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A Risk Based Approach to Calculating Fire Water Demand

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  - Emergency Relief System Design
  - Flare System Design
  - Consequence Analysis
  - Quantitative Risk Assessment (QRA)
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Agenda

- Background
- Technical References
- Quantitative Risk Assessment
  - Hazard Identification
  - Frequency Analysis
  - Consequence Assessment
  - Risk Assessment
- Fire Water Required Demand
  - Application Rates
  - Design Case
- Process Safety Office® SuperChems™ Walkthrough
- Questions?

Background

- Calculate the maximum required fire water demand rate for a liquefied petroleum gas (LPG) storage facility
- Use a risk-based approach to determining need for fixed fire water protection
- Use the risk assessment to determine the worst/most credible scenario for calculating the required maximum capacity of the fire water system

Technical References

- API Recommended Practice 581, *Risk-Based Inspection Methodology* 3rd Edition, April 2016
  - Provides quantitative procedures to establish an inspection program using risk-based methods for pressurized fixed equipment.
  - Determine a probability of failure combined with the consequence of failure to calculate risk
- NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection* 2012 Edition
  - Provides the minimum requirements for the design, installation, and system acceptance testing of water spray fixed systems for fire protection service.
- NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection* 2003 Edition
  - Selection and installation of pumps supplying liquid for fire protection.

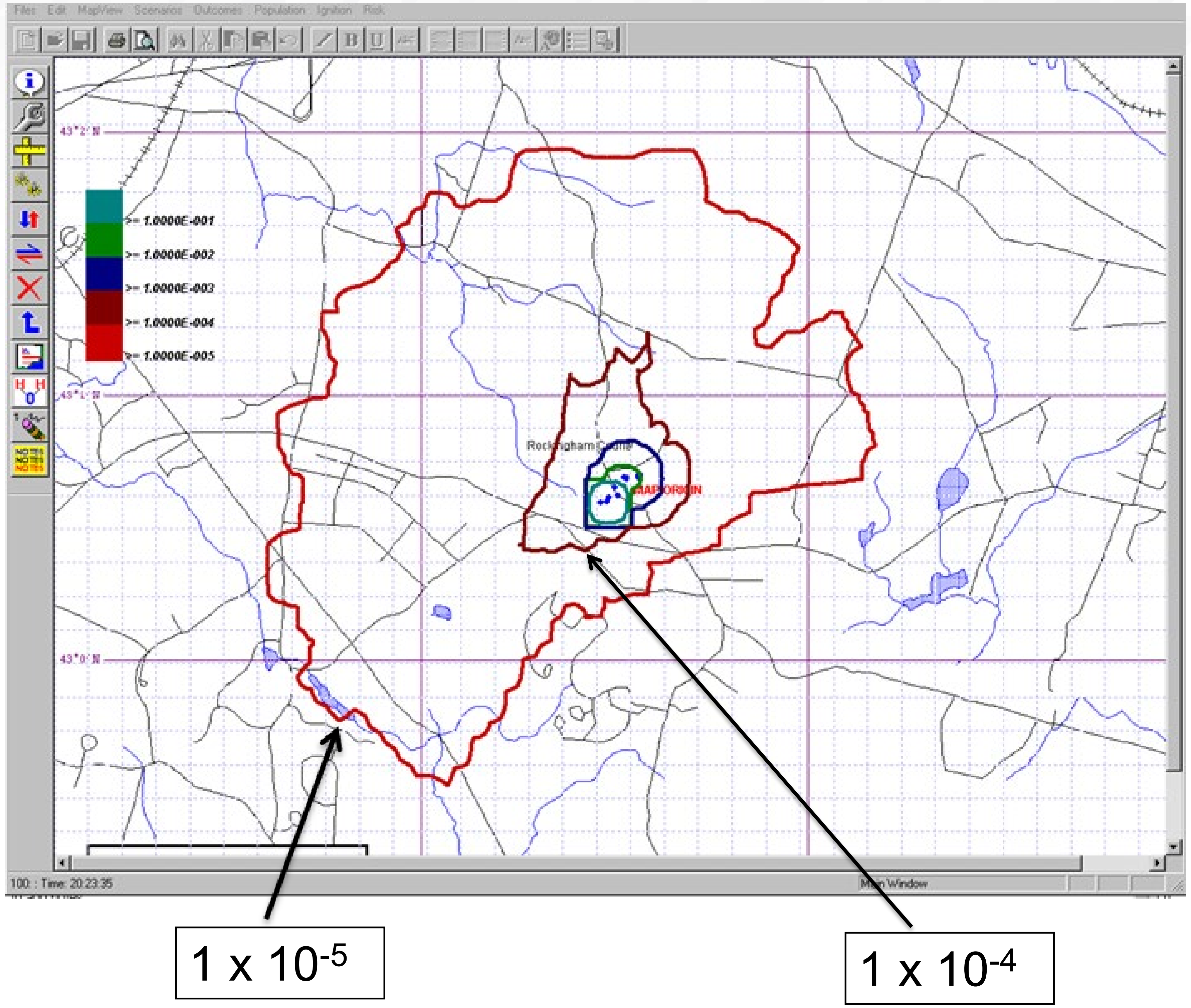
Technical References (cont.)

- API Standard 2510, *Design and Construction of LPG Installations* 8th Edition, October 2011
  - Covers the design, construction, and location of liquefied petroleum gas (LPG) installations
- API Publication 2510A, *Fire-Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities* 2nd Edition, December 1996.
  - Addresses the design, operation, and maintenance of LPG storage facilities from the standpoints of prevention and control of releases, fire protection design, and fire-control measures.
- Center for Chemical Process Safety (CCPS), *Guidelines for Fire Protection in Chemical, Petrochemical and Hydrocarbon Processing Facilities*
  - Fire protections strategy, Fire Prevention, Fire Hazard Analysis, Fire Risk Assessment, Protection Fundamentals, Design Guidance, etc.

Quantitative Risk Assessment (QRA)

Introduction – Basic Quantitative Risk Assessment (QRA) Concepts

- QRA Concepts:
  - Risk = Consequence x Frequency
- Type of Risk Considered:
  - Thermal Radiation Risk Contours



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Introduction – Basic QRA Concepts

- Benefits of Quantitative Risk Assessment
  - Well-established and accepted technique
  - Enables detailed understanding of risks
    - Enables segmentation of risks
    - Risk ranking of scenarios
  - Can be used for likelihood of death, dangerous dose, or financial risk
  - Allows for cost-benefit comparison of risk reduction options
  - Enables application of risk tolerability criteria

Main QRA Steps

- 1. Hazard Identification and Frequency Analysis
- 2. Consequence Assessment
- 3. Risk Assessment

Hazard Identification and Frequency Analysis

Hazard Identification

- Identify equipment or pipelines that contain flammable fluids
- Conducted systematically unit-by-unit
- Loss of Containment Scenarios (LOC)
  - Generic scenarios for process equipment and pipeline failure (1”, 4”, and full-bore size holes) given in API 581
  - A 1-meter hole diameter will be used for the catastrophic release scenario from storage tanks
  - Other likely, non-generic release events

Frequency Analysis: API RP 581 Methodology

- The probability of failure [$P_f(t)$] is estimated using the following equation:

$$P_f(t) = gff \cdot F_{MS} \cdot D_f(t)$$

Source: API RP 581. “Risk-based Inspection Methodology”, Third Edition, 2016.

  - Where gff is the generic frequency failure (representative values from the refining and petrochemical industry failure databases and available in API 581), F_{MS} is the management system factor, and $D_f(t)$ is defined as the damage factor
- Management System Factor (F_{MS}):
  - Determined by filling out questionnaire included in API RP 581. Accounts for facility management systems that directly impact the $P_f(t)$ of a component.
- Damage Factor [$D_f(t)$]:
  - the basic function is to statistically evaluate the amount of damage that may present as a function of time in service and the effectiveness of an inspection activity

Source: API RP 581. “Risk-based Inspection Methodology”, Third Edition, 2016.

Detection and Isolation Time

- API 581 also outlines criteria for the detection and isolation of a system in the event of a loss of containment and the expected release duration
- There are three classes of detection systems and three classes of isolation systems

Class	Type of Detection System
A	Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system.
B	Suitably located detectors to determine when the material is present outside the pressure-containing envelope.
C	Visual detection, cameras, or detectors with marginal coverage.
Class	**Type of Isolation System**
A	Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention.
B	Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak.
C	Isolation dependent on manually-operated valves.

Source: API-581

Source: API RP 581

Detection and Isolation Time (cont.)

- To determine the release duration, a detection class and isolation class must be assigned for each LOC

Leak Duration in Minutes				
Detection	Isolation	1-inch leak	4-inch leak	Catastrophic Rupture
A	A	10	5	5
A	B	20	10	10
A	C	30	20	20
B	A or B	30	20	20
B	C	30	20	20
C	A, B or C	40	20	20

Source: API-581

- Note that equipment inventory may limit durations below the above values. Catastrophic rupture of vessels will use an assumed duration of 60 seconds.

Source: API RP 581

Consequence Assessment

Consequence Assessment

- Quantify the effects and consequences of the LOC scenarios identified during the hazard identification step
- Includes characterization of the sources of release of material or energy and quantification of the health, environmental or economic impacts
  - This analysis will consider effects due to thermal radiation only

Consequence Assessment (cont.)

- Two sets of representative meteorological conditions were used: 5D (most credible case) and 2F (worst case). Based on the Pasquill-Gilford Atmospheric Stability Classes

Surface Wind Speed (m/s)	Daytime Insolation			Nighttime Conditions	
	Strong	Moderate	Slight	Thin Overcast of >4/8 Low Cloud	≤4/8 Cloudiness
<2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Stability Classes:

A. Extremely unstable
B. Moderately unstable
C. Slightly unstable
D. Neutral
E. Slightly stable
F. Moderately stable

Source: NOAA

Consequence Assessment (cont.)

- The following thermal radiation thresholds will be investigated:

Thermal Radiation [kW/m^2]	Description
1.58	Maximum radiant heat intensity at any location where personnel with appropriate clothing can be continuously exposed.
4.73	Maximum radiant heat intensity in areas where emergency actions lasting 2 min to 3 min can be required by personnel without shielding but with appropriate clothing.
6.31	Maximum radiant heat intensity in areas where emergency actions lasting up to 30 s can be required by personnel without shielding but with appropriate clothing. Radiation shielding and/or special protective apparel should be considered above this level.
8.0	Equipment may need water cooling. Cooling can be provided by mobile means.
9.46	Maximum radiant heat intensity at any location where urgent emergency action by personnel is required.
12.5	Thin steel with insulation on the side away from the fire may reach thermal stress level high enough to cause structural failure.
22.0	Limit outlined in API 2510A at which a fixed cooling water system is needed for cooling of an LPG storage vessel
25.0	Unprotected steel will reach thermal stress temperatures that can cause failure.
32.0	Active fire protection system should be provided to protect process equipment exposed above this level
37.5	Sufficient to cause damage to process equipment.

Source: Melhem “Advanced Consequence Analysis”, OGP Report No. 434-14, OGP Report No. 434-15, API 2510A, API 521

Risk Assessment

Risk Tolerability Criteria

- Specific criteria is required for identifying impacted process equipment
- API 2510A states that implementation of the recommendations with that standard should reduce the frequency of LPG storage facility fires to 1 per 100,000 vessel years
- The United Kingdom Offshore Operators Association (UKOOA) and the Health & Safety Executive (HSE) outline a typical accumulative frequency threshold for all risk outcomes of 1.00E-04 yr^{-1} as acceptable

Risk Tolerability Criteria (cont.)

- The frequency threshold to be used for this analysis will be 1.00E-05 yr^{-1} based on API 2510A.
- Once a frequency threshold is established, it will be used in conjunction with the thermal radiation thresholds to determine the fire water requirements
  - Per API 2510A, a thermal radiation threshold of 22.0 kW/m^2 is the limit at which fixed fire water systems is needed for cooling of an LPG storage vessel
  - A storage vessel exposed to thermal radiation of 22.0 kW/m^2 at a frequency greater than 1.00E-05 yr^{-1} will require fixed fire water protection

Fire Water Required Demand Rate

Fire Water Required Demand Rate

- Results from the QRA will be used to:
  - Identify areas and equipment requiring fixed fire water protection
  - Determine the worst/most severe credible cases
- Consequence analysis results of the worst/most severe credible cases will be used to determine the maximum fire water demand rate (i.e., the number of equipment that can simultaneously be exposed to the thermal radiation threshold of 22 kW/m^2 during each scenario)
- Fire water application rates for different equipment types can be found in many different standards such as API 2510, API 2510A, CCPS and NFPA.

Fire Water Application Rates

- Application rates for LPG storage vessels are specifically given in API 2510/API 2510A
- Equipment in this example will be protected by water monitor systems

Fire Exposure	Fire Water Application Rate
Exposure to radiant heat and no flame contact	0-0.1 gpm/ft²
Fixed deluge or water sprays designed to protect against pool fire exposure	≥0.1 gpm/ft²
Water monitor systems designed to protect against pool fire exposure	≥0.2 gpm/ft²
Exposure to radiant heat with direct flame contact	0.1-0.25 gpm/ft²
Exposure to a high-velocity jet flame	250-500 gpm at point of jet contact

Source: API 2510, API 2510A

Fire Water Application Rates (cont.)

- Application rates for other process equipment are given in the CCPS book "Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities"

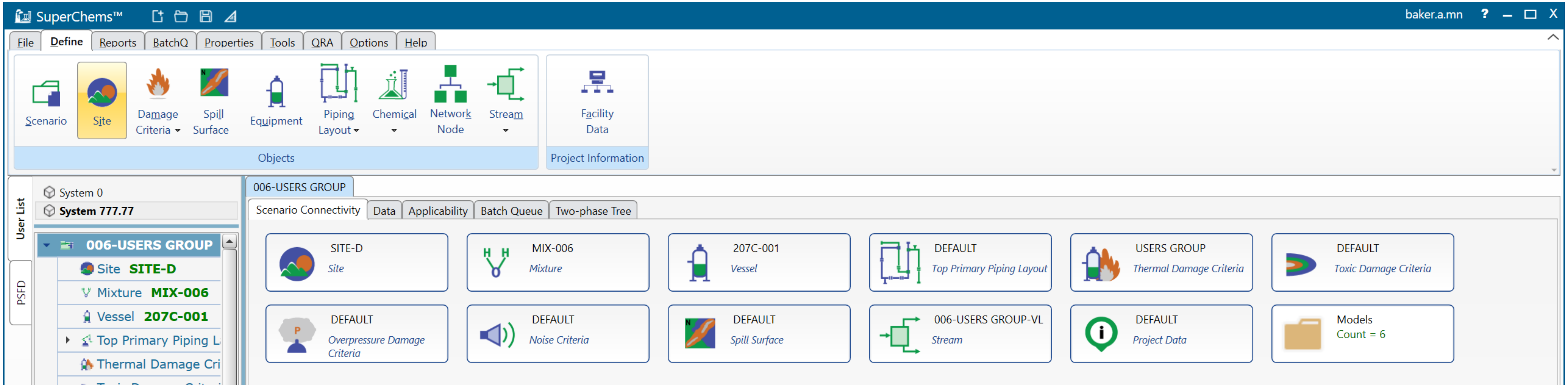
Item	Fire Water Application Rate [gpm/ft²]
Air-Cooled Fin-Tube Heat Exchangers	0.25
Cable Trays	0.30
Compressors	0.25
Exposure Protection	0.25
Fired Heaters	0.25
LPG Loading Racks	0.25
Motors	0.25
Pipe Racks	0.25
Pressurized Storage Tanks	0.25
Pumps	0.25-0.50
Towers	0.25
Turbines	0.25
Vessels and Heat Exchangers	0.25

Source: CCPS book "Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities"

