SAND2015-7380R

# HyRAM V1.0 User's Manual

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## Contents



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# 1. Introduction

## 1.1. What is HyRAM?

HyRAM is a prototype software toolkit that integrates data and methods relevant to assessing the safety of hydrogen fueling and storage infrastructure. The HyRAM toolkit integrates deterministic and probabilistic models for quantifying accident scenarios, predicting physical effects, and characterizing the impact of hydrogen hazards, including thermal effects from jet fires and thermal pressure effects from deflagration. HyRAM incorporates generic probabilities for equipment failures for nine types of components, and probabilistic models for the impact of heat flux on humans and structures, with computationally and experimentally validated models of various aspects of hydrogen release and flame physics.

HyRAM is a software prototype being developed by Sandia National Laboratories for the U.S. Department of Energy's Fuel Cell Technologies Office (FCTO).

## 1.2. Purpose of this guide

This document provides an example of how to use HyRAM to conduct analysis of a fueling facility. This document will guide users through the software and how to enter and edit certain inputs that are specific to the user-defined facility.

This user's manual is intended to capture the main features of HyRAM version 1.0 (any HyRAM version numbered as 1.0.X.XXX). This user guide was created with HyRAM 1.0.0.433. Due to ongoing software development activities, newer versions of HyRAM may have differences from this guide.

## 1.3. Requirements

HyRAM is a software prototype under active development, copyright 2015 Sandia Corporation. A prototype version of HyRAM is available to a limited group of participants in Sandia's alpha testing program. . Users must sign a government use notice (GUN) to participate in the alpha testing program. Users may not use HyRAM as part of commercial activities. The specific terms of the license can be identified by inquiry made to Sandia Corporation or DOE.

HyRAM was designed to be installed any 32-or-64-bit Intel-compatible computer with more than 4GB/RAM and 4GB free persistent storage (hard drive space), running Microsoft Windows 98 or later.

# 2. Basic Functions

## 2.1. Save/Load Workspace

The Save/Load Workspace function can be found in the File menu at the top left corner of the program window. The Save button functions as a “Save As” button. To save a workspace and the resulting data, click the Save Workspace option. To load a workspace that has been previously saved, click the Load Workspace option.

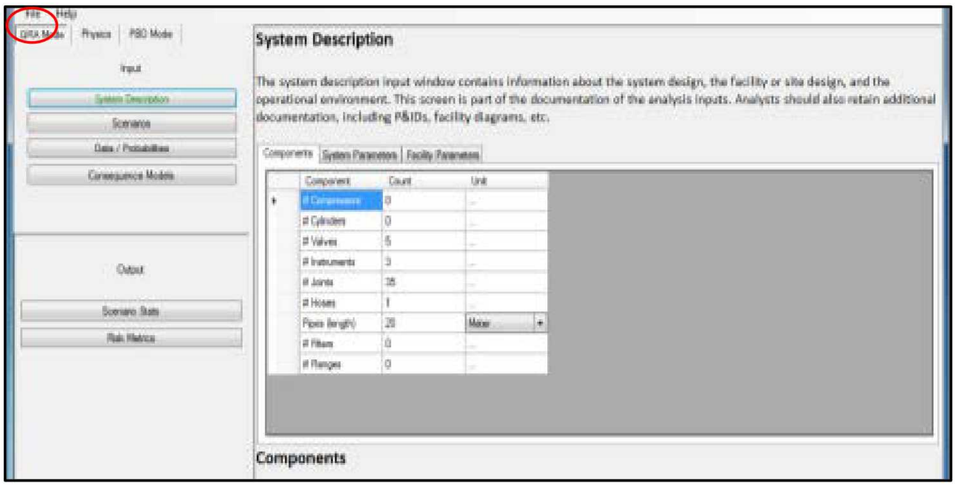



**Figure 1 - Save/Load Workspace**

## 2.2. Changing Units

HyRAM contains a built-in unit conversion function. For variables with a unit, the unit must be selected before inputting a value. If a value is entered before a unit, when a different unit is selected, the software will convert the entered value into the new value corresponding to the selected unit. To change units for a variable, find the drop down bar in the unit column, click on the arrow next to the bar; this will reveal a list of possible units. Click on a new unit to select it.

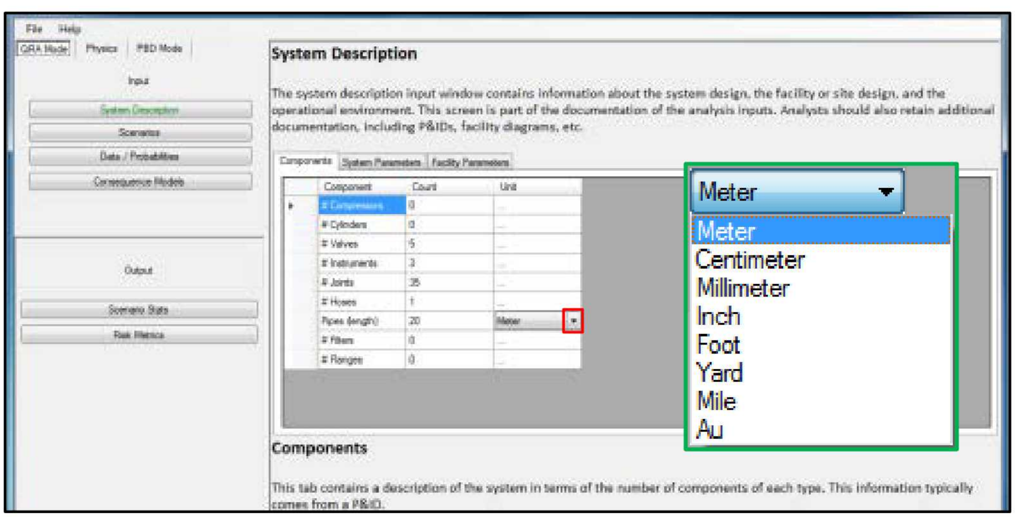



**Figure 2 - Changing Units**

## 2.3. Sorting

All inputs are pre-organized. To change the rank or sorting of a column, click on the title box of the column. This will change the rank to numerical or alphabetical (A to Z) according to that column. Clicking the title box again will reverse the sort order.

Note: Sorting is not enabled for all columns.

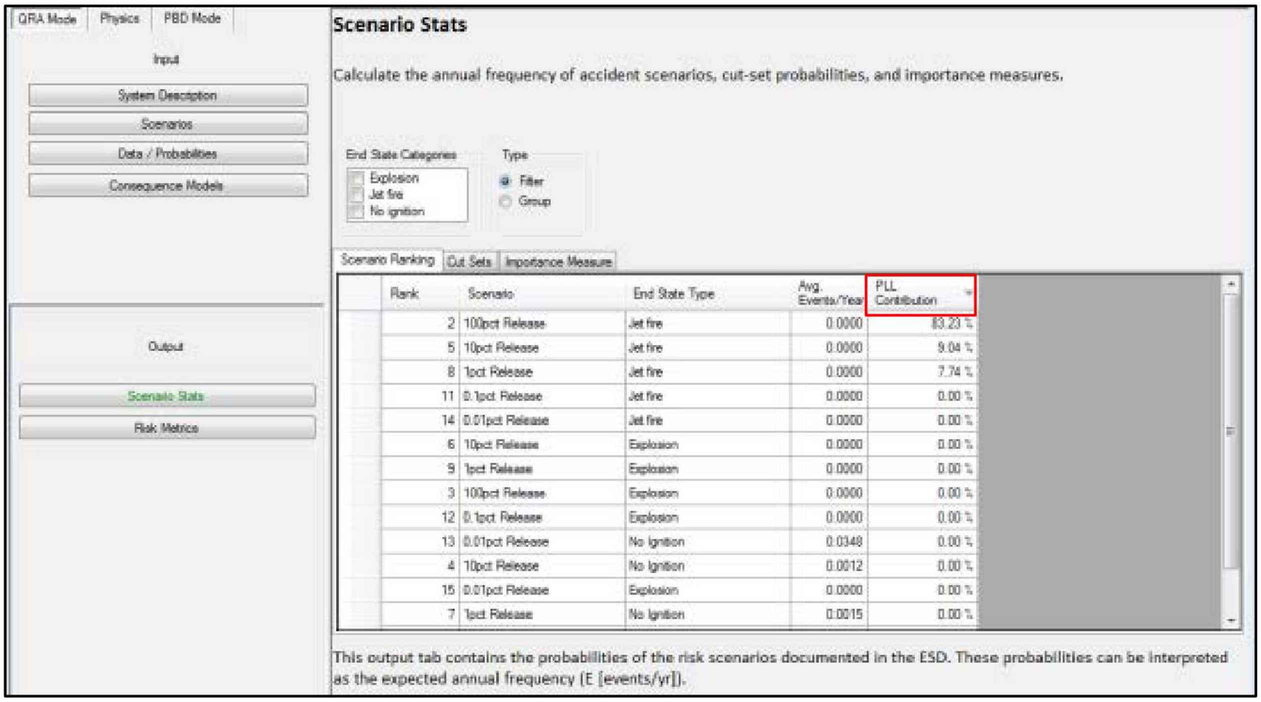



**Figure 3 - Sorting**

## 2.4. Copying tables to paste into other programs

HyRAM tables may be copied into external programs such as Microsoft Word and Excel. To do so, select all of the cells of the table, press Ctrl-C. Tables may be pasted into external programs using Ctrl-V or the pasting options defined by the external program.

## 3. Example case

For this document, the inputs are based off of a generic indoor fueling system that was designed with NFPA 2 requirements and industry practices. The example installation in this example is based off of the indoor fueling example further documented in [1] and [2].

The system is a hydrogen dispenser located within a warehouse facility. The facility is a free-standing industrial frame structure. Interior dimensions are: 100m (length) x 100m (width) x 7.62m (height).There are 50 employees in the warehouse at any time. Personnel each work 2000 hours per year. In this example, most workers are located within 50m of the dispenser due building design. The vehicle fleet contains 150 vehicles that are operated 24hrs/day and 350days/yr. Each vehicle holds 1kg of hydrogen and is refueled once per day.

