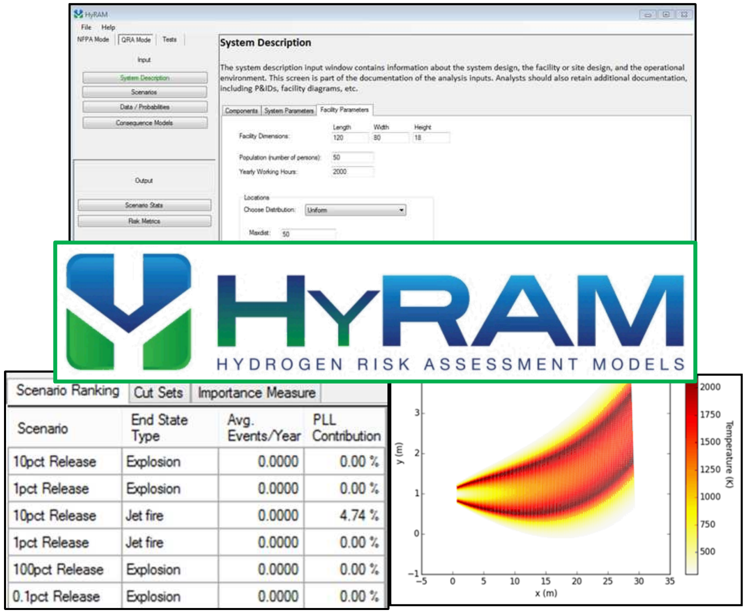
SAND2015-10105PE

HyRAM: A methodology and toolkit for hydrogen QRA & behavior modeling



Katrina M. Groth

Sandia National Laboratories

US DRIVE Codes & Standards Tech Team Meeting
November 12, 2015

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration
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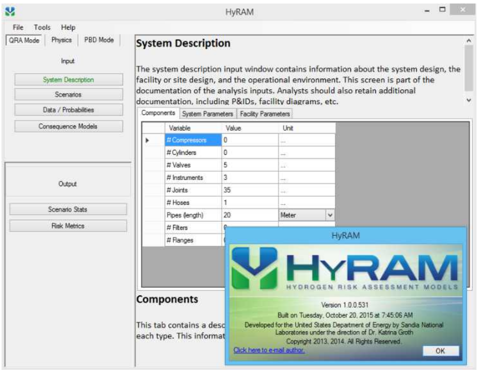
Project approach: Coordinated activities to enable consistent, rigorous, and accepted safety analysis

Risk R&D



Develop integrated methods and algorithms

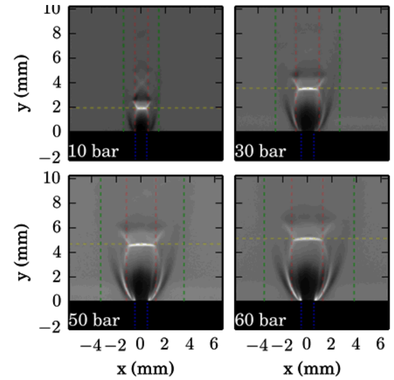
for enabling consistent, logical and defensible QRA

Application in C&S

Apply QRA & behavior models to real problems

in hydrogen infrastructure and emerging technology

Behavior R&D



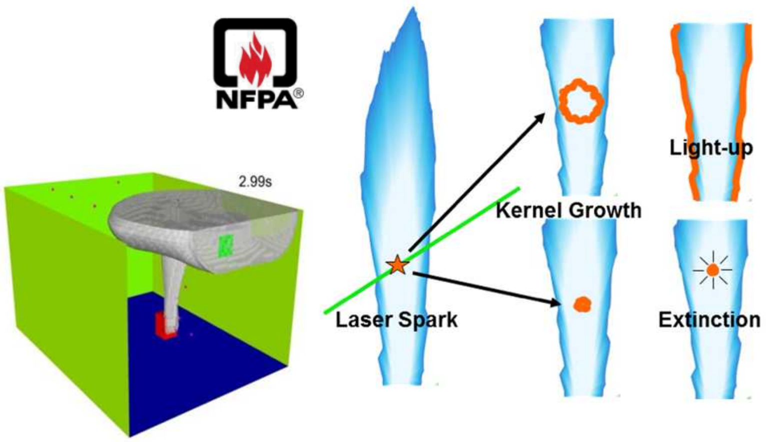
Develop and validate scientific models

to accurately predict hazards and harm from liquid releases, flames, etc.

