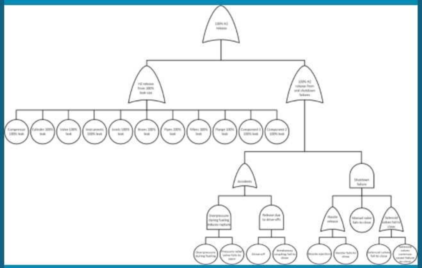
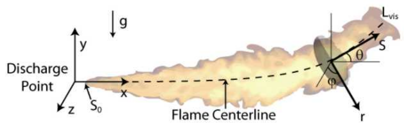
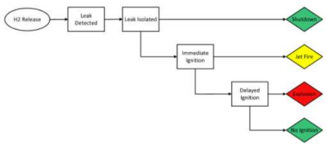
SAND2019-12439C

Overview and Recent Developments for the Hydrogen Risk Assessment Models (HyRAM) Toolkit







HYDROGEN RISK ASSESSMENT MODELS

PRESENTED BY

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2019 Conference on Hydrogen Safety

October 14-15, 2019 - Sacramento, CA

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History of NFPA 2: Hydrogen Technologies Code

Committee on Hydrogen Technology started in 2006

Focus of NFPA 2 is all aspects of hydrogen storage, use, and handling

- Mostly extracted material from other codes (NFPA 55 et al.)
- "production, storage, transfer and use of hydrogen in all occupancies and on all premises"
- "stationary, portable, and vehicular infrastructure applications"

Does not apply to:

- Onboard vehicle or mobile equipment components or systems
- Gaseous mixtures with <95% hydrogen by volume
- Metal hydride storage

Timeline of Risk in Hazard Exposure Setback Distances

Hydrogen-specific setback distances in NFPA codes from ~1960s

~2007 DOE/FCTO funds Sandia to determine risk-informed design basis for hydrogen facility

- Science-based: better understanding will lead to better requirements

2009 SAND report published publicly releasing these results and findings

2011 Edition of NFPA 2 includes revised GH2 setback distances

- Exposures categorized into 3 groups
- Overall risk analysis of design-basis facility
- Previous basis was total inventory of GH2, new basis is pressure and pipe size
- Specified leak size and modeling leads to calculation of setback distances
- ***Significant reduction in some hazard exposure distances***

~2016 Sandia revises setbacks based on revised risk criteria to less conservative values

- Smaller leak size, higher H2 concentration, higher no-harm criteria for heat flux, added safety factor

2020 Edition of NFPA 2 includes revised GH2 setback distances

- ***Further significant reductions in some hazard exposure distances***
- Also change in how setbacks are applied in gaseous/liquid combined system

Currently revising liquid H2 setback distances using same risk-informed process

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

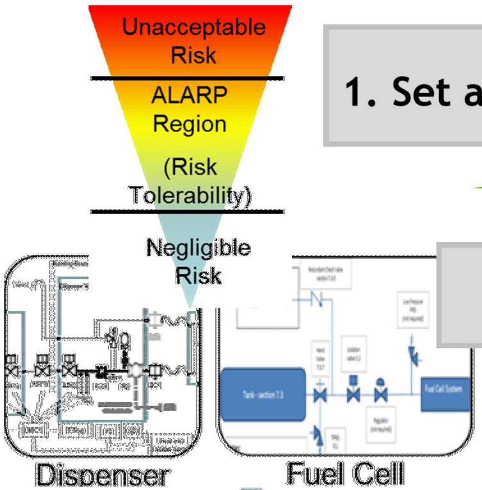
Use of Risk in Hazard Exposure Setback Distances

Overall **risk** assessment
- Assume a representative facility
- Assess the fatality risk of that facility
- Compare risk to existing/equivalent hazardous activity (gasoline station)

Use leak **frequencies** to determine leak size of interest
- 0.1% of pipe area is estimated to include ~95% of all leaks
- 1-10% of pipe area is estimated to include 97-98% of all leaks
- 3% originally chosen, 1% used now

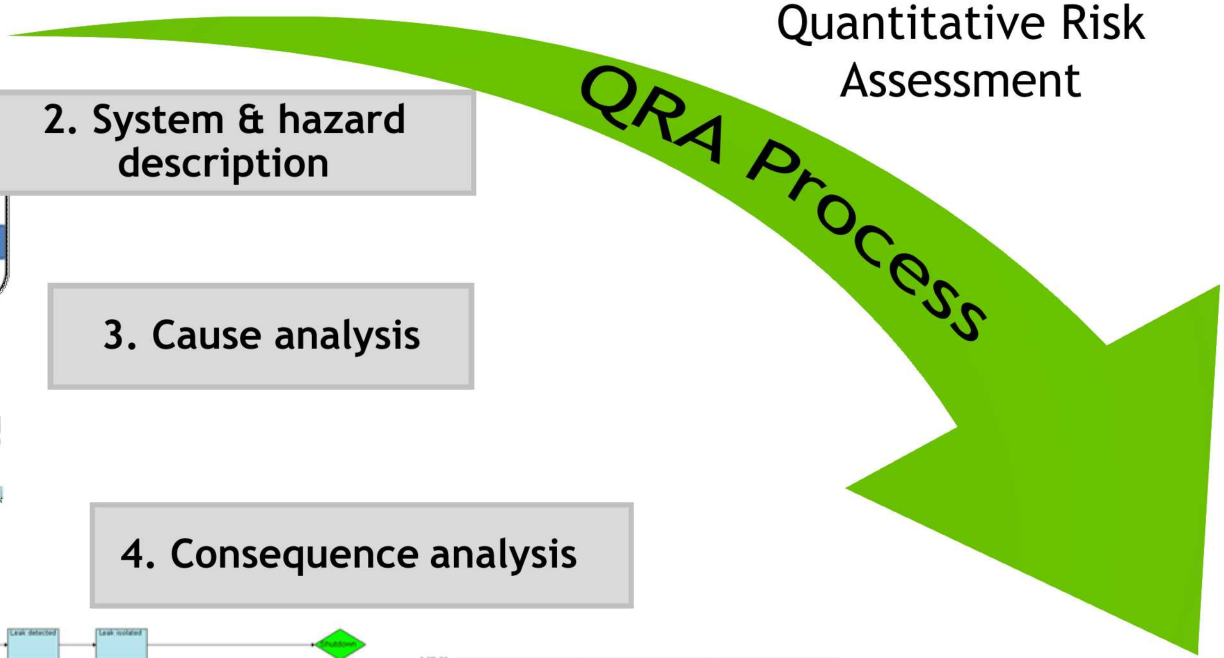
Hydrogen **behavior** models to estimate effect of leak
- Jet flame model to determine heat flux to person at various distances away from leak
- Harm model (no-harm criteria) used to determine distance for setback distance value
- Initial assumption was no-harm with no mitigation
- Updated assumption assumes bystander could move away

