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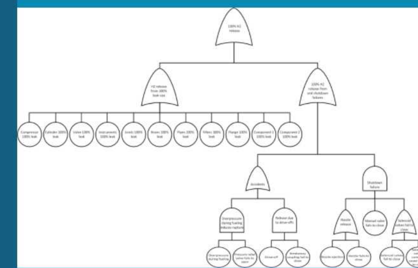
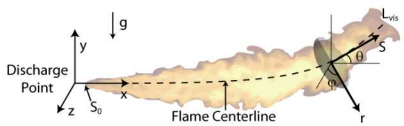
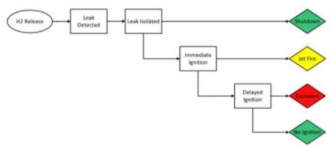


Overview and Development of Hydrogen Risk Assessment Models (HyRAM)





PRESENTED BY

Brian Ehrhart

Web Meeting with NREL Team

8/8/2019

SAND2019-XXXX PE

Introduction to Risk Assessment

Risk takes both **likelihood** and **consequence** into account

Likelihood measures how often or how probable an event is

- Frequency (events per year)
- Probability

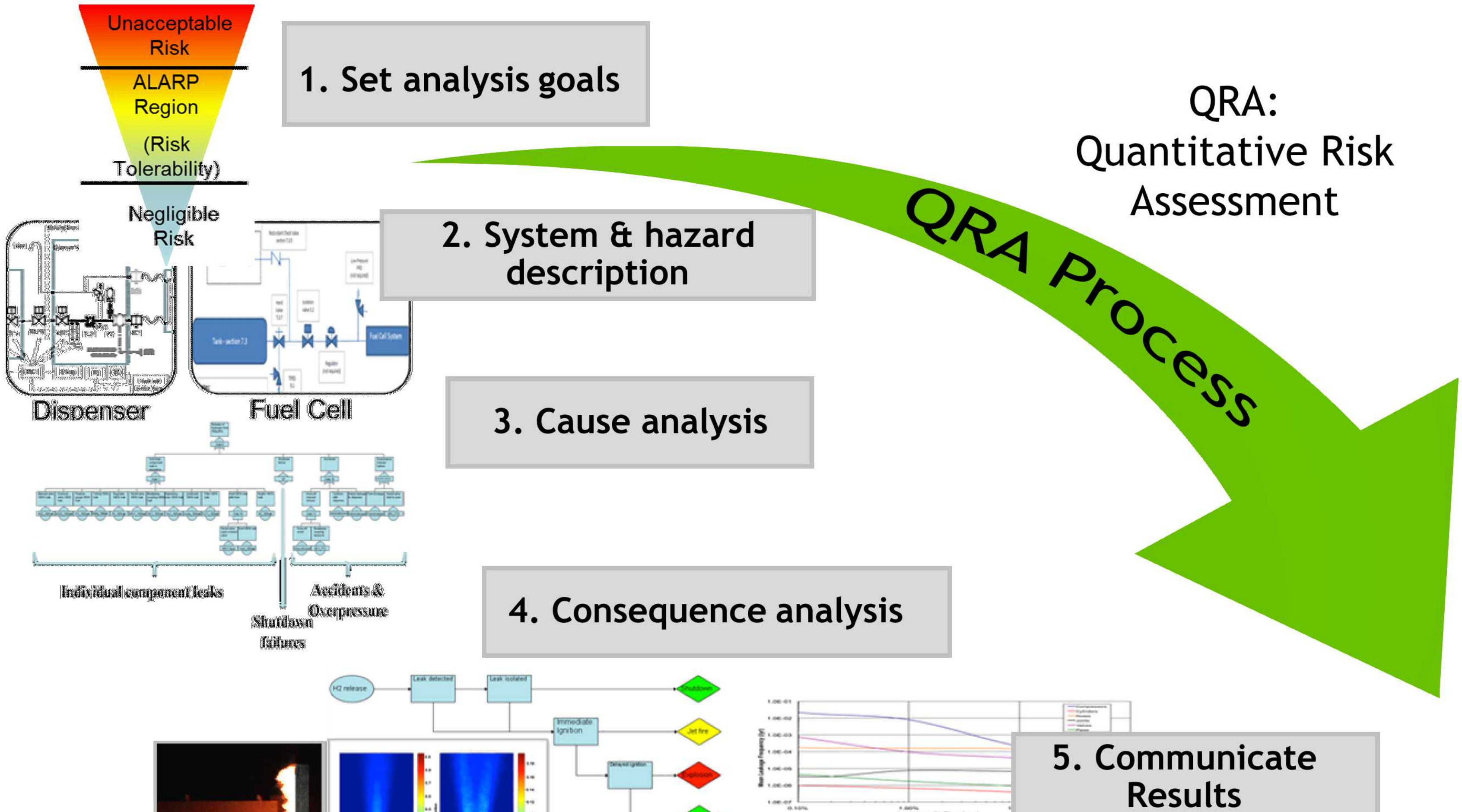
Consequence measures the effects of some event occurring

- Heat flux or overpressure
- Fatalities/injuries
- Economic losses

So the event with the highest risk may not be the most or least likely, and it may not be the worst or best case outcome