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

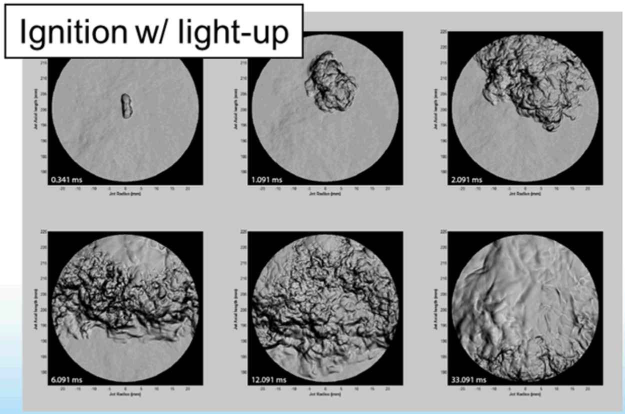
Accelerating deployments via science & engineering *hydrogen behavior* and *quantitative risk assessment (QRA)*

Goal: Facilitate the safe use of hydrogen technologies by providing a science & engineering basis for assessing safety (risk) of H2 systems.



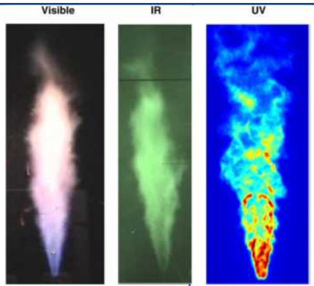
Demonstrated Impact

- Enabling the deployment of refueling stations by developing science-based, risk-informed decision making processes for specification of safety distances in existing code
- Sandia's analysis has enabled the indoor use of fuel cell powered vehicles



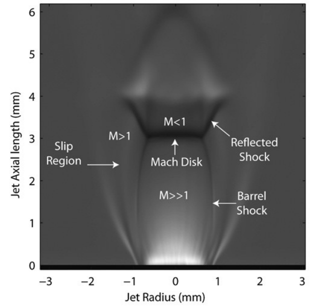
Hydrogen Behavior studies enable predictive capabilities

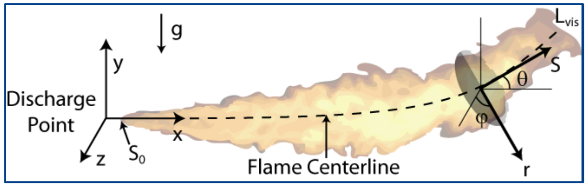
Radiative properties of H2 flames quantified



Barrier walls for risk reduction

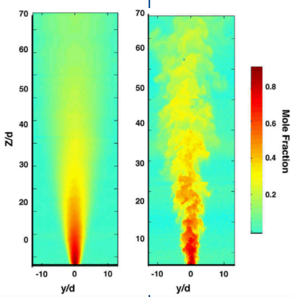
Ignition of under-expanded H2 jets





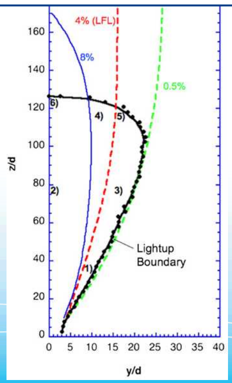
Buoyant jet flame model with multi-source radiation