Analysis in SuperChems™

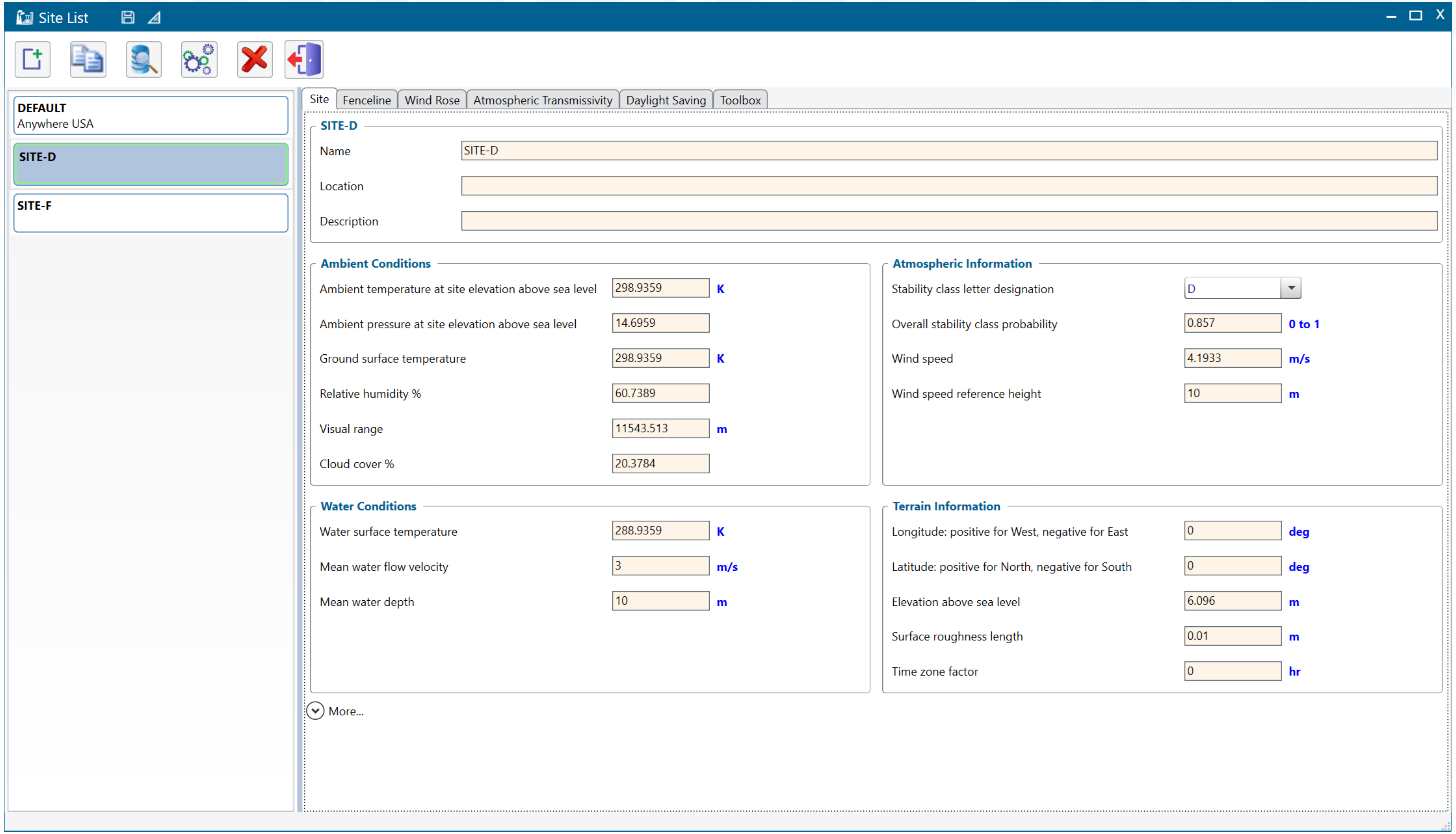
Required SuperChems™ Inputs – Site Data

- First steps when performing analyses like this are the following
  - Define site data (i.e., meteorological conditions, probability of occurrence, wind direction probabilities, wind speed, atmospheric stability class, etc.)
  - Meteorological data for your site can be imported from various sources, such as SAMSON



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Required SuperChems™ Inputs – Site Data



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Required SuperChems™ Inputs – Site Data (cont.)

Site List

DEFAULT
Anywhere USA

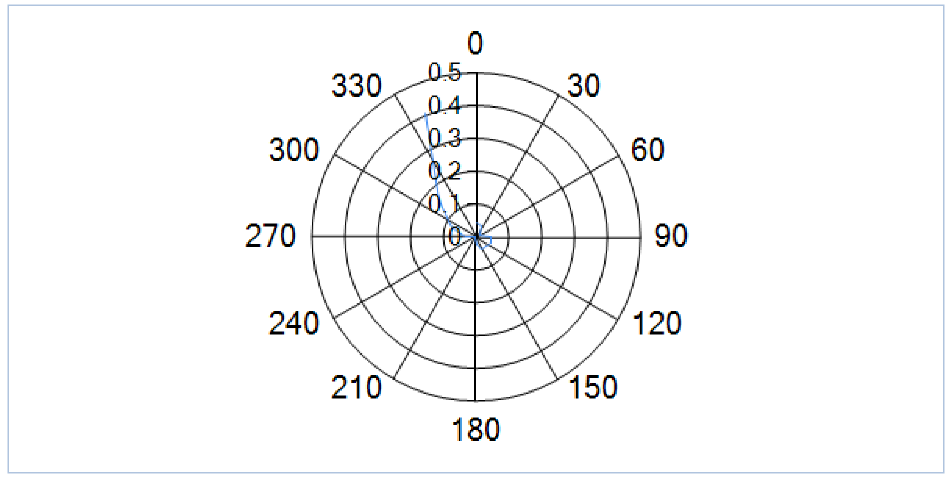
SITE-D

SITE-F

Site | Fenceline | Wind Rose | Atmospheric Transmissivity | Daylight Saving | Toolbox

Wind Rose Data (where wind is blowing from)

Angle	User Data	Probability
0	0.0410	0.0410
22.5	0.0386	0.0386
45	0.0159	0.0159
67.5	0.0149	0.0149
90	0.0445	0.0445
112.5	0.0484	0.0484
135	0.0436	0.0436
157.5	0.0400	0.0400
180	0.0260	0.0260
202.5	0.0046	0.0046
225	0.0031	0.0031
247.5	0.0040	0.0040
270	0.0292	0.0292
292.5	0.0797	0.0797
315	0.1572	0.1572
337.5	0.4094	0.4094
Total	1.0000	1.0000



Windrose Parameters

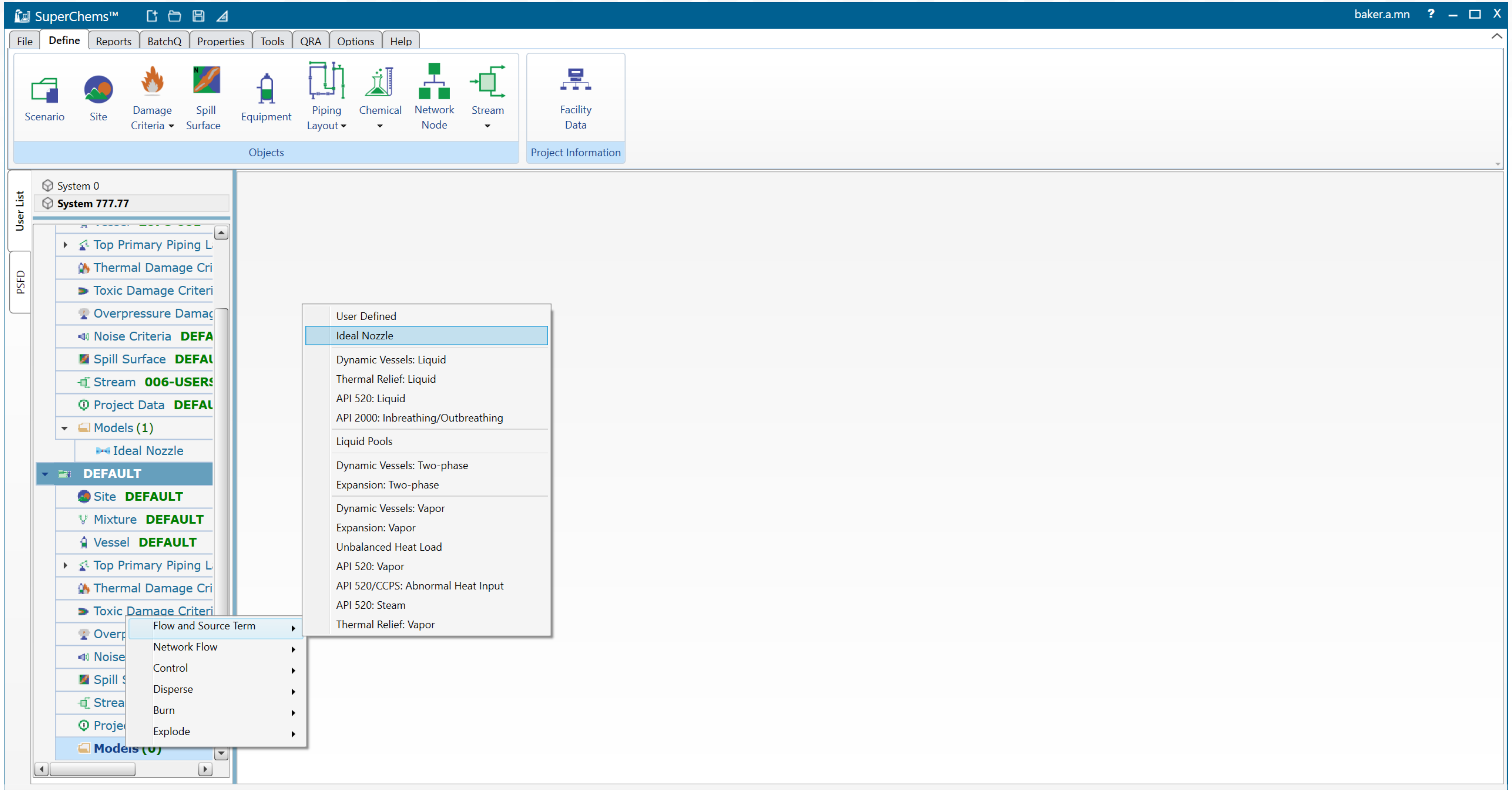
Points Number 16 **Directions**

Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Required SuperChems™ Inputs – Scenario Creation and Source Term

- Create scenarios for all loss of containment (LOC) scenarios identified during the hazard identification step.
  - Each equipment identified will have up to three different hole sizes (1in, 4in, full bore) and one scenario for each meteorological condition analyzed (D5, F2) for a total of six scenarios
  - Source term characterization for each scenario (release rate, angle of release, temperature, composition, release height, release duration, etc.)
    - Release rate and exit temperature can be calculated using the Ideal Nozzle model within SuperChems™

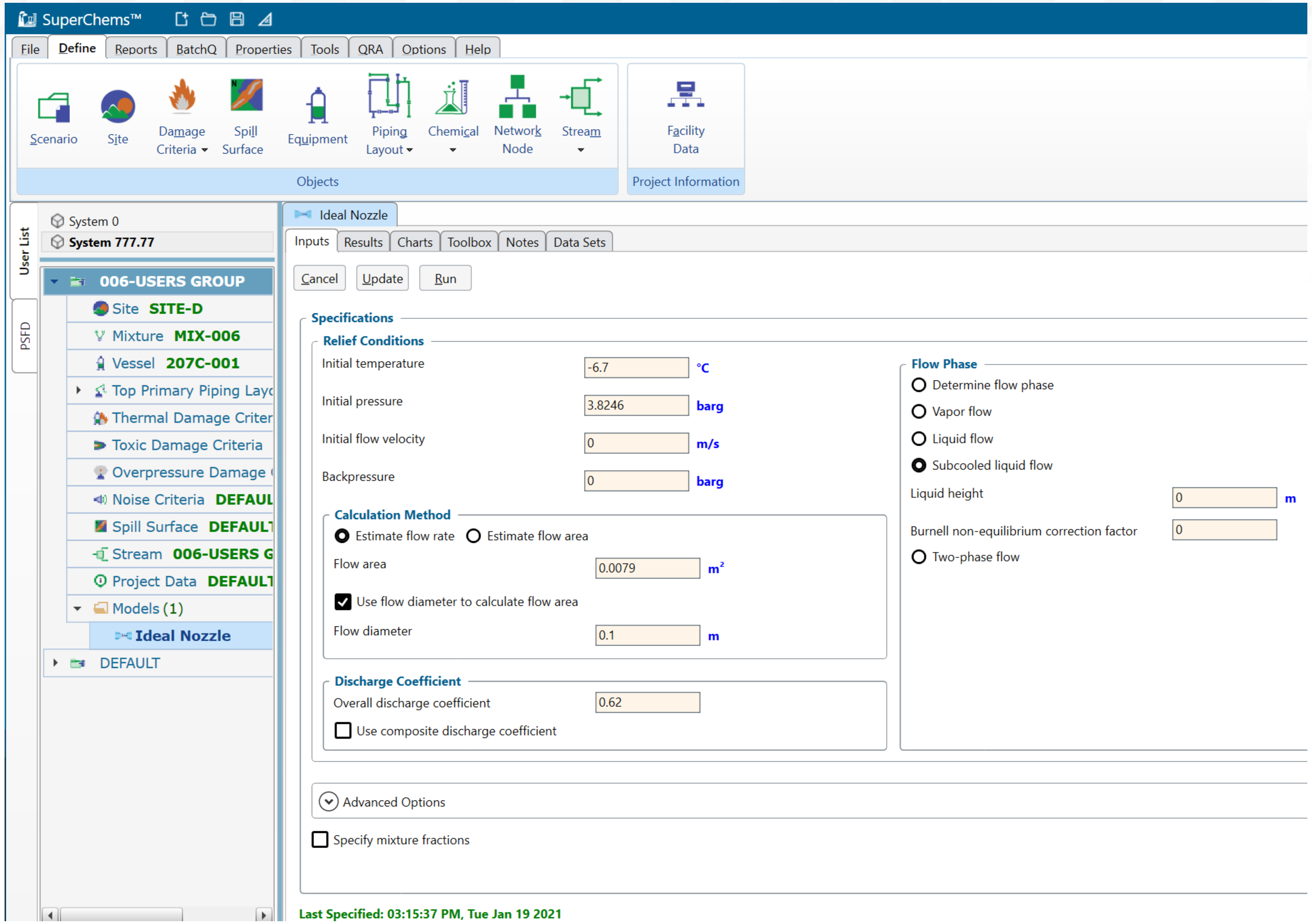
Required SuperChems™ Inputs – Source Term – Ideal Nozzle



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Required SuperChems™ Inputs – Source Term – Ideal Nozzle

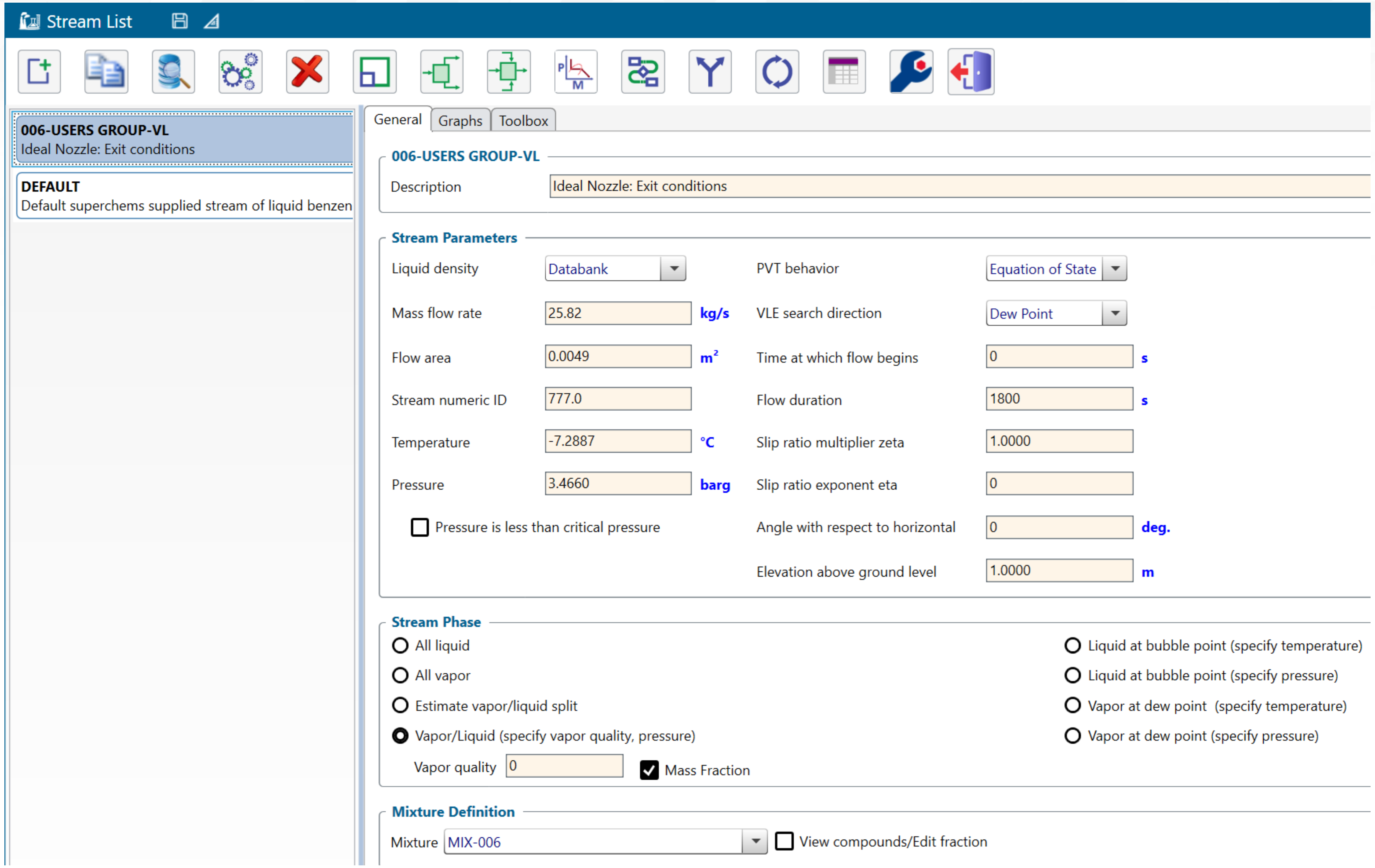
- Inputs based on the normal operating conditions within the equipment
- Flow area based on the hole size (1”, 4” or full bore)
- Export exit conditions to a stream (Select Toolbox tab, then select Create a Stream at Exit Conditions)
- Edit stream