Building a Scientific Platform for Alternative Fuels QRA



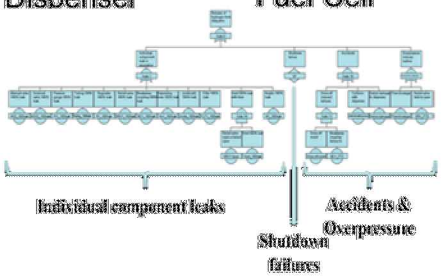
1. Set analysis goals

QRA: Quantitative Risk Assessment

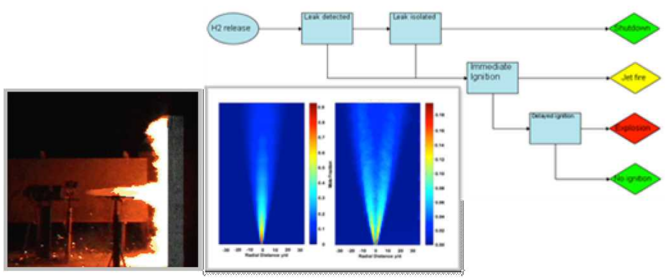


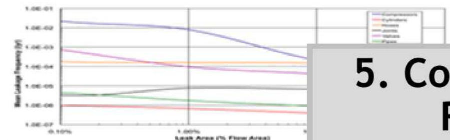
2. System & hazard description

3. Cause analysis



4. Consequence analysis

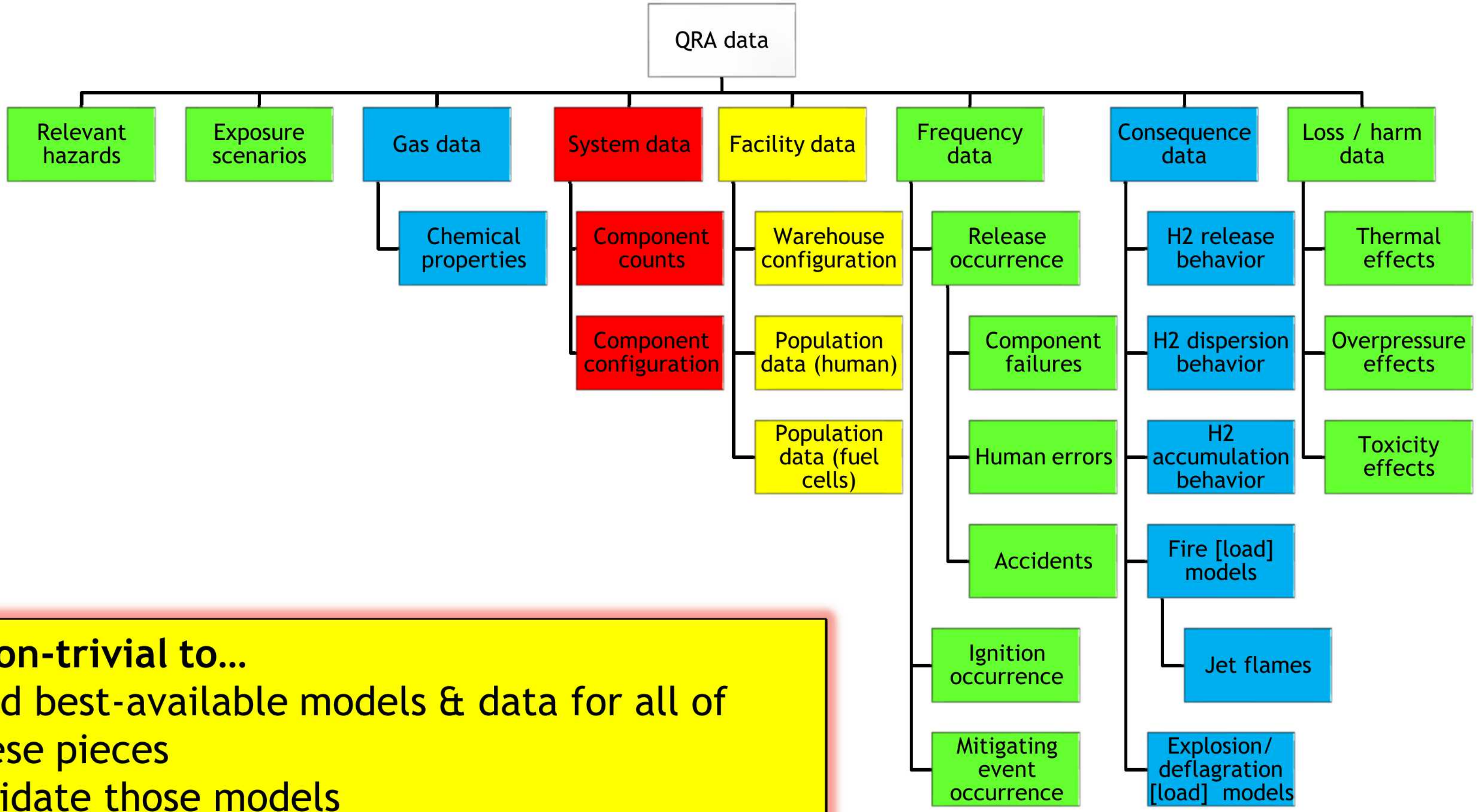




5. Communicate Results