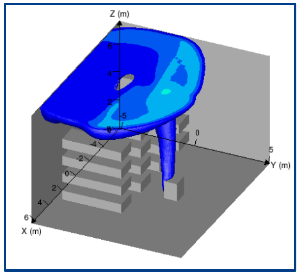
2005 2007 2009 2011 2013 2015 2017



Advanced laser diagnostics applied to turbulent H2 combustion

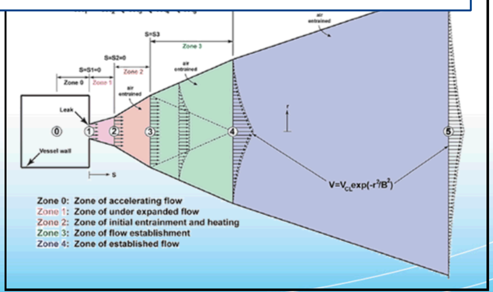
Ignition limits of turbulent H2 flows



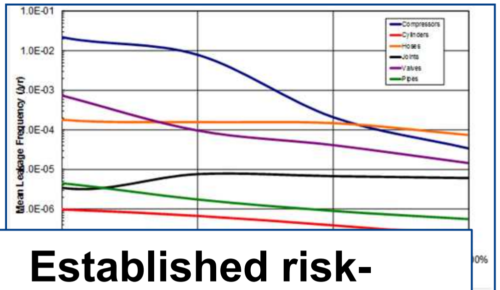


Experiment and simulation of indoor H2 releases

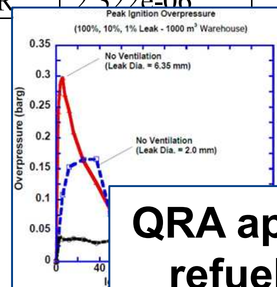
Laboratory-scale characterization of LH2 plumes and jets

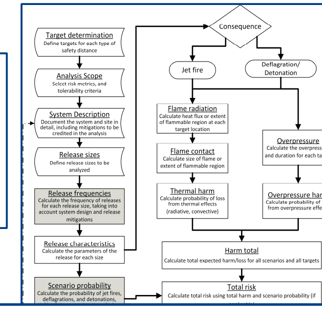


Quantitative Risk Assessment is enabling infrastructure deployment



PLL	5.084e-04
FAR	0.1161
AIR	2.322e-06





Established risk-informed processes for separation distances

QRA applied to indoor refueling to inform code revision

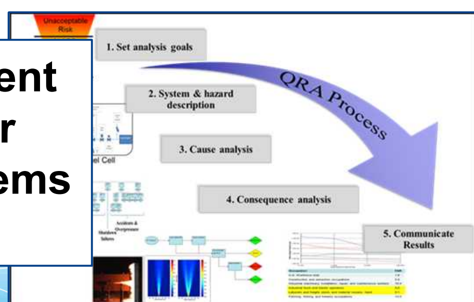
Performance-based system layout demonstrated

ISO TC197 WG24 incorporating QRA and behavior modeling

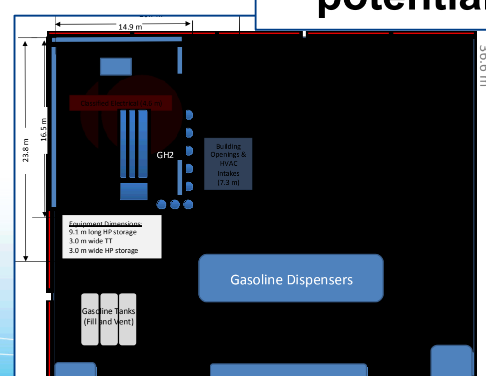
2005 2007 2009 2011 2013 2015 2017

Risk assessment proposed for hydrogen systems at ICHS

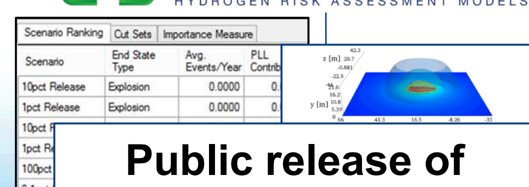
QRA-informed separation distances in NFPA 2



20% station penetration potential due to QRA



HyRAM HYDROGEN RISK ASSESSMENT MODELS



Public release of HyRAM R&D tool

Impact and future potential of QRA and behavior

- **Ongoing activities** applying QRA & behavior models in H2 C&S – reducing barriers
  - GH2 separation distances - NFPA2 Ch. 7 (SAND2014-3416)
  - Indoor fueling requirements - NFPA2 Ch. 10 (SAND2012-10150)
  - Performance-based compliance option - NFPA2 Ch. 5 (SAND2015-4500)
  - Generalized approach for defining country-specific mitigations (e.g., safety distances) – ISO TC197 WG24 (ISO TR-19980-1)
  - Revision of LH_2 separation distances – NFPA 2 (In progress)
- **Additional possible areas of application:** Enclosures (NFPA2 Ch7 and ISO TC197); Evaluate safety impact of different designs; Understand which components drive risk/reliability (and which don't); Quantitative mitigation credit (e.g., the value of flame detector)

