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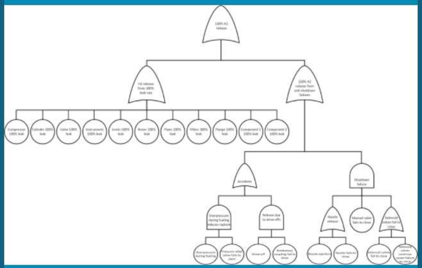
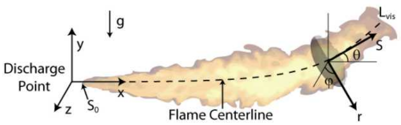
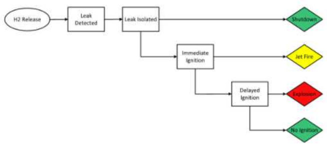


Overview and Development of Hydrogen Risk Assessment Models (HyRAM)





PRESENTED BY

Brian Ehrhart

Sandia and AL H2 Risk Assessment Project Meeting

Air Liquide Paris Innovation Center

3 - 4 July 2019

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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

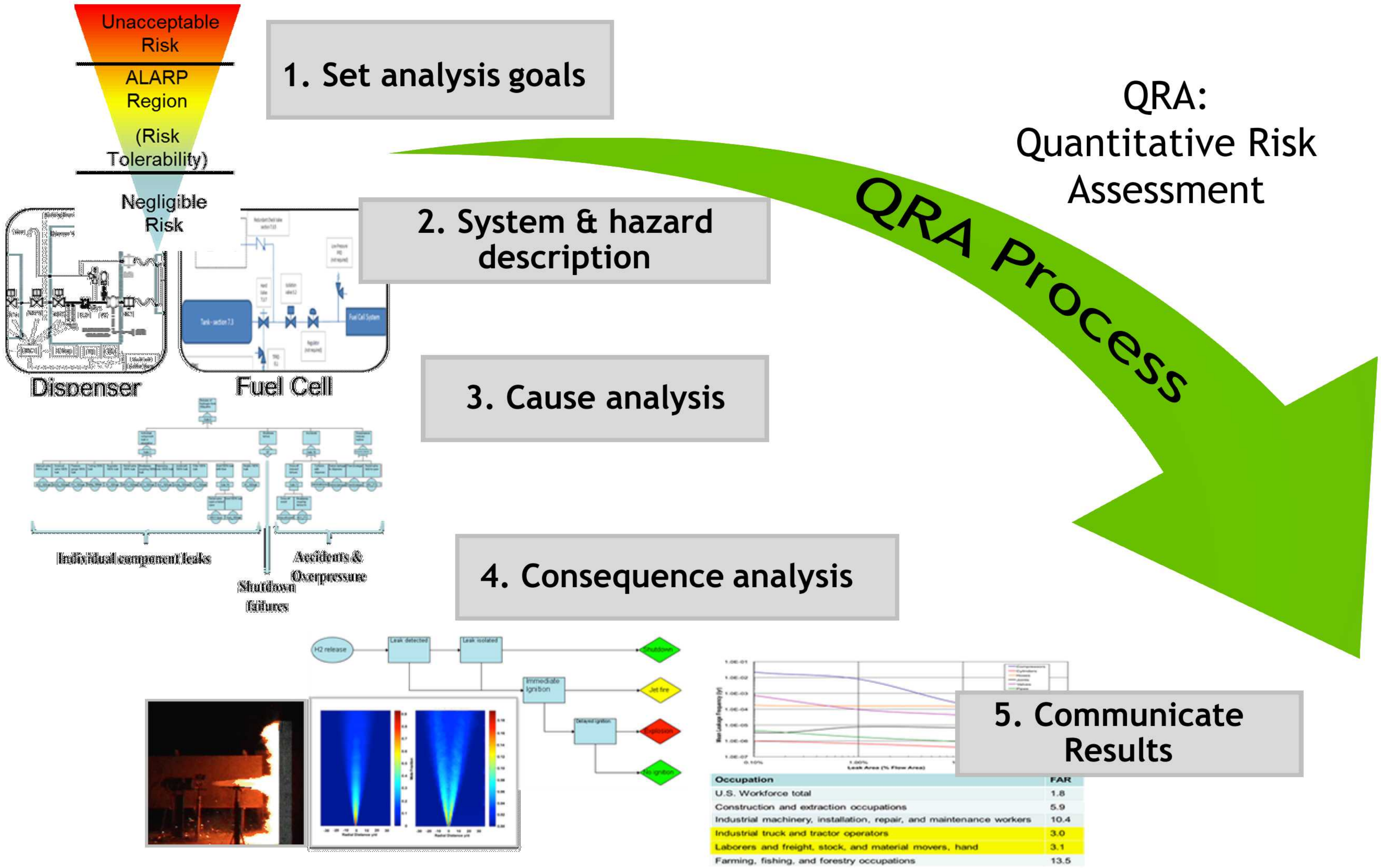
Consequence measures the effects of some event occurring