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

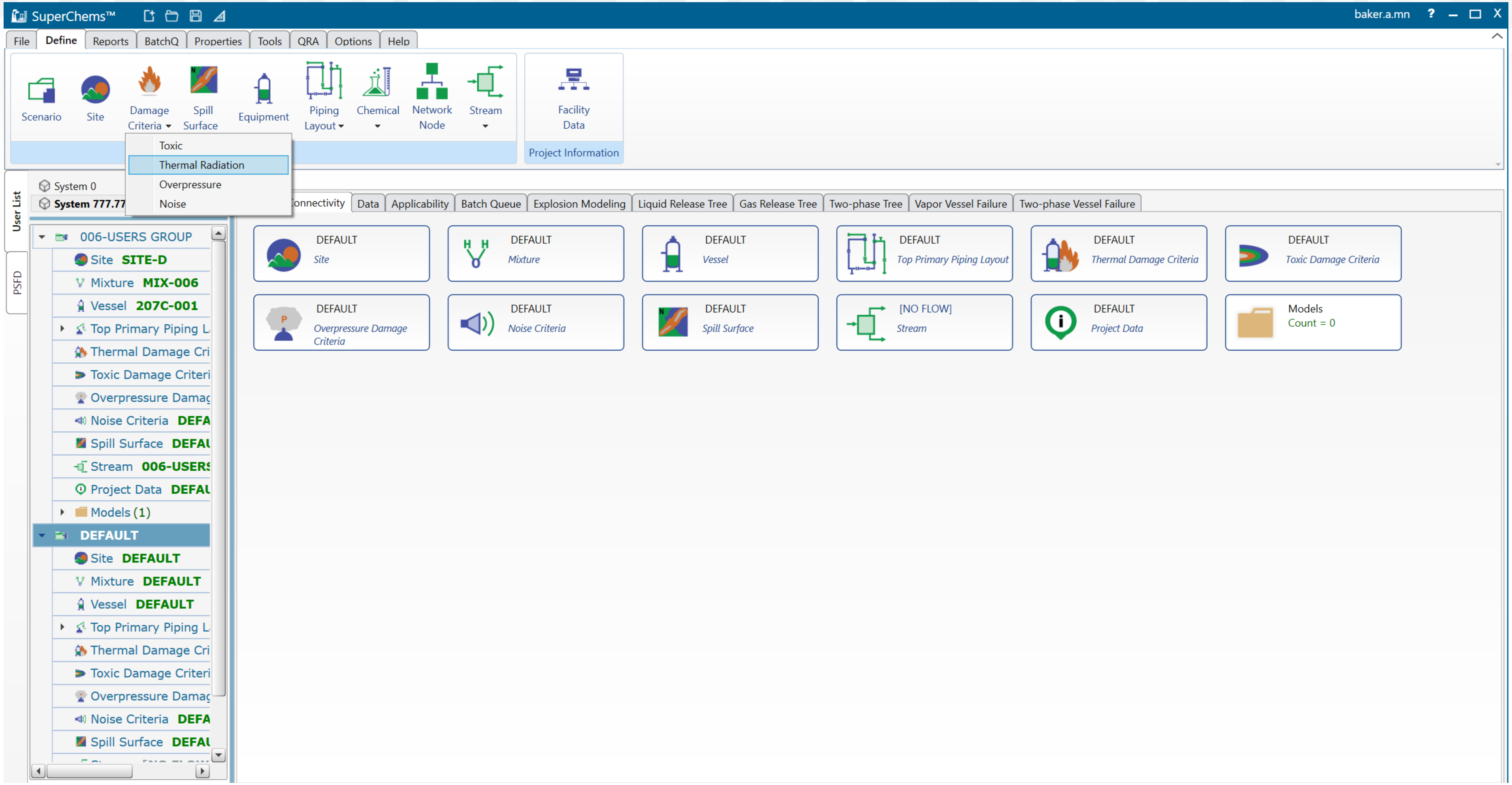
Required SuperChems™ Inputs – Source Term Stream

- In the stream object specify the release duration, release angle and release height in the stream
- Apply stream to respective scenario to be used as the source term input to the consequence models (right click on stream name to apply)



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

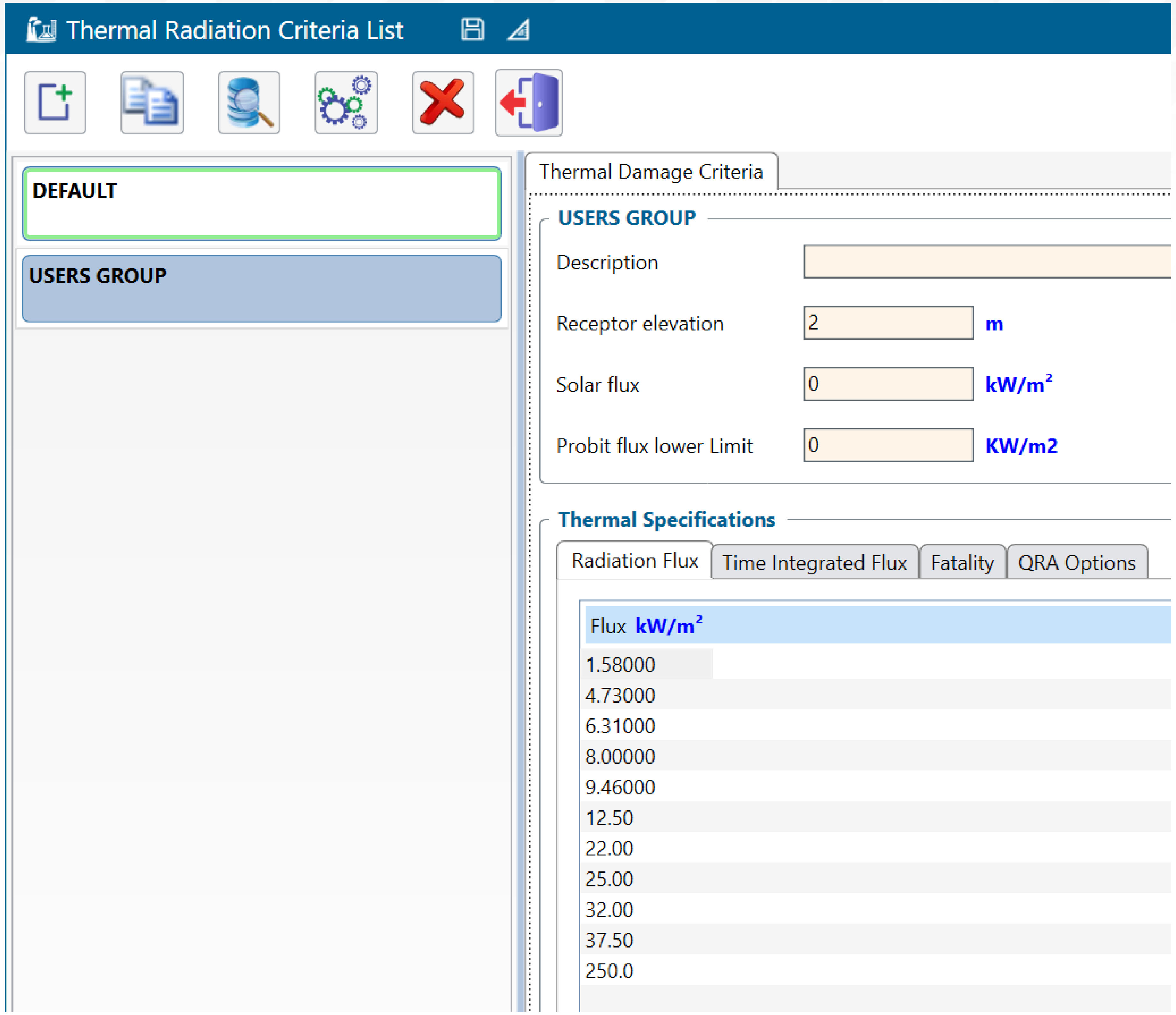
Required SuperChems™ Inputs – Damage Criteria



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Required SuperChems™ Inputs – Damage Criteria – Thermal Radiation

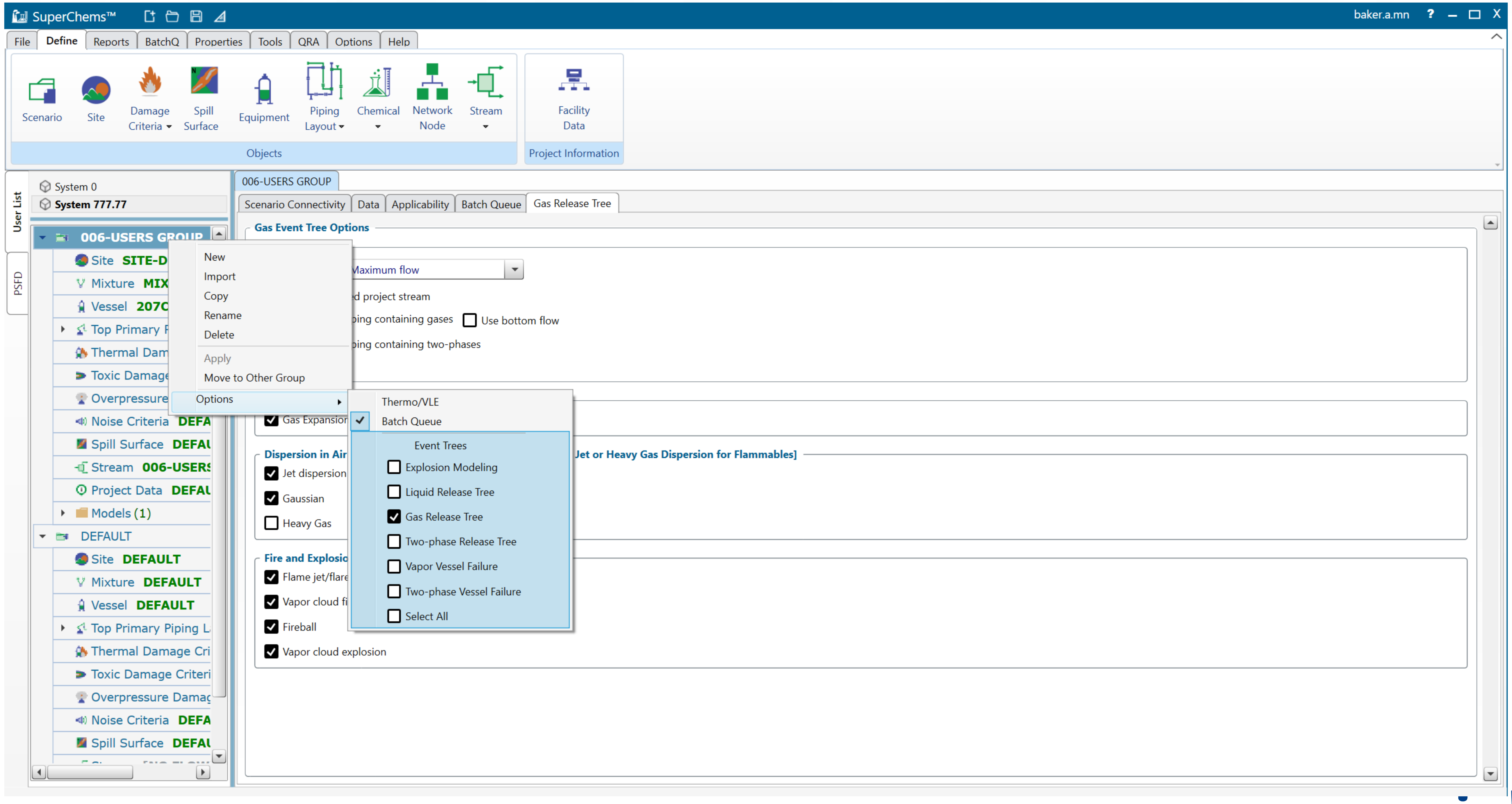
- Define and apply damage criteria (thermal radiation, overpressure, toxicity, noise).
- This example will look at thermal damage criteria only, but similar input options will exist for the other damage criteria
- Apply damage criteria to your scenario



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

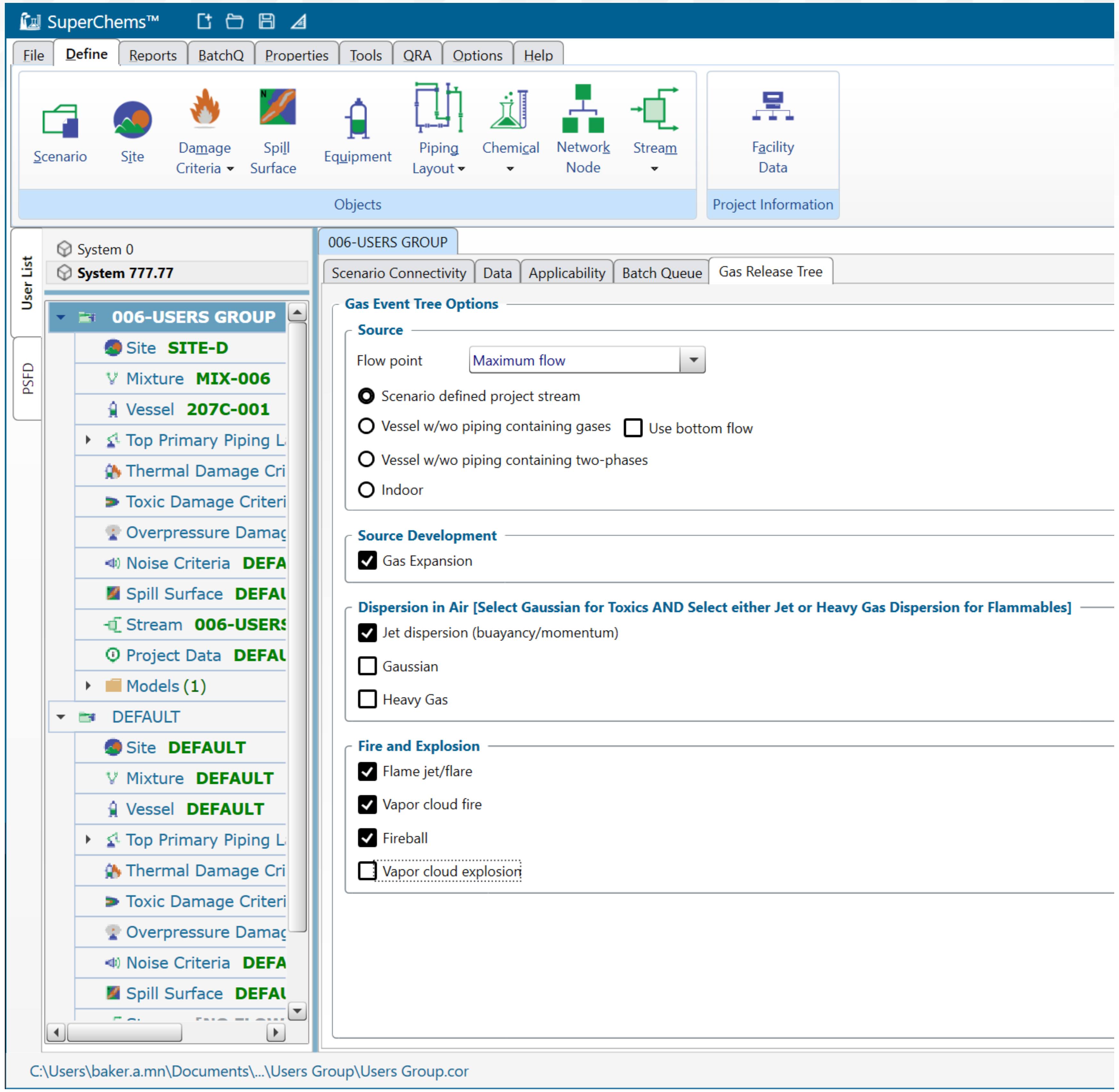
SuperChems™ Event Trees

- Select the consequence models to evaluate using event trees based on the expected release phase. Right click on scenario name and select the relevant event tree.



