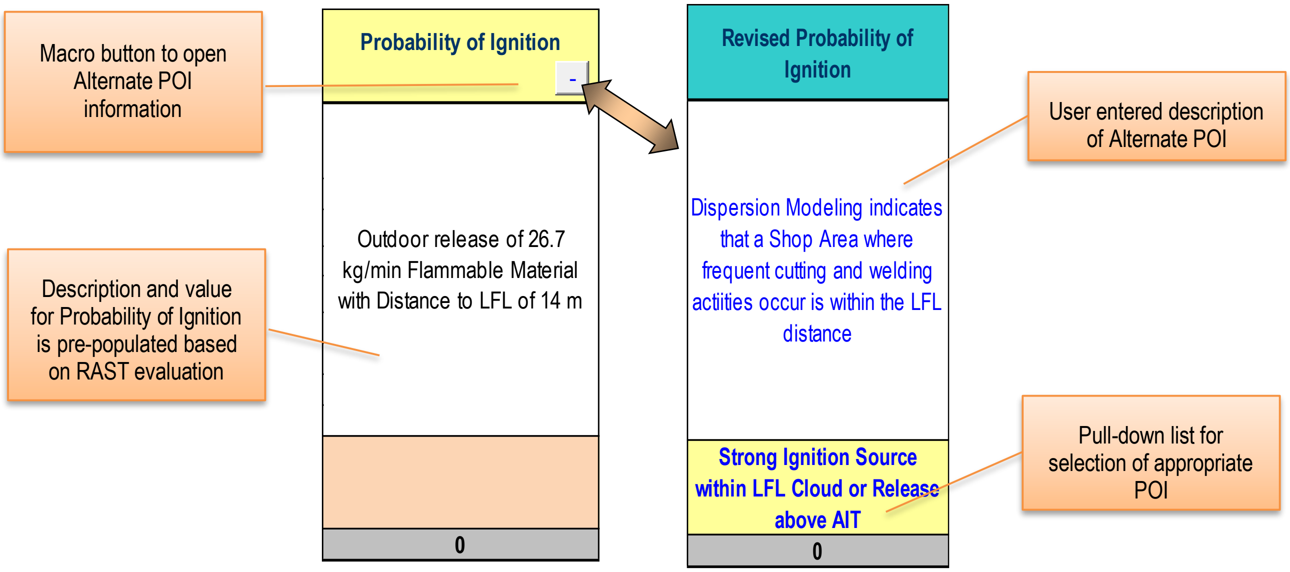


Figure 7.6 Initiating Event

Probability of Ignition (POI)

The POI for an outdoor release is determined in RAST using results of simple dispersion modeling. If needed, an ***Alternate Probability of Ignition*** method may be entered by selecting the "+" macro button. A blank column will be available to enter a User Description and Select the Probability of Ignition from a "pull-down" list. Refer to Figure 7.7.



Macro button to open Alternate POI information

Description and value for Probability of Ignition is pre-populated based on RAST evaluation

Probability of Ignition

Outdoor release of 26.7 kg/min Flammable Material with Distance to LFL of 14 m

0

Revised Probability of Ignition

Dispersion Modeling indicates that a Shop Area where frequent cutting and welding actiities occur is within the LFL distance

Strong Ignition Source within LFL Cloud or Release above AIT

0

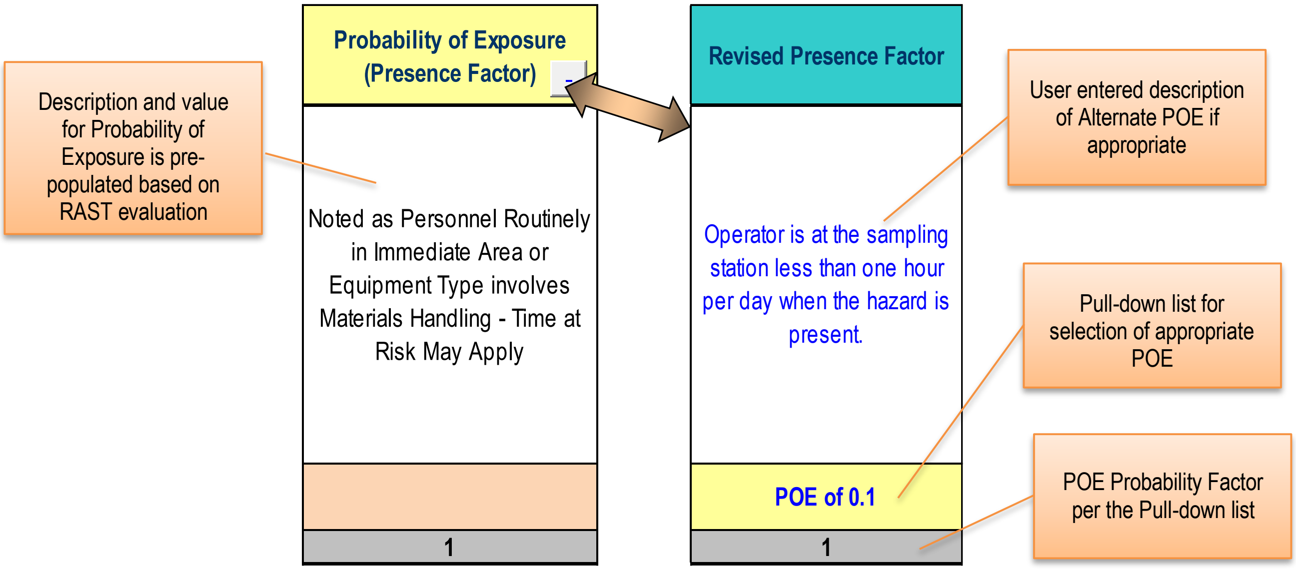
User entered description of Alternate POI

Pull-down list for selection of appropriate POI

Figure 7.7: Probability of Ignition

Probability of Exposure (Presence Factor)

The Presence factor is estimated in the RAST tool based on an Impact Area from simple dispersion or explosion models (similar to a release "footprint" from PHAST modeling) and Population Density of site personnel. An ***Alternate Probability of Exposure*** method may be entered by selecting the "+" macro button. A blank column will be available to enter a User Description and Select the Probability of Exposure from a "pull down" list. Refer to Figure 7.8.



Description and value for Probability of Exposure is pre-populated based on RAST evaluation

Probability of Exposure (Presence Factor)

Noted as Personnel Routinely in Immediate Area or Equipment Type involves Materials Handling - Time at Risk May Apply

1

Revised Presence Factor

Operator is at the sampling station less than one hour per day when the hazard is present.

POE of 0.1

1

User entered description of Alternate POE if appropriate

Pull-down list for selection of appropriate POE

POE Probability Factor per the Pull-down list

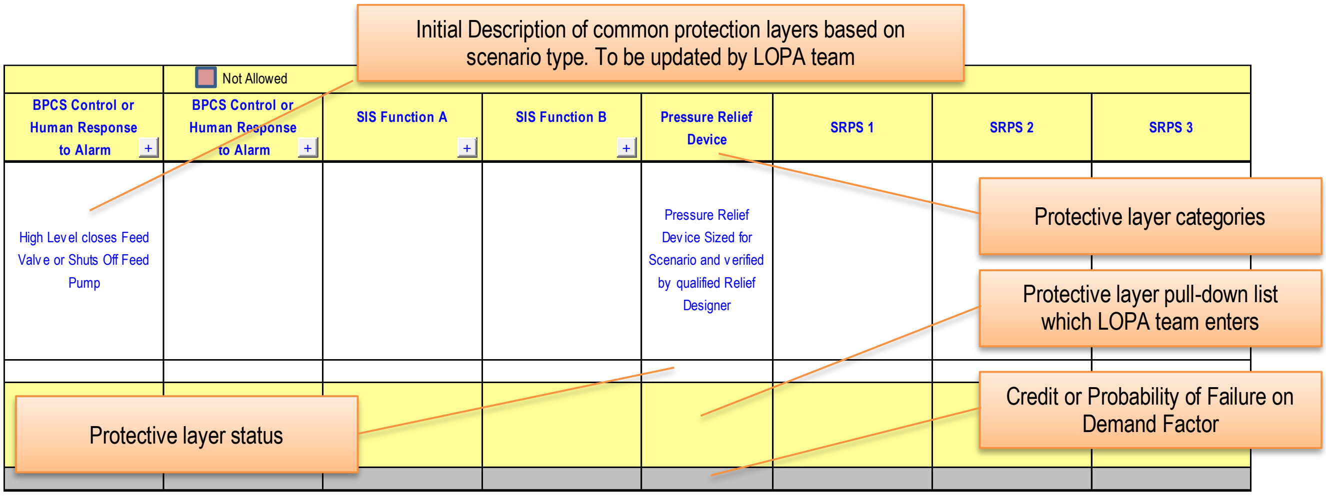
Figure 7.8 Probability of Exposure

An additional column is available within the RAST version of the LOPA workbook to capture **Time at Risk** or Other Enabling Factors. There is no evaluation for Time at Risk within RAST and values are entered from a "pull down" list.

Protective Layers – "Right" Side of LOPA Workbook

The "Right" Side of the LOPA Worksheet (Figure 7.9) represents Protective Layers and includes inputs for Basic Process Control Action, Operator Response to Alarm, SIS (Safety Instrumented System) Functions, Pressure Relief Device, and Safety Related Protective Systems (SRPS). Suggested Protective Layers for Common Scenario Cases are provided the first time Update Scenario is executed. These suggestions may be revised or updated by the Analysis Team. A "pull-down" list for each Protective Layer is used to determine the appropriate LOPA Factor. The status for each Protective Layer may also be captured to aid in prioritization of work. Options include: *Fully Implemented, In Progress and Proposed*.

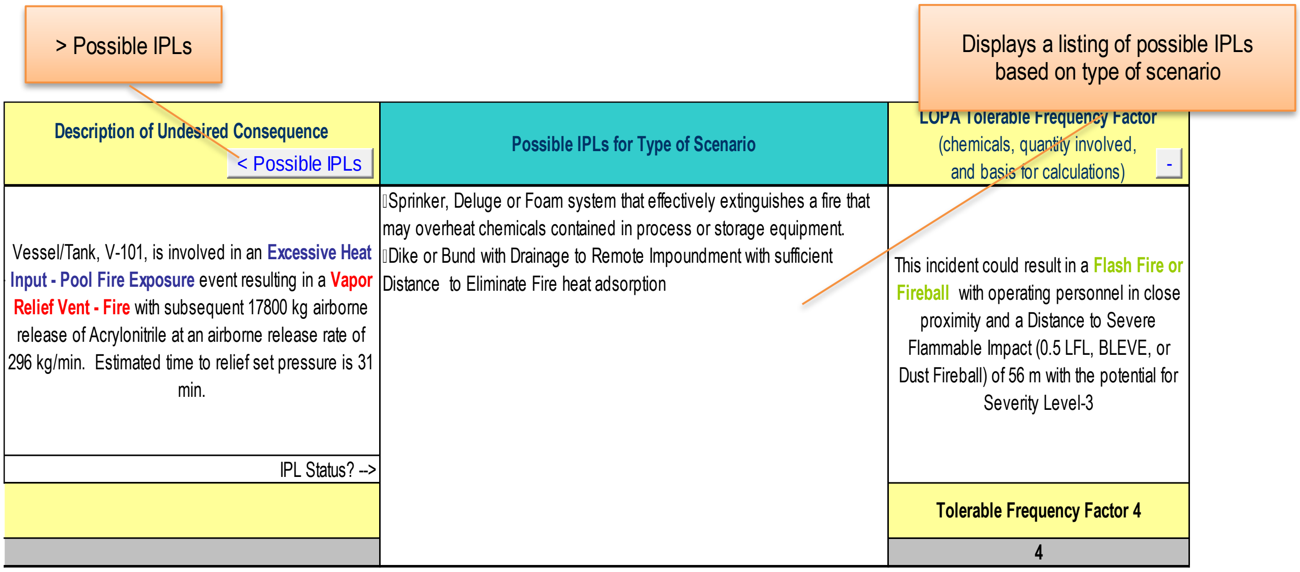
An IPL is considered Independent if it is not adversely affected by the initiating event or any other protection layer *associated within the scenario*. In some cases, however, *the same IPLs may be used to manage related scenarios* such that the PFD should be adjusted. If we have two scenarios with the same loss event and incident outcome but different initiating events, we may need to consider adjusting the PFD. For example: if we have two means for overfill of a tank, one a BPCS level control failure (at a frequency of 0.1 per year) and the other a human error, such as unloading into the wrong tank (at a frequency of 0.1 per year); then total demand on IPLs shared between these scenarios is 0.2 per year. At least one of the shared IPLs should be considered a PFD of 0.2 rather than 0.1 (or 0.02 rather than 0.01, etc.). This "correction" is typically ignored when using only order of magnitude assuming there is sufficient conservatism in the analysis. If, for example, the shared IPL is a SIS loop, then one could specify a PFD of 0.05 rather than 0.1 for a SIL-1 to accommodate.


▨ 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
High Level closes Feed Valve or Shuts Off Feed Pump				Pressure Relief Device Sized for Scenario and verified by qualified Relief Designer			

Figure 7.9: The 'Right Side' of the LOPA Worksheet-IPLs

A list of Possible IPLs may be displayed using the "> Possible IPLs" macro button. A partial listing which may be updated by the Plant or Analysis Team is displayed. Refer to Figure 7.10.