Major elements of HyRAM software

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)

Physics models

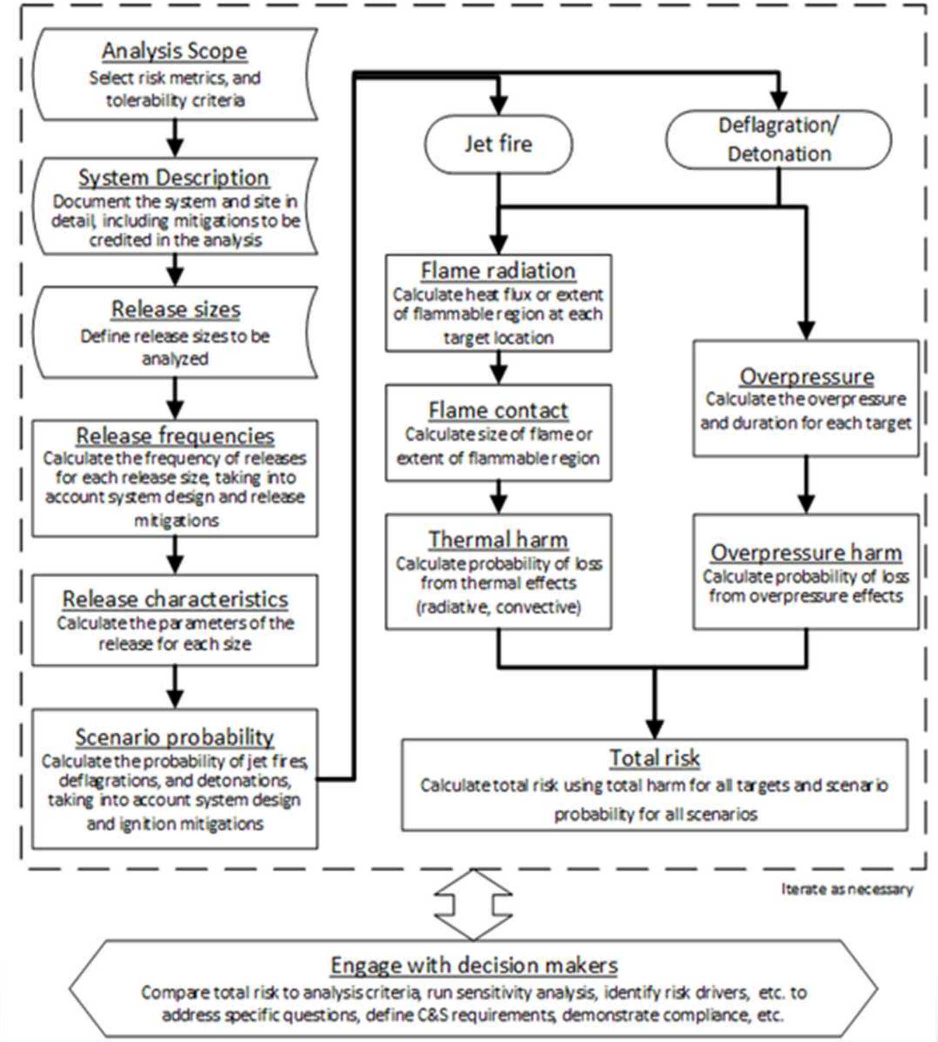
- Properties of Hydrogen
- Unignited releases: Orifice flow; Notional nozzles; Gas jet/plume; Accumulation in enclosures
- Ignited releases: Jet flames w/ and w/o buoyancy; overpressures in enclosures

Mathematics Middleware

- Unit Conversion System
- Math.NET Numerics

Documentation

- Algorithm report (DRAFT ~Nov 2015)
- User guide (SAND2015-7380 R)



+ Anticipated free download via web (~2016)