SuperChems™ Event Trees (cont.)

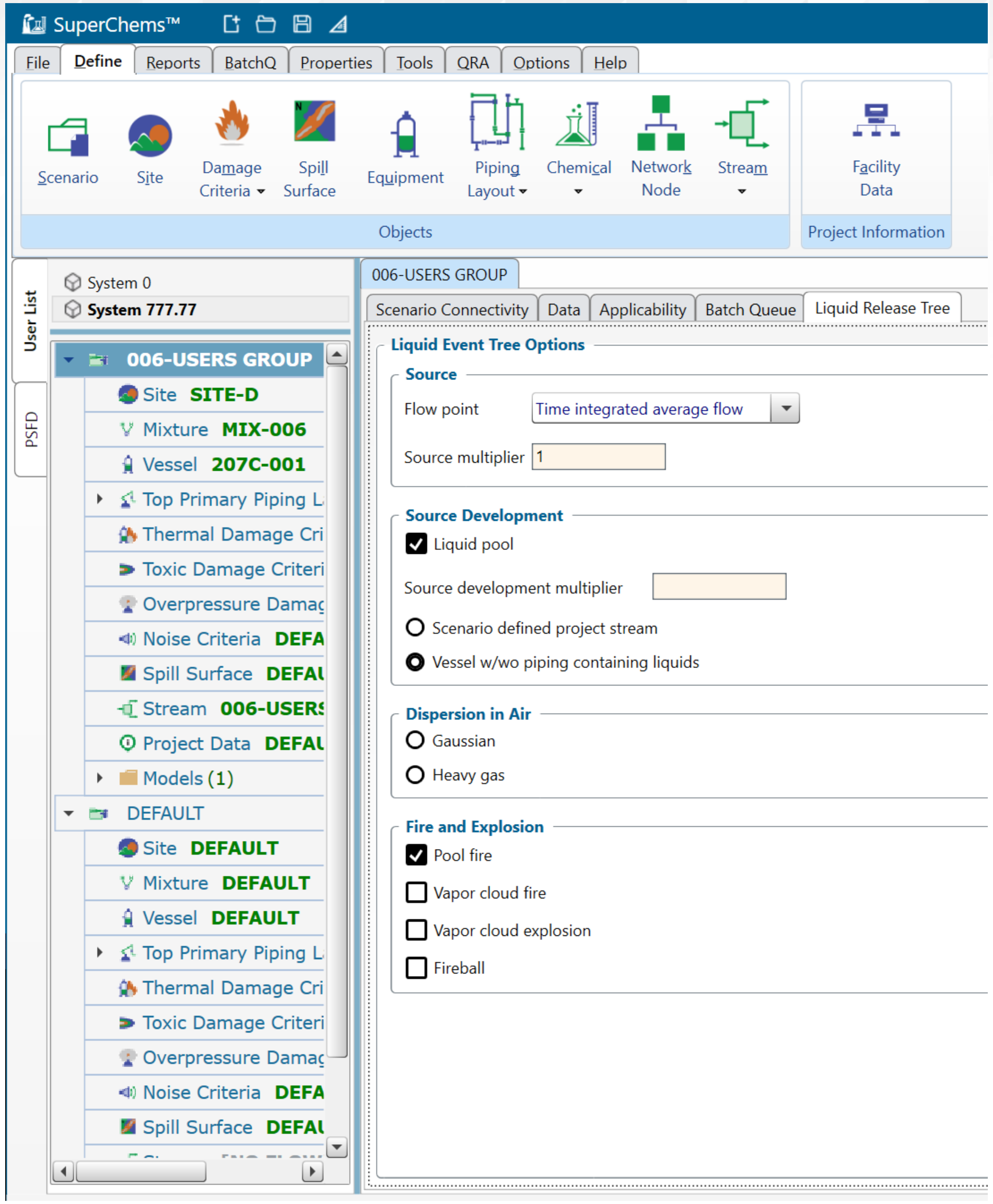
- Gas Release Event Tree (Two Phase Event Tree is similar)
  - Depending on your inputs and project requirements different models can be selected
  - For this example, only models that result in thermal radiation impacts are required



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Event Trees (cont.)

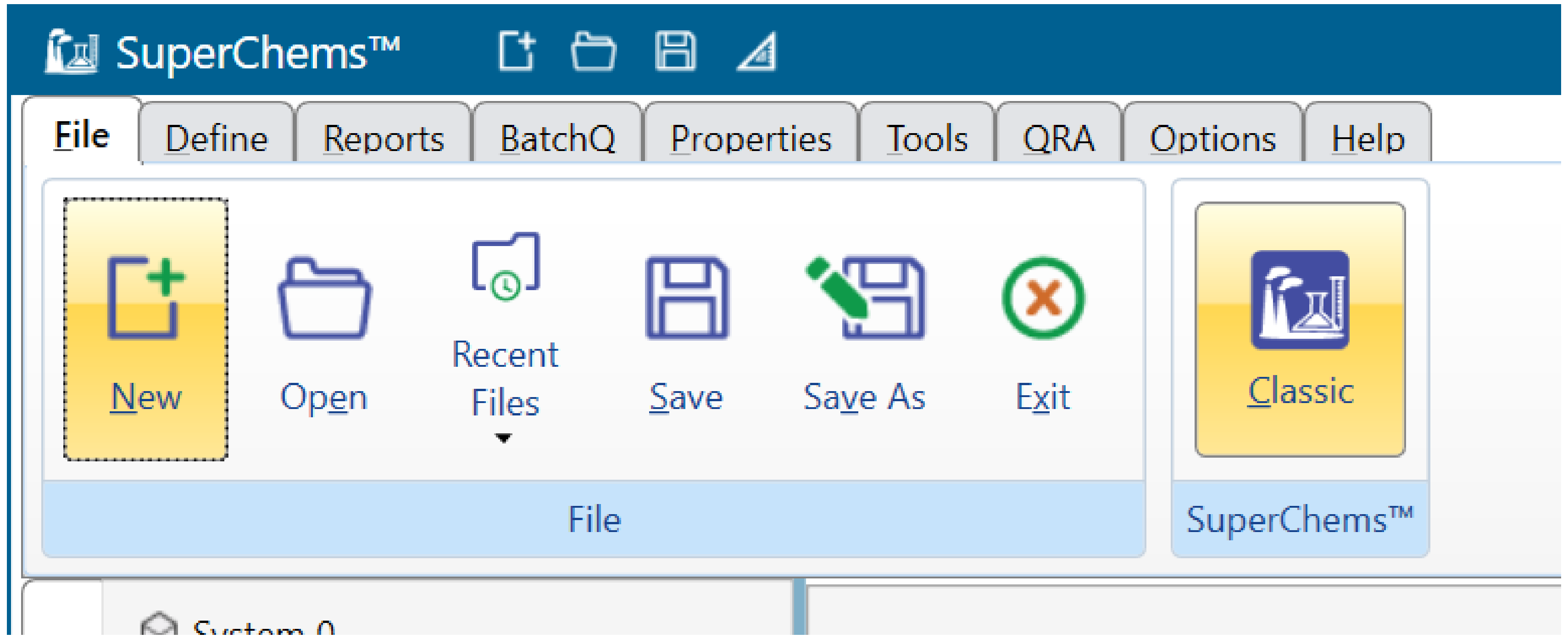
- Liquid Release Event Tree
  - Depending on your inputs and project requirements different models can be selected
  - For this example, only liquid pooling resulting in a pool fire was investigated

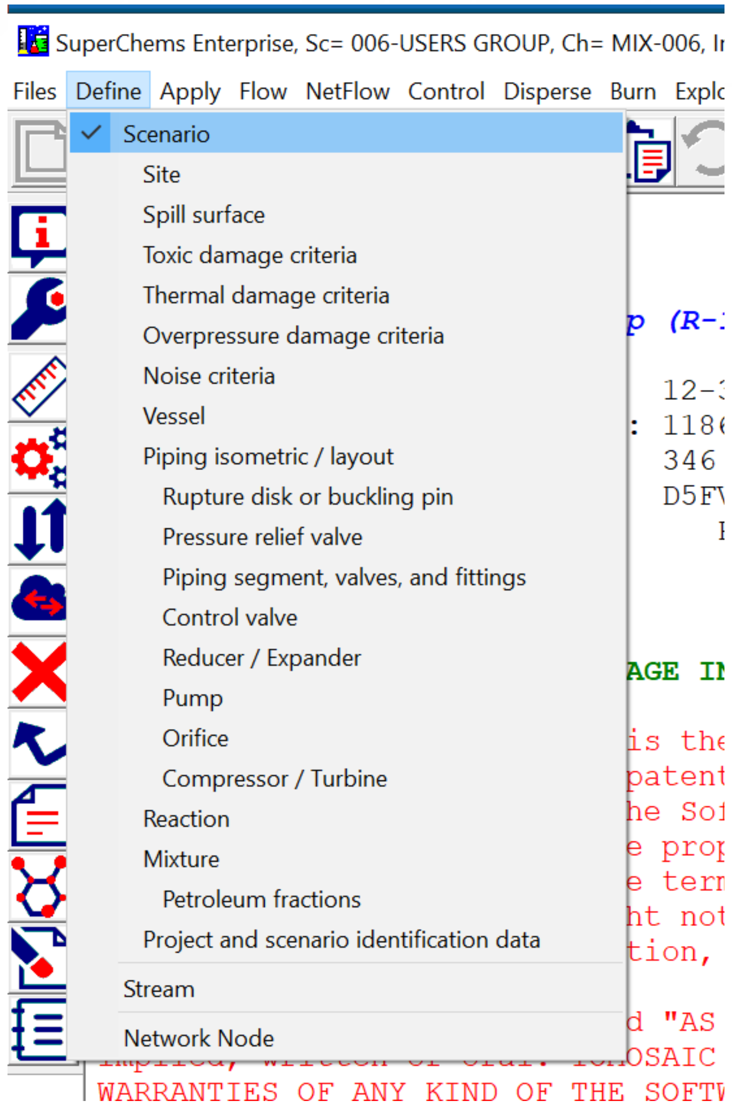


Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Ignition Probabilities (cont.)

- Ignition probabilities for each scenario can be estimated in SuperChems™ using the “Estimate Ignition Probability” tool. First, enter SuperChems Classic, then Define -> Scenario.

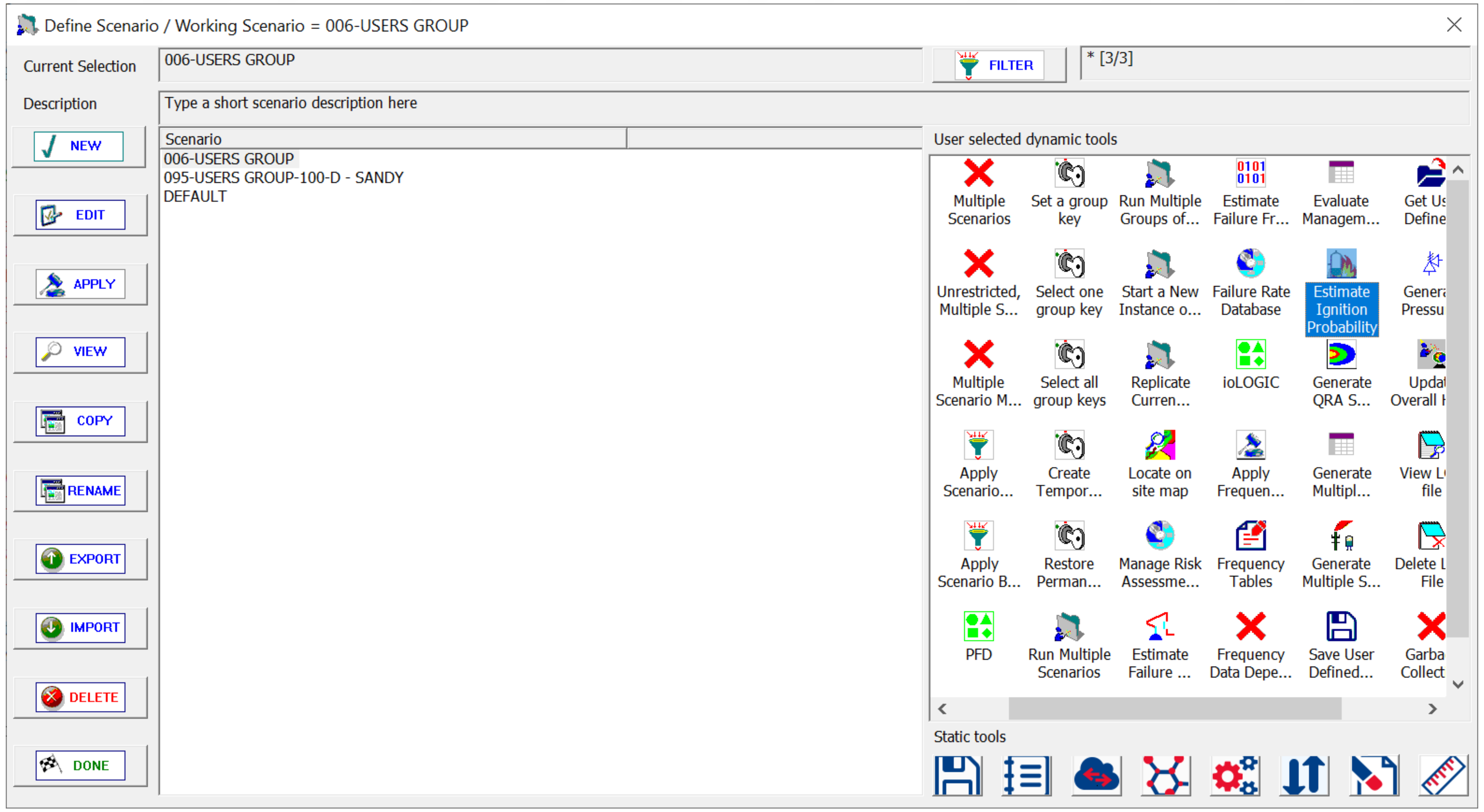


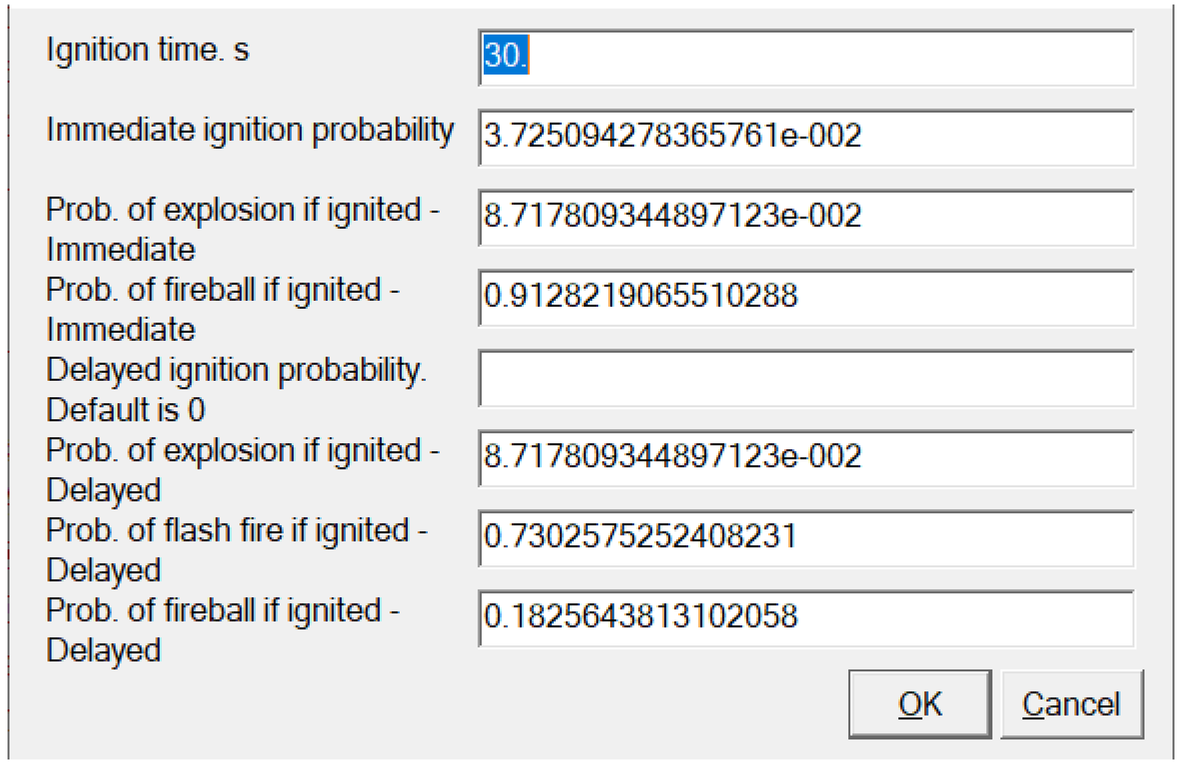


Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Ignition Probabilities (cont.)