The dispenser delivers gaseous hydrogen at 35MPa. The dispenser operates for up to 5 minutes per fueling event, and the internal hydrogen temperature is 15°C. All tubing in the storage system is 3/8" Outer Diameter (OD), 0.065" wall, ASTM A269 seamless 316 stainless steel tubing. The facility temperature is 15°C and pressure is atmospheric (0.101325 MPa). Figure 4 contains the Piping and Instrumentation Diagram (P&ID) for the generic dispenser. The part count only includes components inside the building and on the main process line: 1 hose (3m length); Pipe: 20m; Valves: 5 (ASV2, HV1, BC1, SRV1, N1); Instruments: 3; Joints: 35. The system also contains additional components (not pictured) from indoor supply: 2 cylinders, 2 valves, 2 instruments, 8 joints, 10m piping.

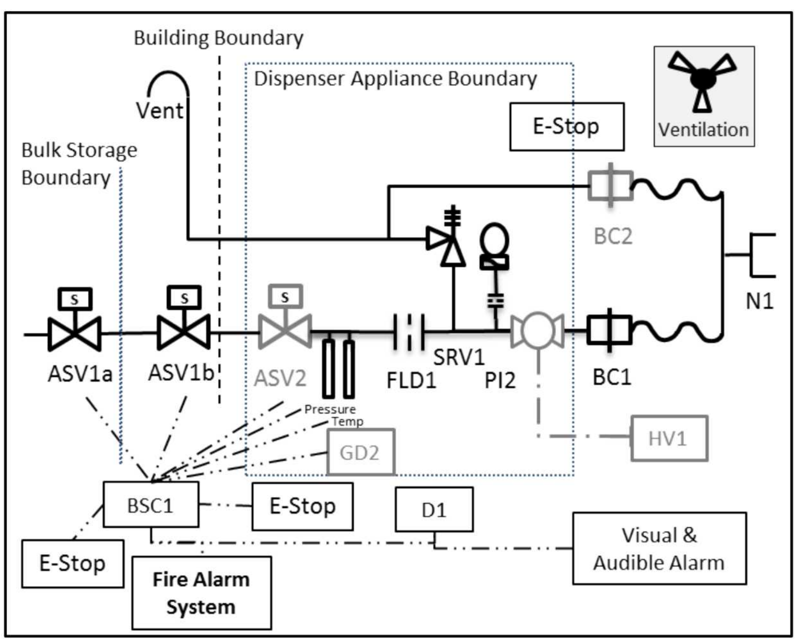



**Figure 4 – P&ID for the generic dispenser used in this example**

# 4. QRA Mode – Input

## 4.1. System Description

The System Description Window contains three tabs (Components, System Parameters, and Facility Parameters) which enable the user to input design specifics about the system.

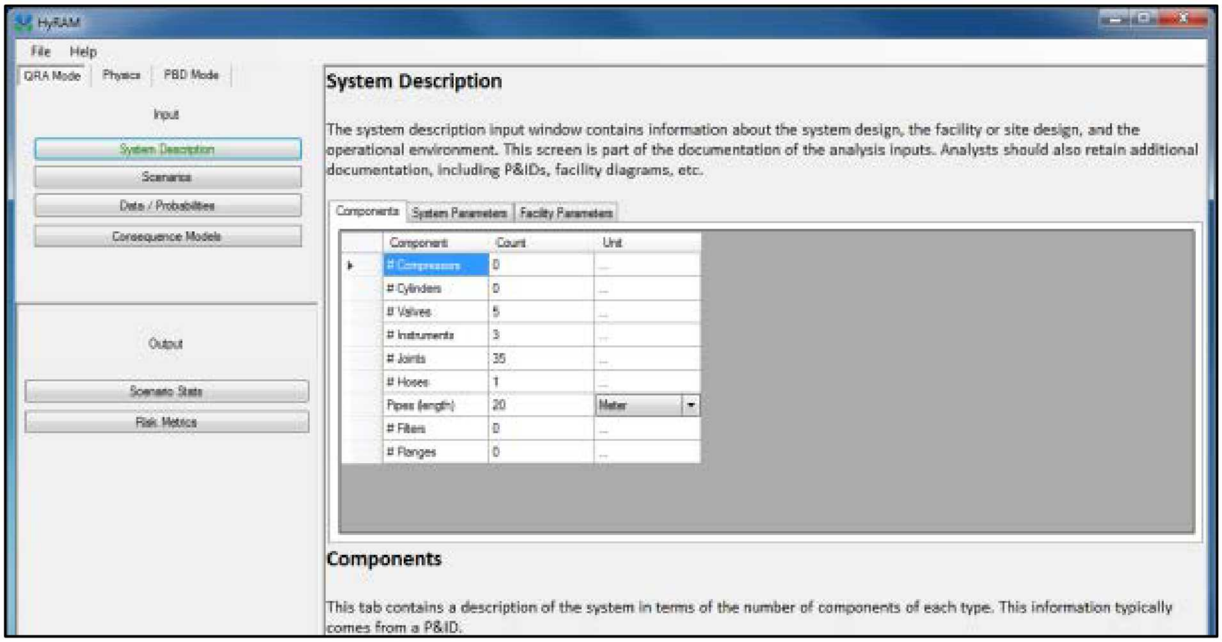
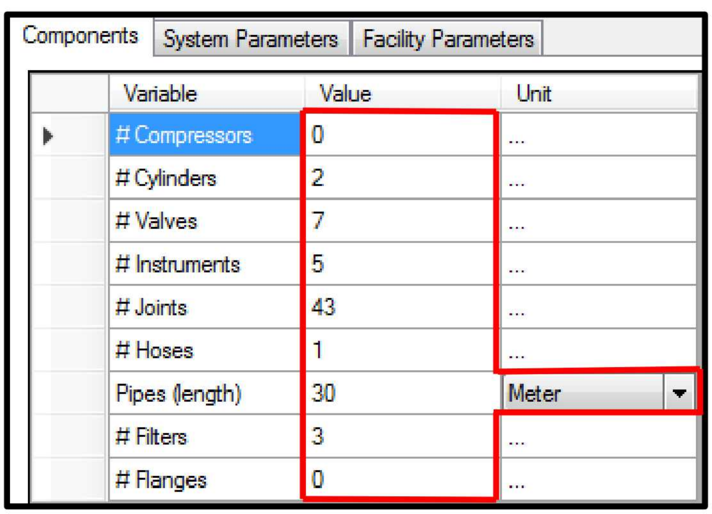



**Figure 5 - System Description Window**

### 4.1.1. Components

The Components Tab contains user input for the number of components of nine types. Refer to a P&ID for the proper number of components. Based on the preceding example, the Components input would be:



Components | System Parameters | Facility Parameters

| Variable | Value | Unit |
|---|---|---|
| # Compressors | 0 | ... |
| # Cylinders | 2 | ... |
| # Valves | 7 | ... |
| # Instruments | 5 | ... |
| # Joints | 43 | ... |
| # Hoses | 1 | ... |
| Pipes (length) | 30 | Meter |
| # Filters | 3 | ... |
| # Flanges | 0 | ... |

**Figure 6 - Components input window**

### 4.1.2. System Parameters

The System Parameters Tab contains Piping and Vehicle Input. This information can be found in the P&ID and the description of the facility.

#### *4.1.2.1. Piping*

The Piping Tab contains inputs for pipe dimensions of the system and the operating conditions (both internal to the system and in the surrounding external environment). This information is used in calculations for release sizes and characteristics. Based on the preceding example, Piping input would be:

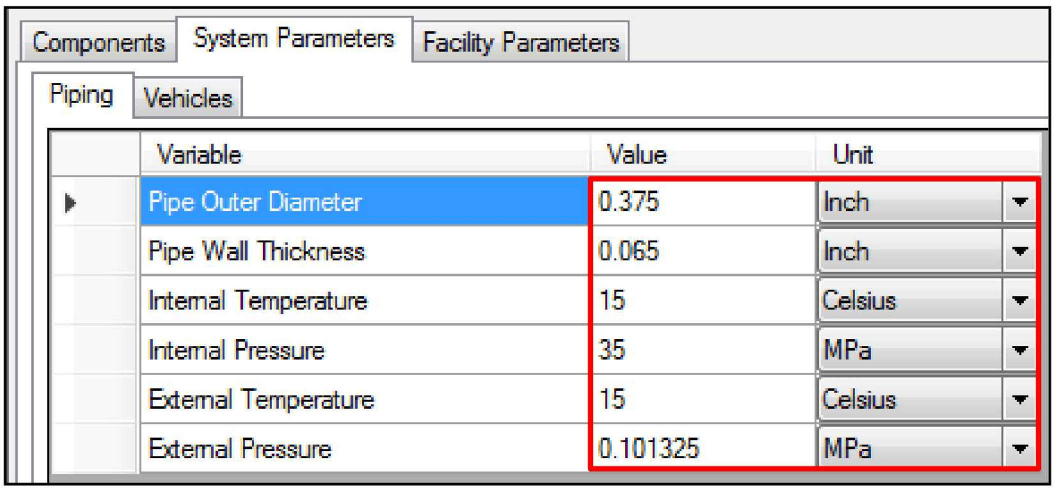



**Figure 7 - Piping input window**

#### *4.1.2.2. Vehicles*

The Vehicles Tab contains inputs for that establish the use conditions of the station. Users input the number of vehicles, the number of fuelings per vehicle, per day, and the number of operating days of the vehicles. HyRAM calculates the demands/yr is the product of those three inputs. Based on the preceding example, Vehicles input would be:

Note: The annual number of demands is used in the calculation of the frequency of releases from elements contained in the FT. If a FT is not used, the user should input 0 for one of the inputs.

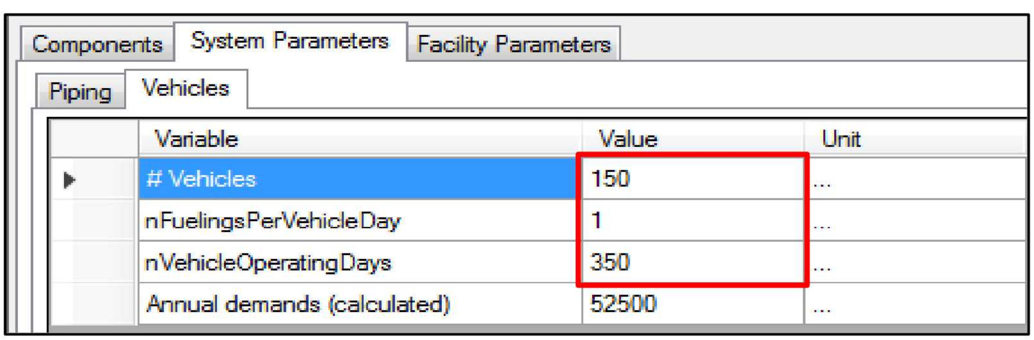



**Figure 8 - Vehicles Input**

### 4.1.3. Facility Parameters

The Facility Parameters Tab contains Facility and Occupants Input.