Motivation for HyRAM: Elements of QRA quality

- **Repeatability**
  - Defined objectives and scope;
  - Clear definitions of failure modes, consequences, criteria, models, and data
  - Document the system, assumptions,
- **Validity & Verifiability**
  - Data, models, system, and analysis must be sufficiently documented for a peer reviewer to evaluate assumptions, completeness, etc.
  - Use experimentally validated models (as available) and published models and data.
- **Comparability**
  - Necessitates flexible modeling tools, documentation of methodology
- **Completeness**
  - Ability to update models as knowledge improves
  - Ensure that analyzed system matches the system as built and operated

HyRAM updates since April (Demo in software)

- Overpressure model in physics mode – initial UI & internal testing
- Reconfigured jet flame physics UI & added more variables for user inputs
- New UIs in QRA mode – occupant/target position, master input editor
- Engineering toolbox
- Testing & validation activities
  - Alpha testers from 8 external partners (industry, labs)
  - Internal software testing & experimental validation
- Documentation: HyRAM software & technical basis
  - KM Groth, ES Hecht & JT Reynolds. *Methodology for assessing the safety of Hydrogen Systems: HyRAM 1.0* ***technical reference*** *manual* SAND2015-DRAFT, ~Nov 2015.)
  - KM Groth and ES Hecht. HyRAM: A **methodology** and toolkit for Quantitative Risk Assessment of Hydrogen Systems. ICHS 2015.
  - HR Zumwalt and KM Groth. *HyRAM V1.0* ***User's Manual*** . -- SAND2015-7380 R.

Recent (FY15) SNL R&D building and using HyRAM

- Applications for C&S
  - AC LaFleur, AB Muna & KM Groth. *Fire Protection Engineering Design Brief Template: Hydrogen Refueling Station* SAND2015-4500.
  - A. C. LaFleur, A. B. Muna and K. M. Groth "Application of Quantitative Risk Assessment for Performance-Based Permitting of Hydrogen Fueling Stations" ICHS 2015.
  - ISO TR-19880 (Accepted via all voting countries Oct. 2015).
- Experimental work to validate models *Turbulent Combustion Lab.*
  - ES Hecht et al. Design of the Cryogenic Hydrogen Release Laboratory. SAND2015-7521.
  - IW Ekoto et al. Liquid Hydrogen Release and Behavior Modeling: State-of-the-Art Knowledge Gaps and Research Needs for Refueling Infrastructure Safety. SAND2014-18776.

Next steps

- FY16:
  - Integration of overpressure model into QRA mode; Add risk-features (Fault Trees);
  - Public release of HyRAM 1.0; Documentation & website
  - Use of HyRAM to develop examples for NFPA 2; ISO-19880 Annex A
- FY17:
  - **Addition of** cold H_2 release models
- Out-years
  - Highly accessible (web-based/app) tool for enabling end-users to implement these algorithms
  - Continue experimental work to generate needed validation data and develop necessary science-based models (e.g. wall interactions)

Long-term vision Fully configurable, tested software product available for users to calculate hydrogen risk values and consequences to design, develop and adapt system designs globally.