- This tool estimates the probability of ignition as well as the probability of the different outcomes





Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Ignition Probabilities (cont.)

- The ignition probability is based on the release rate as shown in the table below

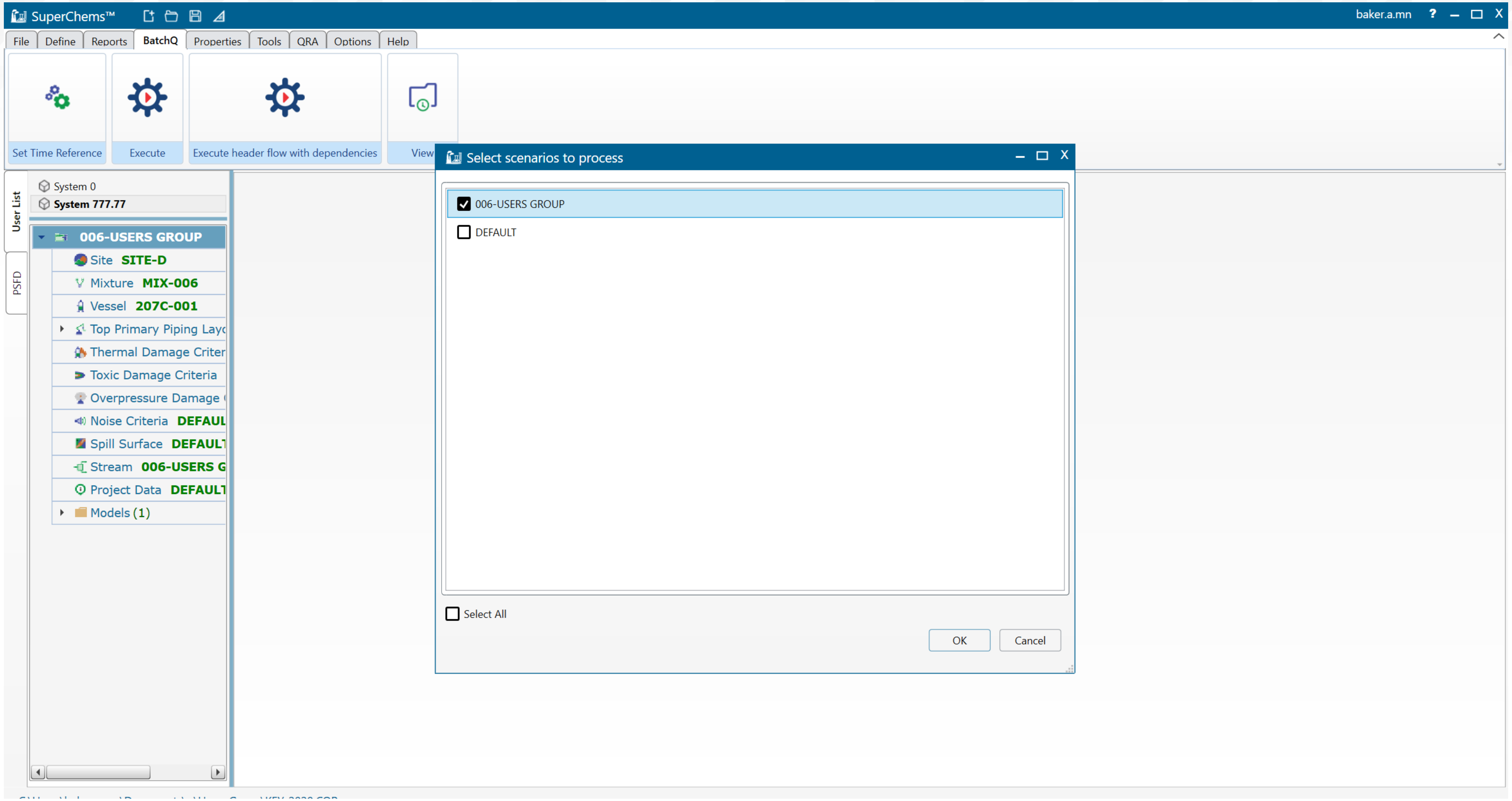
Release Rate	Probability of Ignition		Probability of Explosion given ignition
	Gas	Liquid	
Minor (≤ 1 $kg \cdot s^{-1}$)	0.010	0.010	0.04
Major (1-50 $kg \cdot s^{-1}$)	0.070	0.030	0.12
Massive (≥ 50 $kg \cdot s^{-1}$)	0.300	0.080	0.3

Source: Cox, A.W., Lees, F. P., and Ang, M.L., "Classification of Hazardous Locations", Rugby: Institution of Chemical Engineers, 1990.

SuperChems™ Batch Queue

- Once the event trees have been set up and the ignition probabilities estimated, the models are ready to be run. This is most easily accomplished using the batch queue.
- QRA files can easily have hundreds of separate scenarios, each with multiple consequence models. The batch queue and event trees allow you to select and run all scenarios and models with minimal additional user input.
- Once calculations are complete it is a good idea to do a spot check of results to ensure everything was calculated correctly.

SuperChems™ Batch Queue (cont.)

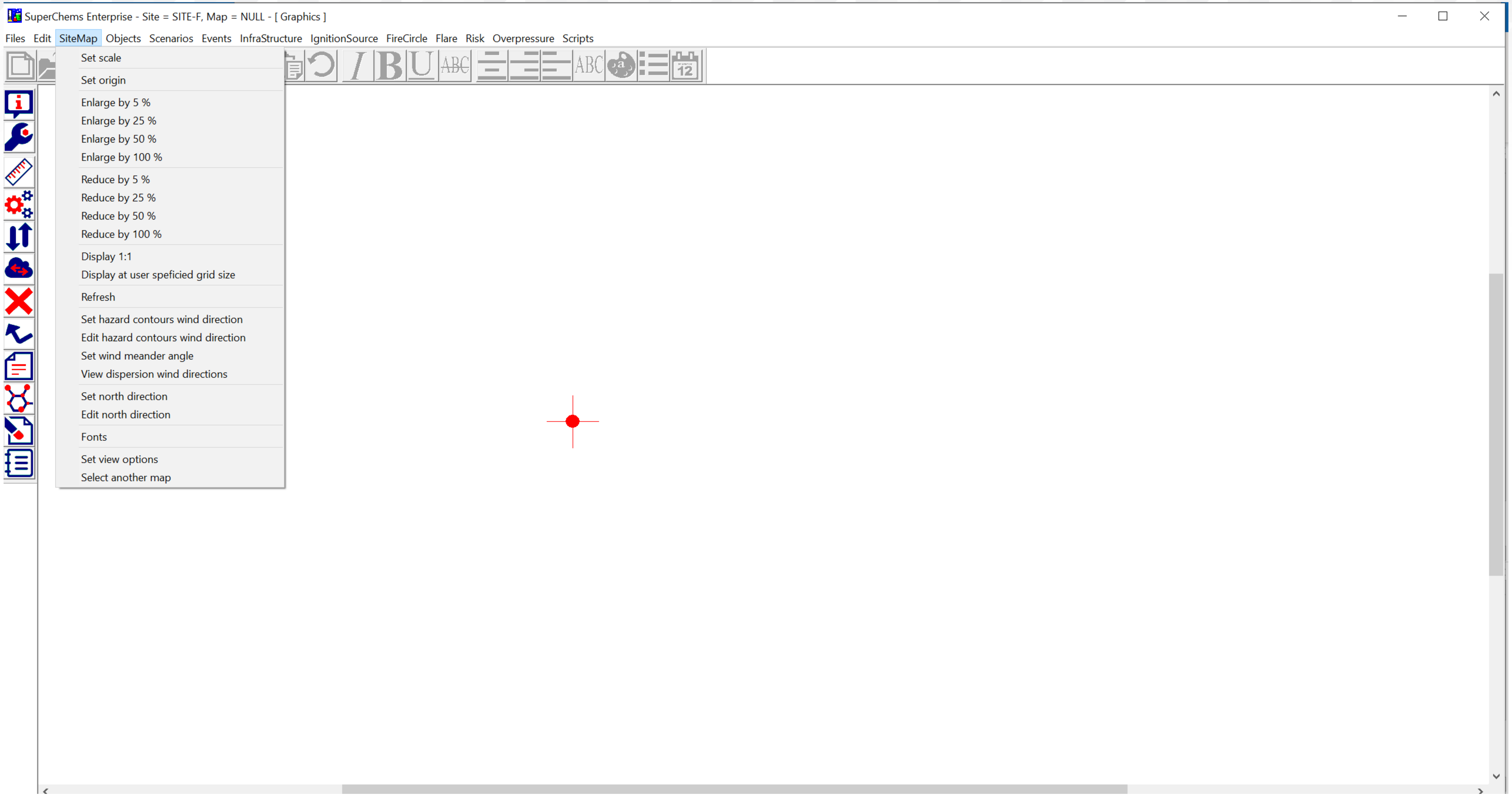


Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Required SuperChems™ Inputs – Site Map

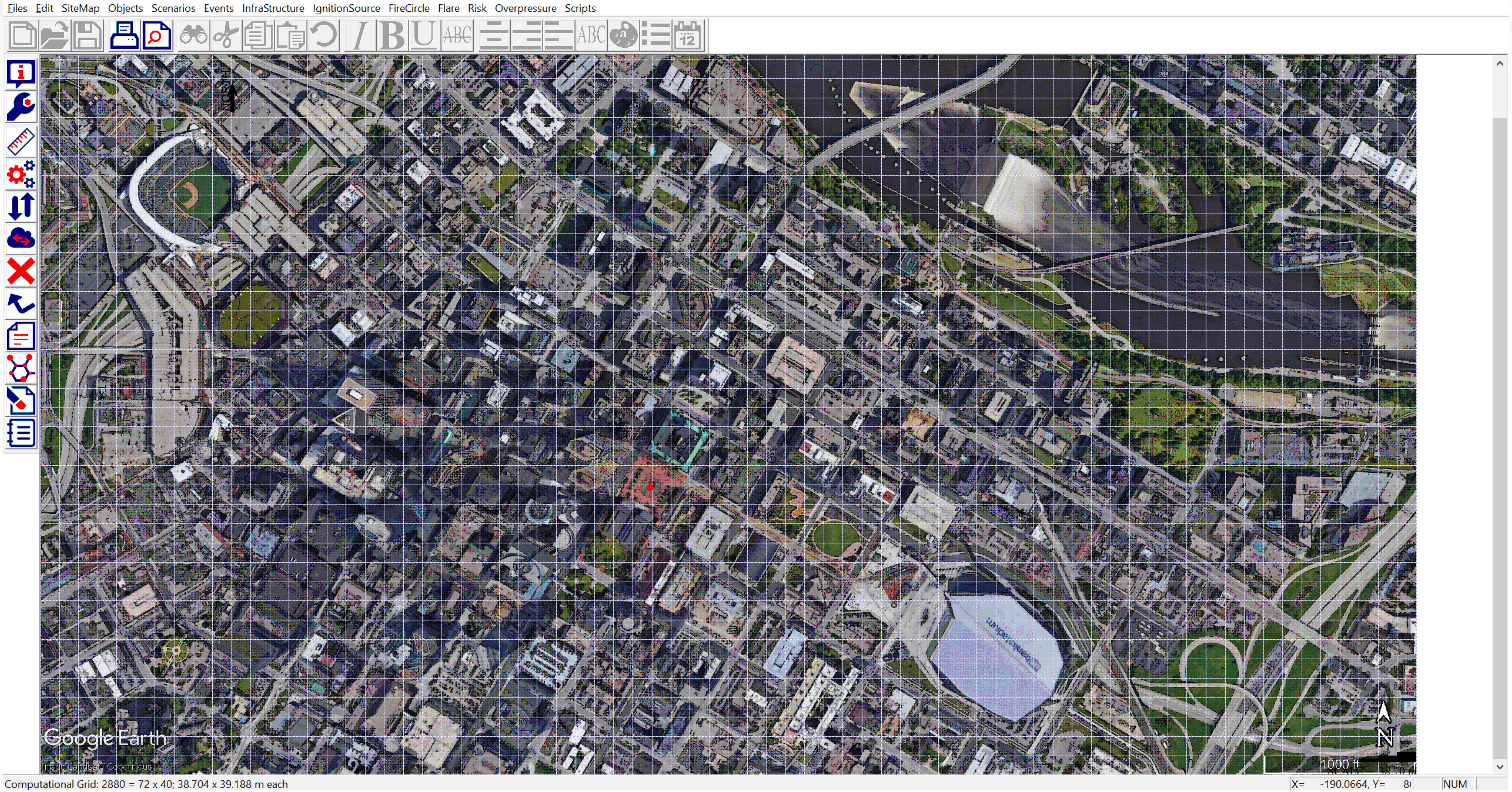
- Define a site map in the QRA module
  - Typically uses a plot plan or Google Earth image of your facility imported to SuperChems™
  - Set origin, north direction and scale so that the LOC scenarios, risk results and consequence results can be plotted accurately on the site map.
  - Define ignition sources (location, ignition probability, presence factor, etc.)
  - Define infrastructure (location, dimensions)
    - Major Equipment
    - Buildings
    - Population
- Based on the site map, assign the proper coordinates to all LOC scenarios

Required SuperChems™ Inputs – Site Map (cont.)



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

Required SuperChems™ Inputs – Site Map (cont.)