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

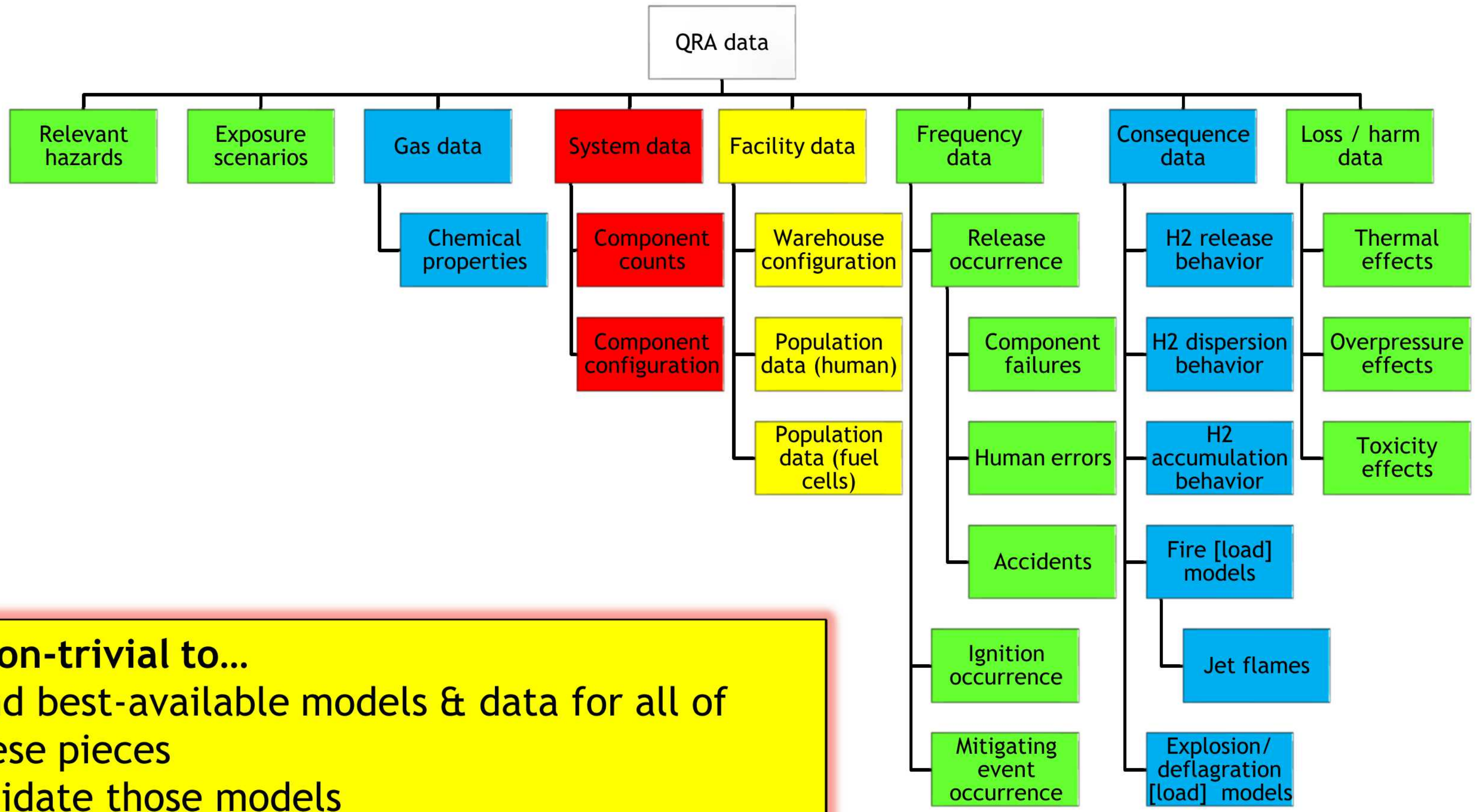
So the event with the highest risk may not be the most or least likely, and it may not be the worst or best case outcome