Remaining challenges & barriers

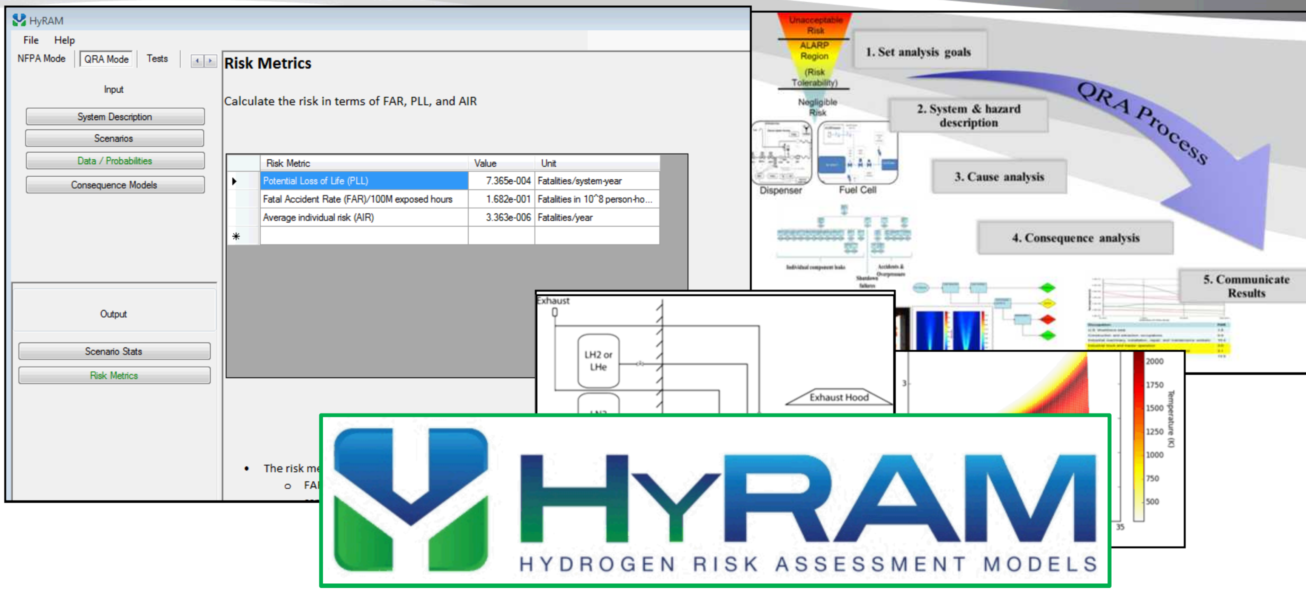
- **Need for financial support from industry via CRADA with CaFCP**
- **Hydrogen Behavior**
  - Address missing/unvalidated behavior models -- provides ability to overcome station-siting barriers
    - Flow/flame surface interactions
    - Physical model based ignition probability
    - High-pressure cryogenic H_2 release behavior
- **QRA/ HyRAM**
  - Extend ability to get system-specific insights
    - Enable sensitivity and uncertainty analysis
    - Deflagration (unconfined) and detonation models
  - Additional reliability/failure data for H2 systems
  - Software validation activities
  - Transition HyRAM beyond prototype (e.g., formal software development activities, software quality assurance)

Summary

- **HyRAM is an integration platform** for state-of-the-art H2 safety models – enables consistent *industry-led* QRA and consequence analysis with documented, referenceable, validated models

- HyRAM 1.0 public release expected in 3-6 months – free download, use-at-your-own-risk.

- Additional models and features are being integrated into HyRAM – cryo, engineering toolkit.
- Ongoing activities for stakeholder engagement, evaluation, verification, and acceptance



Thank you!

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Sources of models & data in HyRAM 1.0