#### *4.1.3.1. Facility*

Warning: This input is not yet used in any calculations. User input is for documentation only.

The Facility Tab contains measurements for the entire facility. Based on the preceding example, Facility input would be:

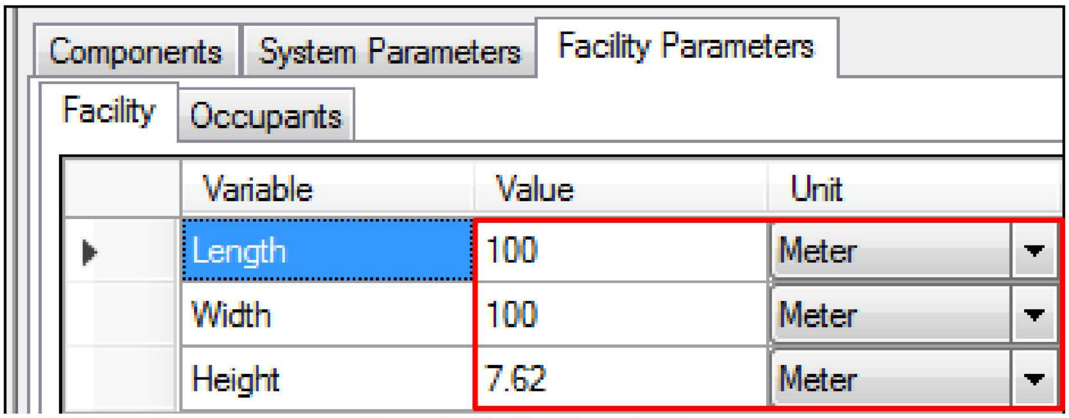



**Figure 9 – Facility dimensions input**

#### *4.1.3.2. Occupants*

The Occupants Tab contains Input details for number of persons on site (e.g., exposed employees) and a function to randomly assign the worker positions based on either a uniform distribution or a normal distribution. This information is used to assign the location ((i.e., the distance from the system) of persons, which are used in harm calculations.

Based on the preceding example, the occupants tab input would be:

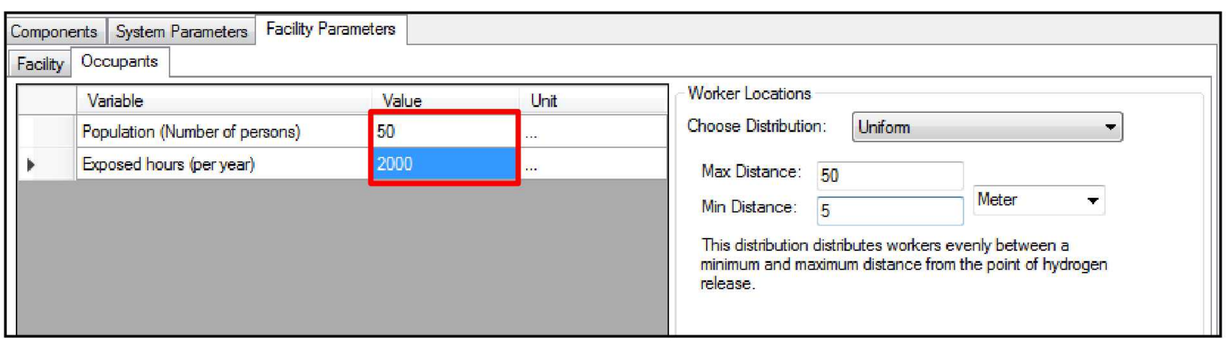



**Figure 10 - Input detail for occupants tab**

These distributions are used to assign determine personnel locations (i.e., the distance from the system, for use in harm calculations).Distribution is available in two options, Normal and Uniform.

Worker positions relative to the storage system could be randomly assigned by sampling form a normal distribution. For the example case, the workers are assumed to be within 50m (we translate this assumption into a normal distribution centered at the dispenser (mu=0) and a standard deviation of 50/3 =16.67. ($\mu$=0, $\sigma$=16.67). Based on the preceding example, Normal Distribution input is shown in Figure 11.

Uniform Distribution distributes worker positions relative to the storage system based on the maximum and minimum distances from the storage system.

Worker positions relative to the storage system are assigned by evenly distributing positions between the maximum distance of an employee from the storage system, 50m, and the minimum distance of an employee from the storage system, 0m. Based on the preceding example, Uniform Distribution input is shown in Figure 12.

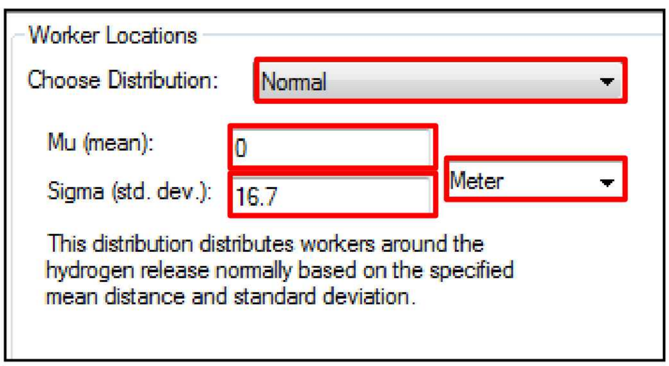



**Figure 11 - Normal Distribution**

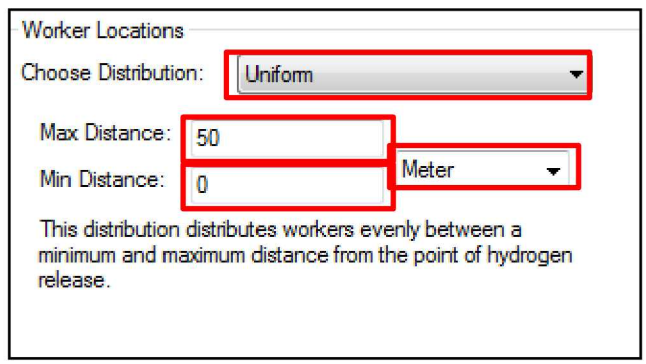



**Figure 12 - Uniform Distribution**

## 4.2. Scenarios

The Scenarios Window contains Event Sequence Diagrams (ESDs), which model the hydrogen release scenarios, and Fault Trees, which model causes of hydrogen releases. Note: The ESDs and FT cannot be modified in HyRAM1.0.

### 4.2.1. Event Sequence Diagrams

The Event Sequence Diagrams Tab illustrates the scenarios that could occur after a hydrogen release, depending on the success of detection/isolation and the time of ignition.

There are three possible outcomes from a hydrogen release scenario: jet fires, explosions, and unignited releases. If hydrogen is not ignited (either due to successful detection/isolation of the leak, or due to lack of ignition), there are no risk-significant consequences. When a high-pressure leak of hydrogen is immediately ignited near the source, the result is a classic turbulent-jet flame. If hydrogen is not immediately ignited, hydrogen can accumulate. If the accumulated hydrogen is subsequently ignited (delayed ignition), the result is an explosion.

The Event Sequence Diagram coded in HyRAM models these scenarios. The user may input a value (between 0.0 and 1.0) for gas and flame detection credit (the probability of successful leak detection and isolation before ignition). This value is the probability associated with the ESD event *yes/true* (upper branch) for a single node "Leak detected and isolated (illustrated as two nodes in Figure 13, but treated as a single node in the HyRAM logic).

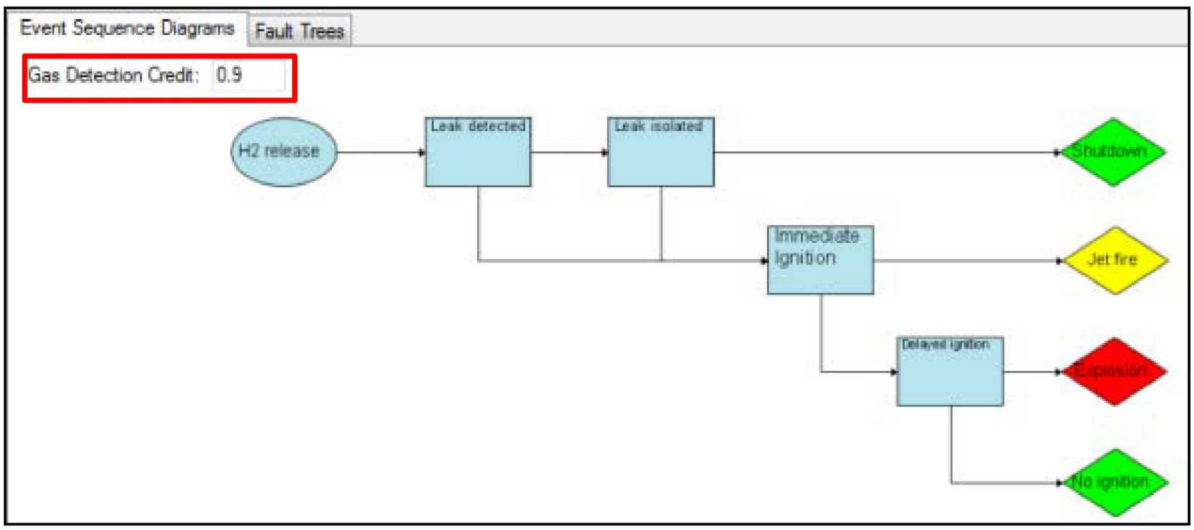



**Figure 13 - Event Sequence Diagram showing the scenarios coded in HyRAM.**

#### 4.2.2. Fault Trees

Warning: This feature is not active (as of version 1.0.0.443) The top event probability from these FTs (5.5e-9 failures/demand) is hard-coded into HyRAM: this value is multiplied by the annual number of demands from Section 4.1.2.2, and the resulting sum is added to the frequency of 100% releases. The models contained on this tab are placeholders for future models.

### 3.3. Data/Probabilities

The Data/Probabilities Window contains the probability of Component Leaks, Component Failures, and Ignition.