- Instead, some combination of the two

Building a Scientific Platform for Hydrogen QRA



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

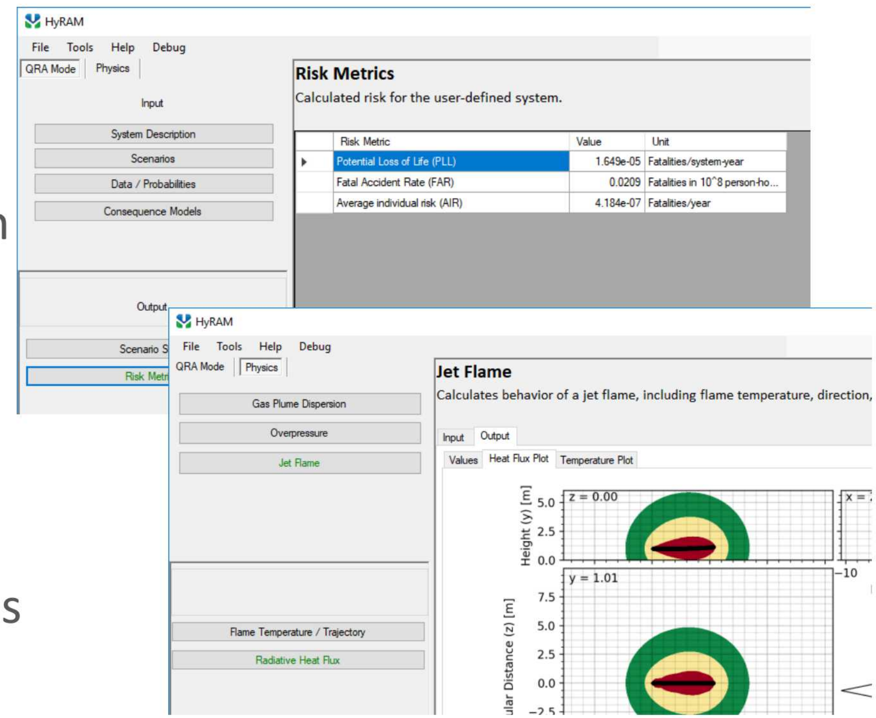
First-of-its-kind integration platform for state-of-the-art hydrogen safety models & data - **built to put the R&D into the hands of industry safety experts**