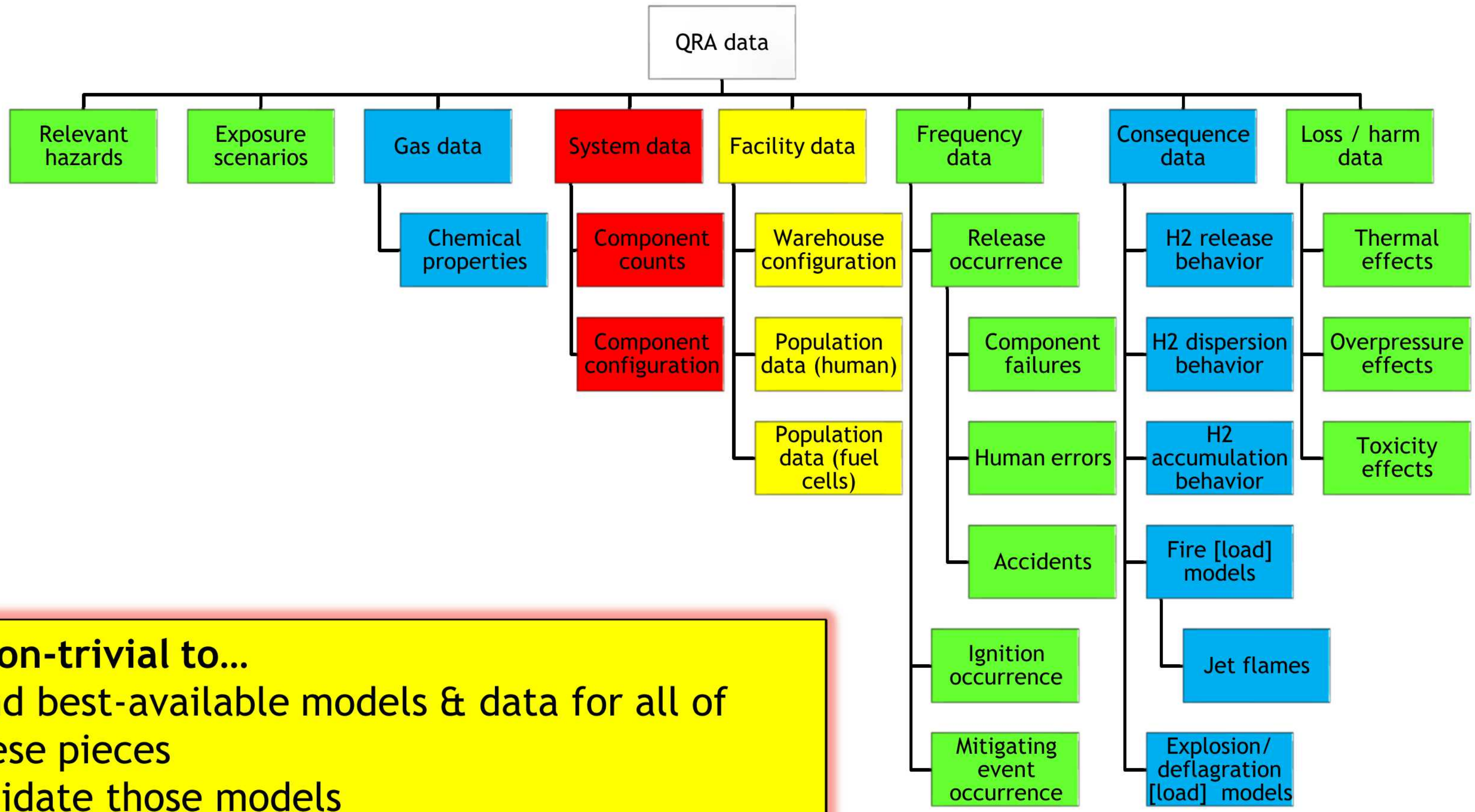
- Instead, some combination of the two

Building a Scientific Platform for Hydrogen QRA



Occupation	FAR
U.S. Workforce total	1.8
Construction and extraction occupations	5.9
Industrial machinery, installation, repair, and maintenance workers	10.4
Industrial truck and tractor operators	3.0
Laborers and freight, stock, and material movers, hand	3.1
Farming, fishing, and forestry occupations	13.5

Challenge: A quality QRA incorporates a large body of information from different areas



It is non-trivial to…

- Find best-available models & data for all of these pieces
- Validate those models
- And combine those all into a single framework

HyRAM: Making hydrogen safety science accessible through integrated tools

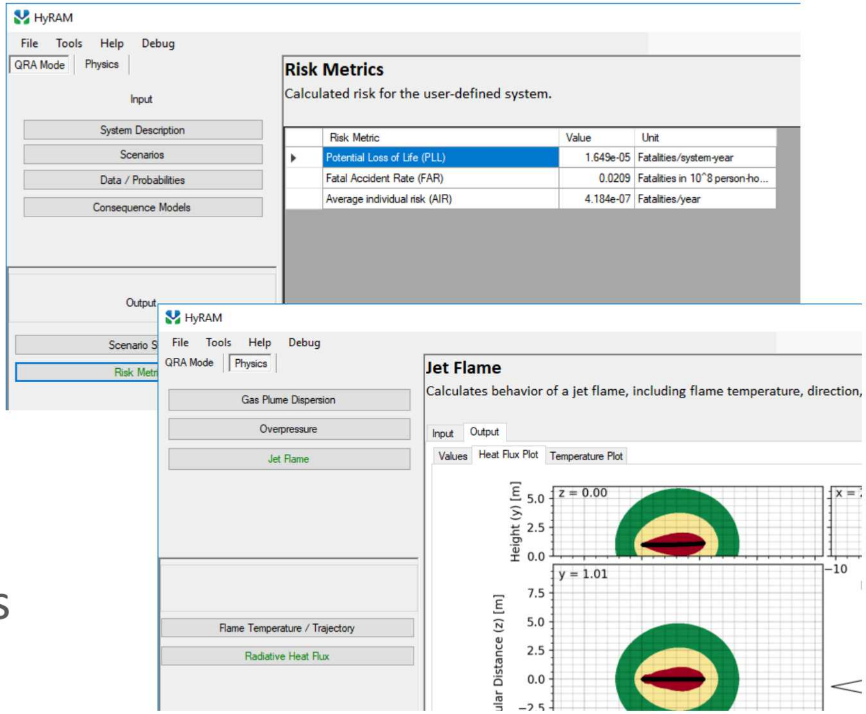
First-of-its-kind integration platform for state-of-the-art hydrogen safety models & data - **built to put the R&D into the hands of industry safety experts**