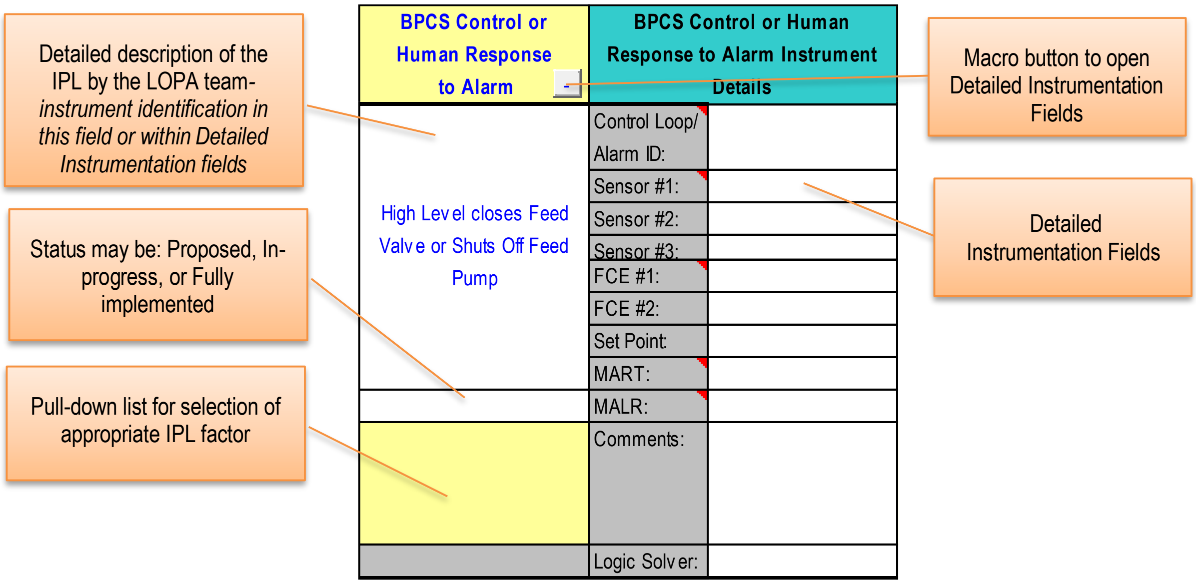
> Possible IPLs

Displays a listing of possible IPLs based on type of scenario

Description of Undesired Consequence < Possible IPLs	Possible IPLs for Type of Scenario	LOPA Tolerable Frequency Factor (chemicals, quantity involved, and basis for calculations) -
Vessel/Tank, V-101, is involved in an Excessive Heat Input - Pool Fire Exposure event resulting in a Vapor Relief Vent - Fire with subsequent 17800 kg airborne release of Acrylonitrile at an airborne release rate of 296 kg/min. Estimated time to relief set pressure is 31 min.	Sprinker, Deluge or Foam system that effectively extinguishes a fire that may overheat chemicals contained in process or storage equipment. Dike or Bund with Drainage to Remote Impoundment with sufficient Distance to Eliminate Fire heat adsorption	This incident could result in a Flash Fire or Fireball with operating personnel in close proximity and a Distance to Severe Flammable Impact (0.5 LFL, BLEVE, or Dust Fireball) of 56 m with the potential for Severity Level-3
IPL Status? -->		Tolerable Frequency Factor 4
		4

Figure 7.10 Possible IPLs Displayed

Additional Information for Automated Protective Layers may be entered by selecting the "+" macro button. An additional column will appear with fields for input of key Instrument Information. Refer to Figure 7.11.



Detailed description of the IPL by the LOPA team- *instrument identification in this field or within Detailed Instrumentation fields*

Status may be: Proposed, In-progress, or Fully implemented

Pull-down list for selection of appropriate IPL factor

Macro button to open Detailed Instrumentation Fields

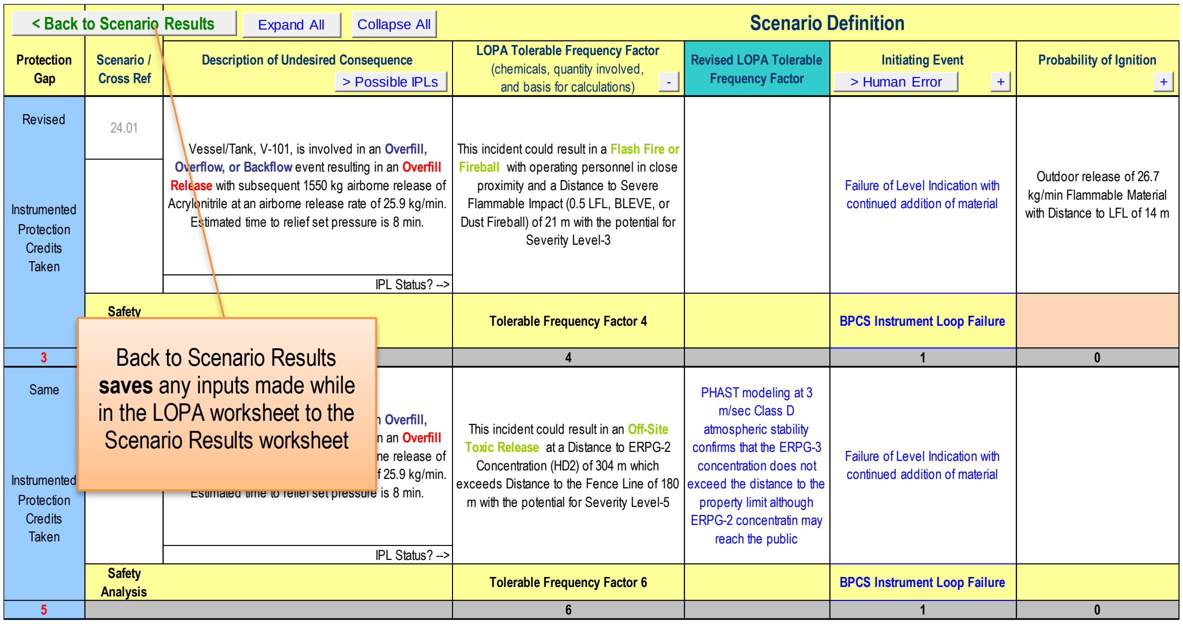
Detailed Instrumentation Fields

BPCS Control or Human Response to Alarm -	BPCS Control or Human Response to Alarm Instrument Details	
High Level closes Feed Valve or Shuts Off Feed Pump	Control Loop/ Alarm ID:	
	Sensor #1:	
	Sensor #2:	
	Sensor #3:	
	FCE #1:	
	FCE #2:	
	Set Point:	
	MART:	
	MALR:	
	Comments:	
	Logic Solver:	

Figure 7.11: Additional IPL Details Displayed

A listing for Safety Related Protection System (SRPS) and associated credits are based on literature examples. Credits may also be "manually" entered representing values agreed upon by Process Safety Subject Matter Experts.

Use *Back to Scenario Results* (Figure 7.12) to Save Information that has been input on the LOPA worksheet. LOPA Information for Each Scenario Case is stored, along with the scenario information, in a single row identified by a unique Scenario number. Manually save the Entire Workbook in the appropriate location.



Protection Gap	Scenario / Cross Ref	Description of Undesired Consequence > Possible IPLs	LOPA Tolerable Frequency Factor (chemicals, quantity involved, and basis for calculations) -	Revised LOPA Tolerable Frequency Factor	Initiating Event > Human Error +	Probability of Ignition +
Revised Instrumented Protection Credits Taken	24.01	Vessel/Tank, V-101, is involved in an **Overfill, Overflow, or Backflow** event resulting in an **Overfill Release** with subsequent 1550 kg airborne release of Acrylonitrile at an airborne release rate of 25.9 kg/min. Estimated time to relief set pressure is 8 min. IPL Status? -->	This incident could result in a **Flash Fire or Fireball** with operating personnel in close proximity and a Distance to Severe Flammable Impact (0.5 LFL, BLEVE, or Dust Fireball) of 21 m with the potential for Severity Level-3		Failure of Level Indication with continued addition of material	Outdoor release of 26.7 kg/min Flammable Material with Distance to LFL of 14 m
	Safety		**Tolerable Frequency Factor 4**		**BPCS Instrument Loop Failure**	
3			4		1	0
Same Instrumented Protection Credits Taken		n **Overfill,** n an **Overfill** ne release of f 25.9 kg/min. Estimated time to relief set pressure is 8 min. IPL Status? -->	This incident could result in an **Off-Site Toxic Release** at a Distance to ERPG-2 Concentration (HD2) of 304 m which exceeds Distance to the Fence Line of 180 m with the potential for Severity Level-5	PHAST modeling at 3 m/sec Class D atmospheric stability confirms that the ERPG-3 concentration does not exceed the distance to the property limit although ERPG-2 concentratin may reach the public	Failure of Level Indication with continued addition of material	
	Safety Analysis		**Tolerable Frequency Factor 6**		**BPCS Instrument Loop Failure**	
5			6		1	0

Back to Scenario Results **saves** any inputs made while in the LOPA worksheet to the Scenario Results worksheet

Figure 7.12 Back to Scenario Results

Example Scenario Selection and LOPA Analysis within RAST

As an example, we will select scenarios associated with the Acrylonitrile Storage Tank, V-101.

STEP 1: Ensure V-101 Information is "Active" within RAST.

From the Main Menu or LOPA Menu, view Equipment Identification. Refer to Figure 7.13.

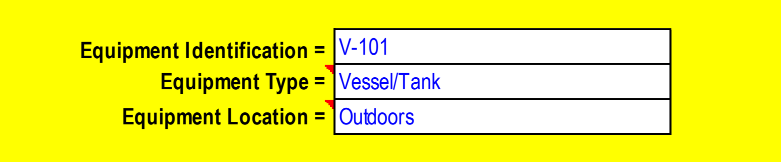
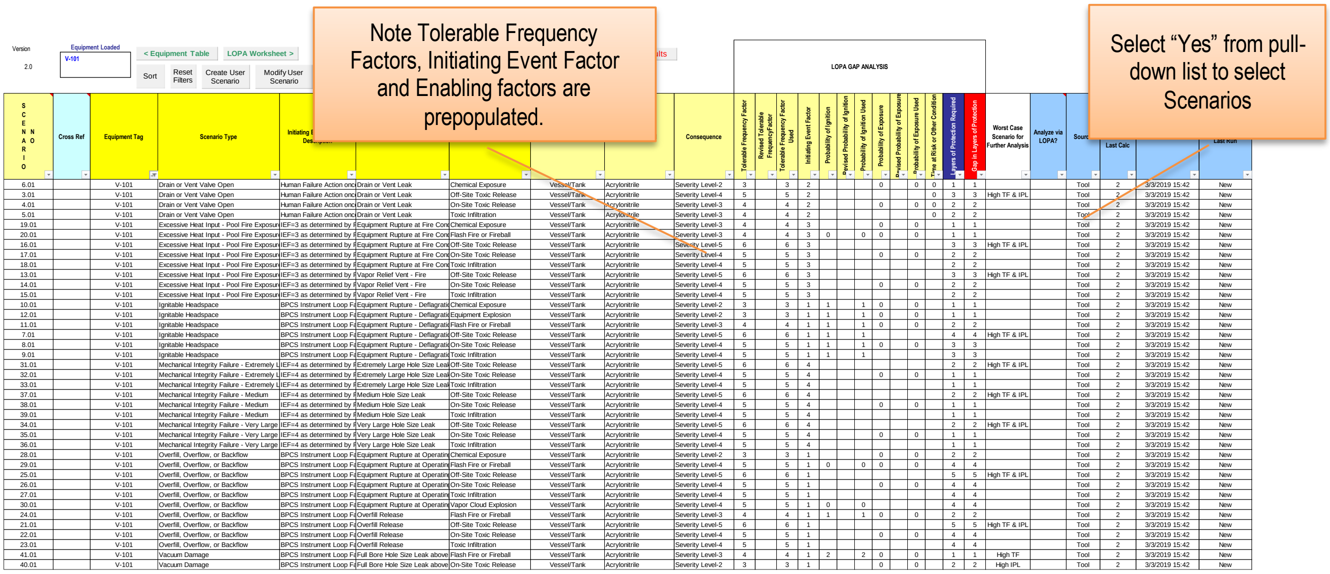

Equipment Identification = V-101
Equipment Type = Vessel/Tank
Equipment Location = Outdoors

Figure 7.13: Equipment Identification on Main Menu

If the Equipment Identification is not is not V-101, use Load Selected from the Equipment Table.

STEP 2: Ensure Analysis is Current. If the Equipment Item has not yet been analyzed or if inputs have changed since the last analysis, Select ***Update Scenario for Equipment Loaded*** which will go to the **Scenario Results** worksheet when completed.

STEP 3: Select Scenario Cases for LOPA Analysis on the Scenario Results worksheet (Figure 7.14). There are many cases listed so focus on those identified as "worst cases" as the case within a broad scenario category having the Highest Tolerable Frequency Factor ("High TF"), Greater Number of IPLs Needed ("High IPL") or both ("High TF & IPL").



Note Tolerable Frequency Factors, Initiating Event Factor and Enabling factors are prepopulated.