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

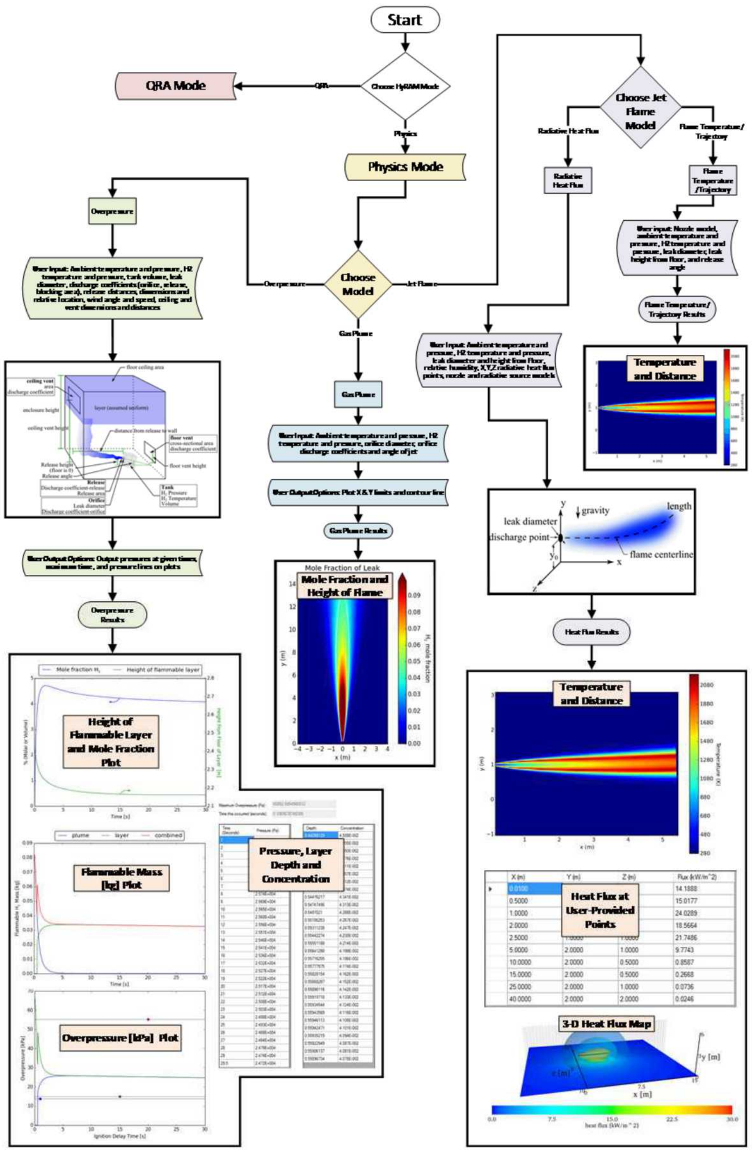
Python for Modules

C# for GUI

Documentation

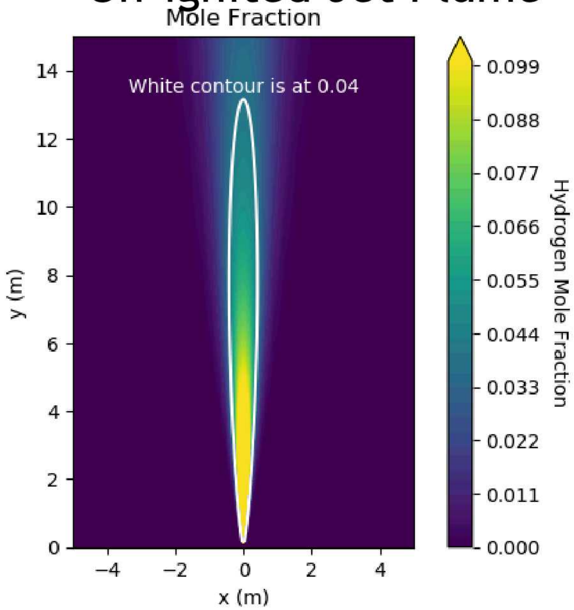
Algorithm report (SAND2017-2998)

User guide (SAND2018-0749)