#### 3.3.1. Component Leaks

The Component Leaks Tab contains assumptions about the frequency of leaks of five size categories, from nine types of components. The size categories are percentages (0.01%, 0.1%, 1%, 10%, and 100% of the pipe area which is calculated from the user input described in Section 4.1.2.1).

HyRAM contains default values for the frequency of releases from each type of component. These frequencies were assembled from generic data from offshore oil, process chemical, and nuclear power industries and documented in [3]. The values in HyRAM are encoded as parameters of a lognormal distribution (*mu* and *sigma*). HyRAM automatically calculates the mean and variance from a given mu and sigma. Users may modify the component leak probabilities by entering new values for mu and sigma for any component

The default Component Leaks for compressors is:

Component Leaks | Component Failures | Ignition Probabilities

Compressors | Cylinders | Filters | Flanges | Hoses | Joints | Pipes | Valves | Instruments

| Leak Size | Mu | Sigma | Mean | Variance |
|---|---|---|---|---|
| 0.01% | -1.72 | 0.21 | 1.83e-001 | 1.58e-003 |
| 0.10% | -3.92 | 0.48 | 2.23e-002 | 1.32e-004 |
| 1.00% | -5.14 | 0.79 | 8.01e-003 | 5.55e-005 |
| 10.00% | -8.84 | 0.84 | 2.06e-004 | 4.31e-008 |
| 100.00% | -11.34 | 1.37 | 3.04e-005 | 5.11e-009 |

**Figure 14 - Component Leaks Input**

### 3.3.2. Component Failures

Warning: This feature is not active (as of version 1.0.0.443) The Component Failures Tab contains the likely failures of specific components, and the parameters of the probability that these failures will occur.

Component Leaks | Component Failures | Ignition Probabilities

Component Failures

| Component | Failure Mode | Distribution Type | Parameter A | Parameter B |
|---|---|---|---|---|
| Nozzle | Pop-off | Beta | 0.5 | 610415.5 |
| BC | Failure to close | Beta | 0.5 | 5031 |
| PRV | Premature open | Beta | 4.5 | 310288.5 |
| PRV | Failure to open | LogNormal | -11.7359368859313 | 0.667849415603714 |
| HV | FTC (human error) | ExpectedValue | 0.001 | |
| ASV | Failure to close | ExpectedValue | 0.002 | |
| ASV | Common cause ... | ExpectedValue | 0.0001276595744... | |
| Nozzle | Failure to close | ExpectedValue | 0.002 | |

Accidents

| Accident | Distribution Type | Parameter A | Parameter B |
|---|---|---|---|
| Driveoff | Beta | 31.5 | 610384.5 |
| Overpressure during fueling | Beta | 3.5 | 310289.5 |

**Figure 15 - Component Failures input window concept**

### 3.3.3. Ignition Probabilities

The Ignition Probabilities Tab contains possible ignition flow rate thresholds and the probability that they will ignite immediately (leading to a jet fire) or with a delay (leading to an explosion).

The default input is based on HySafe values for probabilities of hydrogen ignition. Users may input different values for immediate and/or delayed ignition for any of the defined release rates. Users may also add new release rate categories and remove the current categories.

To add a new Ignition Flow Rate Threshold, enter the value in the kg/s box and click the Add button.To delete an Ignition Flow Rate Threshold, click on the value you want to delete in the Ignition Flow Rate Threshold box and click the Delete Selected button.

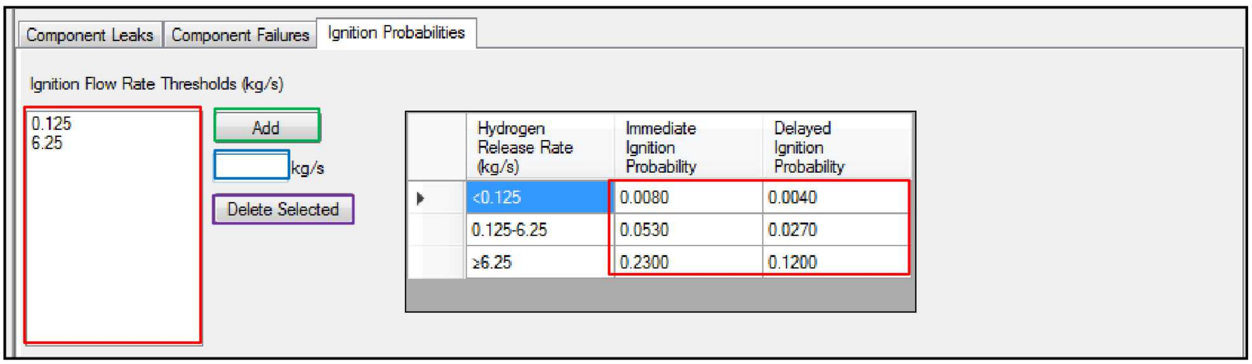



**Figure 16 - Ignition Probabilities Input**

## 3.4 Consequence Models

The Consequence Models Window contains a selection of models used to calculate the physical effects of ignited releases and the probability of harm from a known physical effect.

### 3.4.1. Physical Consequence Models

The Physical Consequence Models Tab contains the Notional Nozzle Model, Flame Radiation Model, and Deflagration Model.

The default selections for physical effect models are the Birch2 notional nozzle model, Houf/Schefer (straight flame) flame radiation model, and Bauwens/Ekoto deflagration model. The default options can be changed by selecting another option from the dropdown menu. Note: Not all model selections are available in HyRAM 1.0alpha.

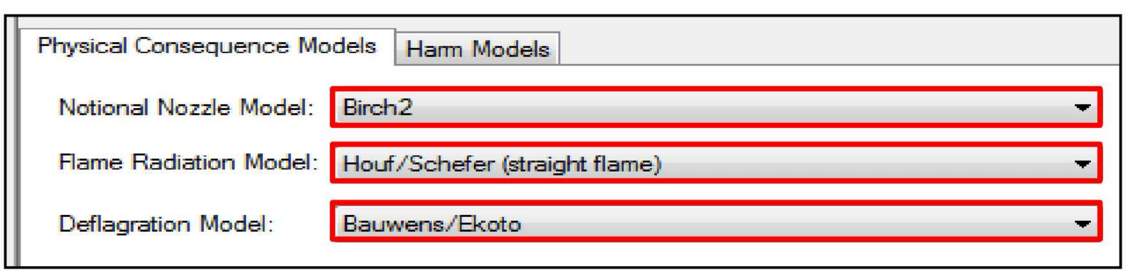



**Figure 17 - Physical Consequence Models Input**

The Deflagration Model has two options, Bauwens/Ekoto (not yet active) and CFD. The CFD model model requires an input of peak overpressure , P_s (default units are Pa) and impulse (always in Pa/sec) for the five release categories.

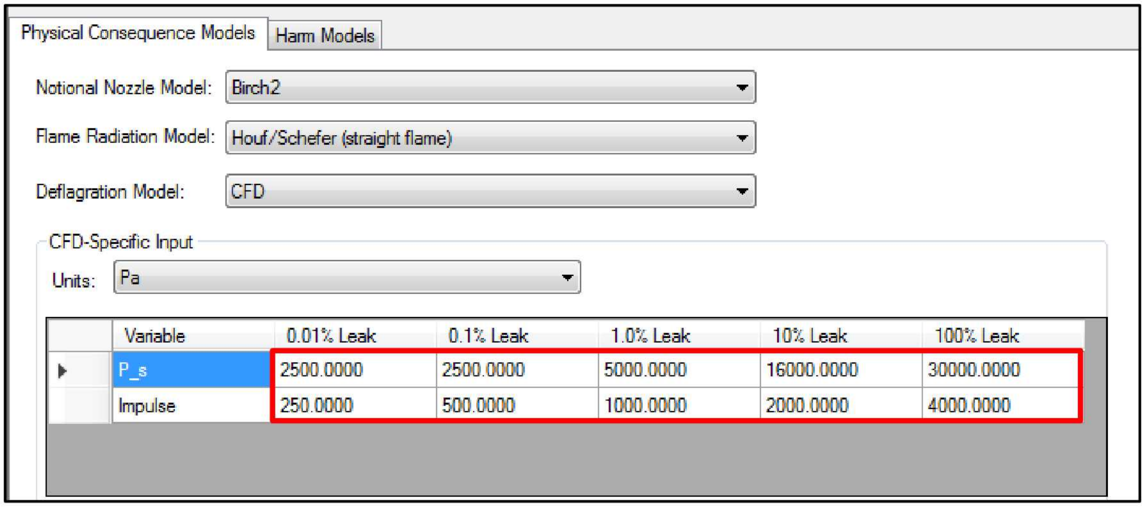



**Figure 18 - CFD input window**

### 3.4.2. Harm Models

The Harm Models Tab contains the Thermal Probit Model and the Overpressure Probit Model. Users may select the preferred probit models by clicking the drop-down next to the model name.

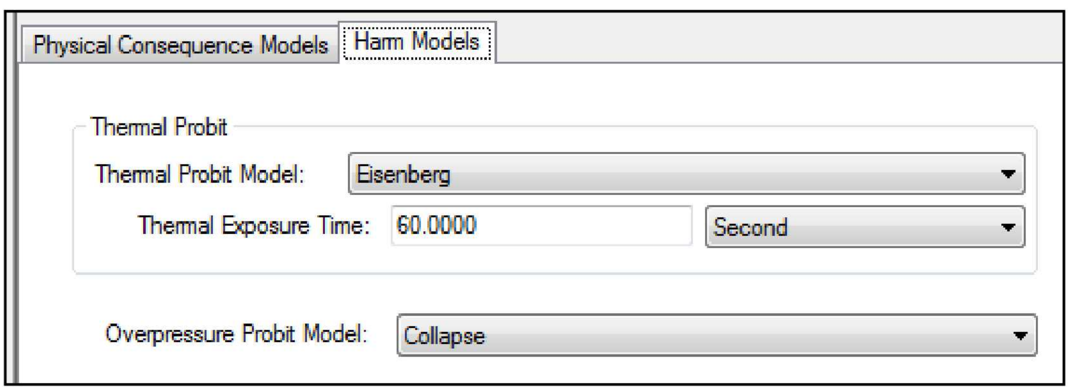



**Figure 19 – Harm model selection window**

# 4. QRA Mode – Output

## 4.1. Scenario Stats

The Scenario Stats window is divided into three sections: Scenario Ranking, Cut Sets, and Importance Measures.