Core functionality:

- Quantitative risk assessment (QRA) methodology
- Frequency & probability data for hydrogen component failures
- Fast-running models of hydrogen gas and flame behaviors

Key features:

- GUI & Mathematics Middleware
- Documented approach, models, algorithms
- Flexible and expandable framework; supported by active R&D



Major Elements of HyRAM Software: Physics Mode

Physics models

Properties of Hydrogen

Unignited releases: Orifice flow; Notional nozzles; Gas jet/plume; Accumulation in enclosures

Ignited releases: Jet flames; overpressures in enclosures

Software Language

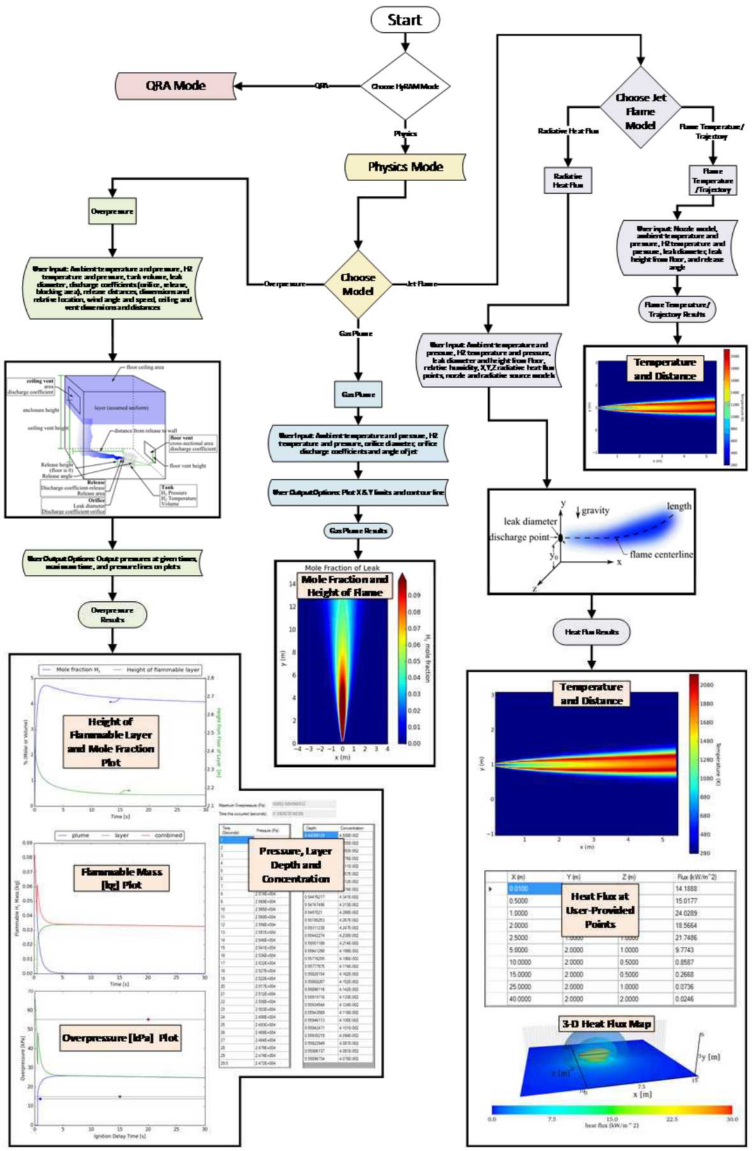
Python for Modules

C# for GUI

Documentation

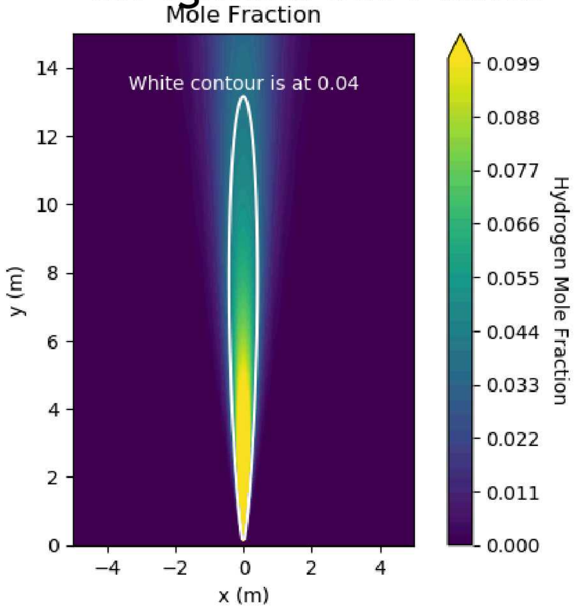
Algorithm report (SAND2017-2998)

User guide (SAND2018-0749)