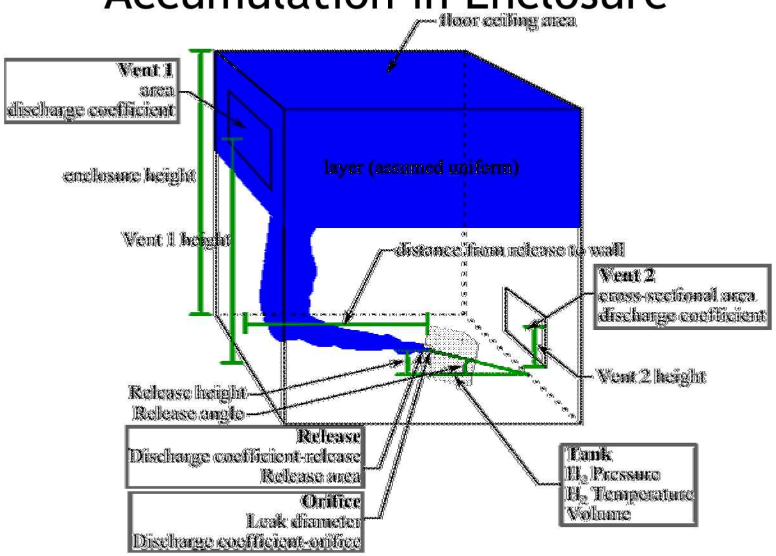


HyRAM Physics Models

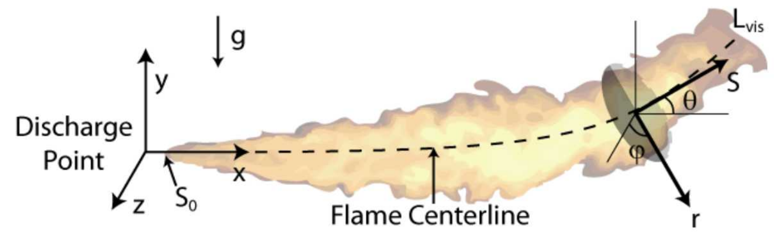
Un-ignited Jet Plume



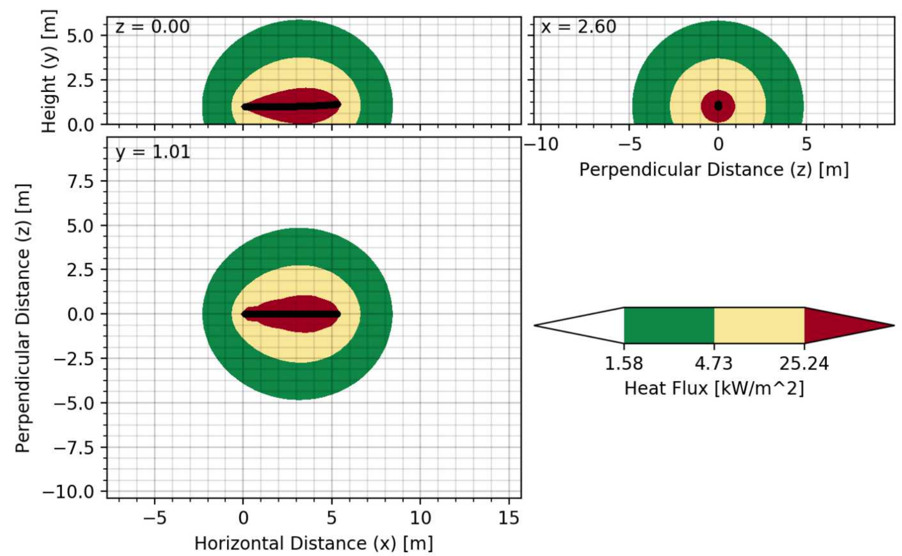
Accumulation in Enclosure



Jet Flame Temperature

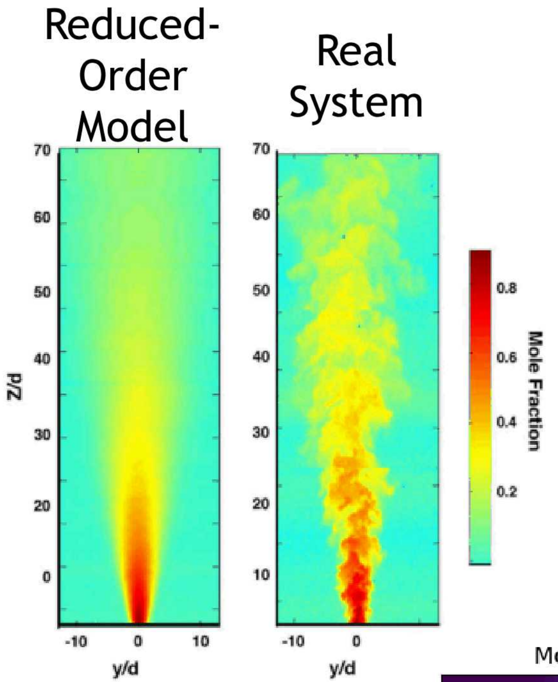


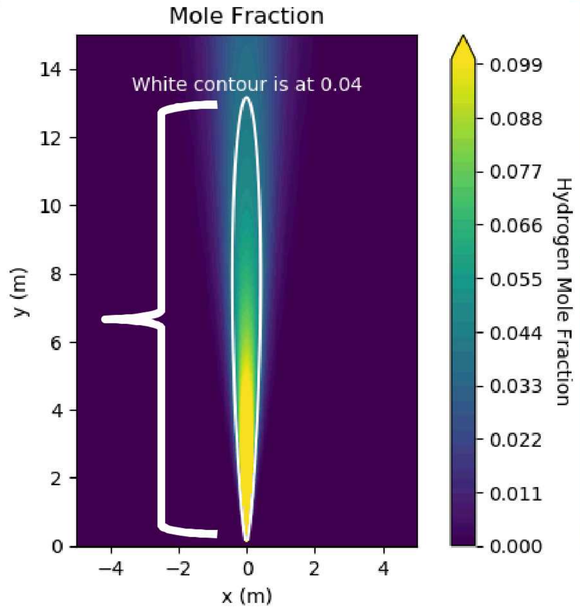
Jet Flame Heat Flux



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?