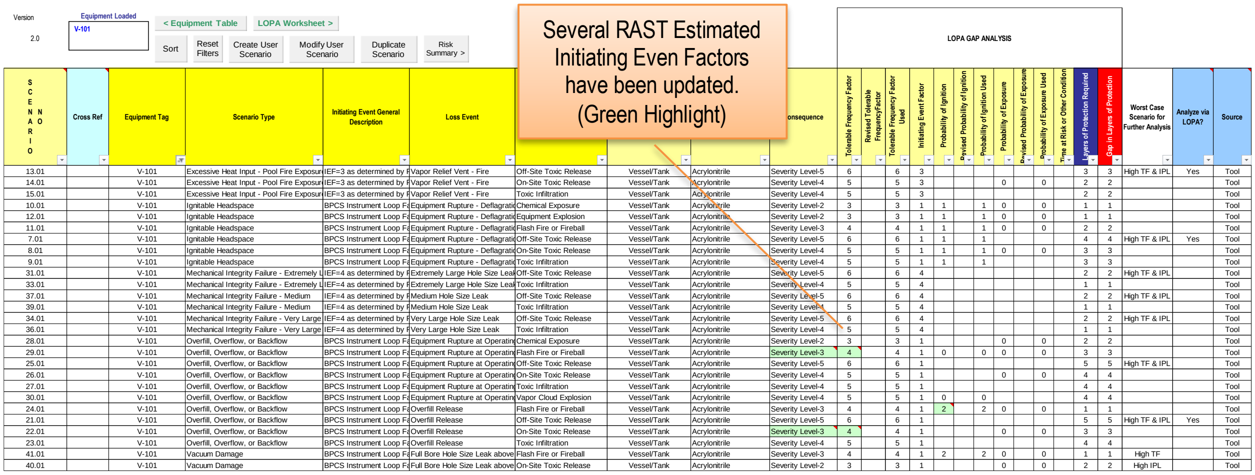
Select “Yes” from pull-down list to select Scenarios

Figure 7.14 Selecting Analyze Via LOPA on Scenario Results Worksheet

Select “Yes” to Analyze via LOPA? for the following five cases to begin with:

- Drain Open
- Excessive Heat – Pool Fire with Vapor Venting
- Excessive Heat – Pool Fire with Equipment Rupture
- Ignitable Headspace
- Overfill

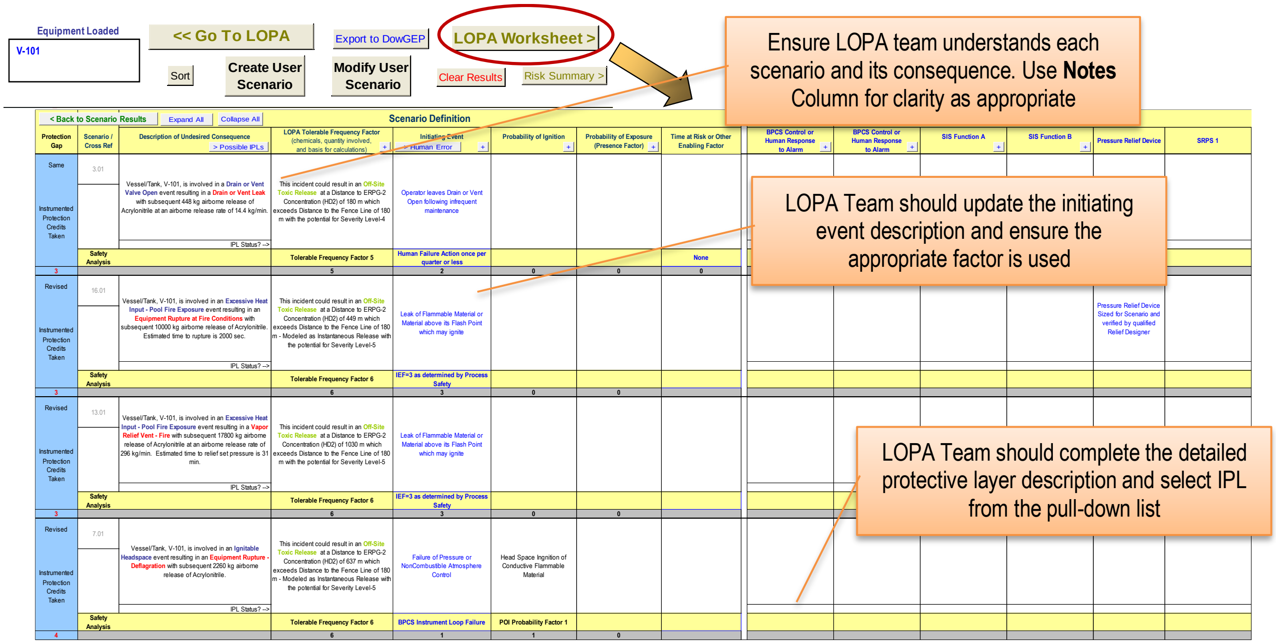
Note that the Tolerable Frequency Factor for many of these Scenarios is high. Return to **Plant Layout** (via the Main Menu) and enter a Dike Area of 200 m^2. Save your change by selecting **Save Input to Equipment Table**. Return to the **LOPA Menu** and ***Update Scenarios for Equipment Loaded*** which again will go to the **Scenario Results** worksheet when completed. Note that several Scenario Cases have been updated (denoted by “green” cells). Entry of a Dike or Containment Area significantly reduces the area for pool evaporation and the total Airborne Quantity, hence lowering the Tolerable Frequency Factors for several scenario cases. Refer to Figure 7.16.



Several RAST Estimated Initiating Even Factors have been updated. (Green Highlight)

Figure 7.15: Modified Initiating Event Factors due to Modification of Inputs

STEP 4: Select LOPA Worksheet. Information from the RAST evaluation will be captured in the LOPA Worksheet for additional inputs and evaluation by the LOPA Team. Refer to Figure 7.16.



Ensure LOPA team understands each scenario and its consequence. Use **Notes** Column for clarity as appropriate

LOPA Team should update the initiating event description and ensure the appropriate factor is used

LOPA Team should complete the detailed protective layer description and select IPL from the pull-down list

Protection Gap	Scenario / Cross Ref	Description of Undesired Consequence	LOPA Tolerable Frequency Factor (chemicals, quantity involved, and basis for calculations)	Initiating Event	Probability of Ignition	Probability of Exposure (Presence Factor)	Time at Risk or Other Enabling Factor	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
Same Instrumented Protection Credits Taken	3.01	Vessel/Tank, V-101, is involved in a Drain or Vent Valve Open event resulting in a Drain or Vent Leak with subsequent 448 kg airborne release of Acrylonitrile at an airborne release rate of 14.4 kg/min. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 180 m which exceeds Distance to the Fence Line of 180 m with the potential for Severity Level-4	Operator leaves Drain or Vent Open following infrequent maintenance									
	Safety Analysis		Tolerable Frequency Factor 5	Human Failure Action once per quarter or less			None						
3			5	2	0	0	0						
Revised Instrumented Protection Credits Taken	16.01	Vessel/Tank, V-101, is involved in an Excessive Heat Input - Pool Fire Exposure event resulting in an Equipment Rupture at Fire Conditions with subsequent 10000 kg airborne release of Acrylonitrile. Estimated time to rupture is 2000 sec. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 449 m which exceeds Distance to the Fence Line of 180 m - Modeled as Instantaneous Release with the potential for Severity Level-5	Leak of Flammable Material or Material above its Flash Point which may ignite								Pressure Relief Device Sized for Scenario and verified by qualified Relief Designer	
	Safety Analysis		Tolerable Frequency Factor 6	IEF=3 as determined by Process Safety									
3			6	3	0	0							
Revised Instrumented Protection Credits Taken	13.01	Vessel/Tank, V-101, is involved in an Excessive Heat Input - Pool Fire Exposure event resulting in a Vapor Relief Vent - Fire with subsequent 17800 kg airborne release of Acrylonitrile at an airborne release rate of 296 kg/min. Estimated time to relief set pressure is 31 min. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 1030 m which exceeds Distance to the Fence Line of 180 m with the potential for Severity Level-5	Leak of Flammable Material or Material above its Flash Point which may ignite									
	Safety Analysis		Tolerable Frequency Factor 6	IEF=3 as determined by Process Safety									
3			6	3	0	0							
Revised Instrumented Protection Credits Taken	7.01	Vessel/Tank, V-101, is involved in an Ignitable Headspace event resulting in an Equipment Rupture - Deflagration with subsequent 2260 kg airborne release of Acrylonitrile. IPL Status? -->	This incident could result in an Off-Site Toxic Release at a Distance to ERPG-2 Concentration (HD2) of 637 m which exceeds Distance to the Fence Line of 180 m - Modeled as Instantaneous Release with the potential for Severity Level-5	Failure of Pressure or NonCombustible Atmosphere Control	Head Space Ingnition of Conductive Flammable Material								
	Safety Analysis		Tolerable Frequency Factor 6	BPCS Instrument Loop Failure	POI Probability Factor 1								
4			6	1	1	0							

Figure 7.16: LOPA Worksheet

STEP 5: Review the Description of Undesired Consequences and LOPA Tolerable Frequency Factor provided by RAST. This Description and Tolerable Frequency Factor are based on a specific RAST analysis and may not be changed. Consider entering User Scenario Cases where these descriptions do not represent a Process Risk associated with the equipment being analyzed. If a more detailed analysis of the Consequence is available which results in a different LOPA Tolerable Frequency Factor, an alternate Tolerable Frequency Factor and Description may be entered and the RAST analysis will not be used.

STEP 6: Review the Initiating Event Description and Update as appropriate. The documentation should be clearly understood by LOPA Team members. ***Determine if the correct Initiating Event Factor has been used and Update if needed.***

Starting with the Open Drain Valve, update the Initiating Description to better reflect how this might occur. Consider how frequently the drain valve might be operated – such as opened less than once per year to prepare the pump or piping for maintenance or opened with each transfer to drain the unloading hose. Change the Initiating Event Factor by using the “pull down” Menu to “Operator Failure Action more than once per quarter” if appropriate.

STEP 7: Review the Enabling Factors and Update as appropriate.

STEP 8: Determine the Most Effective Protective Layers for managing the Process Risk. Protective Layer information is entered on the “Right” Side of the LOPA Workbook. Some common Protective Layers are suggested by RAST which the LOPA Team updates the description and enters the appropriate “Credit” from “pull down” Menu selections for each.

In this Scenario Case, a flammable leak detector with alarm would be documented under “Operator Response to Alarm” if there were sufficient time for Operator Response to stop the leak and significantly reduce the Consequence. This would represent a “Mitigating” Protective Layers and it does not prevent the Loss Event (leak from an open drain valve) from occurring.

STEP 9: Complete the LOPA Analysis by entering any Notes to help explain the Scenario Case. Another column is provided in the RAST version of the LOPA Workbook for capturing Issues and Action Items. In addition, columns are provided for entry of Process Safety, Manufacturing, and Process Control reviewers and Review Date.

STEP 10: Save the LOPA Inputs to the Scenario Results Worksheet. Select **Back to Scenario Results** to save inputs made on the LOPA Worksheet. Once the LOPA Workbook has "closed", the entire RAST spreadsheet should be saved.

Mechanical Integrity Scenarios in RAST

Mechanical Integrity (MI) failures represent nearly 50% of Process Safety Events. These are difficult to analyze within LOPA as a "cause" is not identified other than corrosion or fatigue. Without an identified "cause" only frequent inspection and Mitigating Protective Layers can be used. Fortunately, Mechanical Integrity failures of piping and equipment are not frequent and, in many cases, Protective Layers will not be required.

RAST screens for Mechanical Integrity failures based on "order of magnitude" industry frequency data. This feature is disabled on the LOPA Menu by entering "Yes" to the question "Exclude Mechanical Integrity Scenarios". MI scenarios appear in the Scenario Result workbook as "Piping or Equipment LOPC – xxx" where xxx represent a specific hole size. Screening is performed using four hole sizes: 5 mm, 25 mm, 100 mm, and 250 mm (or other hole sizes entered under the Administrative Parameters).

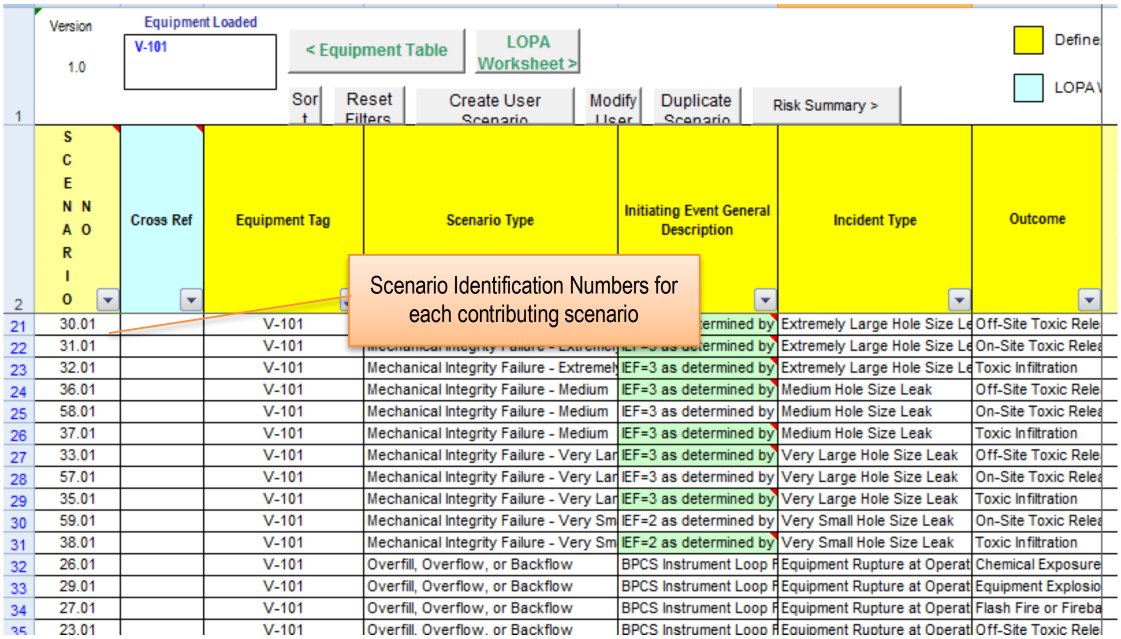
Pool Fire Evaluation

A "general" Initiating Event Factor representing a leak with ignition is used by RAST for initial screening of Pool Fire cases. Estimation of pool fire frequency, however, is complex and requires an evaluation of all potential leak sources of fuel. A Pool Fire Frequency section of this worksheet is available to perform a very simple Fault Tree based on LOPA Scenario information to obtain a more reasonable estimate of the Initiating Event Factor.