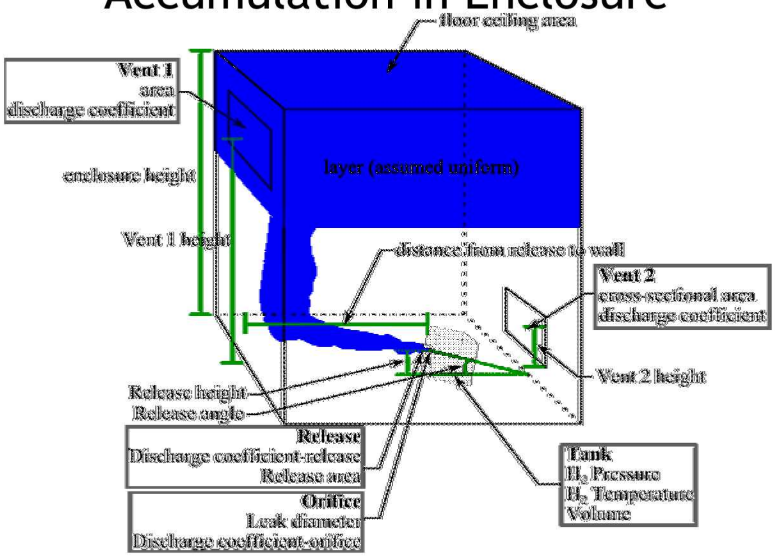


HyRAM Physics Models

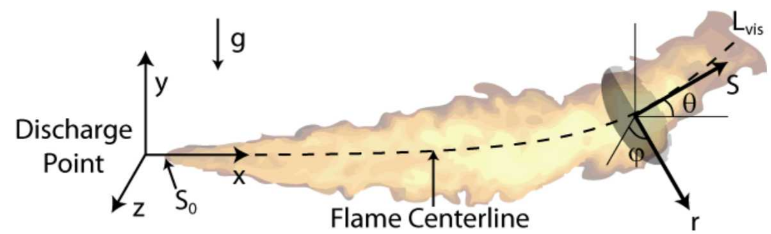
Un-ignited Jet Plume



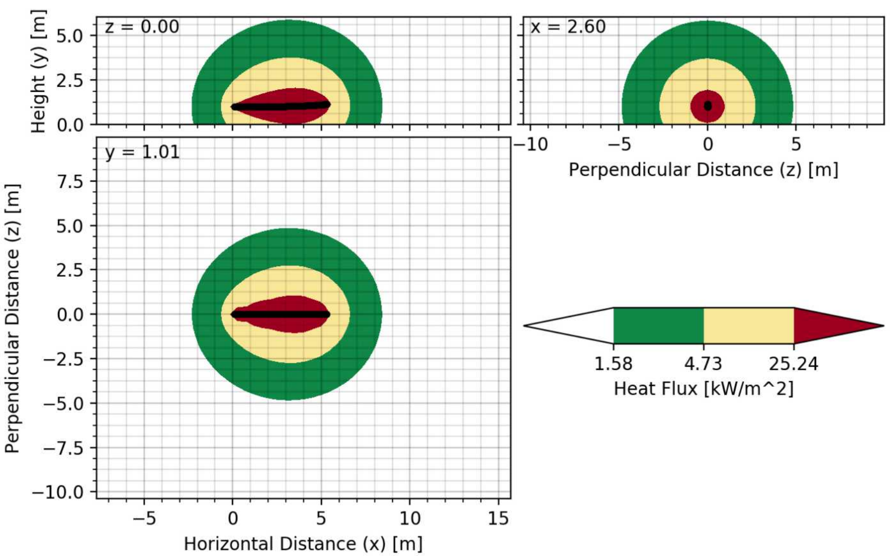
Accumulation in Enclosure



Jet Flame Temperature

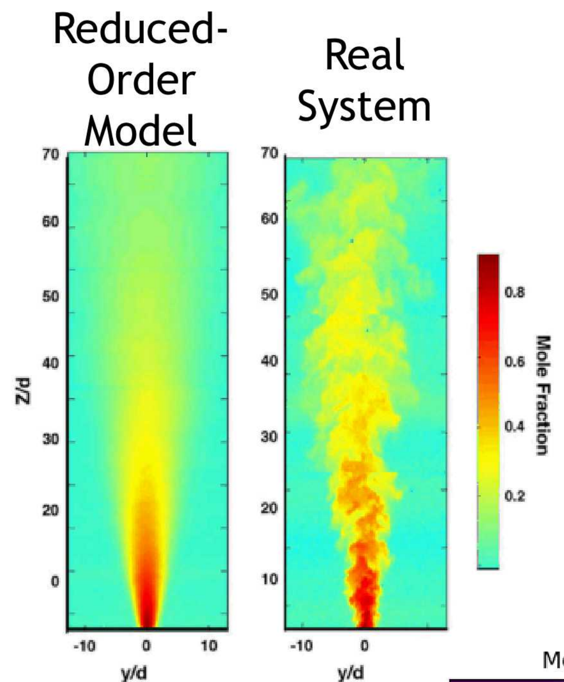


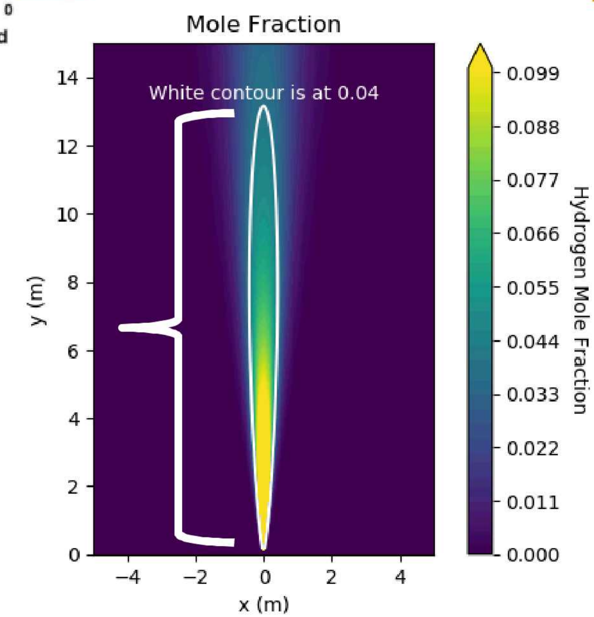
Jet Flame Heat Flux



Benefits of Reduced-Order Models

- Short run-time
- Modeling expert not required
- Useful for quantification
  - If a hydrogen leak occurs, how far away does the hazard get?
- Useful for comparisons
  - What is the effect on safety is a system size is reduced?