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

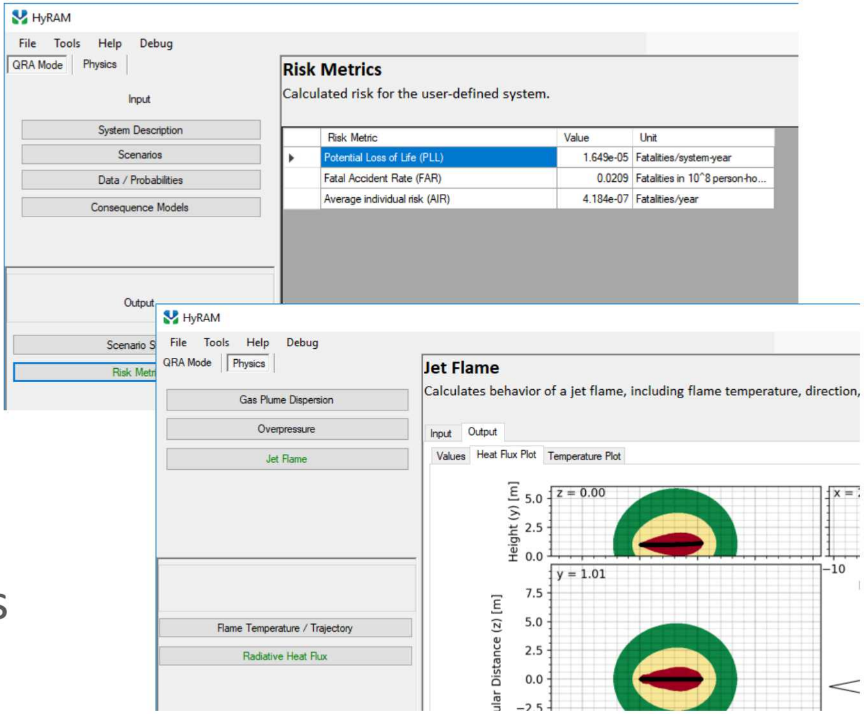
First-of-its-kind integration platform for state-of-the-art hydrogen safety models & data - **built to put the R&D into the hands of industry safety experts**

Core functionality:

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

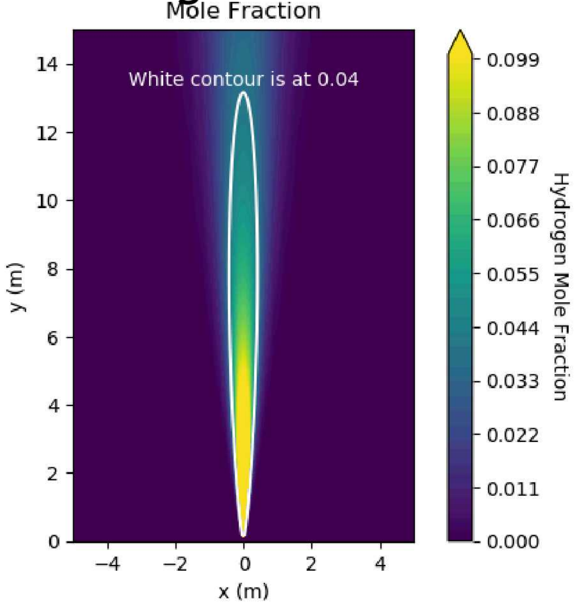
Key features:

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

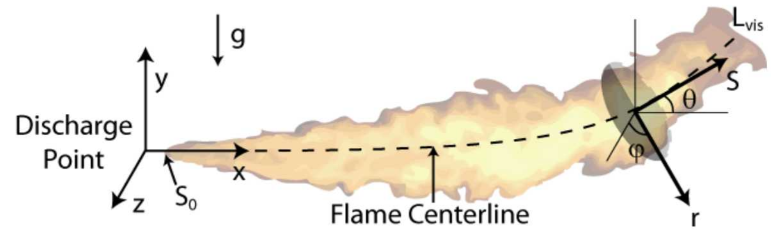


HyRAM Physics Models

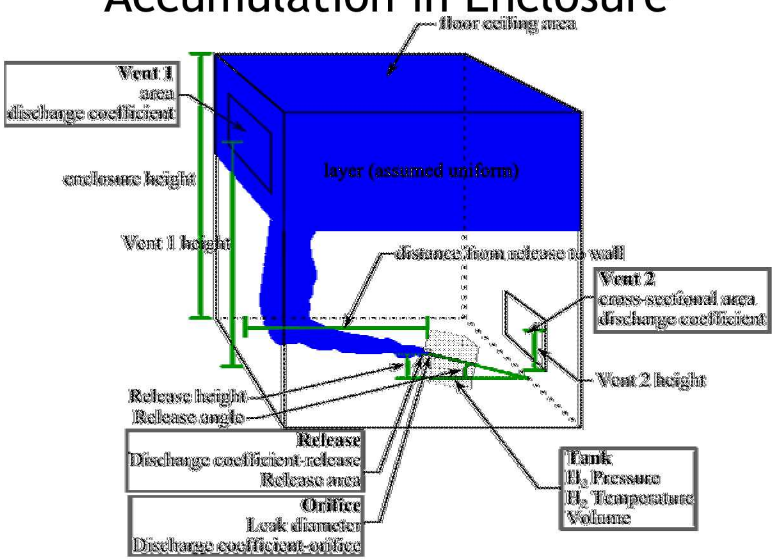
Un-ignited Jet Plume



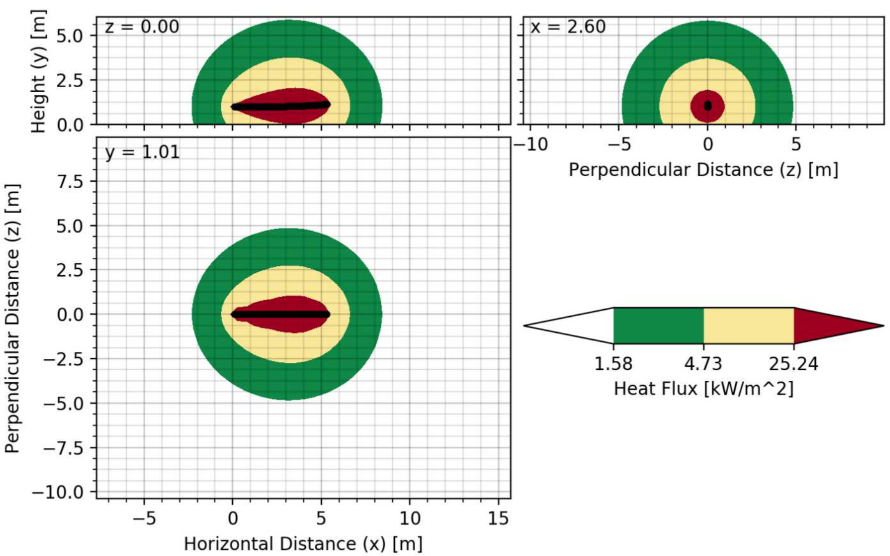
Jet Flame Temperature



Accumulation in Enclosure



Jet Flame Heat Flux



Benefits of Reduced-Order Models

Short run-time

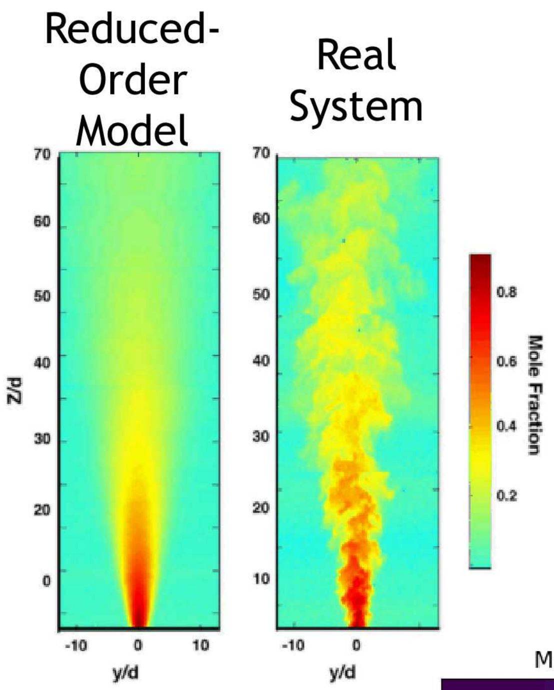
Modeling expert not required

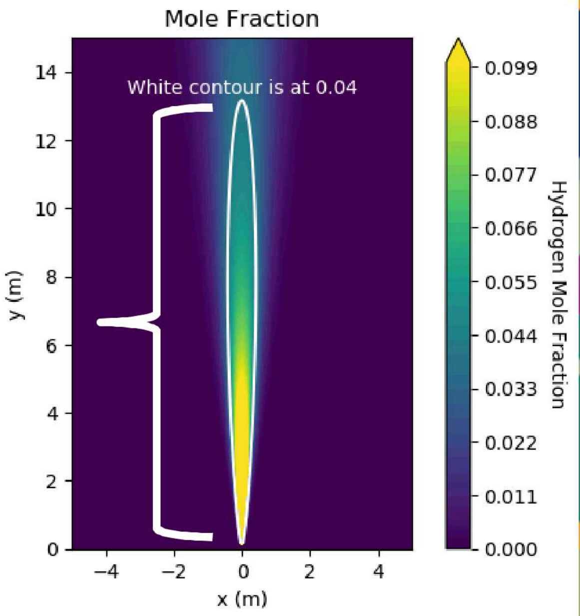
Useful for quantification

- 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?