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation - Google Earth

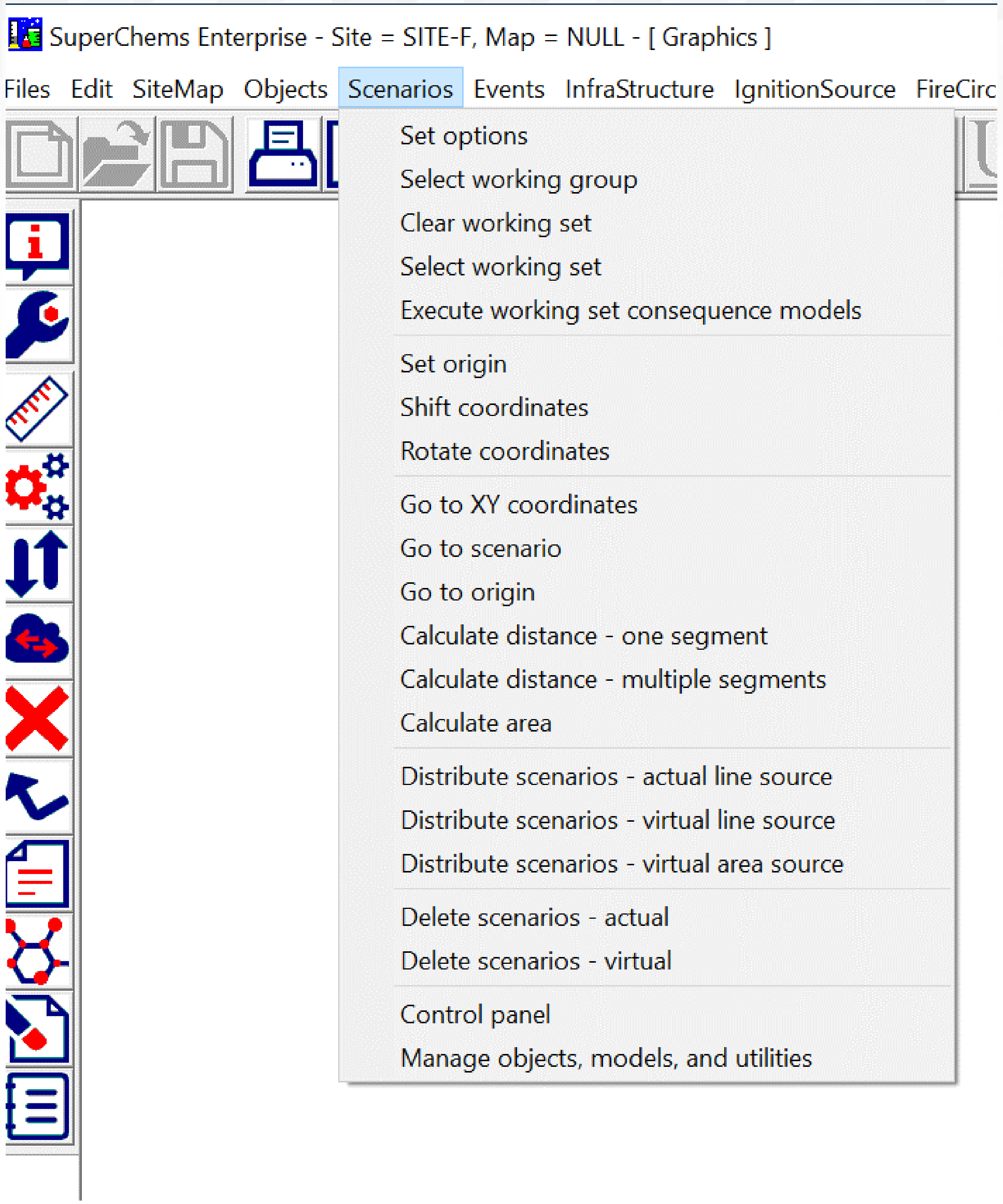
SuperChems™ Risk Calculations

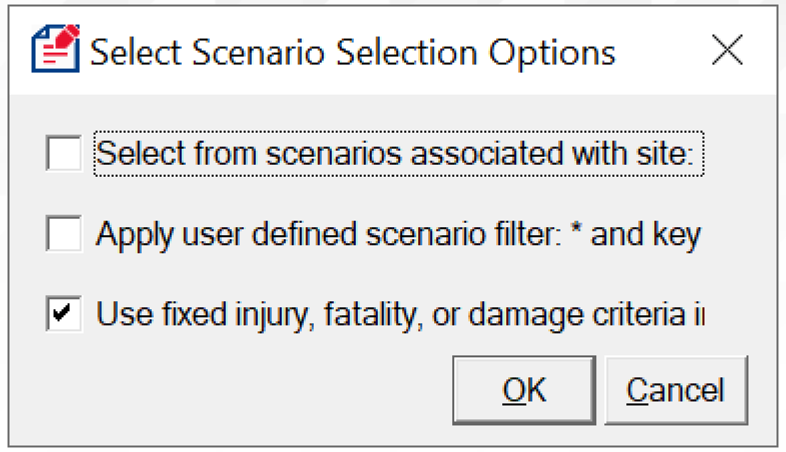
- To determine which equipment will require fixed fire water protection it is necessary to calculate the risk contours for the different thermal radiation thresholds that we analyzed.
  - In particular, the 22 kW/m^2 threshold at a frequency of 1.00E-5yr^{-1} will be used for this example
- Risk is calculated within the QRA module in SuperChems™

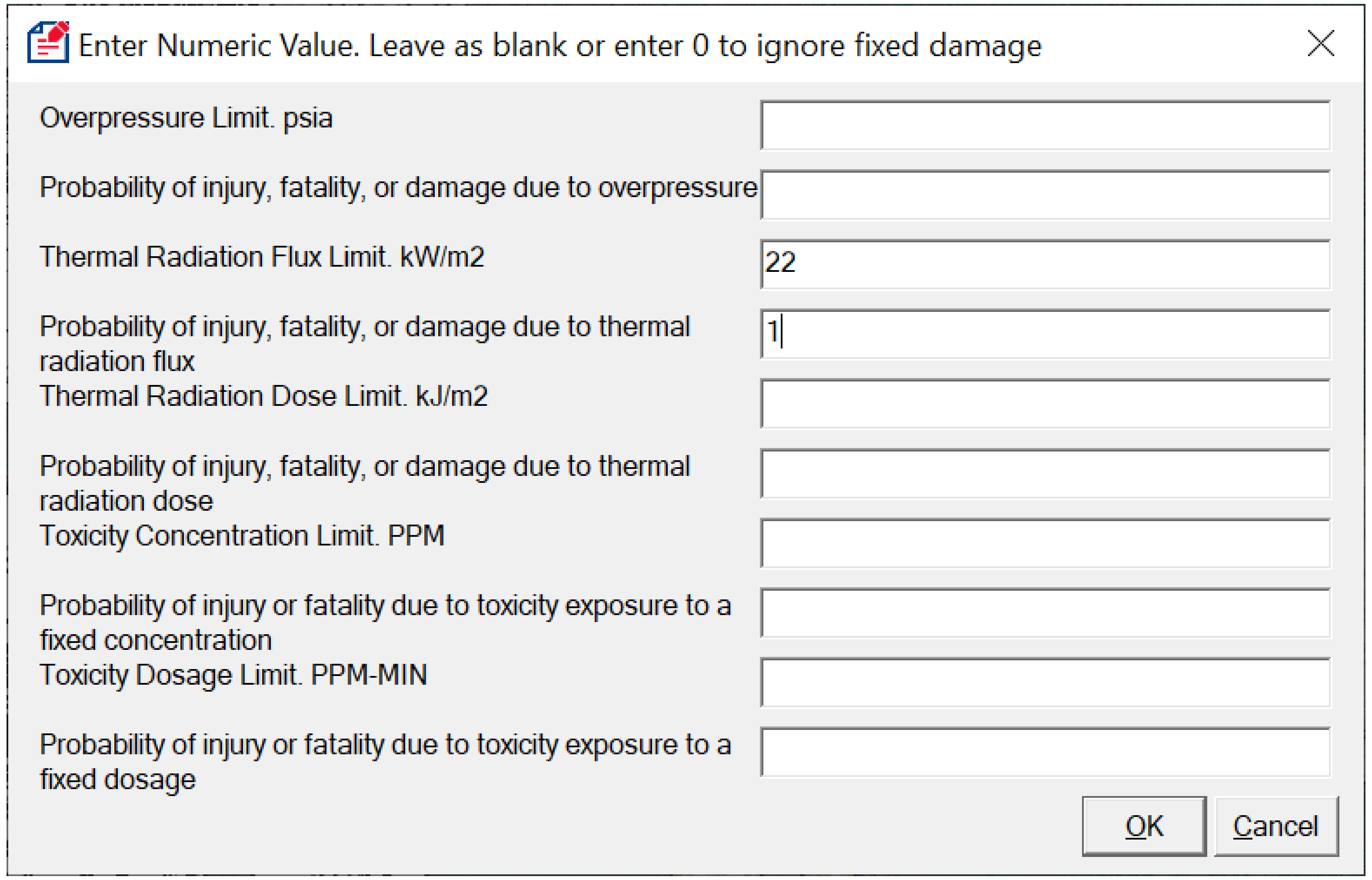
SuperChems™ Risk Calculations (cont.)

- Risk contours for specific thresholds can be calculated by selecting “Use fixed injury, fatality, or damage criteria” under Scenarios -> Set Options.
- After checking that box and selecting ok, another window will pop up where you can enter the threshold of interest. In this case it is 22 kW/m^2.
- Next, under Scenarios -> Select Working Set
  - Select all scenarios for analysis. Once loaded they will appear on the site map with a blue cross.
  - Verify that scenario locations are correctly located on the site map

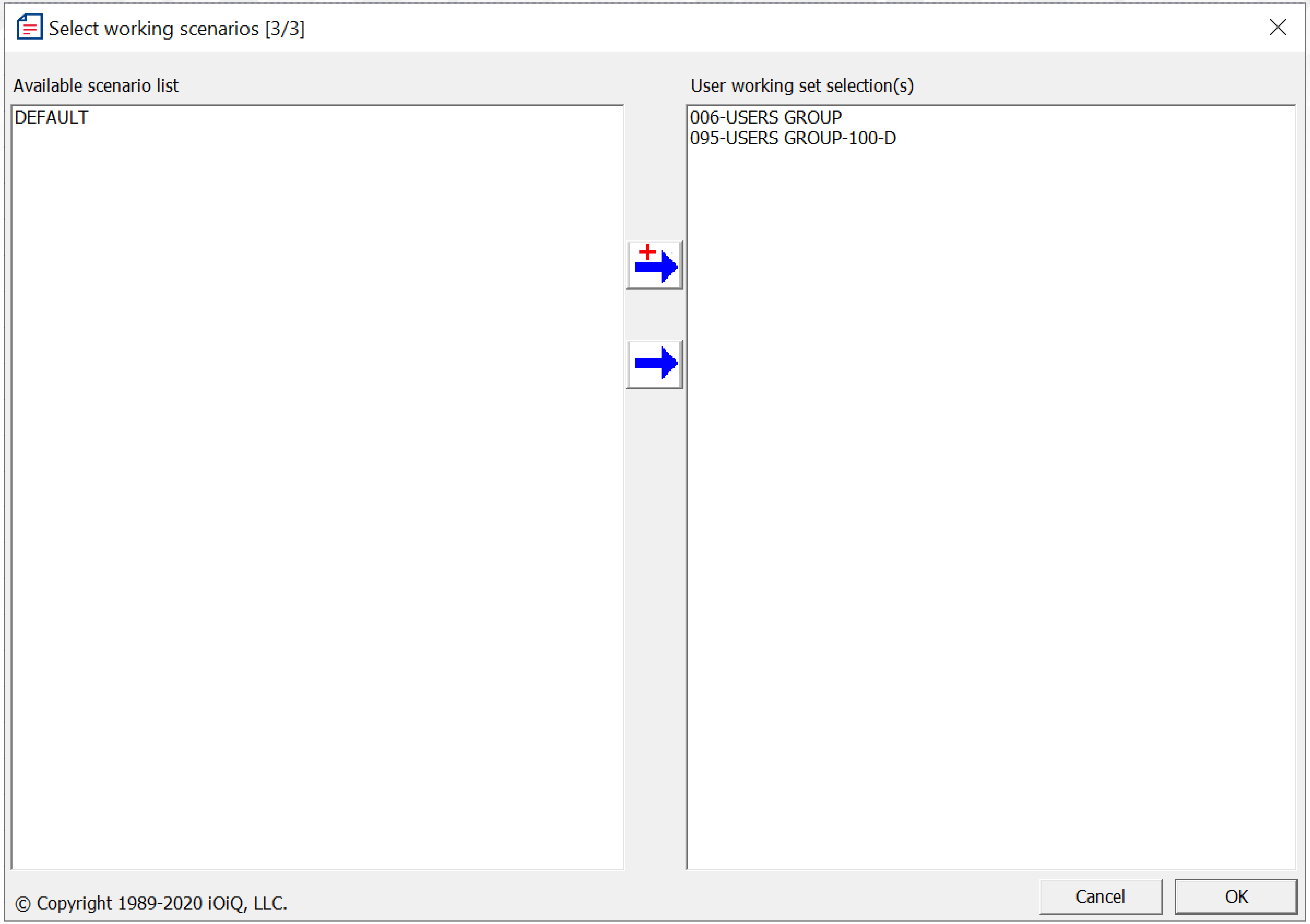
SuperChems™ Risk Calculations (cont.)





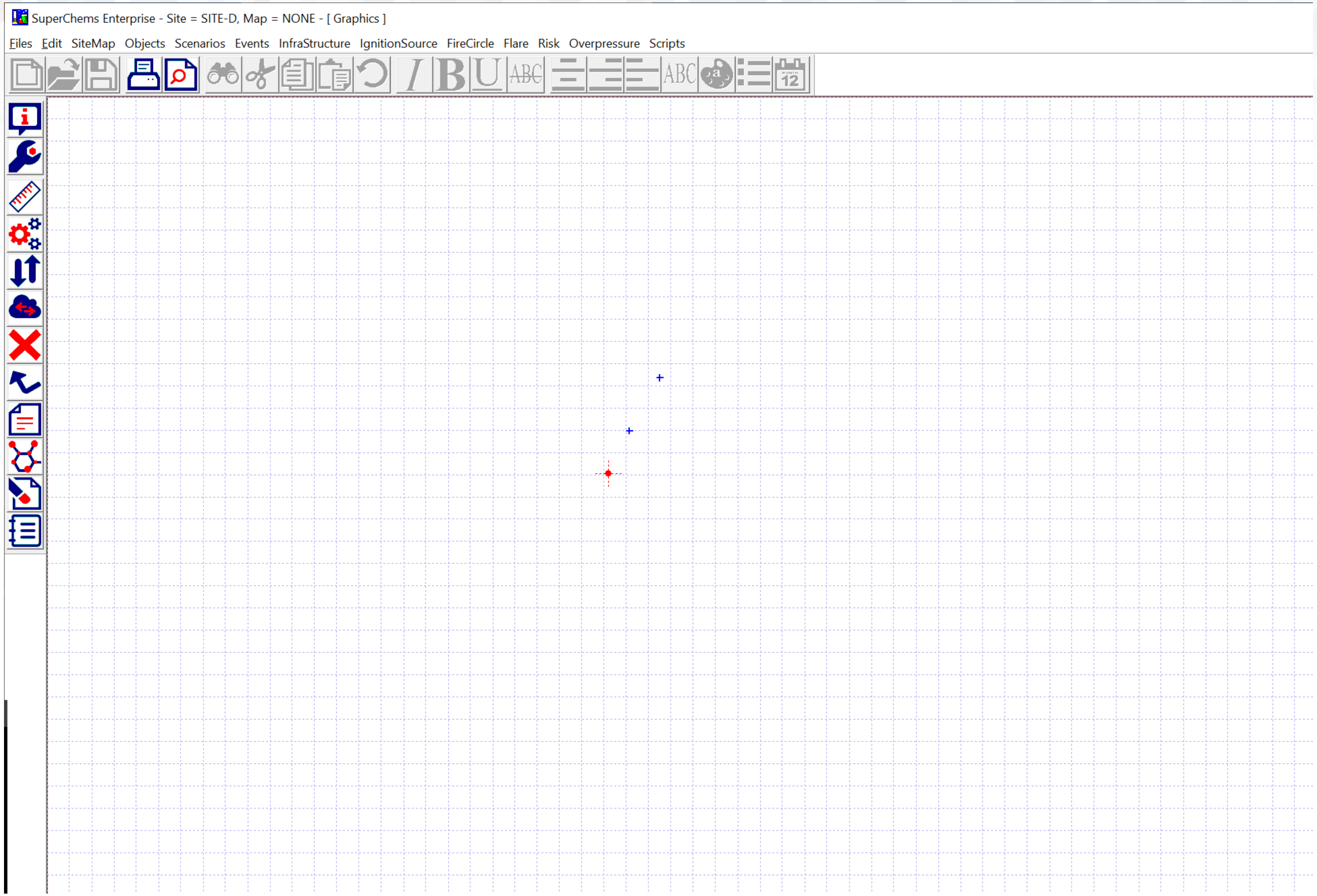


SuperChems™ Risk Calculations (cont.)