More Details on Physics Models

Physics models are 1-dimensional

Un-ignited and ignited jets are 1-D along the jet centerline

- Steady-state
- X- and Y-coordinates are solved for each point along the centerline
  - Gives shape of jet
- Parameters for Gaussian profiles solved for each point along centerline
  - Gives velocities, concentrations away from jet centerline

Accumulation (overpressure) model is 1-D along the height of the enclosure

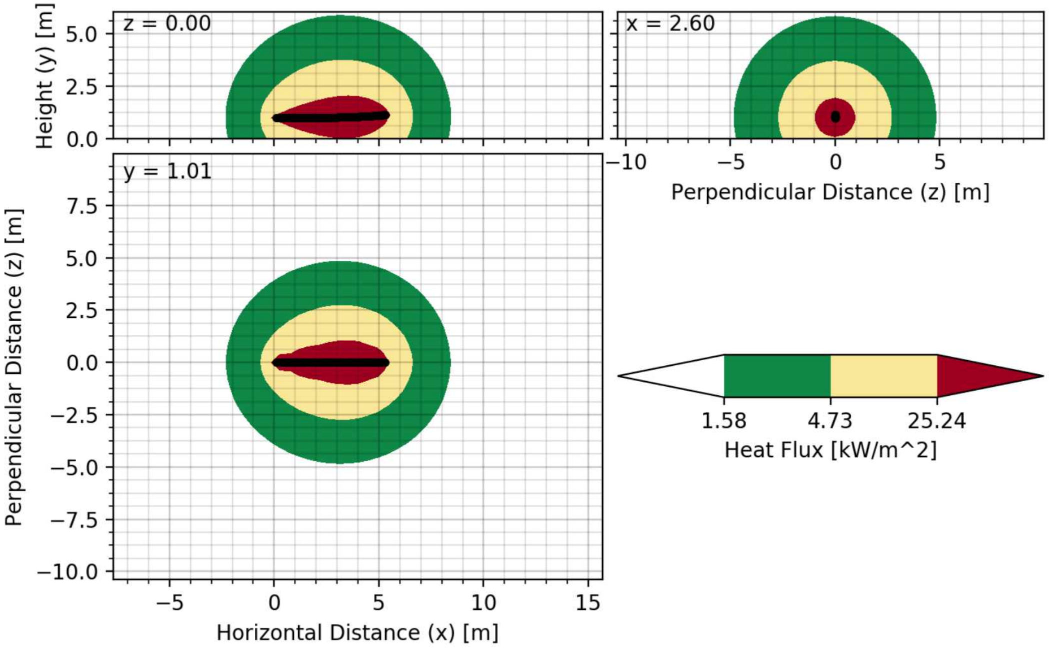
- Upper and lower vents are "points" along this dimension
- Layer is mixture of hydrogen/air and is assumed uniform concentration
- Height of layer changes with time; leak jet and layer solved for at each time step
- Flammable mass just looks at if the H2-in-air concentration is between 4-75vol%, and calculates mass of hydrogen if so
- Overpressure is based on volumetric expansion *only* and is just based on flammable mass

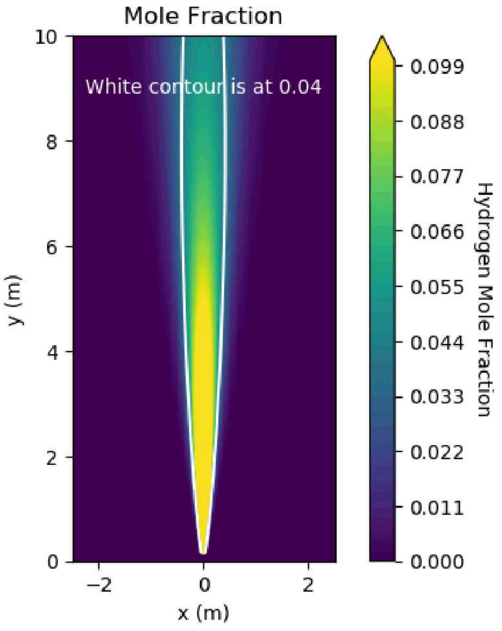
Example Physics Calculations

How far away is a safe distance from a jet flame?

How far away does a flammable concentration of gas reach?

What gets farther: a smaller leak from a high pressure system, or a larger leak from a lower pressure system?