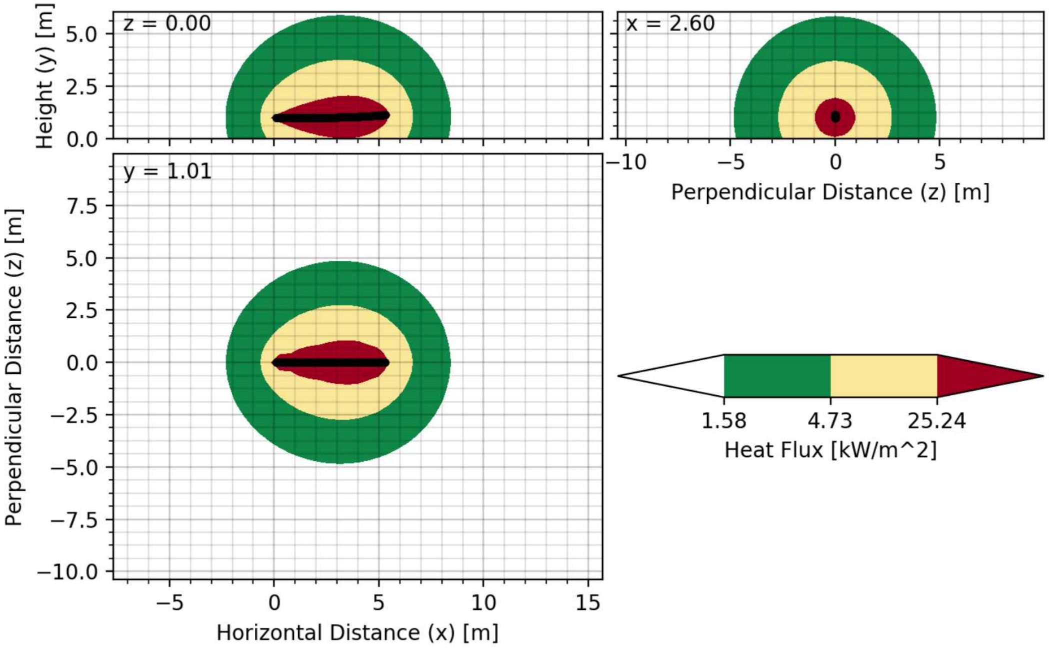


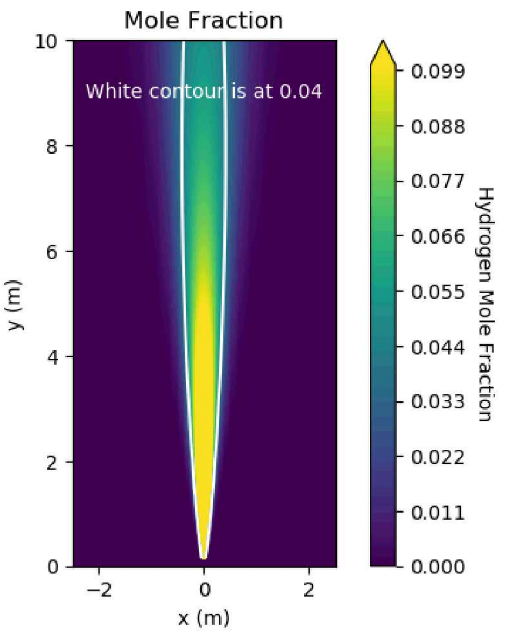
Example Physics Calculations

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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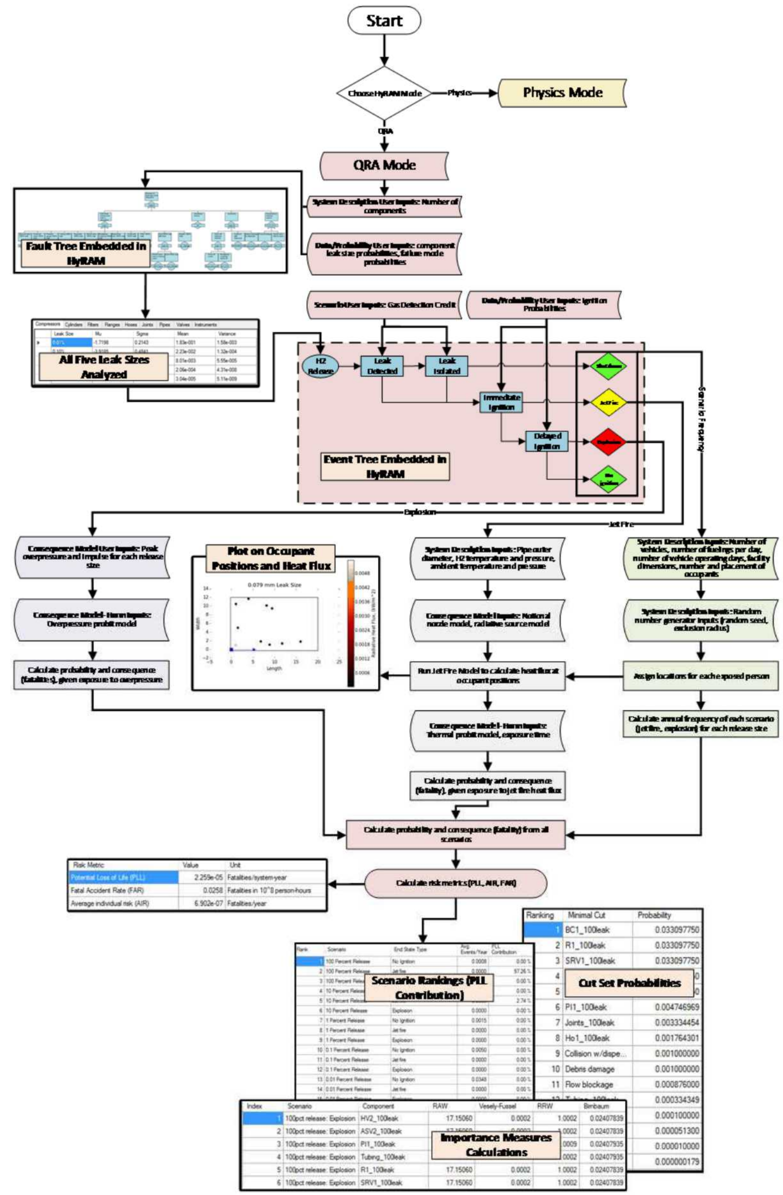
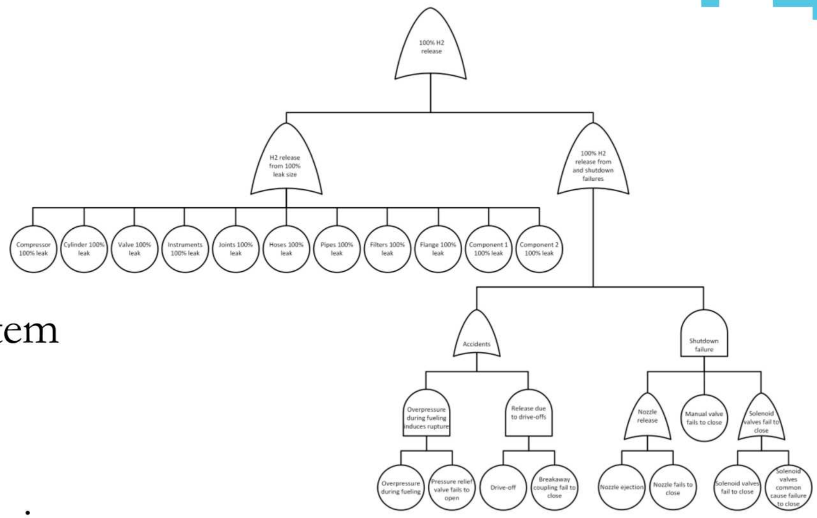


HyRAM QRA Analysis



Fault Trees

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

Event sequence diagram