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

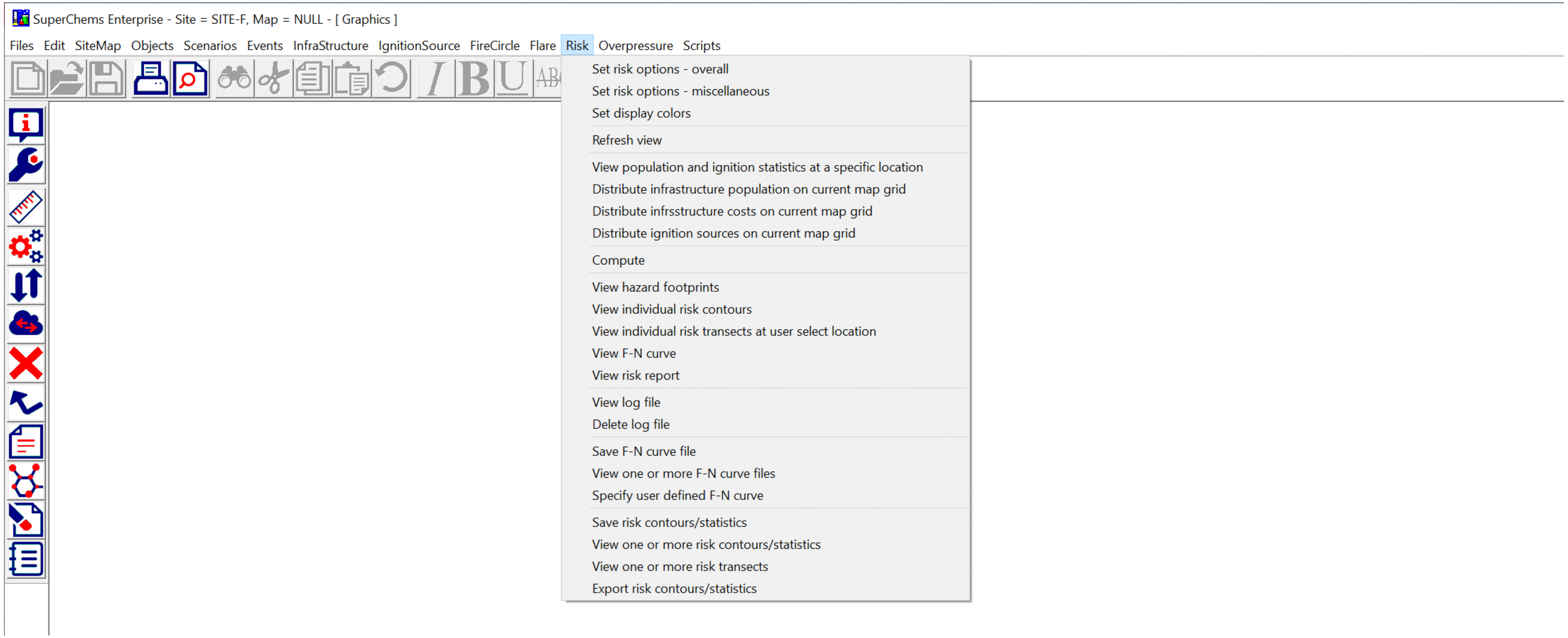
SuperChems™ Risk Calculations (cont.)



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Risk Calculations (cont.)

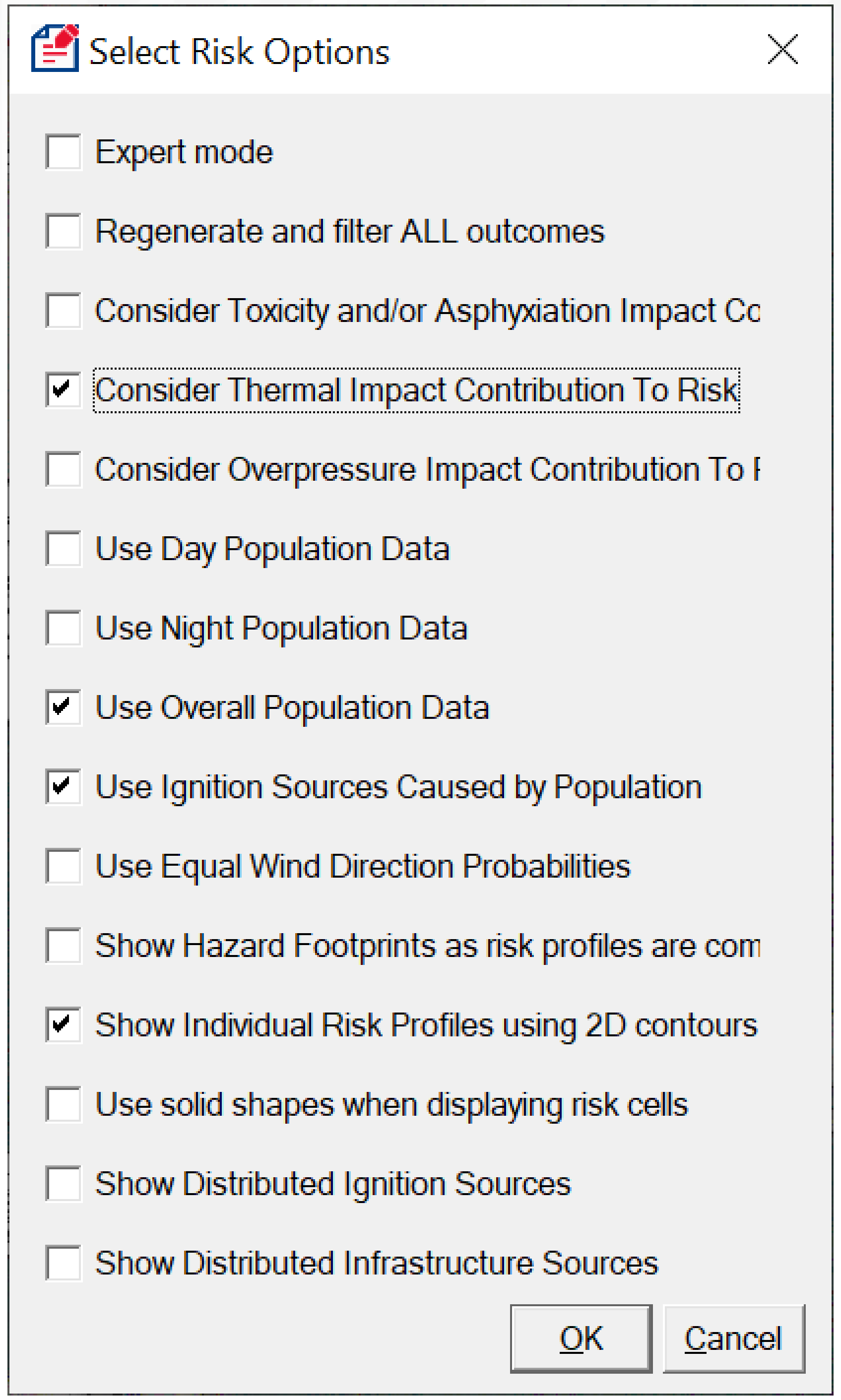
- From here we can then move forward to compute the risk for this threshold and then view the risk contours. This is accomplished using the options under the Risk tab.



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Risk Calculations (cont.)

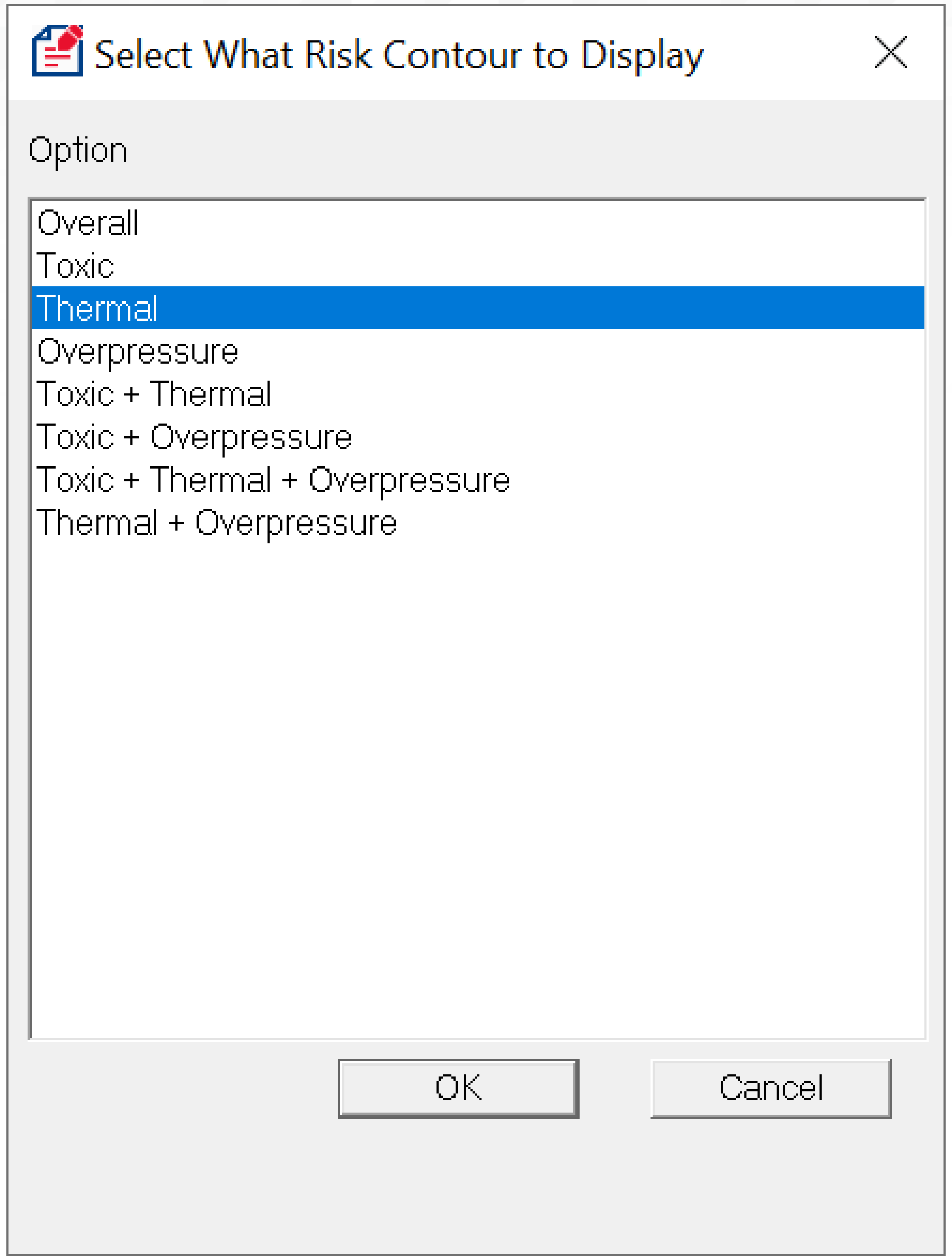
- Under Risk, selecting Compute will cause a window to pop up with different risk options.
  - Interested in Thermal Impact only
  - Use overall population data
  - Consider ignition sources caused by population
  - Show Individual Risk Profiles using 2D contours
- Hitting ok will then start the risk calculations

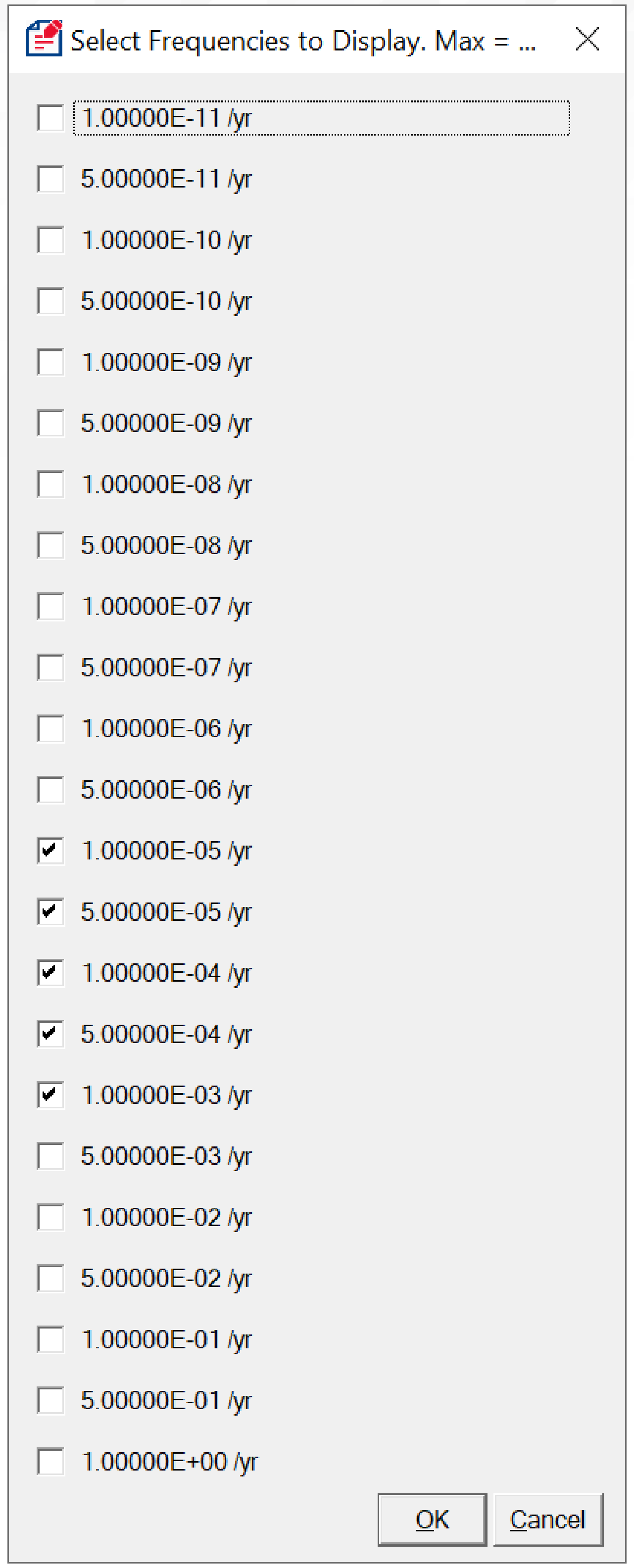


Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Risk Calculations – 22 kW/m^2 Risk Contours

- Once calculations are complete, under the Risk tab, select view individual risk contours
- Select the thermal risk contour
- Once SuperChems™ is done performing some additional calculations, select the frequencies of interest to display

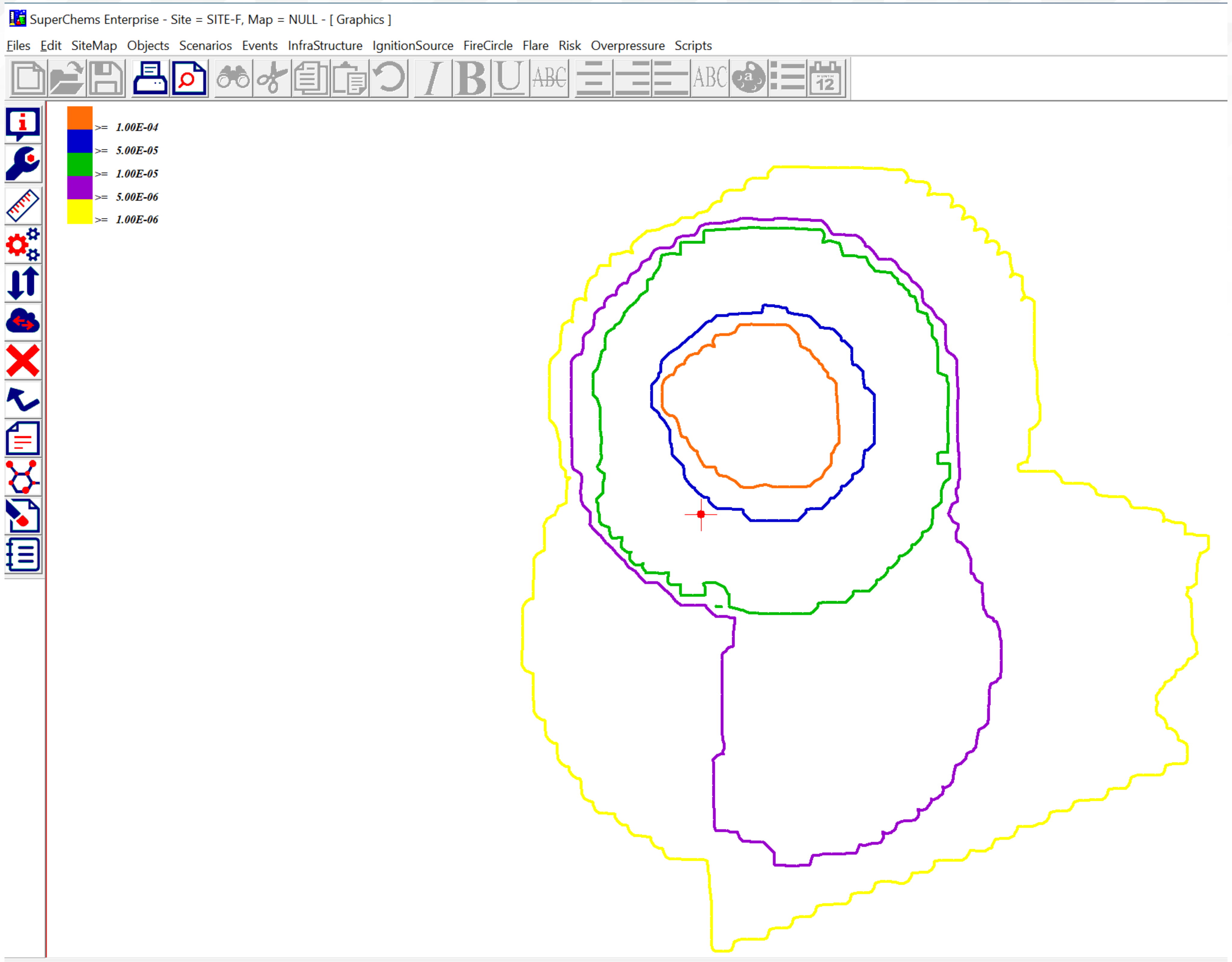




Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

SuperChems™ Risk Calculations – 22 kW/m² Risk Contours (cont.)