Major Elements of HyRAM Software: QRA Mode

QRA Methodology

Risk metrics calculations: FAR, PLL, AIR

Scenario models & frequency

Release frequency

Harm models

Generic Freq. & Prob. data

Ignition probabilities

Component leak frequencies (9 types)

Software Language

Python for Modules

C# for GUI

Documentation

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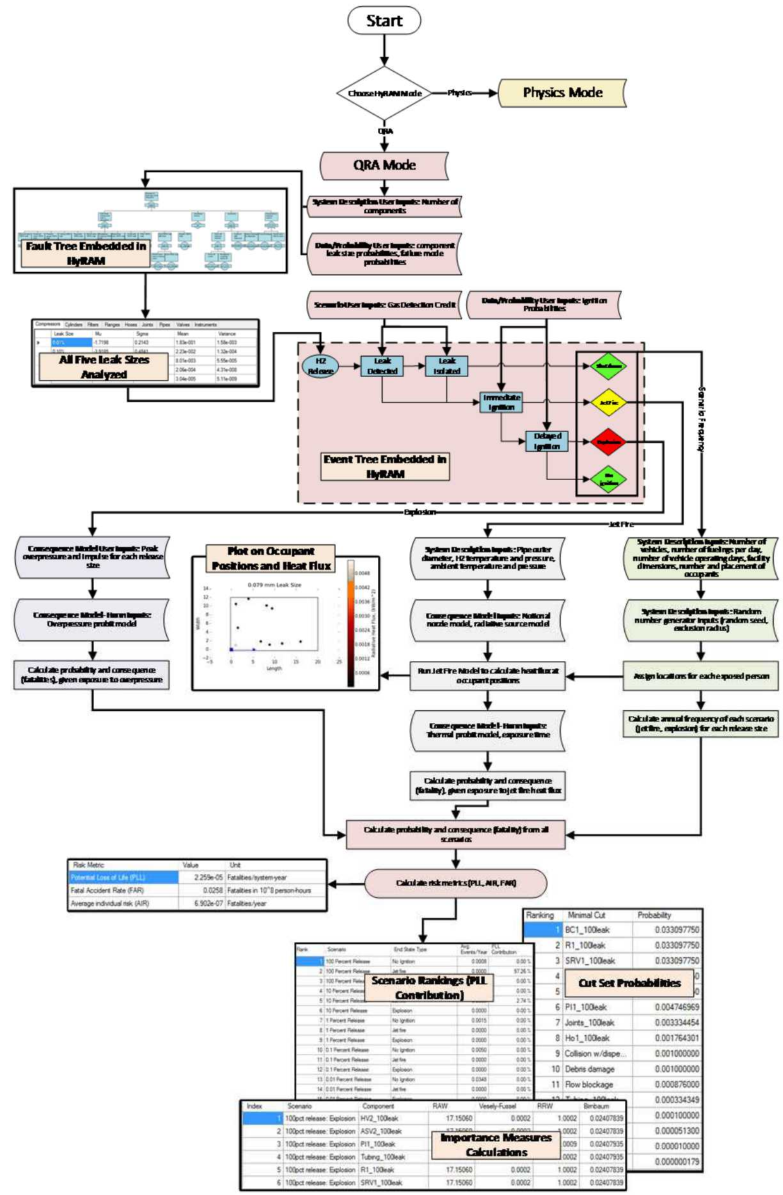
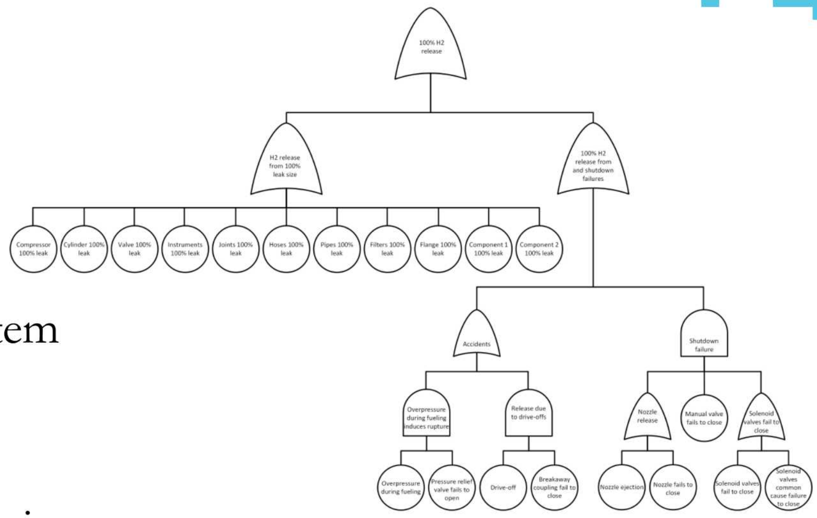


HyRAM QRA Analysis



Fault Trees

- Calculate frequency of different size leaks
- Considers random leaks from equipment in system
- Considers fueling dispenser leak

Event sequence diagram

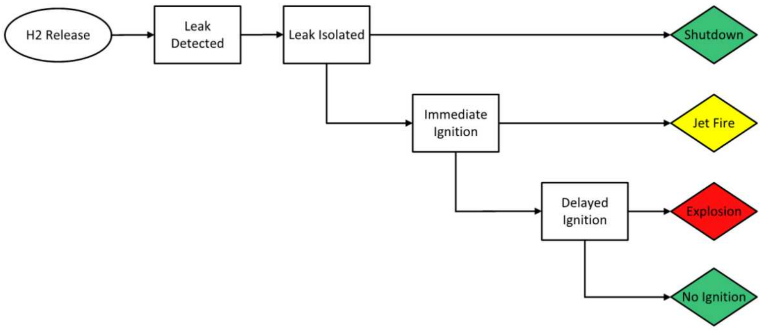
- Considers probability of outcome for each leak size
- Probability of ignition

Consequence

- For ignited releases, calculates harm (fatalities) for each ignited release

Overall Risk

- Combines all of the above to overall risk metric
- Outputs:
  - Overall risk metrics
  - Importance Measures (scenario contribution to overall risk)
  - Cut Sets (expected frequency of leaks from equipment)