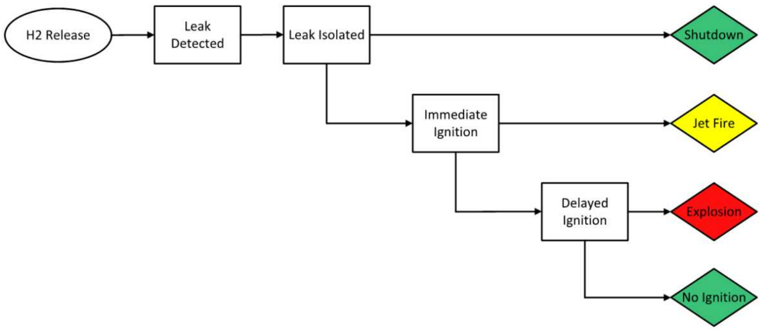
- Considers probability of outcome for each leak size
- Probability of ignition

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)



Example QRA Calculations

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

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

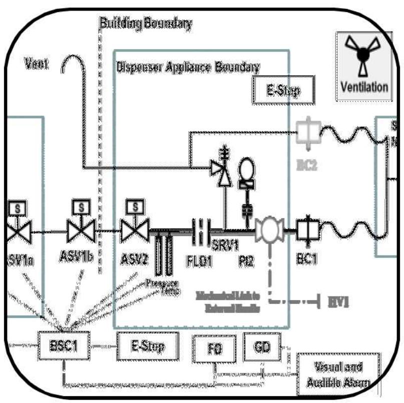
What system component is driving overall risk?