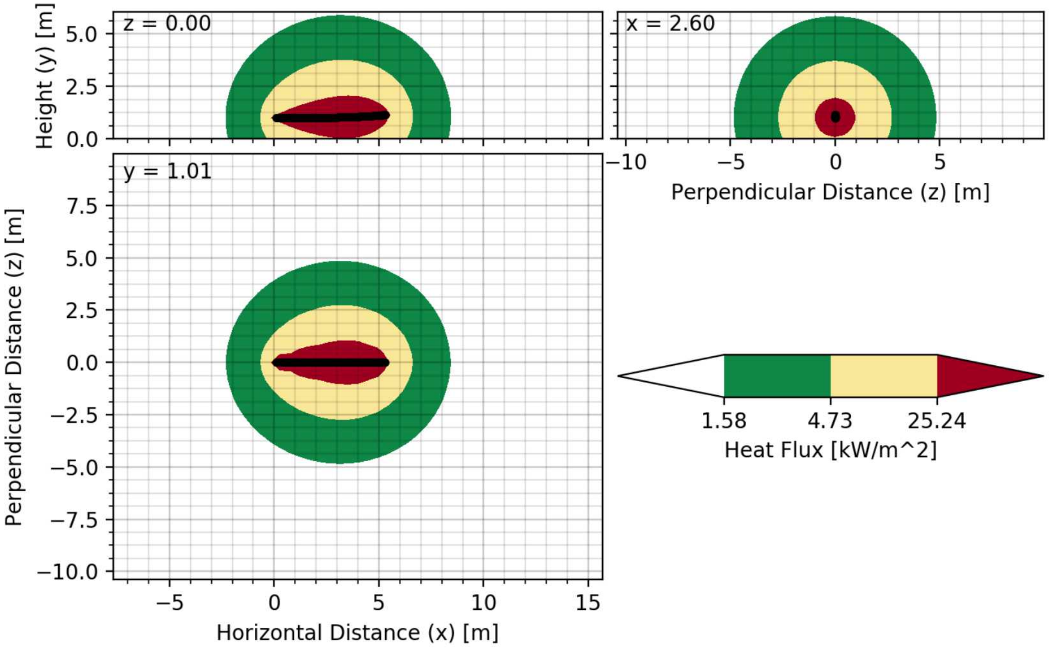


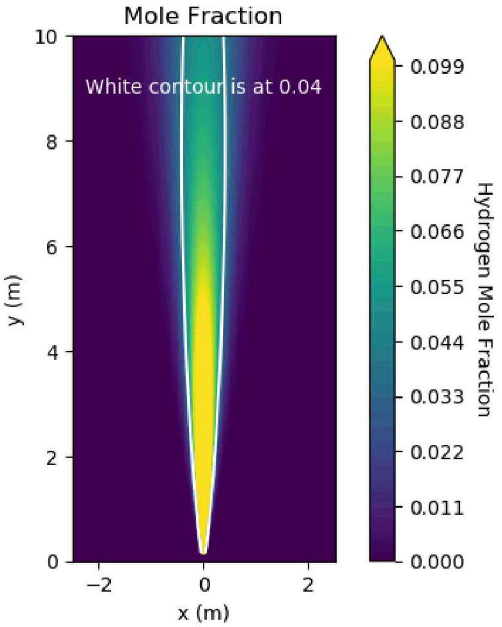
Example Physics Calculations

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

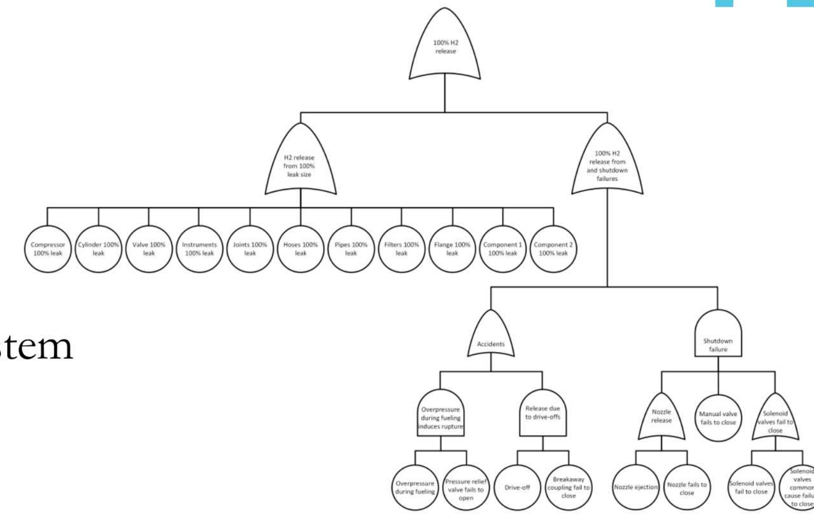
How far away does a flammable concentration of gas reach?