STEP 1: Select Estimate Pool Fire Evaluation from the either the Main Menu or LOPA Menu. *Since the Pool Fire Evaluation Summary is commonly used to determine which equipment may require more detailed evaluation of Pool Fire Frequency, access is located on both the Main Menu and LOPA Menu.*

STEP 2: Identify Scenario Cases (on Scenario Results worksheet) which contribute to a flammable leak near the physical location of the equipment being analyzed (cases with flammable outcome that are not pool fire related). Refer to Figure 7.17. A pool fire scenario impacting V-101 could be caused by spills from V-101, pump P-101, or other tanks within the same dike or containment area.

> To determine scenario cases with flammable outcome not related to pool fire, one may *filter* scenario cases with Outcome of either "Flash, Jet or Pool Fire" or "Vapor Cloud Explosion" or "Building Explosion" and *filter* Scenario Type to exclude "Excessive Heat Input – Pool Fire".
>
> To reduce the number of contributing cases (to less than 10), those with highest frequency should be selected (or those with the smallest sum of Initiating Event plus Probability of Ignition plus non-mitigating Protective Layer factors). The summation of frequencies for the contributing scenarios will not be significantly impacted by excluding the very low frequency cases.

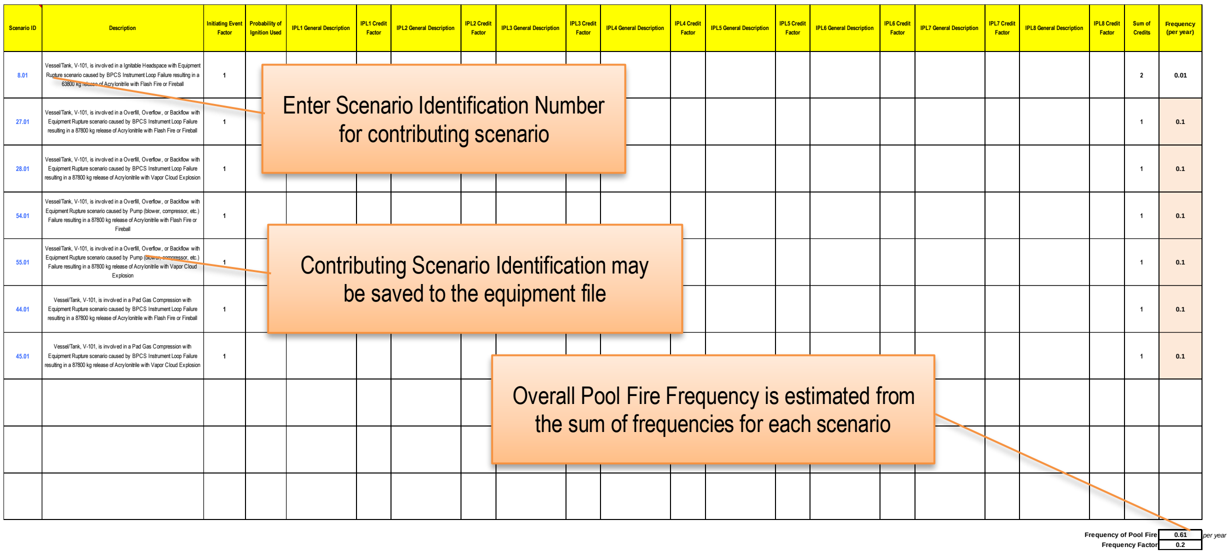


	SCENARIO NO	Cross Ref	Equipment Tag	Scenario Type	Initiating Event General Description	Incident Type	Outcome
21	30.01		V-101		ermined by	Extremely Large Hole Size Le	Off-Site Toxic Rele
22	31.01		V-101		ermined by	Extremely Large Hole Size Le	On-Site Toxic Relea
23	32.01		V-101	Mechanical Integrity Failure - Extremel	IEF=3 as determined by	Extremely Large Hole Size Le	Toxic Infiltration
24	36.01		V-101	Mechanical Integrity Failure - Medium	IEF=3 as determined by	Medium Hole Size Leak	Off-Site Toxic Rele
25	58.01		V-101	Mechanical Integrity Failure - Medium	IEF=3 as determined by	Medium Hole Size Leak	On-Site Toxic Relea
26	37.01		V-101	Mechanical Integrity Failure - Medium	IEF=3 as determined by	Medium Hole Size Leak	Toxic Infiltration
27	33.01		V-101	Mechanical Integrity Failure - Very Lar	IEF=3 as determined by	Very Large Hole Size Leak	Off-Site Toxic Rele
28	57.01		V-101	Mechanical Integrity Failure - Very Lar	IEF=3 as determined by	Very Large Hole Size Leak	On-Site Toxic Relea
29	35.01		V-101	Mechanical Integrity Failure - Very Lar	IEF=3 as determined by	Very Large Hole Size Leak	Toxic Infiltration
30	59.01		V-101	Mechanical Integrity Failure - Very Sm	IEF=2 as determined by	Very Small Hole Size Leak	On-Site Toxic Relea
31	38.01		V-101	Mechanical Integrity Failure - Very Sm	IEF=2 as determined by	Very Small Hole Size Leak	Toxic Infiltration
32	26.01		V-101	Overfill, Overflow, or Backflow	BPCS Instrument Loop F	Equipment Rupture at Operat	Chemical Exposure
33	29.01		V-101	Overfill, Overflow, or Backflow	BPCS Instrument Loop F	Equipment Rupture at Operat	Equipment Explosio
34	27.01		V-101	Overfill, Overflow, or Backflow	BPCS Instrument Loop F	Equipment Rupture at Operat	Flash Fire or Fireba
35	23.01		V-101	Overfill, Overflow, or Backflow	BPCS Instrument Loop F	Equipment Rupture at Operat	Off-Site Toxic Rele

Figure 7.17: Identification of Scenario ID Numbers

STEP 3: Record the Scenario Identification Numbers for scenarios with flammable outcome associated with these Equipment Items.

Enter the Scenario Identification Numbers of the contributing cases in the column on the left side of the Pool Fire worksheet. RAST will retrieve information for each scenario including Protective Layers and summarize in additional columns of the same row. The overall frequency and frequency factor are shown at the bottom right of this worksheet. This frequency factor may then be used for updating the Initiating Event Factor for the Excessive Heat from Pool Fire to V-101 scenario from the LOPA Workbook "pull down" Menu. Refer to Figure 7.18.



Scenario ID	Description	Initiating Event Factor	Probability of Ignition Used	IPL1 General Description	IPL1 Credit Factor	IPL2 General Description	IPL2 Credit Factor	IPL3 General Description	IPL3 Credit Factor	IPL4 General Description	IPL4 Credit Factor	IPL5 General Description	IPL5 Credit Factor	IPL6 General Description	IPL6 Credit Factor	IPL7 General Description	IPL7 Credit Factor	IPL8 General Description	IPL8 Credit Factor	Sum of Credits	Frequency (per year)
8.01	Vessel/Tank, V-101, is involved in a Ignitable Headspace with Equipment Rupture scenario caused by BPCS Instrument Loop Failure resulting in a 63800 kg release of Acrylonitrile with Flash Fire or Fireball	1																		2	0.01
27.01	Vessel/Tank, V-101, is involved in a Overfill, Overflow, or Backflow with Equipment Rupture scenario caused by BPCS Instrument Loop Failure resulting in a 87800 kg release of Acrylonitrile with Flash Fire or Fireball	1																		1	0.1
28.01	Vessel/Tank, V-101, is involved in a Overfill, Overflow, or Backflow with Equipment Rupture scenario caused by BPCS Instrument Loop Failure resulting in a 87800 kg release of Acrylonitrile with Vapor Cloud Explosion	1																		1	0.1
54.01	Vessel/Tank, V-101, is involved in a Overfill, Overflow, or Backflow with Equipment Rupture scenario caused by Pump (blower, compressor, etc.) Failure resulting in a 87800 kg release of Acrylonitrile with Flash Fire or Fireball	1																		1	0.1
55.01	Vessel/Tank, V-101, is involved in a Overfill, Overflow, or Backflow with Equipment Rupture scenario caused by Pump (blower, compressor, etc.) Failure resulting in a 87800 kg release of Acrylonitrile with Vapor Cloud Explosion	1																		1	0.1
44.01	Vessel/Tank, V-101, is involved in a Pad Gas Compression with Equipment Rupture scenario caused by BPCS Instrument Loop Failure resulting in a 87800 kg release of Acrylonitrile with Flash Fire or Fireball	1																		1	0.1
45.01	Vessel/Tank, V-101, is involved in a Pad Gas Compression with Equipment Rupture scenario caused by BPCS Instrument Loop Failure resulting in a 87800 kg release of Acrylonitrile with Vapor Cloud Explosion	1																		1	0.1

Frequency of Pool Fire 0.61 per year
Frequency Factor 0.2

Figure 7.18: Pool Fire Worksheet

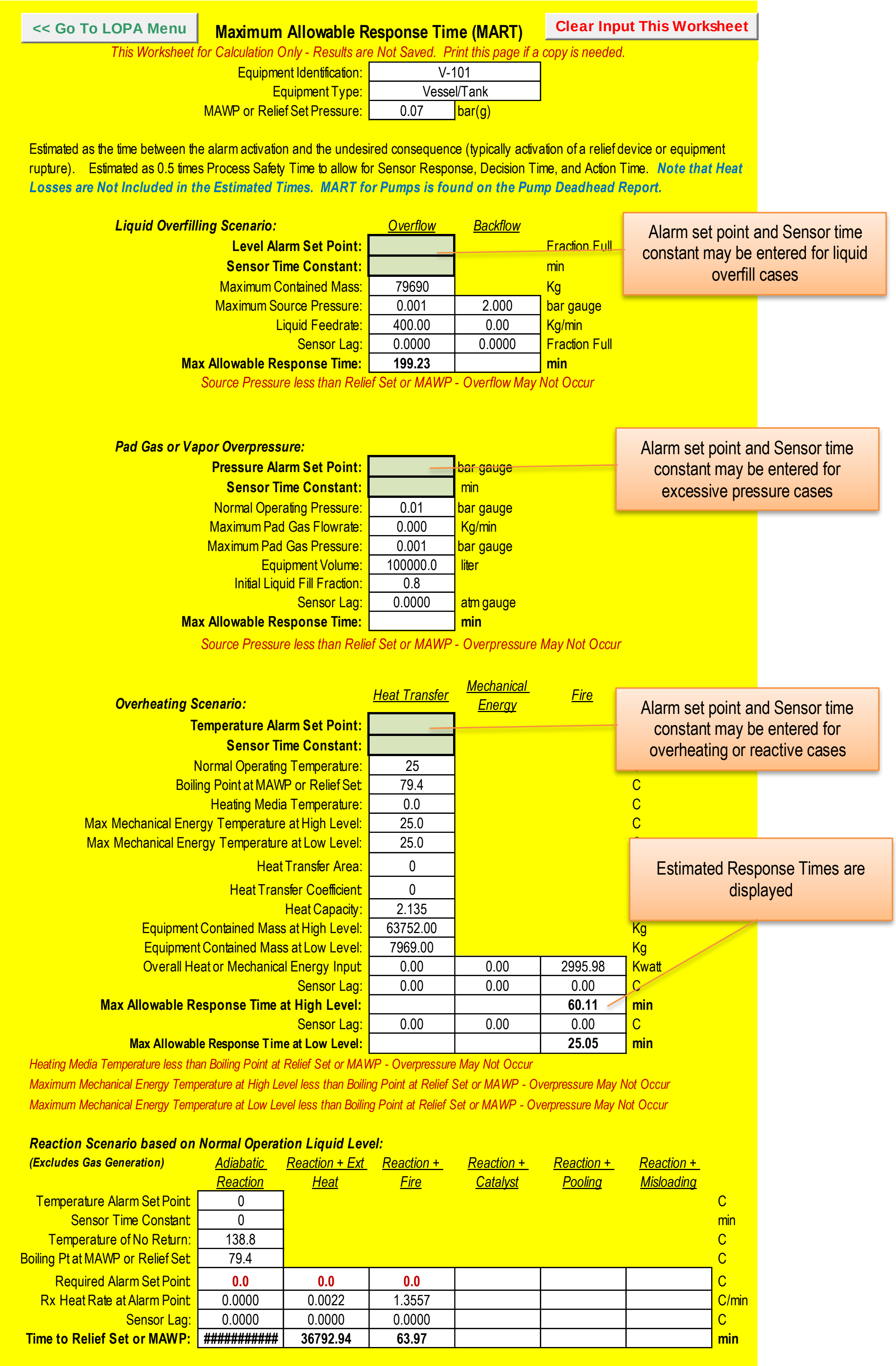
STEP 4: Save the List of Contributing Scenarios by using *the Save Input to Equipment Table* command.

Maximum Allowable Response Time

An estimate of the Maximum Allowable Response Time (MART) is required for each Safety Instrumented System identified within a LOPA analysis. The MART provides key information for specification of the instrumentation. The RAST tool provides a worksheet to assist in MART estimation for common scenarios. The MART-MALT Estimation worksheet is accessed from the LOPA Menu. Refer to Figure 7.19.