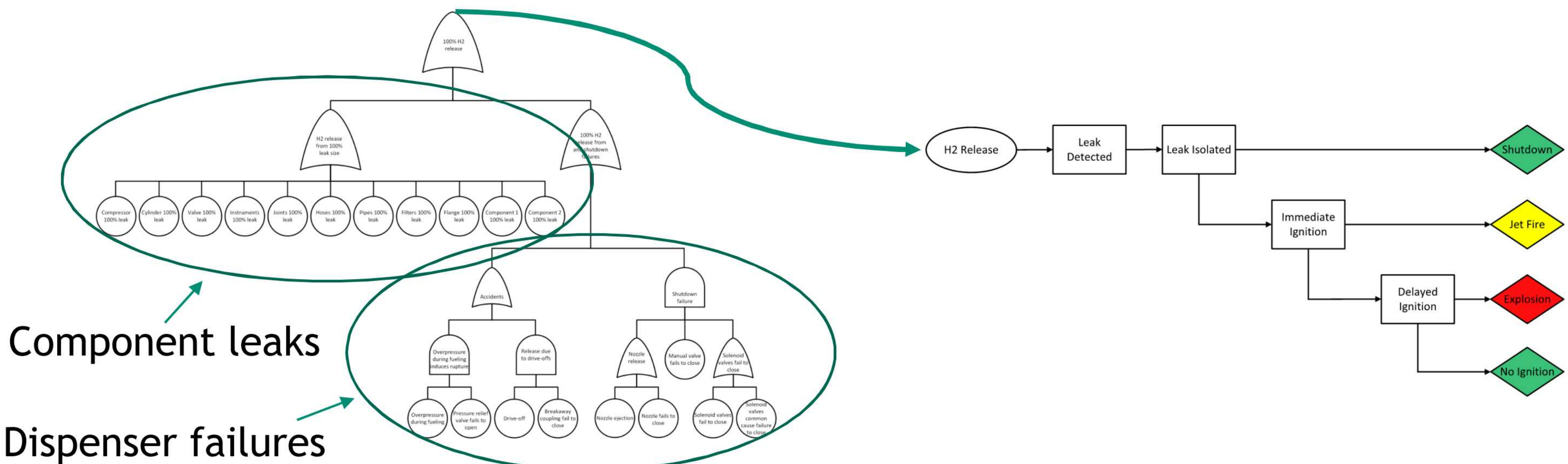
More Details on QRA Calculations: Fault Trees

20 risk scenarios considered
- 5 leak sizes: 0.01%, 0.1%, 1%, 10%, 100% of pipe area
- 4 possible end-states: leak isolated, jet fire, explosion, no ignition

All leak sizes have a fault tree based on random leaks from equipment
- Leak frequencies multiplied by number of components

100% leak size has additional fault tree based on failures from dispenser
- Leak frequencies multiplied by annual fueling demands

All fault tree result values can be over-ridden by user



More Details on QRA Calculations: Consequences

Event sequence diagram considers consequences of leak

All consequences are based on fatalities

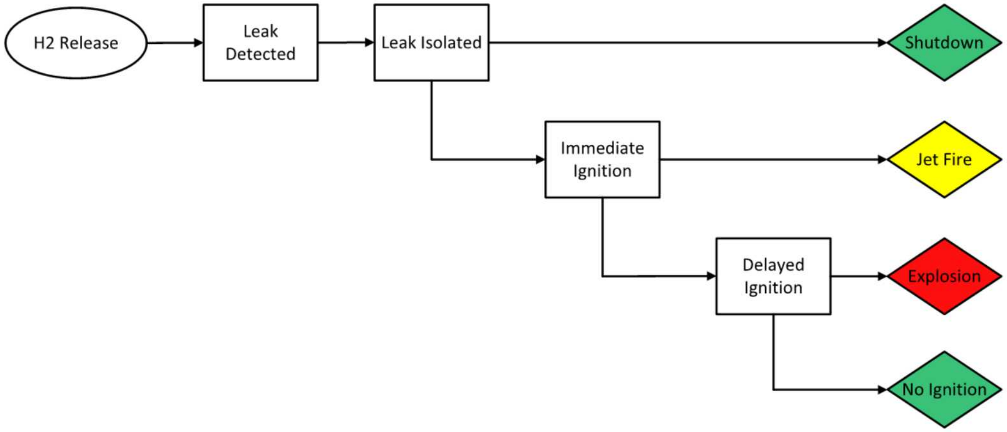
- Injuries or property damage not considered

Jet fire model used to calculate heat flux experienced by occupants

- Probit model used to calculate fatalities for a given heat flux

Overpressure values used for explosion scenarios

- Probit model used to calculate fatalities for a given overpressure
- Currently overpressure values are "dummy" not validated



Example QRA Calculations

What has a lower risk, a system with welded pipe or fittings?

- Comparison of overall system risk

What has a lower risk, fewer people closer to the system, or more people further away from the system?

- Comparison of overall system risk

What system component is driving overall risk?

- PLL contribution in Scenario Ranking
- Component leak frequencies in Cut Sets

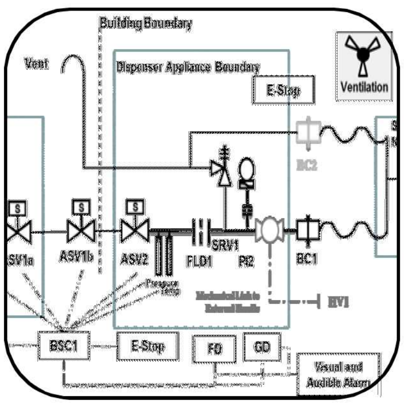
What is the setback distance away from the system to achieve overall risk below a threshold?