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

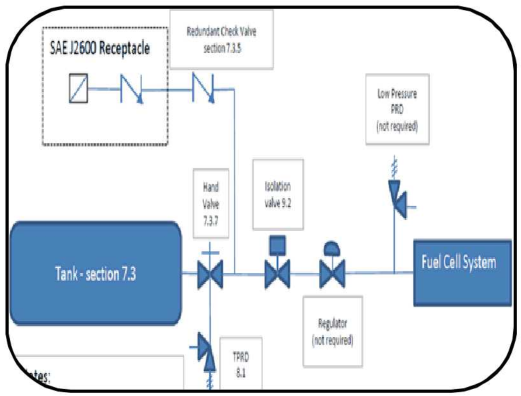
HyRAM QRA Basis

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

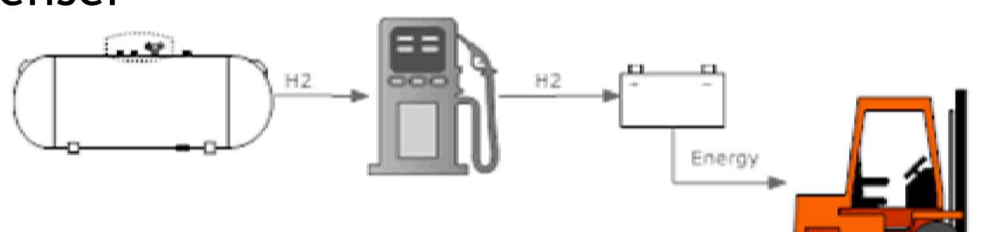


Dispenser



Fuel Cell

Vehicle



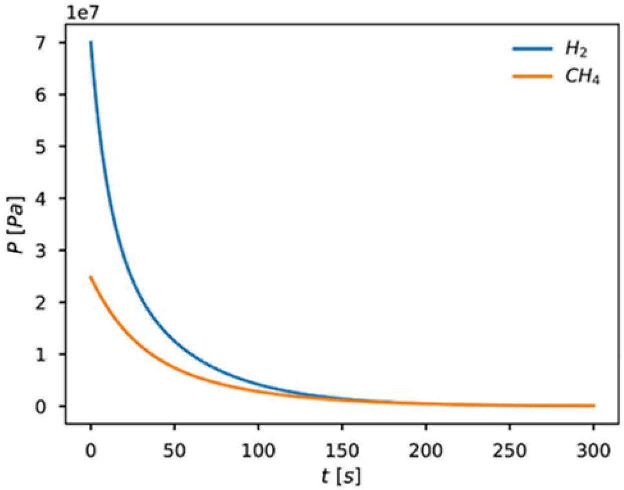
Material/ Energy Flow

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)

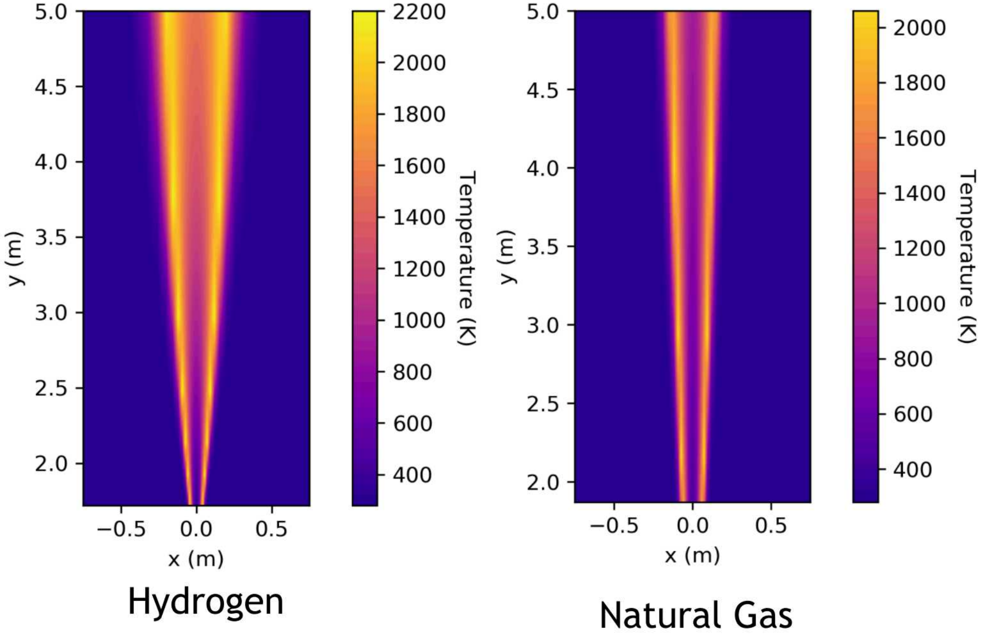
Gas plume:
- Implemented in code, not yet validated
- Will be validated Summer 2019

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? Feedback?

Brian Ehrhart bdehrha@sandia.gov