> ***Overflow and Backflow –*** this section of the MART worksheet estimates the MART from an entered High-Level Alarm Set Point to "hydraulically full" based on the entered Maximum Feed Rate or Maximum Backflow Rate inputs from the Process Conditions worksheet. A value for the Sensor Time Constant may also be entered which will incorporate a first-order time delay into the MART estimate.
>
> ***Pad Gas Overpressure –*** this section of the MART worksheet estimates the MART from an entered High-Pressure Alarm Set Point to the lower of MAWP or Relief Device Set Pressure based on the entered Maximum Pad Gas Rate input from the Process Conditions worksheet. A value for the Sensor Time Constant may also be entered which will incorporate a first-order time delay into the MART estimate.
>
> ***Overheating –*** this section of the MART worksheet estimates the MART from an entered High Temperature Alarm Set Point to the Saturation Temperature at the lower of MAWP or Relief Device Set Pressure based on heat inputs from Heat Transfer, Mechanical Energy, or Fire. A value for the Sensor Time Constant may also be entered which will incorporate a first-order time delay into the MART estimate.
>
> ***Reaction –*** this section of the MART worksheet estimates the MART from an entered desired High Temperature Alarm Set Point to the Saturation Temperature at the lower of MAWP or Relief Device Set Pressure based on heat inputs from various Reaction cases. A value for the Sensor Time Constant may also be entered which will incorporate a first-order time delay into the MART estimate. As reaction heat rate may be very high, an actual High Temperature Alarm Set Point meeting the desired value is returned based on the entered Sensor Time Constant.

Note that the estimates from the MART-MALR worksheet are not saved. Results may be entered in the SIS Instrumentation details of the LOPA workbook.



Maximum Allowable Response Time (MART)

This Worksheet for Calculation Only - Results are Not Saved. Print this page if a copy is needed.

Equipment Identification: V-101
Equipment Type: Vessel/Tank
MAWP or Relief Set Pressure: 0.07 bar(g)

Estimated as the time between the alarm activation and the undesired consequence (typically activation of a relief device or equipment rupture). Estimated as 0.5 times Process Safety Time to allow for Sensor Response, Decision Time, and Action Time. ***Note that Heat Losses are Not Included in the Estimated Times. MART for Pumps is found on the Pump Deadhead Report.***

Liquid Overfilling Scenario:	*Overflow*	*Backflow*	
Level Alarm Set Point:			Fraction Full
Sensor Time Constant:			min
Maximum Contained Mass:	79690		Kg
Maximum Source Pressure:	0.001	2.000	bar gauge
Liquid Feedrate:	400.00	0.00	Kg/min
Sensor Lag:	0.0000	0.0000	Fraction Full
Max Allowable Response Time:	**199.23**		**min**

Source Pressure less than Relief Set or MAWP - Overflow May Not Occur

Alarm set point and Sensor time constant may be entered for liquid overfill cases

Pad Gas or Vapor Overpressure:		
Pressure Alarm Set Point:		bar gauge
Sensor Time Constant:		min
Normal Operating Pressure:	0.01	bar gauge
Maximum Pad Gas Flowrate:	0.000	Kg/min
Maximum Pad Gas Pressure:	0.001	bar gauge
Equipment Volume:	100000.0	liter
Initial Liquid Fill Fraction:	0.8	
Sensor Lag:	0.0000	atm gauge
Max Allowable Response Time:		**min**

Source Pressure less than Relief Set or MAWP - Overpressure May Not Occur

Alarm set point and Sensor time constant may be entered for excessive pressure cases

Overheating Scenario:	*Heat Transfer*	*Mechanical Energy*	*Fire*	
Temperature Alarm Set Point:				
Sensor Time Constant:				
Normal Operating Temperature:	25			
Boiling Point at MAWP or Relief Set:	79.4			C
Heating Media Temperature:	0.0			C
Max Mechanical Energy Temperature at High Level:	25.0			C
Max Mechanical Energy Temperature at Low Level:	25.0			C
Heat Transfer Area:	0			
Heat Transfer Coefficient:	0			
Heat Capacity:	2.135			
Equipment Contained Mass at High Level:	63752.00			Kg
Equipment Contained Mass at Low Level:	7969.00			Kg
Overall Heat or Mechanical Energy Input:	0.00	0.00	2995.98	Kwatt
Sensor Lag:	0.00	0.00	0.00	C
Max Allowable Response Time at High Level:			**60.11**	**min**
Sensor Lag:	0.00	0.00	0.00	C
Max Allowable Response Time at Low Level:			**25.05**	**min**

Alarm set point and Sensor time constant may be entered for overheating or reactive cases

Estimated Response Times are displayed

Heating Media Temperature less than Boiling Point at Relief Set or MAWP - Overpressure May Not Occur
Maximum Mechanical Energy Temperature at High Level less than Boiling Point at Relief Set or MAWP - Overpressure May Not Occur
Maximum Mechanical Energy Temperature at Low Level less than Boiling Point at Relief Set or MAWP - Overpressure May Not Occur

Reaction Scenario based on Normal Operation Liquid Level:

(Excludes Gas Generation)	*Adiabatic Reaction*	*Reaction + Ext Heat*	*Reaction + Fire*	*Reaction + Catalyst*	*Reaction + Pooling*	*Reaction + Misloading*	
Temperature Alarm Set Point:	0						C
Sensor Time Constant:	0						min
Temperature of No Return:	138.8						C
Boiling Pt at MAWP or Relief Set:	79.4						C
Required Alarm Set Point:	**0.0**	**0.0**	**0.0**				C
Rx Heat Rate at Alarm Point:	0.0000	0.0022	1.3557				C/min
Sensor Lag:	0.0000	0.0000	0.0000				C
Time to Relief Set or MAWP:	**###########**	**36792.94**	**63.97**				**min**

Figure 7.19 Maximum Allowable Response Time

Maximum Allowable Leak Rate

An estimate of the Maximum Allowable Leak Rate is also required for each Safety Instrumented System identified within a LOPA analysis. This provides key information in the specification of instrumentation. The RAST tool provides a worksheet to assist in this estimation. The MART-MALT Estimation worksheet is accessed from the LOPA Menu. Refer to Figure 7.20.

The Maximum Allowable Leak Rate is either based on *Limiting* the incident outcome to prevent a potentially serious human impact OR based on *Stopping* or *Delaying* the Event Sequence. For example:

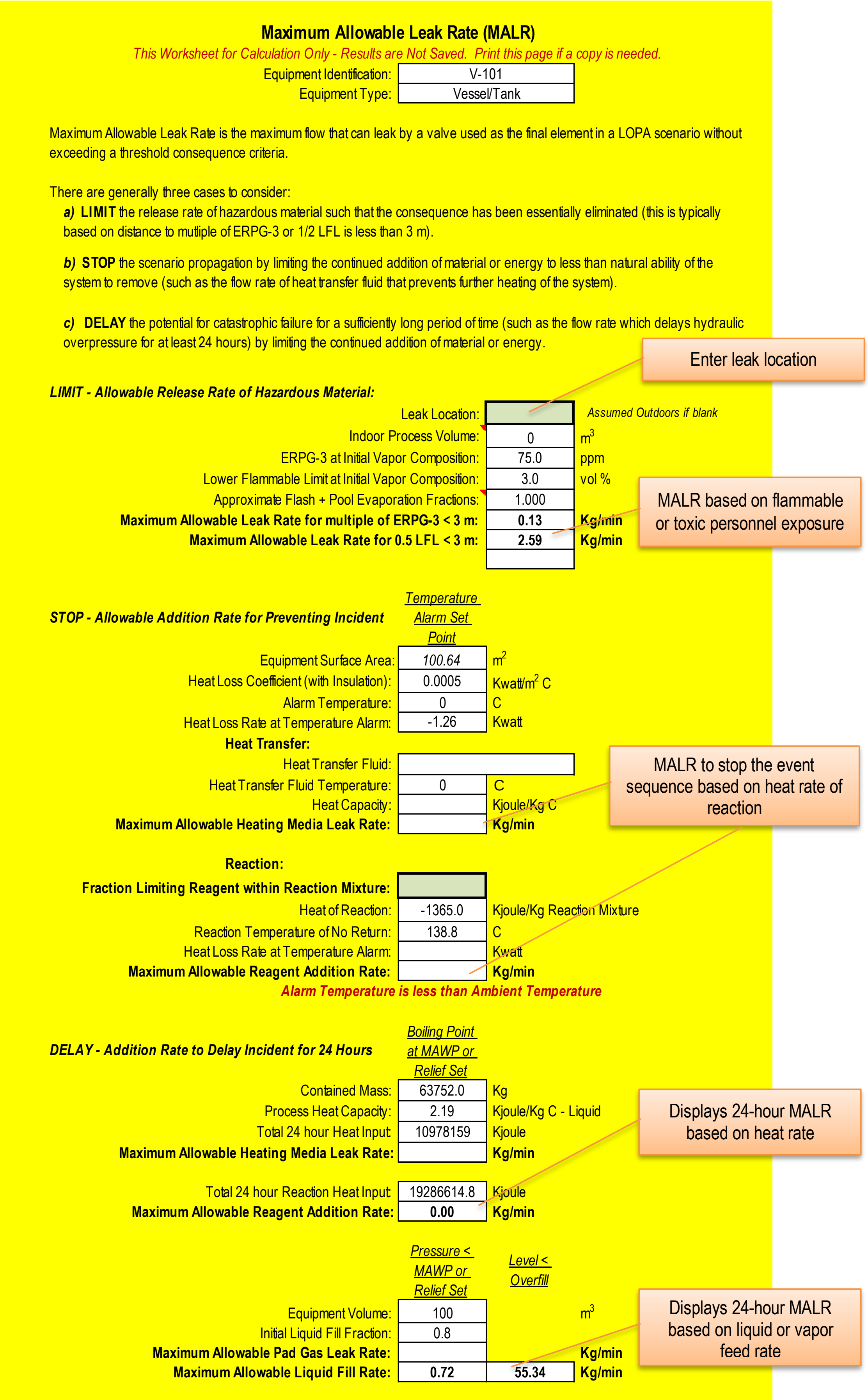
> ***LIMIT the release rate to Prevent a Potentially Serious Human Impact*** would be reducing the release rate such that a multiple of ERPG-3 or ½ LFL distance is less than 3 m (10 ft) or O_2 concentration within a confined work area is greater than 19.5 volume %.
>
> ***STOP the Event Sequence from reaching Process Conditions*** *that could lead to a Release*. This may involve limiting the maximum pressure within the Equipment Item to below the MAWP or the Relief Set Pressure. For example, limit the flow rate of heat transfer fluid such that the maximum temperature is below that where the vapor pressure exceeds the MAWP or Relief Set Pressure resulting in no release.
>
> ***DELAY the Event Sequence from reaching potential Release conditions for a Sufficiently Long Period of Time*** – which is commonly accepted as 24 hours. For example, limit the feed rate to a vessel such that the volume from alarm activation to overfill takes longer than 24 hours.

Allowable Release Rate of Hazardous Material - this section of the MALR worksheet estimates the MALR for a hazardous release such that a multiple of ERPG-3 or ½ LFL distance is less than 3 m (10 ft). The leak location ("Indoors" or "Outdoors") must be entered or the "default" of "Outdoors" is used. If the location is indoors, the Release Rate corresponding to O_2 concentration greater than 19.5 volume % is also reported.

Allowable Addition Rate for Preventing Loss Event - this section of the MALR worksheet estimates the MALR is based on an overall heat balance. The first estimate is the Maximum Allowable Heating Media Flow to limit the maximum temperature from increasing above the entered Temperature Alarm Set Point. The second estimate is the Maximum Allowable Reagent Flow Rate that limits the reaction temperature from increasing above the entered Temperature Alarm Set Point based on an entered Fraction of Limiting Reagent within the total equipment contents.

Addition Rate to Delay Loss Event for 24 Hours - this section of the MALR worksheet estimates the MALR based on an overall material and energy balance. The first estimate is the Maximum Allowable Heating Media Flow to limit the maximum temperature to less than the boiling point at the lower of MAWP or Relief Device Set Pressure over 24 hours. The second estimate is the Maximum Allowable Reagent Flow Rate that limits the reaction temperature to less than the boiling point at the lower of MAWP or Relief Device Set Pressure based on a Fraction of Limiting Reagent within the total equipment contents over 24 hours. The third estimate is the Feed Rate or Pad Gas Flow Rate that limits Maximum Pressure to the lower of MAWP or Relief Device Set Pressure from the High-Pressure Alarm Set Point over 24 hours. (Note that Maximum Pressure from Liquid Feed Rate is based on "compression" of the vapor head space in this estimate.)

Note that the estimates from the MART-MALR worksheet are not saved. Results may be entered in the SIS Instrumentation details of the LOPA workbook.



Maximum Allowable Leak Rate (MALR)

This Worksheet for Calculation Only - Results are Not Saved. Print this page if a copy is needed.

Equipment Identification: V-101

Equipment Type: Vessel/Tank

Maximum Allowable Leak Rate is the maximum flow that can leak by a valve used as the final element in a LOPA scenario without exceeding a threshold consequence criteria.

There are generally three cases to consider:

a) **LIMIT** the release rate of hazardous material such that the consequence has been essentially eliminated (this is typically based on distance to mutliple of ERPG-3 or 1/2 LFL is less than 3 m).

b) **STOP** the scenario propagation by limiting the continued addition of material or energy to less than natural ability of the system to remove (such as the flow rate of heat transfer fluid that prevents further heating of the system).

c) **DELAY** the potential for catastrophic failure for a sufficiently long period of time (such as the flow rate which delays hydraulic overpressure for at least 24 hours) by limiting the continued addition of material or energy.