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





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

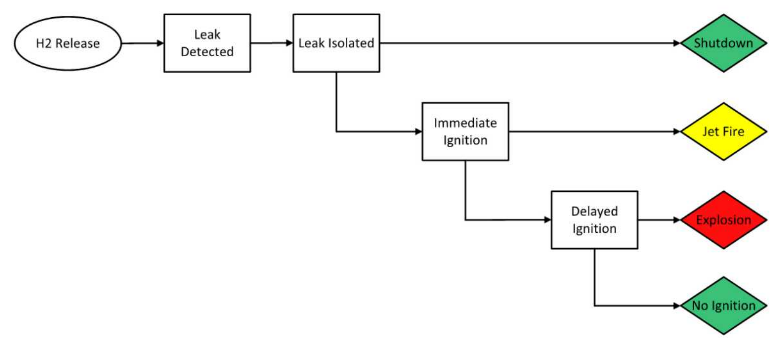
- Considers probability of outcome for each leak size
- Probability of ignition

Consequence

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

Overall Risk

- Combines all of the above to overall risk metric



Example QRA Calculation

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?

Recent Developments – HyRAM 2.0

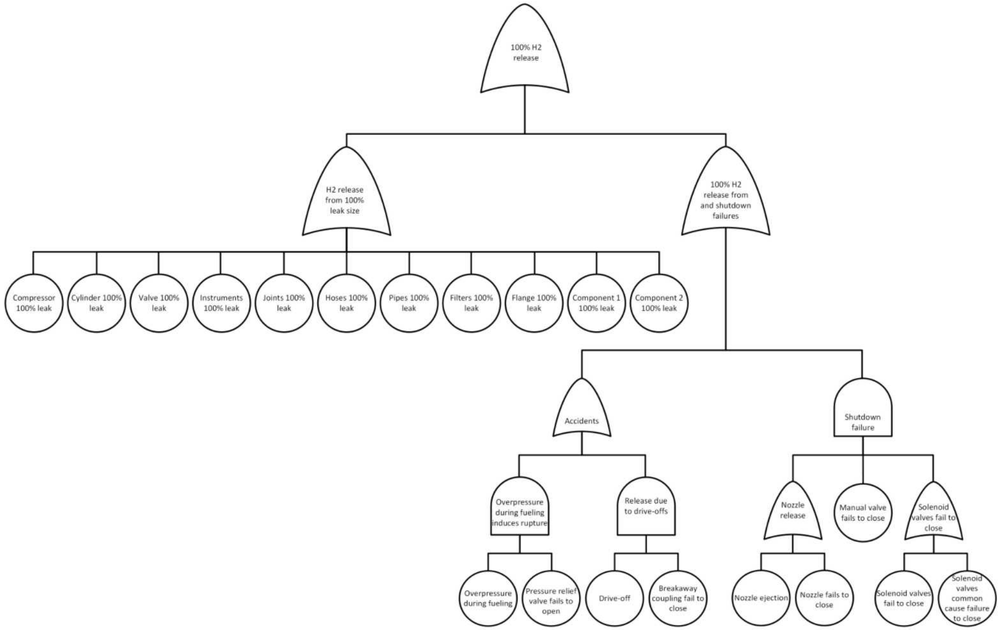
HyRAM 2.0.0 released July 2019

Open Source

- Windows-only installer available for GUI
- Source code available on GitHub

Flexible Fault Tree Analysis

- Override fault tree results for any leak size – ability to use custom external fault trees
- Customizable inputs for dispenser fault tree



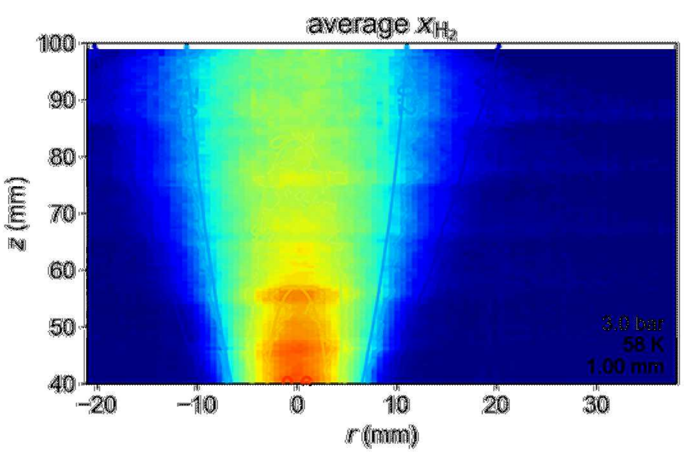
Incorporation of Additional Alternative Fuels

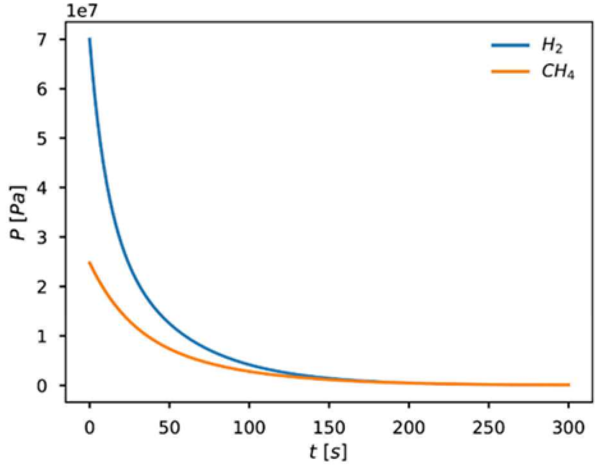
Analysis **beyond gaseous hydrogen**

Larger-scale applications need liquid hydrogen
- More light-duty vehicles
- Heavy-duty trucks
- Rail and maritime

Liquid Hydrogen (**LH2**) to be incorporated
- ***Critical to address NFPA 2 setback distances for LH2***
- Model and leak frequency validation in-progress

Additional models for the risk analysis of alternative fuels
- CNG, LNG, propane





Thank you!