- SuperChems™ will now display the risk contours overlaid on the site map
- All equipment located within the 1.00E-05 yr⁻¹ contour requires fixed fire water protection



Source: Process Safety Office® SuperChems™ - ioMosaic Corporation

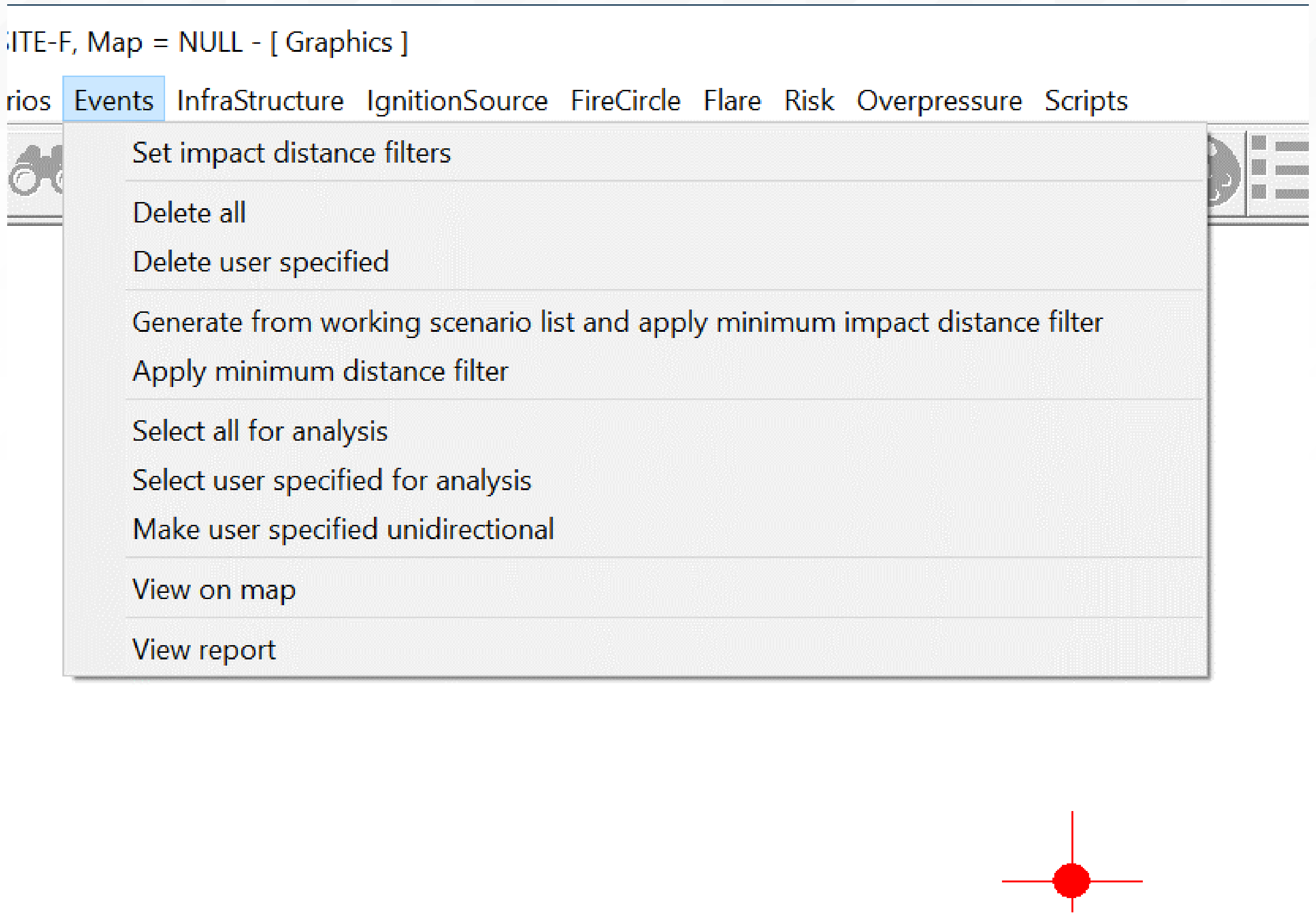
Fire Water Demand Calculation

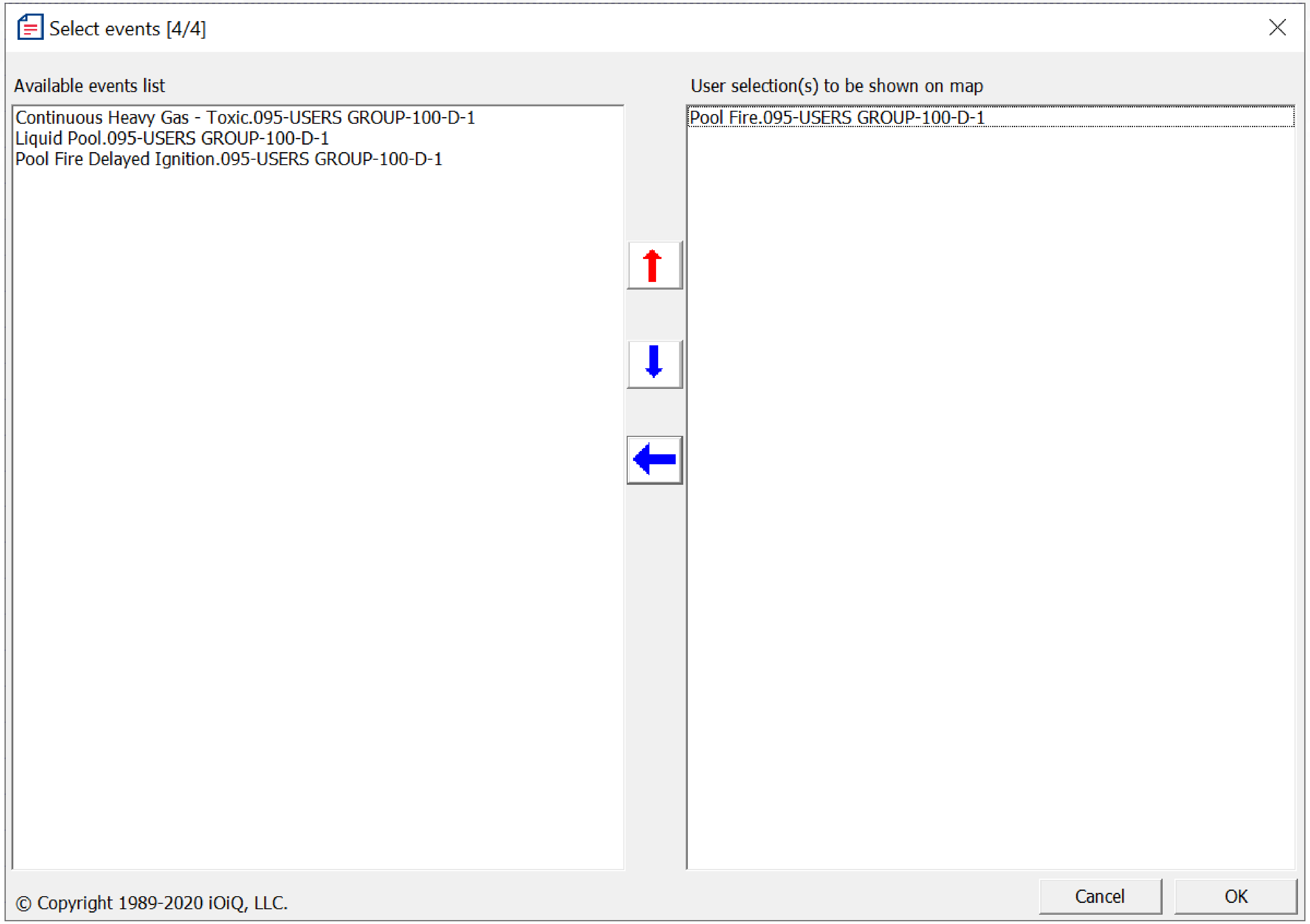
- Now that we know which equipment will require fixed fire water protection, it is necessary to determine the maximum expected demand rate
- This will be based on the consequences of the worst/most severe credible cases determined during the risk analysis
  - In the QRA module under “Events” select View Report to generate a report of all events analyzed
  - Compare the product of frequency and impact distance of each event (remember, risk = consequence x frequency) to determine which events have the highest risk
  - Generally, by designing for “credible” cases it will limit scenarios to the 4” hole size or smaller when determining the maximum fire water demand rate

Fire Water Demand Calculation (cont.)

- Once the worst/most severe credible cases have been determined the consequence results can be overlaid on the site map to show which equipment will require protection simultaneously
  - Under Scenarios, clear working set, then select working set
  - Under events, select user specified for analysis and select the specific event
  - Under events, select view on map

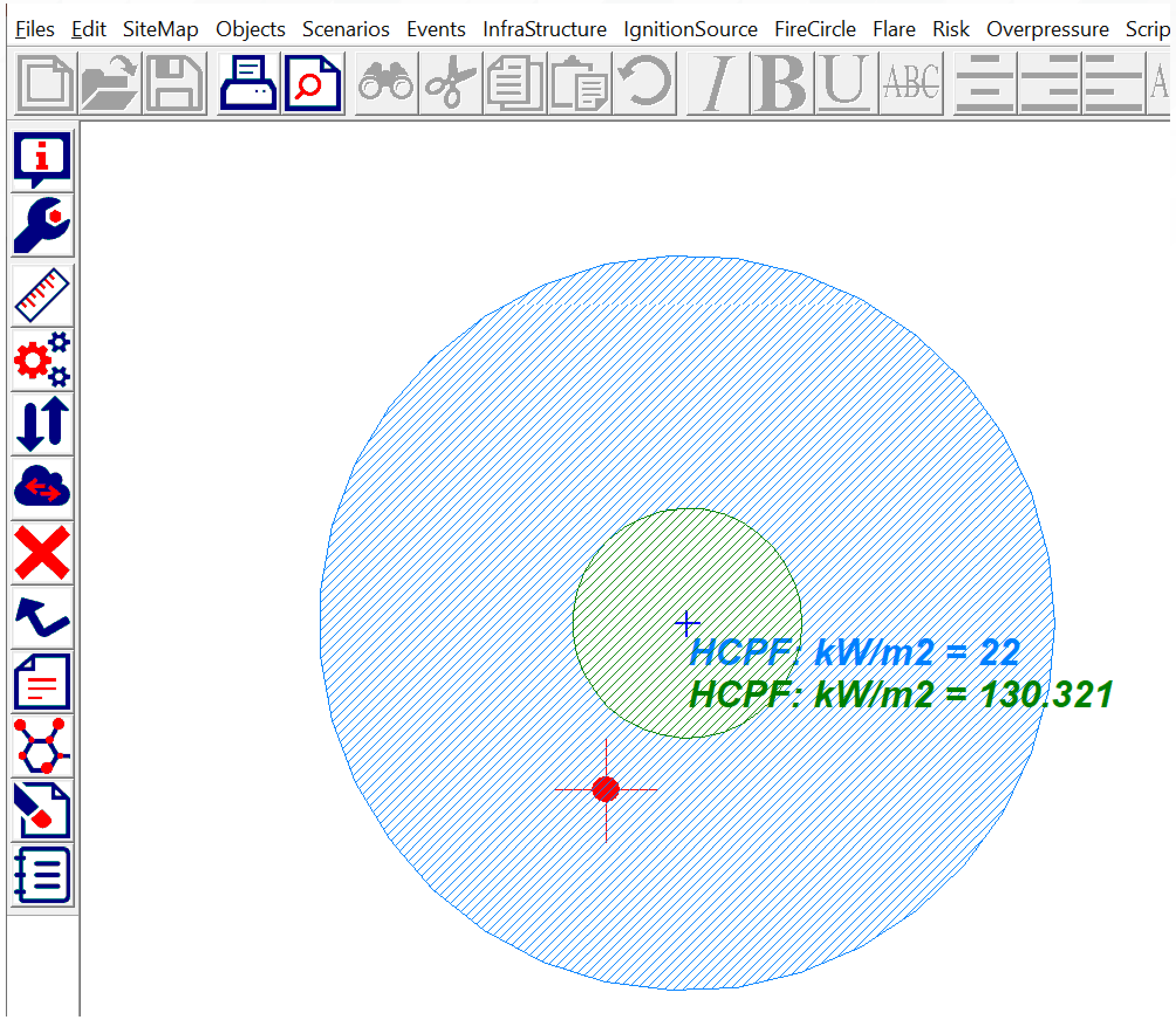
SuperChems™ Risk Calculations (cont.)





Fire Water Demand Calculation (cont.)

- In this example, all equipment within the 22 kW/m² contour will require simultaneous protection
- By plotting the consequences of a pool fire in this way it can show you what equipment are impacted as well as which sides of the equipment will be impacted.
- For example, a large storage tank located West of the pool will only experience heat input on the side facing the pool fire



Fire Water Demand Calculation (cont.)

- Based on the consequence modeling graph a table similar to that below can be used to calculate the actual fire water demand rate based on the equipment surface area and fire water application rates.
- Here we see a 4" hole on TK-104 that affects five different pieces of equipment. Based on the consequence modeling graph it is expected that TK-104 may be engulfed, while the other tanks and process vessels will be exposed to radiant heat

Fire Water System Worst-Case - TK-104 - 4" Hole Size					
Equipment Exposed	Surface Area of Equipment [ft2]	Percentage of Equipment Exposed to Fire	Geographic Area of Equipment Exposed to Fire	Application Rate [gpm/ft2]	Fire Water Demand Rate [gpm]
TK-101	-	0%	N/A	0.00	-
TK-102	-	0%	N/A	0.00	-
TK-103	20,000	50%	Southern Hemisphere	0.20	2,000
TK-104	20,000	100%	All	0.25	5,000
TK-105	20,000	50%	Northern Hemisphere	0.20	2,000
D-100	500	100%	All	0.25	125
D-200	500	100%	All	0.25	125
				Total	9,250

Fire Water Demand Calculation (cont.)

- The total required demand rate is calculated to be 9,250 gpm
- Depending on the size and equipment distribution of your facility it may be necessary to evaluate multiple scenarios at different locations to determine the highest demand rate for each area
- Once the required demand rate is determined for the fire water system a hydraulic model should be developed to determine the adequacy of your fire water network

Questions?

About ioMosaic Corporation

Through innovation and dedication to continual improvement, ioMosaic has become a leading provider of integrated process safety and risk management solutions. ioMosaic has expertise in a wide variety of areas, including pressure relief systems design, process safety management, expert litigation support, laboratory services, training, and software development.

ioMosaic offers integrated process safety and risk management services to help you manage and reduce episodic risk. Because when safety, efficiency, and compliance are improved, you can sleep better at night. Our extensive expertise allows us the flexibility, resources, and capabilities to determine what you need to reduce and manage episodic risk, maintain compliance, and prevent injuries and catastrophic incidents.

Our mission is to help you protect your people, plant, stakeholder value, and our planet.

For more information on ioMosaic, please visit: **www.ioMosaic.com**