LIMIT - Allowable Release Rate of Hazardous Material:

Leak Location:		*Assumed Outdoors if blank*
Indoor Process Volume:	0	m^3
ERPG-3 at Initial Vapor Composition:	75.0	ppm
Lower Flammable Limit at Initial Vapor Composition:	3.0	vol %
Approximate Flash + Pool Evaporation Fractions:	1.000	
Maximum Allowable Leak Rate for multiple of ERPG-3 < 3 m:	**0.13**	**Kg/min**
Maximum Allowable Leak Rate for 0.5 LFL < 3 m:	**2.59**	**Kg/min**

STOP - Allowable Addition Rate for Preventing Incident

	Temperature Alarm Set Point	
Equipment Surface Area:	*100.64*	m^2
Heat Loss Coefficient (with Insulation):	0.0005	Kwatt/m^2 C
Alarm Temperature:	0	C
Heat Loss Rate at Temperature Alarm:	-1.26	Kwatt
Heat Transfer:		
Heat Transfer Fluid:		
Heat Transfer Fluid Temperature:	0	C
Heat Capacity:		Kjoule/Kg C
Maximum Allowable Heating Media Leak Rate:		**Kg/min**
Reaction:		
Fraction Limiting Reagent within Reaction Mixture:		
Heat of Reaction:	-1365.0	Kjoule/Kg Reaction Mixture
Reaction Temperature of No Return:	138.8	C
Heat Loss Rate at Temperature Alarm:		Kwatt
Maximum Allowable Reagent Addition Rate:		**Kg/min**

Alarm Temperature is less than Ambient Temperature

DELAY - Addition Rate to Delay Incident for 24 Hours

	Boiling Point at MAWP or Relief Set	
Contained Mass:	63752.0	Kg
Process Heat Capacity:	2.19	Kjoule/Kg C - Liquid
Total 24 hour Heat Input	10978159	Kjoule
Maximum Allowable Heating Media Leak Rate:		**Kg/min**
Total 24 hour Reaction Heat Input	19286614.8	Kjoule
Maximum Allowable Reagent Addition Rate:	**0.00**	**Kg/min**

	Pressure < MAWP or Relief Set	*Level < Overfill*	
Equipment Volume:	100		m^3
Initial Liquid Fill Fraction:	0.8		
Maximum Allowable Pad Gas Leak Rate:			**Kg/min**
Maximum Allowable Liquid Fill Rate:	**0.72**	**55.34**	**Kg/min**

Enter leak location

MALR based on flammable or toxic personnel exposure

MALR to stop the event sequence based on heat rate of reaction

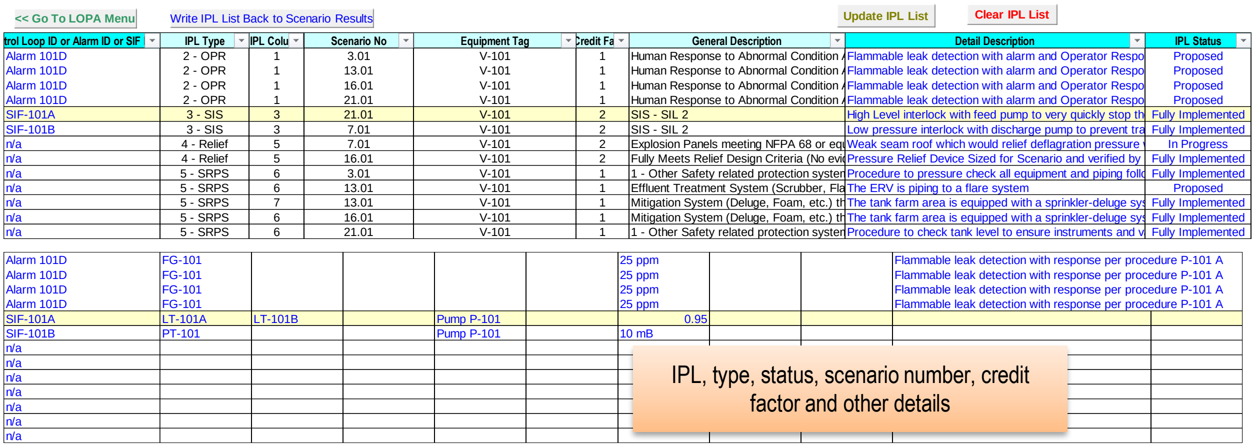
Displays 24-hour MALR based on heat rate

Displays 24-hour MALR based on liquid or vapor feed rate

Figure 7.20: Maximum Allowable Leak Time

Protection Layer Summary

A listing of each unique Protective Layer associated with a specific Equipment Item is displayed on the IPL Summary worksheet. This worksheet is accessed from the LOPA Menu. The Refresh macro (top center of the worksheet) should be used to update the information shown. Refer to Figure 7.21.



trol Loop ID or Alarm ID or SIF	IPL Type	IPL Colu	Scenario No	Equipment Tag	Credit Fa	General Description	Detail Description	IPL Status
Alarm 101D	2 - OPR	1	3.01	V-101	1	Human Response to Abnormal Condition /	Flammable leak detection with alarm and Operator Respo	Proposed
Alarm 101D	2 - OPR	1	13.01	V-101	1	Human Response to Abnormal Condition /	Flammable leak detection with alarm and Operator Respo	Proposed
Alarm 101D	2 - OPR	1	16.01	V-101	1	Human Response to Abnormal Condition /	Flammable leak detection with alarm and Operator Respo	Proposed
Alarm 101D	2 - OPR	1	21.01	V-101	1	Human Response to Abnormal Condition /	Flammable leak detection with alarm and Operator Respo	Proposed
SIF-101A	3 - SIS	3	21.01	V-101	2	SIS - SIL 2	High Level interlock with feed pump to very quickly stop th	Fully Implemented
SIF-101B	3 - SIS	3	7.01	V-101	2	SIS - SIL 2	Low pressure interlock with discharge pump to prevent tra	Fully Implemented
n/a	4 - Relief	5	7.01	V-101	2	Explosion Panels meeting NFPA 68 or equ	Weak seam roof which would relief deflagration pressure	In Progress
n/a	4 - Relief	5	16.01	V-101	2	Fully Meets Relief Design Criteria (No evid	Pressure Relief Device Sized for Scenario and verified by	Fully Implemented
n/a	5 - SRPS	6	3.01	V-101	1	1 - Other Safety related protection systen	Procedure to pressure check all equipment and piping follc	Fully Implemented
n/a	5 - SRPS	6	13.01	V-101	1	Effluent Treatment System (Scrubber, Fla	The ERV is piping to a flare system	Proposed
n/a	5 - SRPS	7	13.01	V-101	1	Mitigation System (Deluge, Foam, etc.) th	The tank farm area is equipped with a sprinkler-deluge sys	Fully Implemented
n/a	5 - SRPS	6	16.01	V-101	1	Mitigation System (Deluge, Foam, etc.) th	The tank farm area is equipped with a sprinkler-deluge sys	Fully Implemented
n/a	5 - SRPS	6	21.01	V-101	1	1 - Other Safety related protection systen	Procedure to check tank level to ensure instruments and v	Fully Implemented

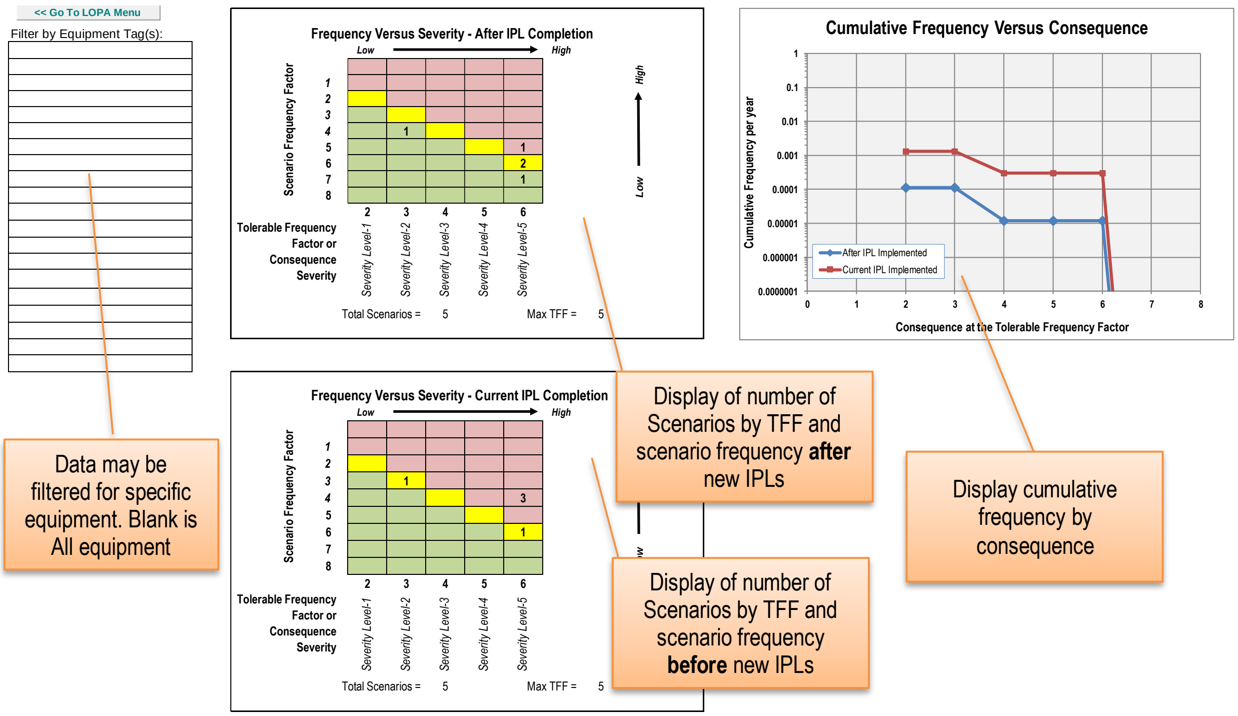
Alarm 101D	FG-101					25 ppm			Flammable leak detection with response per procedure P-101 A	
Alarm 101D	FG-101					25 ppm			Flammable leak detection with response per procedure P-101 A	
Alarm 101D	FG-101					25 ppm			Flammable leak detection with response per procedure P-101 A	
Alarm 101D	FG-101					25 ppm			Flammable leak detection with response per procedure P-101 A	
SIF-101A	LT-101A	LT-101B		Pump P-101		0.95				
SIF-101B	PT-101			Pump P-101		10 mB				
n/a										
n/a										
n/a										
n/a										
n/a										
n/a										
n/a										

IPL, type, status, scenario number, credit factor and other details

Figure 7.21: Independent Protection Layer Summary

Risk Summary

The status for Protective Layers may be entered for each Scenario in the LOPA Workbook. A table of LOPA Consequence (as Tolerable Frequency Factor) versus LOPA Frequency is developed for all "Analyzed" Scenarios with and without fully implemented Protective Layers. This Risk Graph Summary is provided to assist in prioritization of Risk Reduction capital spending. The Risk Summary may be viewed for ALL Equipment Items within the Equipment Table or "filtered" to only the specific Equipment Items selected on the left side of this worksheet. The *Risk Summary* is accessed through the LOPA Menu. Refer to Figure 7.22.



Data may be filtered for specific equipment. Blank is All equipment

Display of number of Scenarios by TFF and scenario frequency **after** new IPLs

Display of number of Scenarios by TFF and scenario frequency **before** new IPLs

Display cumulative frequency by consequence

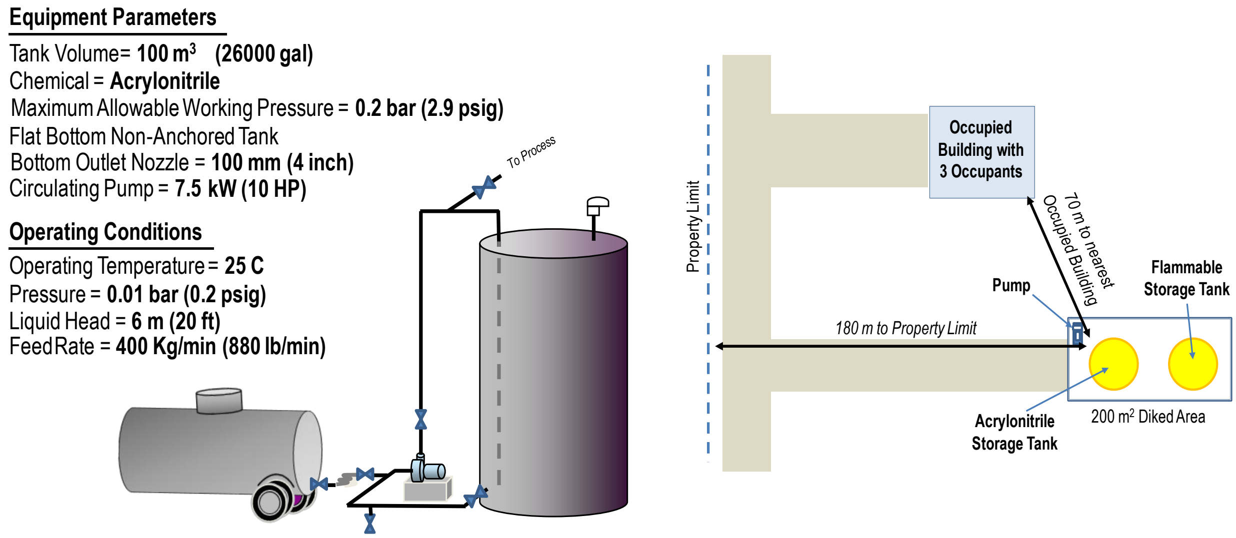
Figure 7.22: Risk Summary Worksheet

8. CASE STUDY

To gain familiarity with the RAST spreadsheet tool, we will continue with the Example Problem described in the Getting Started section.