Questions? Feedback?

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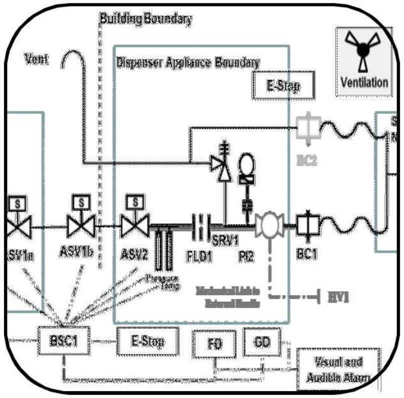
http://hyram.sandia.gov/

Technical Backup Slides

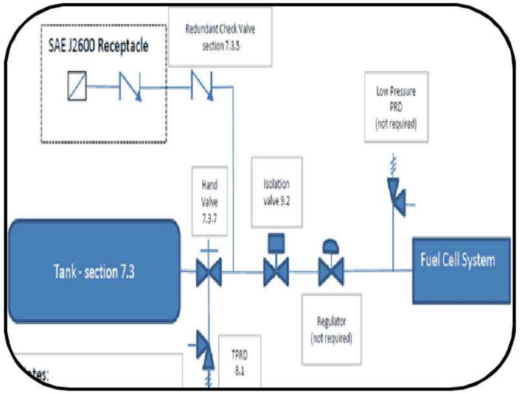
HyRAM QRA Basis

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

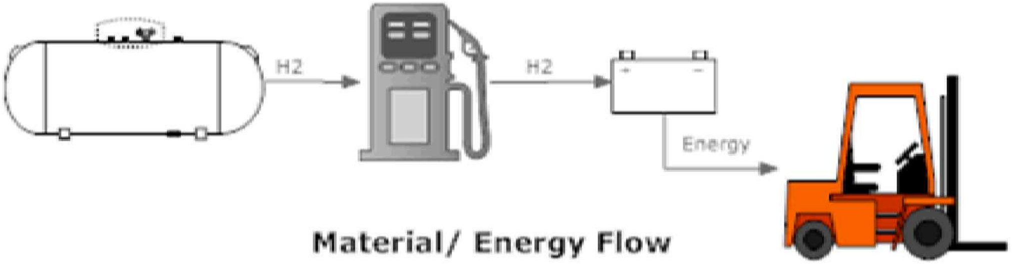


Dispenser



Fuel Cell

Vehicle



Material/ Energy Flow

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

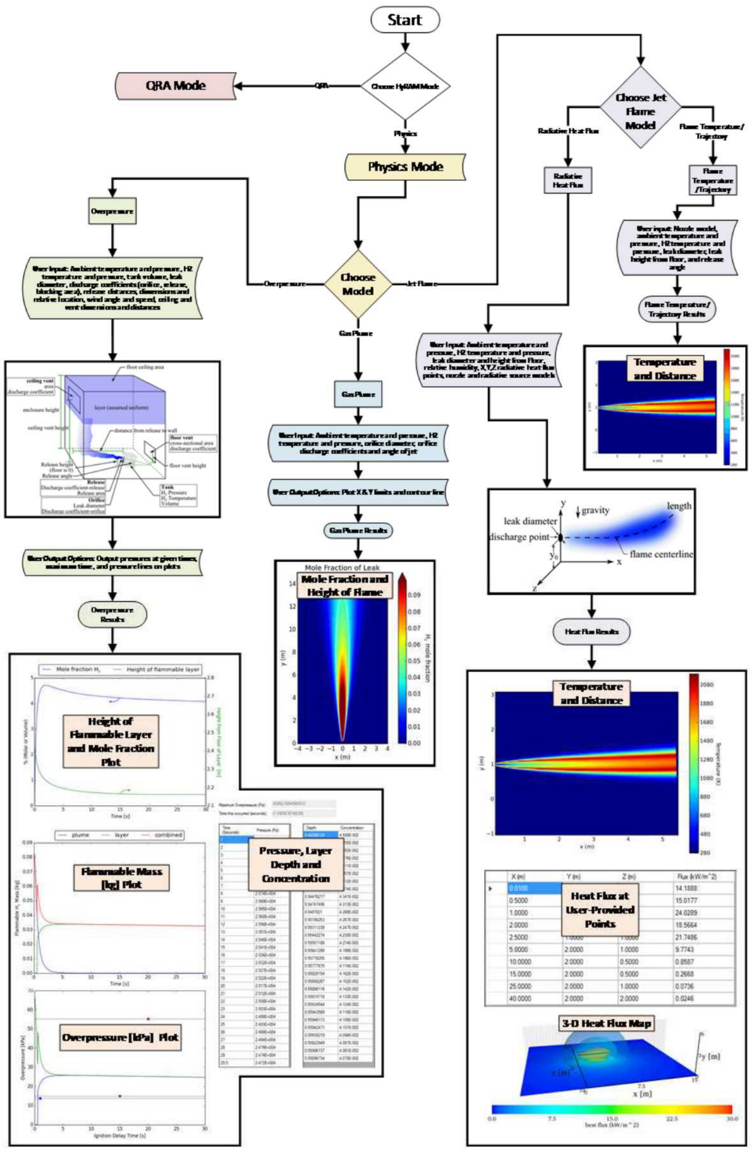
Python for Modules

C# for GUI

Documentation

Algorithm report (SAND2017-2998)

User guide (SAND2018-0749)