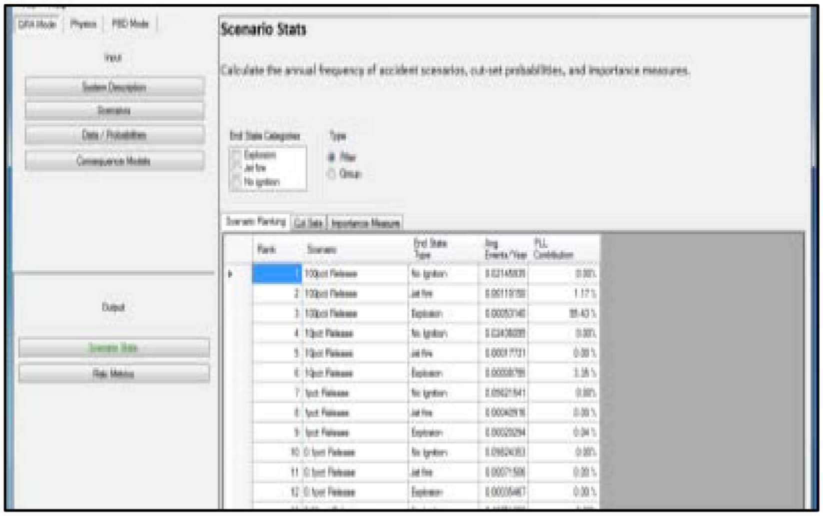



**Figure 20 - Scenario Stats Window**

### 4.1.1. Scenario Ranking

The Scenario Ranking Tab contains the end state types, frequencies, and PLL contribution for all leak sizes. By default, the results are sorted by leak size. These results can be sorted by any of the headings by clicking on the heading name (we recommend sorting by Avg. Events/Year or by PLL). Based on previous examples/inputs, the Scenario Ranking output would be:

Scenario Ranking | Cut Sets | Importance Measure

| Rank | Scenario | End State Type | Avg. Events/Year | PLL Contribution |
|---|---|---|---|---|
| 1 | 100pct Release | No Ignition | 0.0220 | 0.00 % |
| 2 | 100pct Release | Jet fire | 0.0001 | 20.09 % |
| 3 | 100pct Release | Explosion | 0.0001 | 77.32 % |
| 4 | 10pct Release | No Ignition | 0.0223 | 0.00 % |
| 5 | 10pct Release | Jet fire | 0.0000 | 0.00 % |
| 6 | 10pct Release | Explosion | 0.0000 | 2.57 % |
| 7 | 1pct Release | No Ignition | 0.0452 | 0.00 % |
| 8 | 1pct Release | Jet fire | 0.0000 | 0.00 % |
| 9 | 1pct Release | Explosion | 0.0000 | 0.03 % |
| 10 | 0.1pct Release | No Ignition | 0.0550 | 0.00 % |
| 11 | 0.1pct Release | Jet fire | 0.0000 | 0.00 % |
| 12 | 0.1pct Release | Explosion | 0.0000 | 0.00 % |
| 13 | 0.01pct Release | No Ignition | 0.1616 | 0.00 % |
| 14 | 0.01pct Release | Jet fire | 0.0001 | 0.00 % |
| 15 | 0.01pct Release | Explosion | 0.0001 | 0.00 % |

**Figure 21 - Scenario Ranking Output**

The filter option allows users to view the Scenario results tab for an individual end state type. To filer the results, click which end state type(s) you would like to have isolated in the End State Categories box. The grouping option is not currently enabled.

End State Categories: ☐ Explosion, ☑ Jet fire, ☐ No ignition
Type: ◉ Filter, ○ Group

Scenario Ranking | Cut Sets | Importance Measure

| Rank | Scenario | End State Type | Avg. Events/Year | PLL Contribution |
|---|---|---|---|---|
| 2 | 100pct Release | Jet fire | 0.0001 | 20.09 % |
| 5 | 10pct Release | Jet fire | 0.0000 | 0.00 % |
| 8 | 1pct Release | Jet fire | 0.0000 | 0.00 % |
| 11 | 0.1pct Release | Jet fire | 0.0000 | 0.00 % |
| 14 | 0.01pct Release | Jet fire | 0.0001 | 0.00 % |

**Figure 22 – Scenario results filtered to show only jet fire end states**

#### 4.1.2. Cut Sets

The Cut Sets Tab is currently Display Only – no results are generated in V1.0.0.443.

#### 4.1.3. Importance Measure

The Importance Measure Tab is currently Display Only – no results are generated in V1.0.0.443.

### 4.2. Risk metrics

The Risk Metrics Window contains the results of the calculated risk in terms of Fatal Accident Rate (FAR), Potential Loss of Life (PLL), and Average Individual Risk (AIR).

Based on previous examples/inputs, the Risk Metrics output would be:

| Risk Metric | Value | Unit |
|---|---|---|
| Potential Loss of Life (PLL) | 1.170e-03 | Fatalities/system-year |
| Fatal Accident Rate (FAR)/100M exposed hours | 0.2672 | Fatalities in 10^8 person-hours |
| Average individual risk (AIR) | 5.345e-06 | Fatalities/year |

**Figure 23 - Risk Metrics Output**

# 5. Physics Mode

## 5.1. Jet Flame

### 5.1.1. Plot T/Plot Iso

The Plot T/Plot Iso window contains variables that calculate and plot flame characteristics.Plot T is the plot of the flame's temperature versus distance from the flame source. Plot Iso is the plot of isometric counters of where heat fluxreaches three specific values: 1.577kW/m2 (no harm to humans for long exposures) 4.732 kW/m2, (Pain after after 20s possible first degree burn) and 25.237 kW/m2 (100% lethality to humans from a 60s exposure):

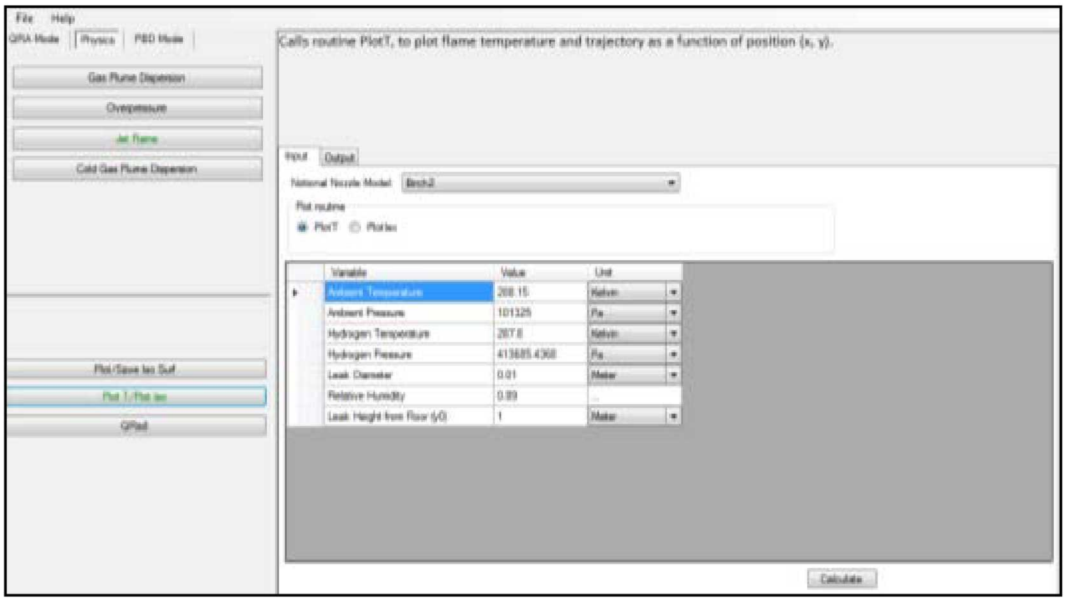



**Figure 24- Plot T/Plot Iso input window**

The Plot Iso contains a selection box for the radiation source methodology: multiple radiation sources, or single point radiation source.

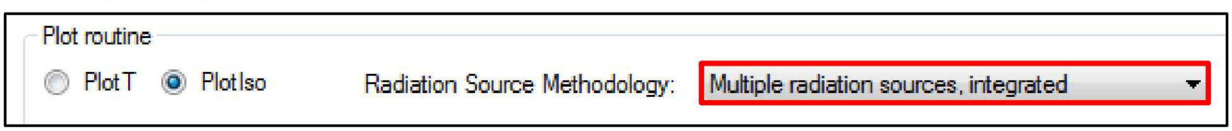



**Figure 25– Selection box for radiation source methodology**

In this example, we model a low pressure hydrogen storage tank located in a warehouse that is 15°C, has a relative humidity of 0.89, and has a pressure of 1.01325 Bar. The hydrogen within the storage system is 14.5°C and is under a pressure of 4.137 Bar. The dispenser experiences a leak with a diameter 0.01m. The leak height from the floor is 1m.