A Case Study – Input Information

Under Getting Started, the following example was shared:



Equipment Parameters

Tank Volume= **100 m^3 (26000 gal)**
Chemical = **Acrylonitrile**
Maximum Allowable Working Pressure = **0.2 bar (2.9 psig)**
Flat Bottom Non-Anchored Tank
Bottom Outlet Nozzle = **100 mm (4 inch)**
Circulating Pump = **7.5 kW (10 HP)**

Operating Conditions

Operating Temperature = **25 C**
Pressure = **0.01 bar (0.2 psig)**
Liquid Head = **6 m (20 ft)**
Feed Rate = **400 Kg/min (880 lb/min)**

In addition to the Storage Tank, perform analysis for the Tank Truck and Pump with 200 m transfer piping.

Additional input information includes:

Storage Tank, V-101

- **Flat Bottom Non-Anchored Tank within a 200 m^2 diked or bunded area and 70000 Kg of other flammables in the area.**
- **Relief Device PVRV-101 is a 250 mm (10 inch) diameter PVRV set at 0.07 barg (1 psig). The Relief Discharge Elevation is 6 m (20 ft) with Horizontal discharge.**
- **V-101 is maintained with a non-ignitable atmosphere. The maximum pad gas source pressure is regulated to 1 barg (14.5 psig) with a maximum flow of 100 standard m^3/hour (3500 ft^3/hr.)**
- **V-101 is "vapor balanced" with the Tank Truck during unloading.**
- **The maximum liquid level is 6 meters and the tank is not rated for full vacuum.**

Acrylonitrile Tank Truck

- **The truck volume is 21 m^3 (5500 gal) with a maximum allowable working pressure of 1 barg (14.5 psig) and not rated for full vacuum.**
- **The maximum liquid level is 2 meters.**
- **A 75 mm (3 inch) diameter hose is used for unloading at a flow rate of 400 Kg/min (880 lb./min).**
- **An operator is present during the unloading operation.**

Pump, P-101 with Associated Piping

- **The Pump is a 75 mm (3 inch) suction Centrifugal with a Double Mechanical Seal located within the 200 m^2 diked area.**
- **The maximum pump discharge pressure is 3 barg (43.5 psig) and maximum allowable working pressure is 10 barg (145 psig).**
- **The associated process piping is roughly 200 m length with 20 flanges.**

Acrylonitrile Reaction Data

- **Heat of Reaction: - 326 cal/g**
- **Activation Energy: 32 Kcal/g mole**
- **Detected Onset Temperature: 190 C**
- **Detected Onset Rate: 0.08 C/min**
- **Test Method: ARC with Phi Factor of 2.1**

A Case Study – Screening Evaluations

For each Equipment Item:

- ☐ **Complete the necessary Inputs**
- ☐ **Determine the F&EI and CEI**
- ☐ **Review the Hazards and Potential Loss Event Consequences and note which hazards will likely need to be analyzed**
- ☐ **Review the Scenario List (on the Scenario Identification worksheet) and note any scenarios or Tolerable Frequency Factors that may not seem reasonable**
- ☐ **Review the Relief Effluent Screening for PVRV-101**

A Case Study – Preliminary Risk Analysis

For each Equipment Item:

- ☐ Review the List of Scenarios and add additional scenarios you feel should be considered.
- ☐ Update Scenarios and Select those appropriate for LOPA Analysis.
- ☐ Complete LOPA Analysis for at least 2 Scenarios for each Equipment Item.
- ☐ Estimate the Maximum Allowable Response Time and Maximum Allowable Leak Rate for at least one Scenario

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10. GLOSSARY

Acute Hazard: The potential for injury or damage to occur as a result of an instantaneous or short duration exposure to the effects of an incident.

Administrative Controls: Procedural mechanism for controlling, monitoring, or auditing human performance, such as lock out/tagout procedures, bypass approval processes, car seals, and permit systems.

Asset Integrity Management: A process safety management system for ensuring the integrity of assets throughout their life cycle.

Atmospheric Dispersion: The low momentum mixing of a gas or vapor with air. The mixing is the result of turbulent energy exchange, which is a function of wind (mechanical eddy formation) and atmospheric temperature profile (thermal eddy formation).

Audit: A systematic, independent review to verify conformance with prescribed standards of care using a well-defined review process to ensure consistency and to allow the auditor to reach defensible conclusions.

Barrier: Anything used to control, prevent, or impede energy flows. Includes engineering (physical, equipment design) and administrative (procedures and work processes). See also Layer of Protection.

Basic Process Control System: A system that responds to input signals from the process and its associated equipment, other programmable systems, and/or from an operator, and generates output signals causing the process and its associated equipment to operate in the desired manner and within normal production limits.

Blast Wave: The overpressure wave traveling outward from an explosion point.

Boiling Liquid Expanding Vapor Explosion (BLEVE): A type of rapid phase transition in which a liquid contained above its atmospheric boiling point is rapidly depressurized, causing a nearly instantaneous transition from liquid to vapor with a corresponding energy release. A BLEVE of flammable material is often accompanied by a large aerosol fireball, since an external fire impinging on the vapor space of a pressure vessel is a common cause. However, it is not necessary for the liquid to be flammable to have a BLEVE occur.

Bow-Tie Diagram: A diagram for visualizing the types of preventive and mitigative barriers which can be used to manage risk. These barriers are drawn with the threats on the left, the unwanted event at the center, and the consequences on the right, representing the flow of the hazardous materials or energies through its barriers to its destination. The hazards or threats can be proactively addressed on the left with specific barriers (safeguards, layers of protection) to help prevent a hazardous event from occurring; barriers reacting to the event to help reduce the event's consequences are shown on the right.

Catastrophic Release: An uncontrolled loss of containment of toxic, reactive, or flammable materials from a process that has the potential for causing onsite or offsite acute health effects, significant environmental effects (e.g., compromise of a public drinking water supply), or significant on-site or off-site property damage.

Center for Chemical Process Safety (CCPS): is a not-for-profit, corporate membership organization within the American Institute for Chemical Engineers (AIChE) that identifies and addresses process safety needs for a variety of facilities involved with handling, storing, using or processing, and transporting hazardous materials

Checklist Analysis: A hazard evaluation procedure using one or more pre-prepared lists of process safety considerations to prompt team discussions of whether the existing safeguards are adequate.

Chemical Process Quantitative Risk Assessment (CPQRA or QRA): The quantitative evaluation of expected risk from potential incident scenarios. It examines both consequences and frequencies, and how they combine into an overall measure of risk. The CPQRA process is always preceded by a qualitative systematic identification of process hazards. The CPQRA results may be used to make decisions, particularly when mitigation of risk is considered.

Combustible Dust: A finely divided combustible particulate solid that presents a flash fire hazard or explosion hazard when suspended in air or the process specific oxidizing medium over a range of concentrations.

Common Cause Failure: The failure of more than one component, item, or system due to the same cause.

Condensed Phase Explosion: An explosion that occurs when the material is present in the form of a liquid or solid.

Conditional Modifier: One of several possible probabilities included in scenario risk calculations, generally when risk criteria endpoints are expressed in impact terms (e.g., fatalities) instead of in primary loss event terms (e.g., release, vessel rupture). Conditional modifiers include, but are not limited to: probability of a hazardous atmosphere, probability of ignition, probability of explosion, probability of personnel presence, probability of injury or fatality, and probability of equipment damage or other financial impact.

Confined Explosion (or Building Explosion): An explosion of fuel-oxidant mixture inside a closed system (e.g. vessel or building).

Confinement: Obstacles such as walls and ceilings of a building, vessel, pipe, etc. that serve to limit the expansion of a dispersing or exploding vapor cloud.

Congestion: Obstacles in the path of the flame that generate turbulence.

Consequence: The undesirable result of a loss event, usually measured in health and safety effects, environmental impacts, loss of property, and business interruption costs.

Consequence Analysis: The analysis of the expected effects of incident outcome cases, independent of frequency or probability.

Consequence Screening: The evaluation of consequence severity to determine the extent and detail to which risk analysis is warranted.

De Minimis Risk: A level of risk that would be perceived by most to be broadly acceptable, and not requiring further reduction.

Deflagration: A combustion that propagates by heat and mass transfer through the un-reacted medium at a velocity less than the speed of sound.

Demand: A plant condition or event which requires a protective system or device to take appropriate action in order to prevent a hazard. (1) A signal or action that should change the state of a device, or (2) an opportunity to act, and thus, to fail.

Detection System: A mechanical, electrical, or chemical device that automatically identifies the presence of a material or a change in environmental conditions such as pressure, temperature, or composition.

Detonation: A release of energy caused by the propagation of a chemical reaction in which the reaction front advances into the unreacted substance at greater than sonic velocity in the unreacted material.

Deviation: A process condition outside of established design limits, safe operating limits, or standard operating procedures.

Dike (or berm): An embankment or wall built to act as a barrier blocking passage of liquids to surrounding areas.

Domino Effect: The triggering of secondary events, such as toxic releases, by a primary event, such as an explosion, such that the result is an increase in consequences or area of an effect zone. Generally considered only when a significant escalation of the original incident results.

Dose: Time-integrated concentration

Effect Zone: For an incident that produces an incident outcome of toxic release, the area over which the airborne concentration equals or exceeds some level of concern. For a flammable release, the area over which a particular incident outcome case produces an effect based on a specified criterion.

Equipment: A piece of hardware which can be defined in terms of mechanical, electrical or instrumentation components contained within its boundaries.

Enabling Condition: A condition that is not a failure, error or a protection layer but makes it possible for an incident sequence to proceed to a consequence of concern. It consists of a condition or operating phase that does not directly cause the scenario, but that must be present or active in order for the scenario to proceed to a loss event; expressed as a dimensionless probability.

Event: An occurrence involving a process that is caused by equipment performance or human action or by an occurrence external to the process.

Event Sequence: A specific unplanned sequence of events composed of initiating events and intermediate events that may lead to an incident

Explosion: A release of energy that causes a pressure discontinuity or blast wave.

F-N Curve: A plot of cumulative frequency versus consequences (often expressed as number of fatalities).

Facility: The physical location where a management system activity is performed. In early life-cycle stages, a facility may be the company's central research laboratory, pilot plant, or the engineering offices of a technology vendor. In later stages, the facility may be a typical chemical plant, storage terminal, distribution center, or corporate office. In the context of this document, a facility is a portion of or a complete plant, unit, site, complex or offshore platform or any combination thereof.

Failure: an unacceptable difference between expected and observed performance.

Fault Tree Analysis (FTA): A method used to analyze graphically the failure logic of a given event, to identify various failure scenarios (called cut-sets), and to support the probabilistic estimation of the frequency of the event.

Final Element: Process control or safety device that implements the physical action necessary to achieve or maintain a safe state; e.g., valves, switch gear, and motors, including their auxiliary elements (such as the solenoid valve used to operate a valve).

Fireball: The atmospheric burning of a fuel-air cloud in which the energy is mostly emitted in the form of radiant heat. The inner core of the fuel release consists of almost pure fuel whereas the outer layer in which ignition first occurs is a flammable fuel-air mixture. As buoyancy forces of the hot gases begin to dominate, the burning cloud rises and becomes more spherical in shape.

Flammable: A gas that can burn with a flame if mixed with a gaseous oxidizer such as air or chlorine and then ignited. The term flammable gas includes vapors from flammable or combustible liquids above their flash points.

Flash Fire: A fire that spreads by means of a flame front rapidly through a diffuse fuel, such as a dust, gas, or the vapors of an ignitable liquid, without the production of damaging pressure.

Frequency: Number of occurrences of an event per unit time (e.g., 1 event in 1000 yr. = 1 x 10-3 events/yr.).

Globally Harmonized System (**GHS):** system for Classification and Labeling of Chemicals adopted by the United Nations (https://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html) Its official title: "Globally Harmonized System of Classification and Labelling of Chemicals (GHS)"

Hazard: An inherent chemical or physical characteristic that has the potential for causing damage to people, property, or the environment.

Hazard and Operability Study (HAZOP): A systematic qualitative technique to identify process hazards and potential operating problems using a series of guide words to study process deviations. A HAZOP is used to question every part of a process to discover what deviations from the intention of the design can occur and what their causes and consequences may be. This is done systematically by applying suitable guidewords. This is a systematic detailed review technique, for both batch and continuous plants, which can be applied to new or existing processes to identify hazards.

Hazard Distance: the distance from a release location to a concentration or blast overpressure of concern. For example, the distance to a fraction of the lower flammable limit may represent the distance below which severe human harm from a flash fire might occur.

Hazard Evaluation: Identification of individual hazards of a system, determination of the mechanisms by which they could give rise to undesired events, and evaluation of the consequences of these events on health (including public health), environment and property. Uses qualitative techniques to pinpoint weaknesses in the design and operation of facilities that could lead to incidents.

Hazard Identification: The inventorying of material, system, process and plant characteristics that can produce undesirable consequences through the occurrence of an incident.

Hazard Identification and Risk Analysis Study (HIRA): A collective term that encompasses all activities involved in identifying hazards and evaluating risk at facilities, throughout their life cycle, to make certain that risks to employees, the public, or the environment are consistently controlled within the organization's risk tolerance.