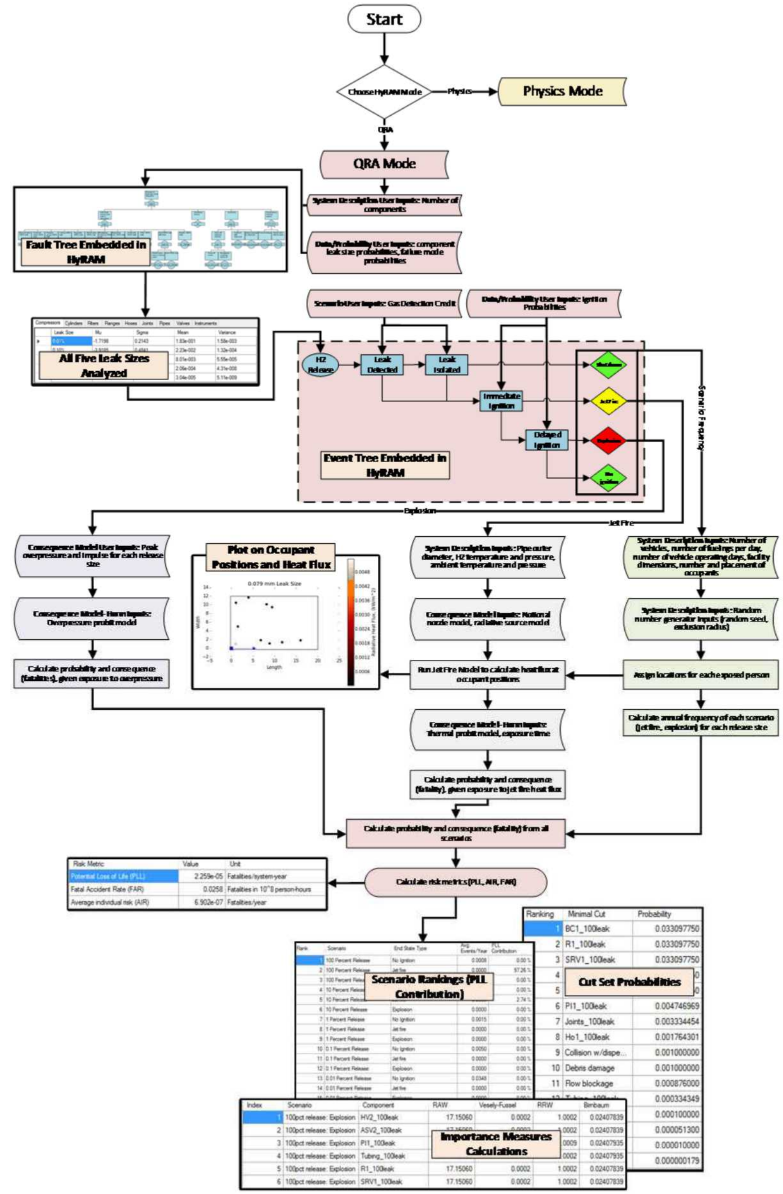
Major Elements of HyRAM Software: QRA Mode

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
Algorithm report (SAND2017-2998)
User guide (SAND2018-0749)



Current Status of Alternative Fuels Risk Assessment Models (AltRAM)

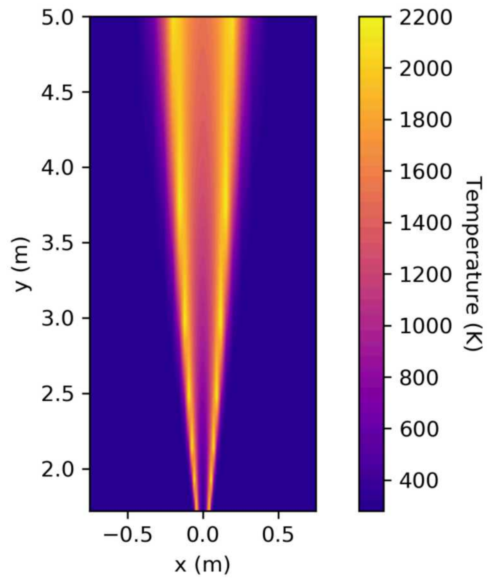
Gas plume:
- Implemented in code, not yet validated
- Will be validated Summer 2019

Cold plume:
- Implemented and validated

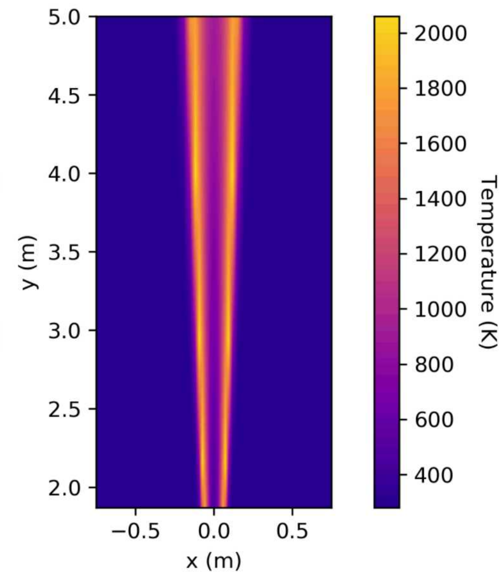
Jet fire:
- Implemented in code, not yet validated
- Will be validated Summer 2019

All models still need to be implemented in GUI

Physics models need to be incorporated with QRA models



Hydrogen



Natural Gas