Based on the preceding example, the Plot T/Plot Iso input would be:

| | Variable | Value | Unit |
|---|---|---|---|
| ▶ | Ambient Temperature | 15 | Celsius |
| | Ambient Pressure | 1.01325 | Bar |
| | Hydrogen Temperature | 14.5 | Celsius |
| | Hydrogen Pressure | 4.137 | Bar |
| | Leak Diameter | 0.01 | Meter |
| | Relative Humidity | 0.89 | ... |
| | Leak Height from Floor (y0) | 1 | Meter |

**Figure 26- Plot T/Plot Iso Input**

The resulting Plot T output would be:

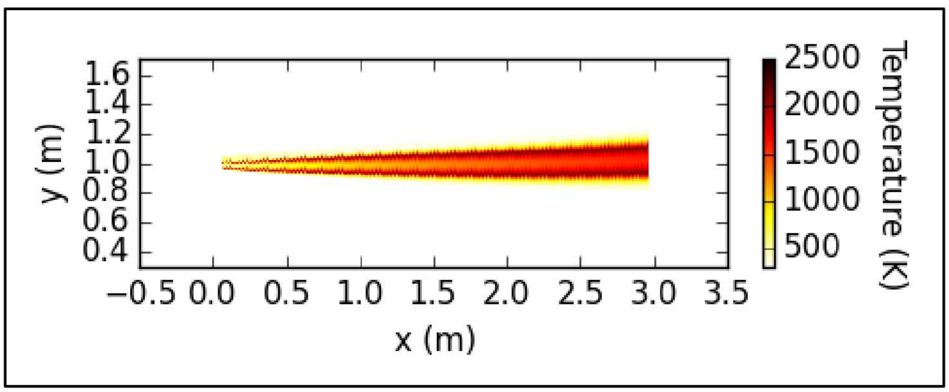



**Figure 27- Plot T Output**

With a single point radiation source, the resulting Plot Iso output would be:

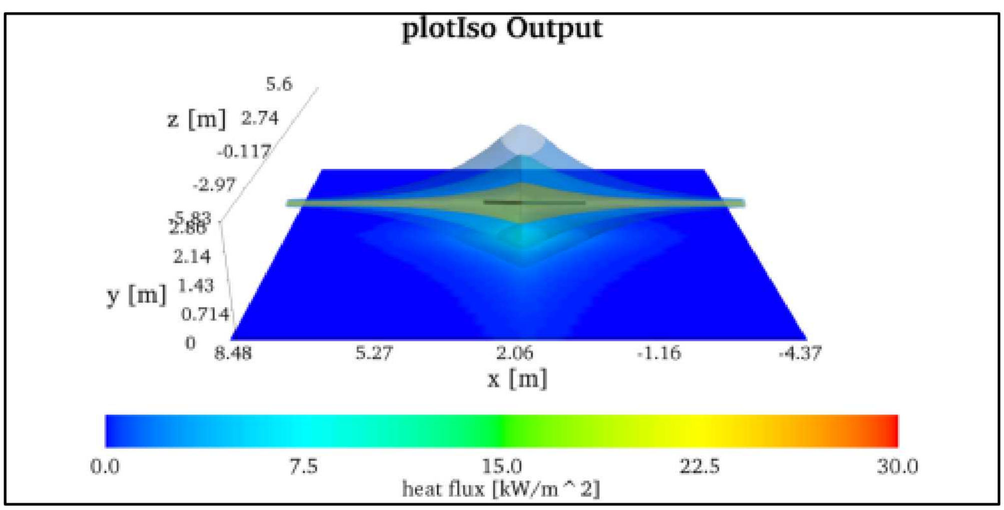



**Figure 28 - Plot Iso Single Point Radiation Source Output**

With multiple radiation sources, the resulting Plot Iso output would be:

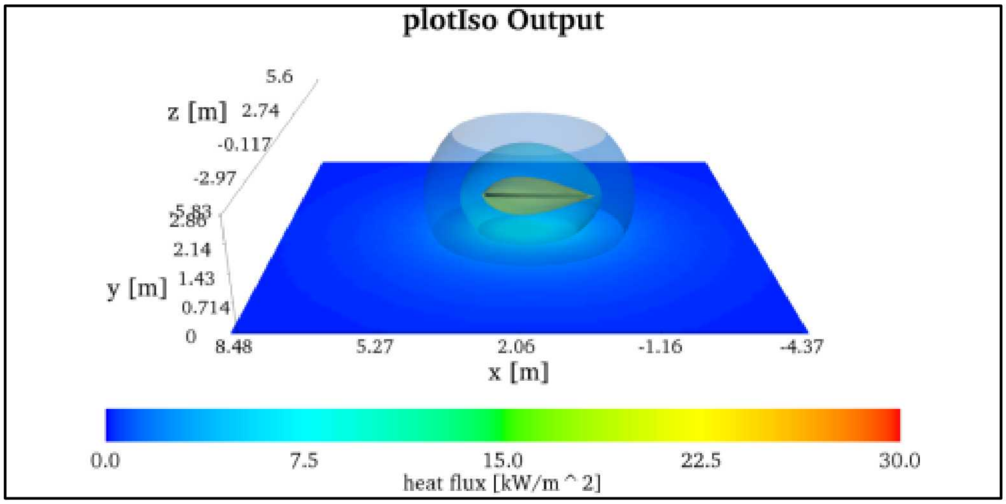



**Figure 29- Plot Iso Multiple Radiation Sources Output**

### 5.1.2. QRad

The QRad window contains the variables and calculations of a heat flux plot.

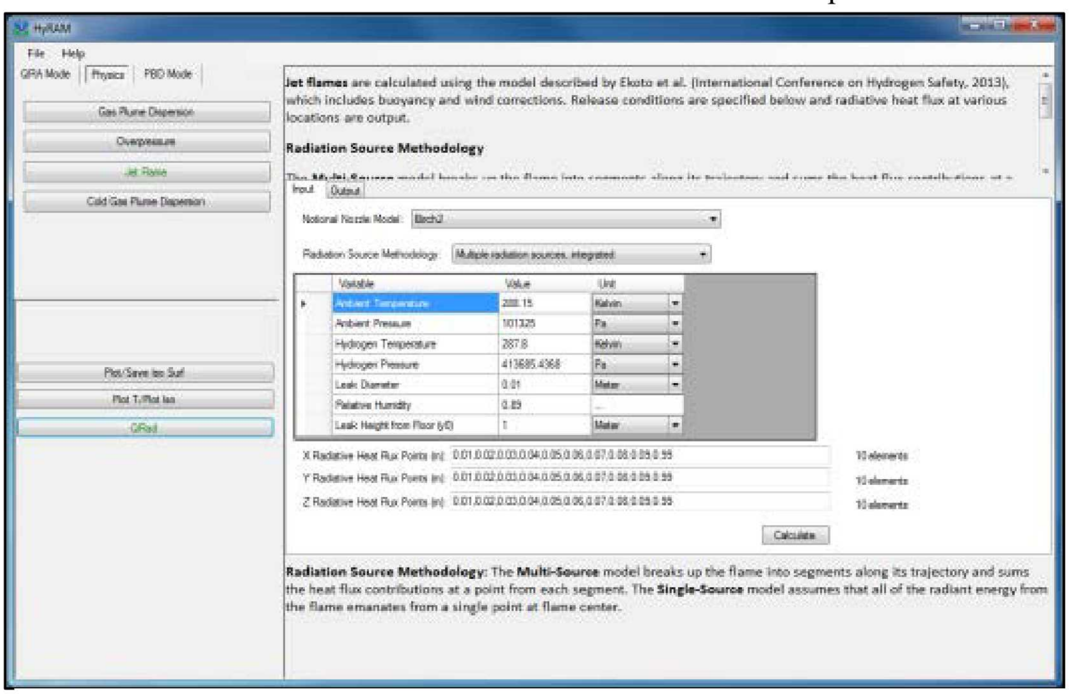



**Figure 30 – Qrad input window**

The low pressure storage system is located in a warehouse that is 15°C, has a relative humidity of 0.89, and has a pressure of 1.01325 Bar. The hydrogen within the storage system is 14.5°C and is under a pressure of 4.137 Bar. The dispenser experiences a leak with a diameter 0.01m. The leak height from the floor is 1m. There are multiple sources of radiation. The flame and trajectory is displayed by the notional nozzle model: Birch2. Flame temperature samples are taken every meter away from the jet flame up to 10 meters and are measured by width (x), length (z), and height (y).

Based on the preceding example, the QRad input would be:

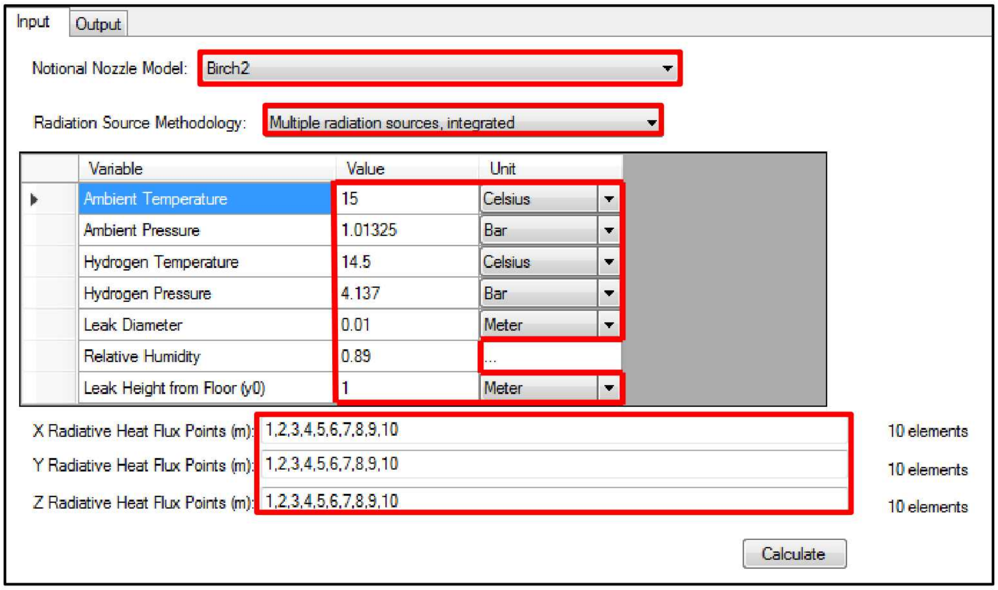
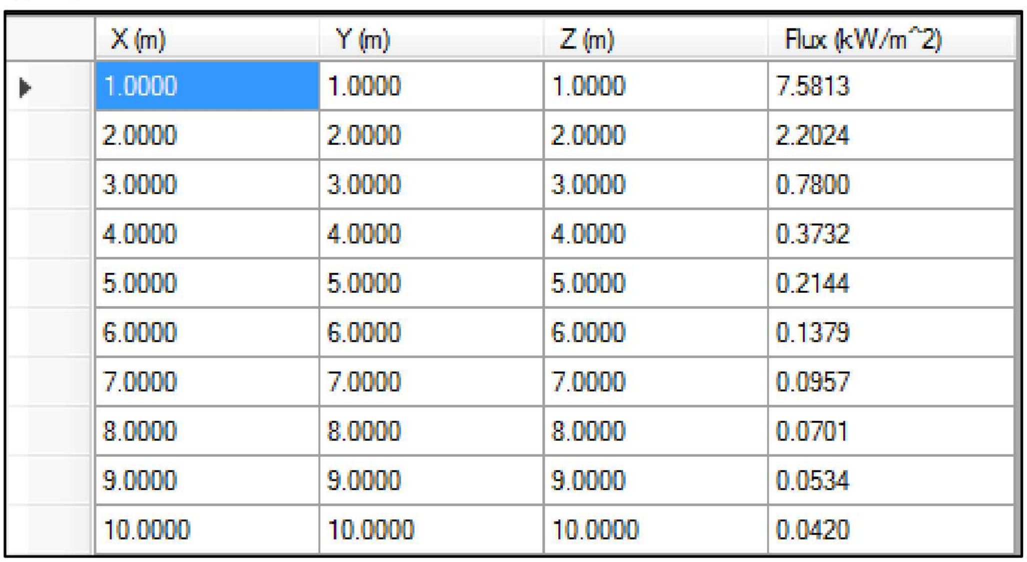