Hazard Screening: The evaluation of hazard severity to determine the extent to which hazard assessment and subsequent risk analysis is warranted.

Hazardous Chemical: A material that is toxic, reactive, or flammable and is capable of causing a process safety incident if released. Also, Hazardous material.

Human Error: Intended or unintended human action or inaction that produces an inappropriate result. Includes actions by designers, operators, engineers, or managers that may contribute to or result in accidents.

Human Reliability Analysis: A method used to evaluate whether system-required human-actions, tasks, or jobs will be completed successfully within a required time period. Also used to determine the probability that no extraneous human actions detrimental to the system will be performed.

Hybrid Mixture: A mixture of a flammable gas with either a combustible dust or combustible mist.

Impact: A measure of the ultimate loss and harm of a loss event. Impact may be expressed in terms of numbers of injuries and/or fatalities, extent of environmental damage and/or magnitude of losses such as property damage, material loss, lost production, market share loss, and recovery costs.

Incident: An event, or series of events, resulting in one or more undesirable consequences, such as harm to people, damage to the environment, or asset/business losses. Such events include fires, explosions, releases of toxic or otherwise harmful substances.

Incident Investigation: A systematic approach for determining the causes of an incident and developing recommendations that address the causes to help prevent or mitigate future incidents. See also Root cause analysis and Apparent cause analysis.

Incident Outcome: The physical manifestation of the incident: for toxic materials, the incident outcome is a toxic release, while for flammable materials; the incident outcome could be a boiling liquid expanding vapor explosion (BLEVE), flash fire, vapor cloud explosion (VCE), etc.

Independent Protection Layer (IPL): A device, system, or action that is capable of preventing a scenario from proceeding to the undesired consequence without being adversely affected by the initiating event or the action of any other protection layer associated with the scenario.

Individual Risk: The risk to a person in the vicinity of a hazard. This includes the nature of the injury to the individual, the likelihood of the injury occurring, and the time period over which the injury might occur.

Inherently Safer Design: A way of thinking about the design of chemical processes and plants that focuses on the elimination or reduction of hazards, rather than on their management and control.

Initiating Cause (or Initiating Event): The operational error, mechanical failure, or external event or agency that is the first event in an incident sequence and marks the transition from a normal situation to an abnormal situation.

Interlock: A protective response which is initiated by an out-of-limit process condition. Instrument which will not allow one part of a process to function unless another part is functioning. A device such as a switch that prevents a piece of equipment from operating when a hazard exists. To join two parts together in such a way that they remain rigidly attached to each other solely by physical interference. A device to prove the physical state of a required condition and to furnish that proof to the primary safety control circuit.

Jet Fire: A fire type resulting from the discharge of liquid, vapor, or gas into free space from an orifice, the momentum of which induces the surrounding atmosphere to mix with the discharged material.

Layer of Protection Analysis (LOPA): An approach that analyzes one incident scenario (cause-consequence pair) at a time, using predefined values for the initiating event frequency, independent protection layer failure probabilities, and consequence severity, in order to compare a scenario risk, estimate to risk criteria for determining where additional risk reduction or more detailed analysis is needed. Scenarios are identified elsewhere, typically using a scenario-based hazard evaluation procedure such as a HAZOP Study.

Level of Concern: The concentration of an airborne chemical above which there may be adverse human health effects experience as a result of a short-term exposure during an episodic release.

Likelihood: A measure of the expected probability or frequency of occurrence of an event. This may be expressed as an event frequency (e.g., events per year), a probability of occurrence during a time interval (e.g., annual probability) or a conditional probability (e.g., probability of occurrence, given that a precursor event has occurred).

Loss Event: Point in time in an abnormal situation when an irreversible physical event occurs that has the potential for loss and harm impacts. Examples include release of a hazardous material, ignition of flammable vapors or ignitable dust cloud, and over-pressurization rupture of a tank or vessel. An incident might involve more than one loss event, such as a flammable liquid spill (first loss event) followed by ignition of a flash fire and pool fire (second loss event) that heats up an adjacent vessel and its contents to the point of rupture (third loss event). Generally synonymous with hazardous event.

Loss of Primary Containment (LOPC): An unplanned or uncontrolled release of material from primary containment, including non-toxic and non-flammable materials (e.g., steam, hot condensate, nitrogen, compressed CO2 or compressed air).

Management of Change: A management system to identify, review, and approve all modifications to equipment, procedures, raw materials, and processing conditions, other than replacement in kind, prior to implementation to help ensure that changes to processes are properly analyzed (for example, for potential adverse impacts), documented, and communicated to employees affected.

Mechanical Integrity (or Equipment Integrity, Asset Integrity): A management system focused on ensuring that equipment is designed, installed, and maintained to perform the desired function.

Mean Time Between Failure (MTBF): For a stated period in the life of a functional unit, the mean value of the length of time between consecutive failures under stated conditions.

Mitigate: Reduce the impact of a loss event.

Mitigative Safeguard: A safeguard that is designed to reduce loss event impact.

National Fire Protection Agency (**NFPA**): A United States trade association, that creates and maintains standards and codes for usage and adoption by local governments.

Near-Miss: An unplanned sequence of events that could have caused harm or loss if conditions were different or were allowed to progress, but actually did not.

Normal Operations: Any process operations intended to be performed between startup and shutdown to support continued operation within safe upper and lower operating limits.

Occupant Vulnerability: Proportion of building occupants that could potentially suffer an injury or fatality if a postulated event were to occur. The level of injury is defined according to the technical basis of the occupant vulnerability model being used.

Off-Site Population: Persons located outside of the site property line that may be impacted by an on-site incident.

On-Site Personnel: Employees, contractors, visitors, service providers, and others present at the facility.

Operating Procedures: Written, step by step instructions and information necessary to operate equipment, compiled in one document including operating instructions, process descriptions, operating limits, chemical hazards, and safety equipment requirements.

Operator: An individual responsible for monitoring, controlling, and performing tasks as necessary to accomplish the productive activities of a system. Operator is also used in a generic sense to include people who perform a wide range of tasks (e.g., readings, calibration, incidental maintenance, manage loading/unloading, and storage of hazardous materials).

Parameter: A quantity describing the relation of variables within a given system. Note: A parameter may be constant or depend on the time or the magnitude of some system variables.

Passive System: A system in which failures are only revealed by testing or when a demand has occurred.

Personal Protective Equipment (PPE): Equipment designed to protect employees from serious workplace injuries or illnesses resulting from contact with chemical, radiological, physical, electrical, mechanical, or other workplace hazards. Besides face shields, safety glasses, hard hats, and safety shoes, PPE includes a variety of devices and garments, such as goggles, coveralls, gloves, vests, earplugs, and respirators.

Physical Explosion: The catastrophic rupture of a pressurized gas/vapor-filled vessel by means other than reaction, or the sudden phase-change from liquid to vapor of a superheated liquid.

Piping and Instrument Diagram (P&ID): A diagram that shows the details about the piping, vessels, and instrumentation.

Pool Fire: The combustion of material evaporating from a layer of liquid at the base of the fire.

Potential Explosion Site (PES): A volume within a plant with sufficient congestion and/or confinement that a flammable vapor cloud ignited there could likely develop into an explosion.

Pre-Initiating Safeguard: A safeguard that acts to prevent an initiating event or cause from occurring.

Preventive Safeguard: A safeguard that forestalls the occurrence of a particular loss event, given that an initiating cause has occurred; i.e., a safeguard that intervenes between an initiating cause and a loss event in an incident sequence.

Prevention: The process of eliminating or preventing the hazards or risks associated with a particular activity. Prevention is sometimes used to describe actions taken in advance to reduce the likelihood of an undesired event.

Probability: The expression for the likelihood of occurrence of an event or an event sequence during an interval of time, or the likelihood of success or failure of an event on test or on demand. Probability is expressed as a dimensionless number ranging from 0 to 1.

Probit: A random variable with a mean of 5 and a variance of 1, which is used in various effect models. Probit-based models derived from experimental dose-response data, are often used to estimate the health effect that might result based upon the intensity and duration of an exposure to a harmful substance or condition (e.g., exposure to a toxic atmosphere, or a thermal radiation exposure).

Process Hazard Analysis (PHA): An organized effort to identify and evaluate hazards associated with processes and operations to enable their control. This review normally involves the use of qualitative techniques to identify and assess the significance of hazards. Conclusions and appropriate recommendations are developed. Occasionally, quantitative methods are used to help prioritized risk reduction.

Process Safety Management Systems: Comprehensive sets of policies, procedures, and practices designed to ensure that barriers to episodic incidents are in place, in use, and effective.

Process Safety: A disciplined framework for managing the integrity of operating systems and processes handling hazardous substances by applying good design principles, engineering, and operating practices. It deals with the prevention and control of incidents that have the potential to release hazardous materials or energy. Such incidents can cause toxic effects, fire, or explosion and could ultimately result in serious injuries, property damage, lost production, and environmental impact.

Process Safety Review: An inspection of a plant/process unit, drawings, procedures, emergency plans and/or management systems, etc., usually by an on-site team and usually problem-solving in nature. (See "Audit" for contrast).

Qualitative: Based primarily on description and comparison using historical experience and engineering judgment, with little quantification of the hazards, consequences, likelihood, or level of risk.

Quantitative Risk Analysis: The systematic development of numerical estimates of the expected frequency and severity of potential incidents associated with a facility or operation based on engineering evaluation and mathematical techniques.

Reliability: Core attribute of a protection layer related to the probability that the equipment operates according to its specification for a stated period of time under all relevant conditions.

Risk: A measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury.

Risk Analysis: The estimation of scenario, process, facility and/or organizational risk by identifying potential incident scenarios, then evaluating and combining the expected frequency and impact of each scenario having a consequence of concern, then summing the scenario risks, if necessary, to obtain the total risk estimate for the level at which the risk analysis is being performed.

RiskBased Process Safety (RBPS): The Center for Chemical Process Safety's process safety management system approach that uses risk-based strategies and implementation tactics that are commensurate with the risk-based need for process safety activities, availability of resources, and existing process safety culture to design, correct, and improve process safety management activities.

Risk Matrix: A tabular approach for presenting risk tolerance criteria, typically involving graduated scales of incident likelihood on the Y-axis and incident consequences on the X-Axis.

Risk Management: The systematic application of management policies, procedures, and practices to the tasks of analyzing, assessing, and controlling risk in order to protect employees, the general public, the environment, and company assets, while avoiding business interruptions. Includes decisions to use suitable engineering and administrative controls for reducing risk.

Risk Tolerance Criteria: A predetermined measure of risk used to aid decisions about whether further efforts to reduce the risk are warranted.

Safeguard: Any device, system, or action that either interrupts the chain of events following an initiating event or that mitigates the consequences. A safeguard can be an engineered system or an administrative control. Not all safeguards meet the requirements of an IPL.

Safety Instrumented System (SIS): A separate and independent combination of sensors, logic solvers, final elements, and support systems that are designed and managed to achieve a specified safety integrity level. A SIS may implement one or more Safety Instrumented Functions (SIFs).

Scenario: A detailed description of an unplanned event or incident sequence that results in a loss event and its associated impacts, including the success or failure of safeguards involved in the incident sequence.

Screening Criteria: A predetermined measure, standard, or rule (typically based upon company or regulatory requirements), on which a judgment or decision can be based.

Severity: The maximum credible consequences or effects, assuming no safeguards are in place.

Screening Tool: A simplified model with limited capabilities, suitable for screening-level studies.

Spray Distance: The maximum distance a fluid travels before the velocity slows and/or the fluid falls to the ground.

Societal Risk: A measure of risk to a group of people. It is most often expressed in terms of the frequency distribution of multiple casualty events.

Source Term: The release parameters (e.g. magnitude, rate, duration, orientation, temperature) that are the initial conditions for determining the consequences of the loss event for a hazardous material and/or energy release to the surroundings. For vapor dispersion modeling, it is the estimation, based on the release specification, of the actual cloud conditions of temperature, aerosol content, density, size, velocity and mass to be input into the dispersion model.

Tolerable Frequency: The maximum frequency for a specific consequence that is regarded as tolerable/

Tolerable Frequency Factor (TFF): - $\log_{10}$ of the tolerable frequency

Tolerable Risk Level: The maximum level of risk of a particular technical process or condition that is regarded as tolerable in the context of the circumstances in questions.

Vapor Cloud Explosion (VCE): The explosion resulting from the ignition of a cloud of flammable vapor, gas, or mist in which flame speeds accelerate to sufficiently high velocities to produce significant overpressure.

Virtual Source: The offset in distance to the specified source of a gas or vapor release that results in a maximum concentration of 100% at the source using a Gaussian dispersion model.

What-If Analysis: A scenario-based hazard evaluation procedure using a brainstorming approach in which typically a team that includes one or more persons familiar with the subject process asks questions or voices concerns about what could go wrong, what consequences could ensue, and whether the existing safeguards are adequate.

Worst Case: A conservative (high) estimate of the consequences of the most severe incident identified.

11. Revision History

Revision	Date	Description
1.0	08-Apr-2018	Initial issue. Originally donated documentation with minor modifications.
1.1	13-Sep-2018	Minor corrections reflecting update of RAST Software. Addressed minor formatting issues.
1.2	11-Feb-2018	Updated Introduction. Updated terms to align with CCPS Process Safety Glossary. Addition of Glossary to Manual.
2.0	25-Mar-2019	Major revisions to RAST Software reflected in the CHEF Manual, the CHEF Workbook, this RAST User’s Manual. Includes some technical clarification, updates and improved descriptions reflecting feedback on earlier editions.
2.1	22-Apr-2019	Addressed minor formatting issues.