- Overall system risk

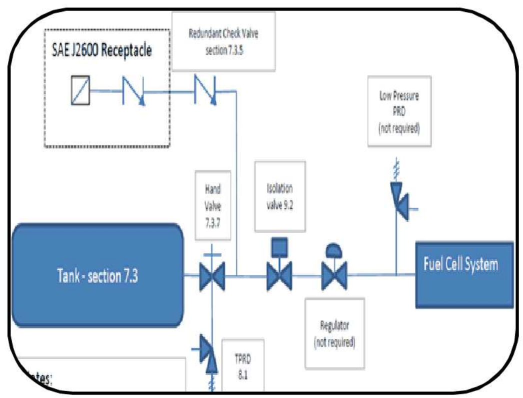
HyRAM QRA Basis

Focused on a gaseous hydrogen dispenser fueling forklifts located in a warehouse

Analysis can be altered for generic fueling stations, but applicability is limited beyond that scope

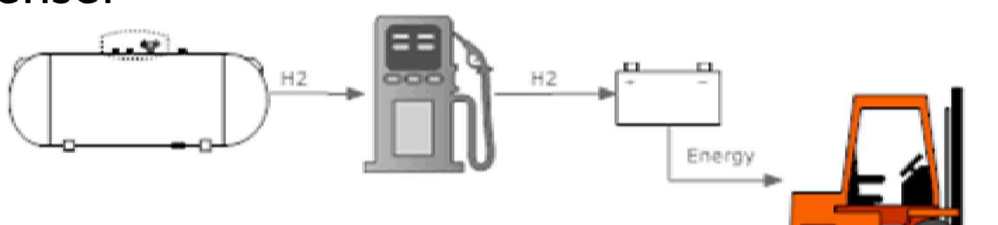


Dispenser



Fuel Cell

Vehicle



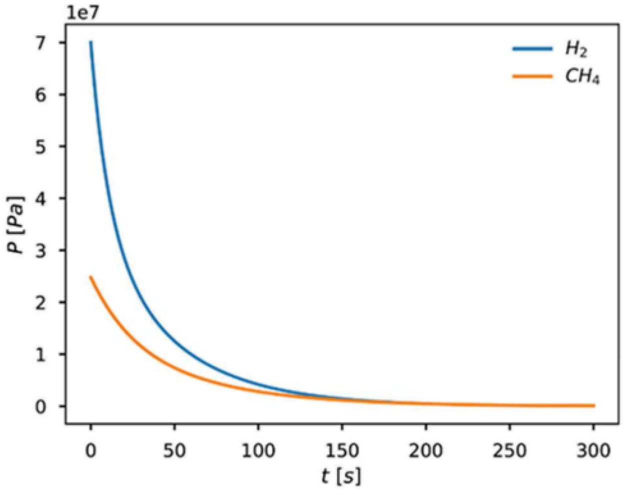
Material/ Energy Flow

Incorporation of Alternative Fuels

Analysis **beyond hydrogen**

Customization of the components, failure modes and accidents, will allow for the risk analysis of alternative fuels (CNG, LNG, propane) ***with the addition of the appropriate physics/behavior models***

Component release frequencies, failure frequencies, accident frequencies, ignition probabilities and gas detection probabilities would all have to be calculated



Current Status of Alternative Fuels Risk Assessment Models (AltRAM)

Gas plume:

- Implemented in code, not yet validated
- Will be validated Summer 2019

Cold plume:

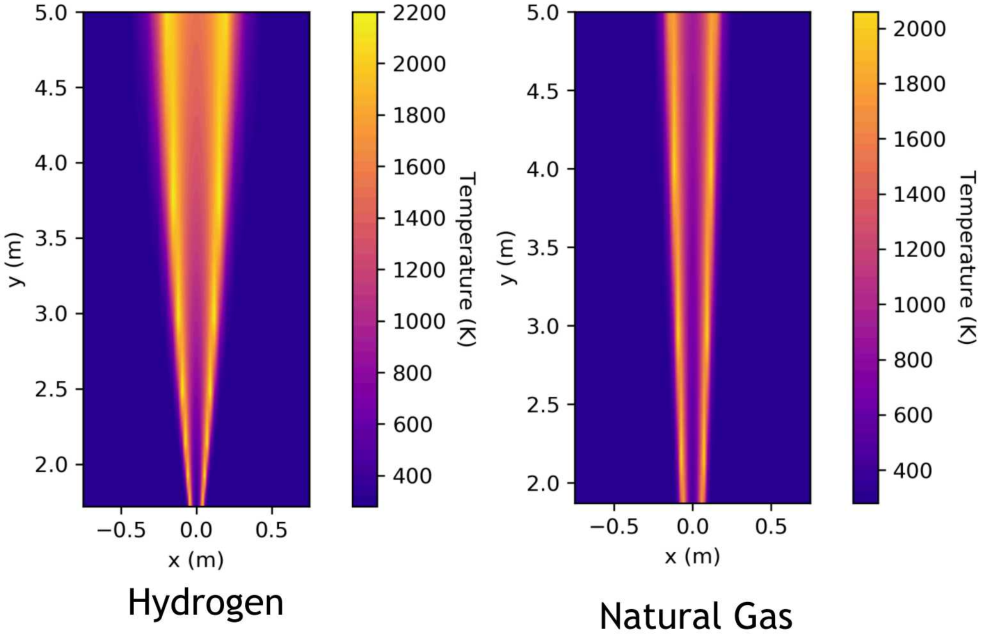
- Implemented and validated

Jet fire:

- Implemented in code, not yet validated
- Will be validated Summer 2019

All models still need to be implemented in GUI

Physics models need to be incorporated with QRA models



Thank you!

Questions?