**Figure 31 - QRad Input**

The resulting output would be:



| X (m) | Y (m) | Z (m) | Flux (kW/m^2) |
|---|---|---|---|
| 1.0000 | 1.0000 | 1.0000 | 7.5813 |
| 2.0000 | 2.0000 | 2.0000 | 2.2024 |
| 3.0000 | 3.0000 | 3.0000 | 0.7800 |
| 4.0000 | 4.0000 | 4.0000 | 0.3732 |
| 5.0000 | 5.0000 | 5.0000 | 0.2144 |
| 6.0000 | 6.0000 | 6.0000 | 0.1379 |
| 7.0000 | 7.0000 | 7.0000 | 0.0957 |
| 8.0000 | 8.0000 | 8.0000 | 0.0701 |
| 9.0000 | 9.0000 | 9.0000 | 0.0534 |
| 10.0000 | 10.0000 | 10.0000 | 0.0420 |

**Figure 32 - QRad Output**

5.2. Overpressure

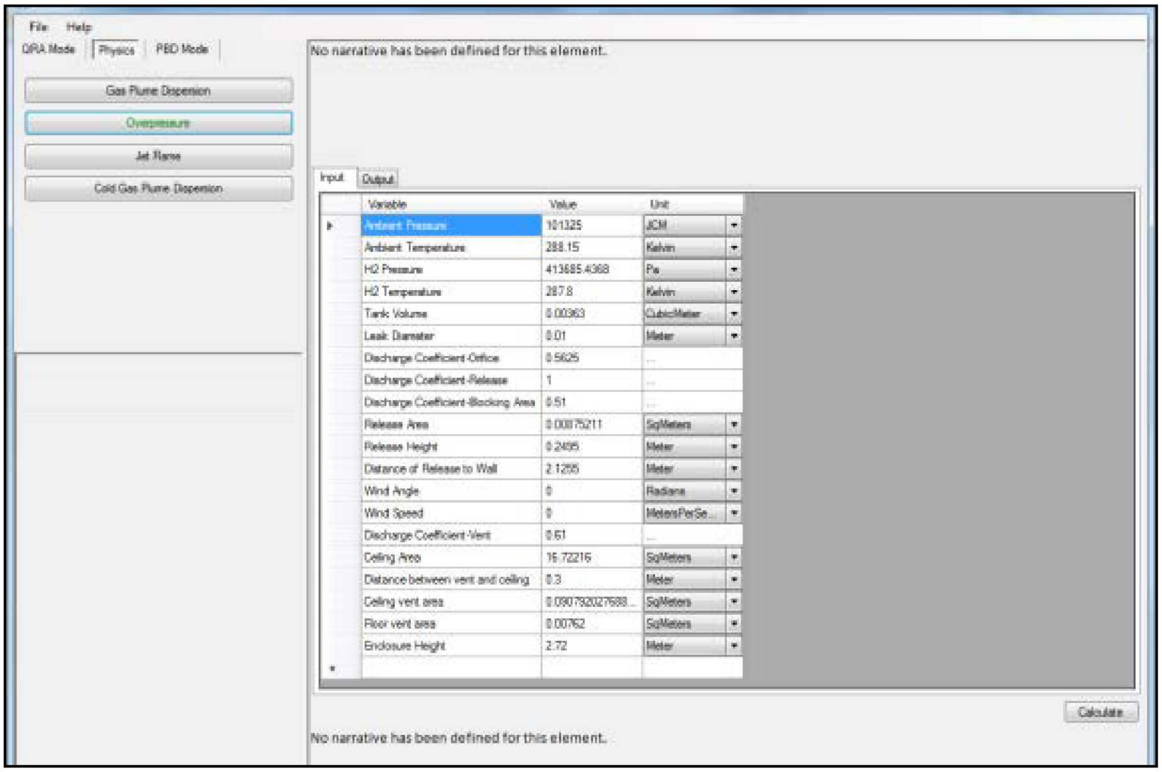


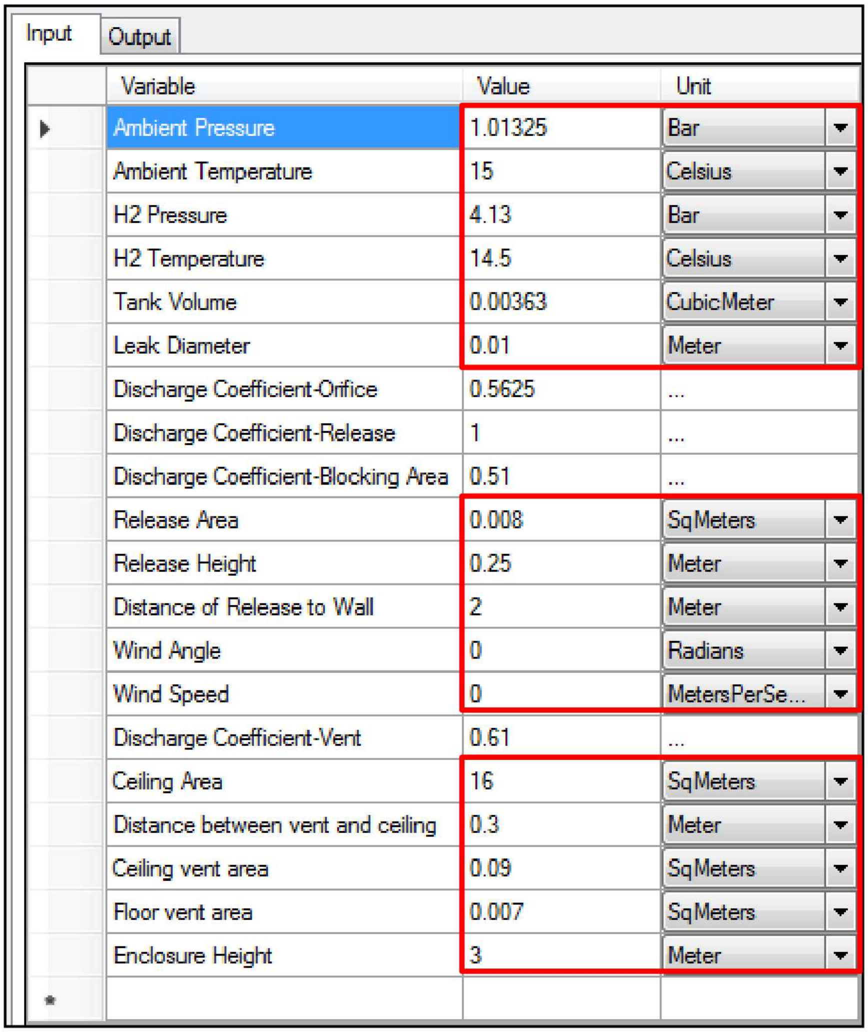

**Figure 33 - Overpressure Input Window**

### 5.2.1. Overpressure Input

The Input Tab contains measurements for Overpressure of the storage system.

Ex: The enclosure contains one tank that is 0.00363m³. The tank holds hydrogen at a pressure of 4.13 Bar and a temperature of 14.5°C. The enclosure's interior dimensions are: 4m (length) x 4m (width). The enclosure height is 3m. The area of the ceiling is 16m². There is one ceiling vent and one floor vent. The ceiling vent area is 0.09m² and the floor vent area is 0.007m². The ceiling vent is 0.3m from the actual ceiling. The temperature and pressure of the enclosure are 15°C and 1.01325 Bar, respectively. There is no wind around the enclosure. The tank experiences overpressure, resulting in a leak. The leak's diameter is 0.01m. The area of the leak is 0.008m² and reaches a height of 0.25m. The distance between the leak and the enclosure wall is 2m.

Based on the preceding example, the Overpressure input would be:



Input | Output

| Variable | Value | Unit |
|---|---|---|
| Ambient Pressure | 1.01325 | Bar |
| Ambient Temperature | 15 | Celsius |
| H2 Pressure | 4.13 | Bar |
| H2 Temperature | 14.5 | Celsius |
| Tank Volume | 0.00363 | CubicMeter |
| Leak Diameter | 0.01 | Meter |
| Discharge Coefficient-Orifice | 0.5625 | ... |
| Discharge Coefficient-Release | 1 | ... |
| Discharge Coefficient-Blocking Area | 0.51 | ... |
| Release Area | 0.008 | SqMeters |
| Release Height | 0.25 | Meter |
| Distance of Release to Wall | 2 | Meter |
| Wind Angle | 0 | Radians |
| Wind Speed | 0 | MetersPerSe... |
| Discharge Coefficient-Vent | 0.61 | ... |
| Ceiling Area | 16 | SqMeters |
| Distance between vent and ceiling | 0.3 | Meter |
| Ceiling vent area | 0.09 | SqMeters |
| Floor vent area | 0.007 | SqMeters |
| Enclosure Height | 3 | Meter |

**Figure 34 - Overpressure input window**

### 5.2.2. Output

Warning: This feature will change in the next release after V1.0.0.443). The current output for Overpressure is:

| Value |
|---|
| 3.187E+012 |
| 3.000E+001 |

# 5. Summary of HyRAM input and output parameters

## 5.2. QRA Mode Input

### 5.2.1. System Description Input

The System Description window contains information about the system itself, such as the components, system parameters, and facility parameters.

| HyRAM Input Screen | HyRAM Input Parameter | Example User Input Values |
|---|---|---|
| Components | Compressors | 1 |
| | Cylinders | 3 |
| | Valves | 34 |
| | Instruments | 11 |
| | Joints | 10 |
| | Hoses | 2 |
| | Pipes (length in meters) | 3 |
| | Filters | 3 |
| | Flanges | 0 |
| System Parameters- Piping | Pipe OD | 1.7145 cm |
| | Pipe wall thickness | 0.23114 cm |
| | Internal Temperature | 15 C |
| | Internal Pressure | 1034 bar |
| | External Temperature | 15 C |
| | External Pressure | 1.01325 bar |
| System Parameters - Vehicles | Number of Vehicles | 50 |
| | # Fuelings Per Vehicle Day | 1 |
| | Vehicle Operating Days | 360 |
| | Annual demands (calculated from categories above) | 18,000 |
| Facility Parameters- Facilities | Length | 100 m |
| | Width | 100 m |
| | Height | 100 m |
| Occupants | Population | 1 |
| | Working hours per year | 6480 hrs |
| | Distribution | Uniform |
| | Max Distance | 53 m |
| | Min Distance | 53 m |

### 5.2.2. Scenarios

The Scenarios window contains different scenarios and outcomes displayed as event sequence diagrams and fault trees. In the current version of HyRAM, these defaults cannot be modified.

### 5.2.3. Data/Probabilities

The Data/Probabilities window contains the probability of certain events to occur, such as component leaks, component failures, and ignition. Users may modify the ignition probabilities and the component leak probabilities. The component failures tab is inactive in V1.0.0.443.

### 5.2.4. Consequence Models

The Consequence Models window contains selectors for the different models used to calculate physical effects of ignited releases and the probability of harm from a known physical effect.

| HyRAM Input Screen | HyRAM Input Parameter | Example user Input Values |
|---|---|---|
| Consequence Models - Physical Consequence | Notional Nozzle | Birch2 |
| | Flame Radiation Model | Ekoto/Houf (curved flame) |
| | Deflagration Model | CFD<br>P_s = [0,0,0,0,0]<br>Impulse = [0,0,0,0,0] |
| Model Parameters - Harm | Thermal Probit | Tsao |
| | Thermal Exposure | 60 sec |
| | Overpressure Probit | Lung Eisenberg |

## 5.3. QRA Mode Output

### 5.3.1. Risk Metrics

The Risk Metrics window calculates risk in terms of Fatal Accident Rate (FAR), Potential Loss of Life (PLL), and Average Individual Risk (AIR).

| Risk metric | Value | Unit |
|---|---|---|
| Potential Loss of Life (PLL) | 1.044e-05 | Fatalities/system-year |
| Fatal Accident Rate (FAR)/100M exposed hours | 0.0024 | Fatalities in 10^8 person-hours |
| Average individual risk (AIR) | 4.768e-08 | Fatalities/year |

### 5.3.2. Scenario Stats

The Scenario Stats window displays the probabilities of risk scenarios and calculates frequencies of accident scenarios, cut-set probabilities, and importance measures. (Only scenario ranking is active in current version. Cut sets and important measures are placeholders for future versions).

| Rank | Scenario (start) | End state type | Avg. events/yr | PLL contribution |
|---|---|---|---|---|
| 1 | 100pct Release | No Ignition | 0.0008 | 0.00 % |
| 2 | 100pct Release | Jet fire | 0.0000 | 83.23 % |
| 3 | 100pct Release | Explosion | 0.0000 | 0.00 % |
| 4 | 10pct Release | No Ignition | 0.0012 | 0.00 % |
| 5 | 10pct Release | Jet fire | 0.0000 | 9.04 % |
| 6 | 10pct Release | Explosion | 0.0000 | 0.00 % |
| 7 | 1pct Release | No Ignition | 0.0015 | 0.00 % |
| 8 | 1pct Release | Jet fire | 0.0000 | 7.74 % |
| 9 | 1pct Release | Explosion | 0.0000 | 0.00 % |
| 10 | 0.1pct Release | No Ignition | 0.0050 | 0.00 % |
| 11 | 0.1pct Release | Jet fire | 0.0000 | 0.00 % |
| 12 | 0.1pct Release | Explosion | 0.0000 | 0.00 % |
| 13 | 0.01pct Release | No Ignition | 0.0348 | 0.00 % |
| 14 | 0.01pct Release | Jet fire | 0.0000 | 0.00 % |
| 15 | 0.01pct Release | Explosion | 0.0000 | 0.00 % |

## 5.4. Physics Input

### 5.4.1. Jet Flame Input windows

| HyRAM Input Parameter | Example input value |
|---|---|
| Notional Nozzle Model | Birch 2 |
| Radiation Source Methodology | Multiple radiation sources, integrated |
| Ambient Temperature | 15 C |
| Ambient Pressure | 1 atm |
| Hydrogen Temperature | 20 C |
| Hydrogen Pressure | 700 bar |
| Leak Diameter | 0.1 cm |
| Relative Humidity | 0.89 |
| Leak Height from Ground | 1 m |
| X radiative heat flux points (m) (Flame centerline) | 0.1,1,2,3,5,10,20,25,30,50 |
| Y radiative heat flux points (m) (Vertical) | 1,1,1,1,1,1,1,1,1,1 |
| Z radiative heat flux points (m) (Perpendicular to flame) | 0,0,0,0,0,0,0,0,0,0 |

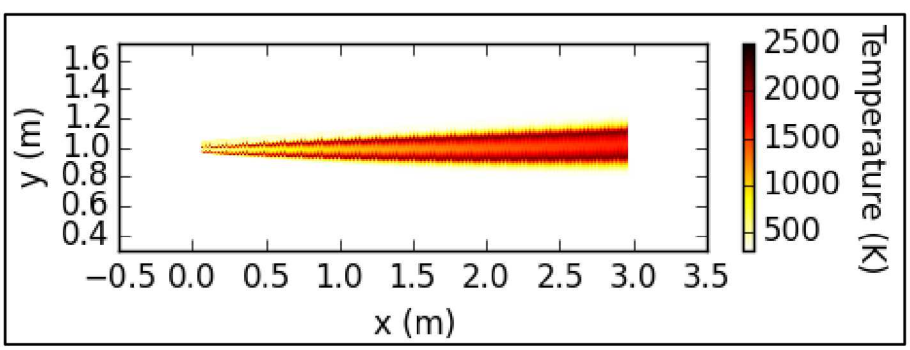
### 5.4.2. Overpressure Input

| HyRAM Input Parameter | Example Input Value |
|---|---|
| Ambient Pressure | 1 |
| Ambient Temperature | 288.15 |
| H2 Pressure | 413685.4368 |
| H2 Temperature | 287.8 |
| Tank Volume | 0.00363 |
| Leak Diameter | 0.01 |
| Discharge Coefficient-Orifice | 0.5625 |
| Discharge Coefficient-Release | 1 |
| Discharge Coefficient-Blocking Area | 0.51 |
| Release Area | 0.00875211 |
| Release Height | 0.2495 |
| Distance of Release to Wall | 2.1255 |
| Wind Angle | 0 |
| Wind Speed | 0 |
| Discharge Coefficient-Vent | 0.61 |
| Ceiling Area | 16.72216 |
| Distance between vent and ceiling | 0.3 |
| Ceiling vent area | 0.090792027688745 |
| Floor vent area | 0.00762 |
| Enclosure Height | 2.72 |

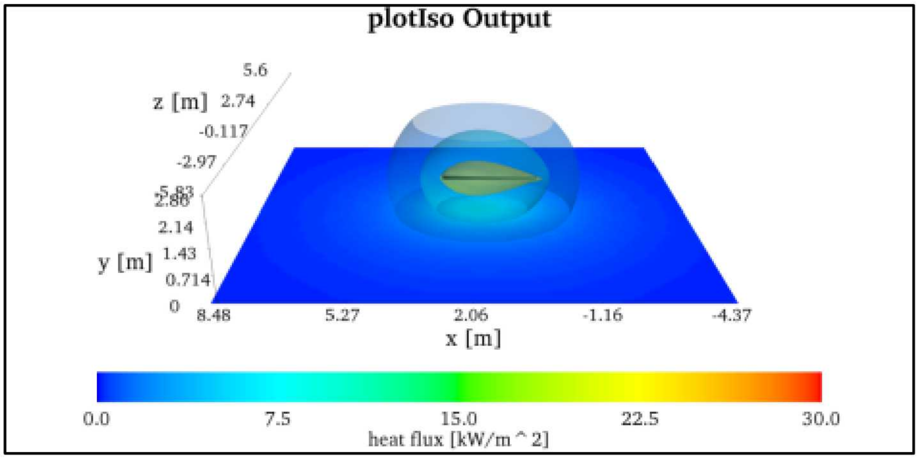
## 5.5. Physics Mode Outputs

### 5.5.1. Jet Flame Output windows

PlotT outputs a figure illustrating the flame temperature (K) at position (x, y):



Plot ISO outputs a figure illustrating three dimensional contours of where reaches three specific values: 1.577kW/m$^2$ (no harm for long exposures) 4.732 kW/m$^2$, (Pain after after 20s possible first degree burn) and 25.237 kW/m$^2$ (100% lethality from a 60s exposure):




Qrad outputs radiative heat flux *kW/m^2) at position [X,Y,Z]:

| X (m) | Y (m) | Z (m) | Flux (kW/m^2) |
|---|---|---|---|
| 0.1 | 1 | 0 | 107.5162 |
| 1 | 1 | 0 | 4721.8748 |
| 2 | 1 | 0 | 3470.9343 |
| 3 | 1 | 0 | 23.1591 |
| 5 | 1 | 0 | 1.4066 |
| 10 | 1 | 0 | 0.1923 |
| 20 | 1 | 0 | 0.0368 |
| 25 | 1 | 0 | 0.0222 |
| 30 | 1 | 0 | 0.0148 |
| 50 | 1 | 0 | 0.0048 |

## 6. References

[1] .K. M. Groth, J. L. LaChance and A. P. Harris (2013). "Design-stage QRA for indoor vehicular hydrogen fueling systems;" *Proceedings of the European Society for Reliability Annual Meeting (ESREL 2013)*, Amsterdam, September 29 - October 2.

[2] K. M. Groth, J. L. LaChance and A. P. Harris (2012). *Early-Stage Quantitative Risk Assessment to Support Development of Codes and Standard Requirements for Indoor Fueling of Hydrogen Vehicles*. SAND2012-10150, Sandia National Laboratories, Albuquerque, NM November.

[3] J. LaChance, W. Houf, B. Middleton and L. Fluer (2009), *Analyses to Support Development of Risk-Informed Separation Distances for Hydrogen Codes and Standards*. SAND2009-0874, Sandia National Laboratories, Albuquerque, NM March.