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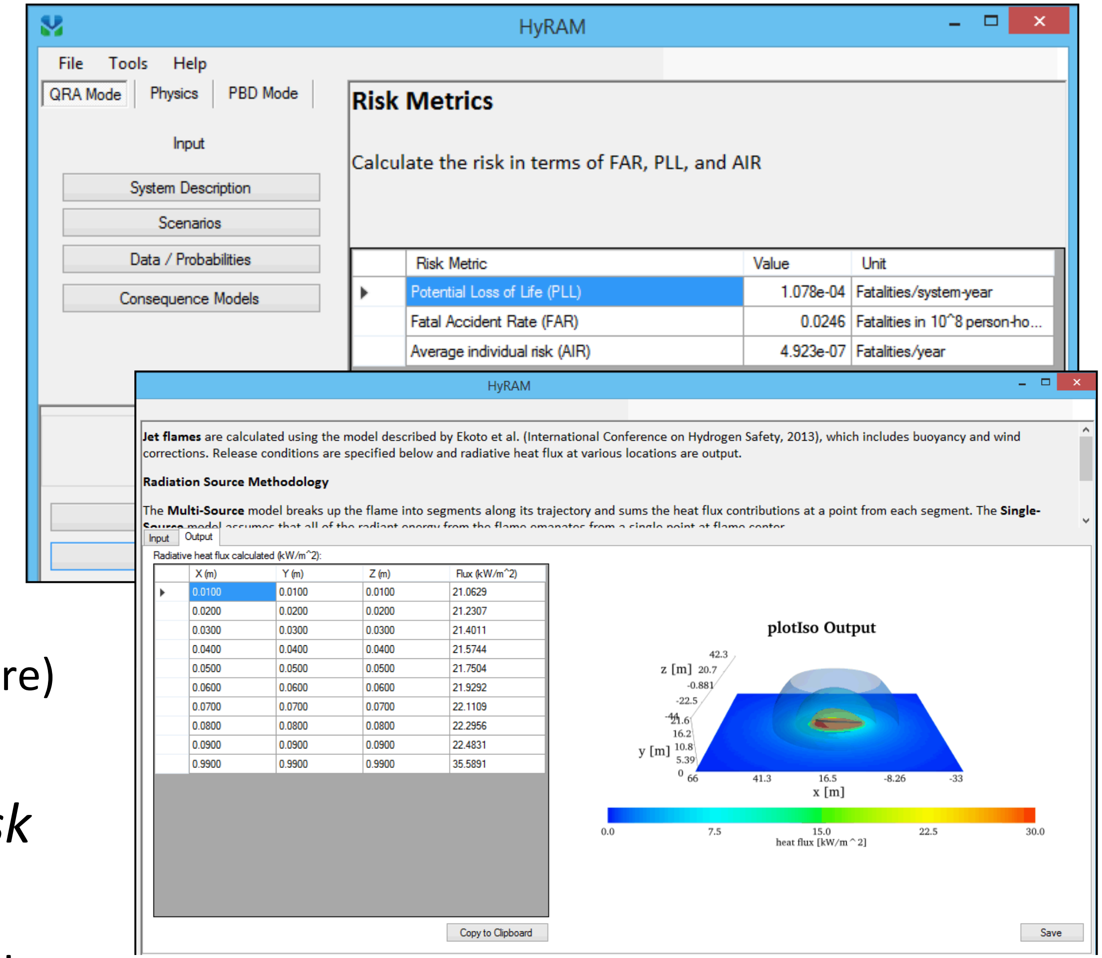
HyRAM in one slide

- **Integration platform** for state-of-the-art hydrogen safety models & data
  - Generic reliability data for H2 systems
  - Standardized scenarios and models
  - H2 phenomena (gas release, ignition, heat flux, overpressure)
- Software built to enable **industry-led** *quantitative risk assessments* (QRAs)
  - Puts the R&D into the hands of H2 industry safety experts



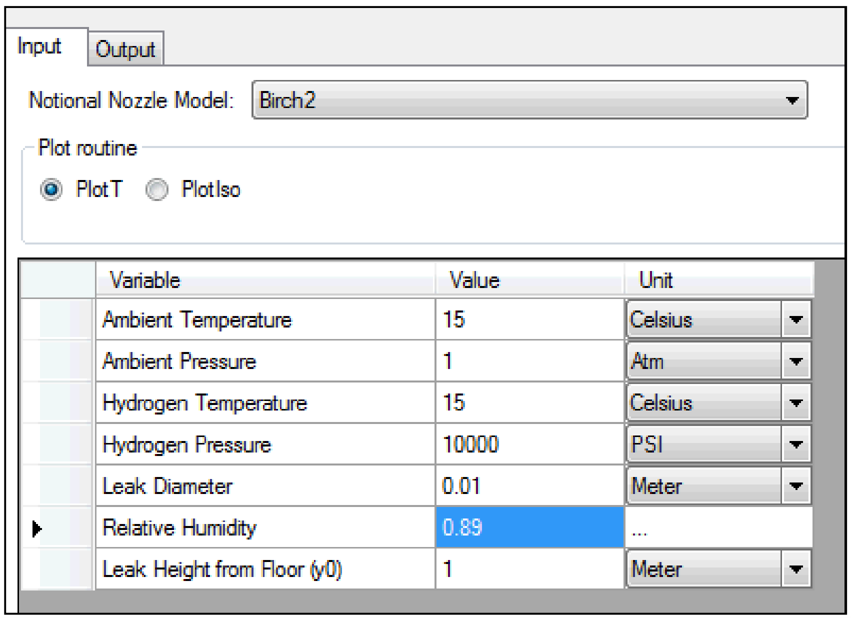
HYRAM
HYDROGEN RISK ASSESSMENT MODELS

Example HyRAM calculation: Jet Flame physics

Consequence-only modeling

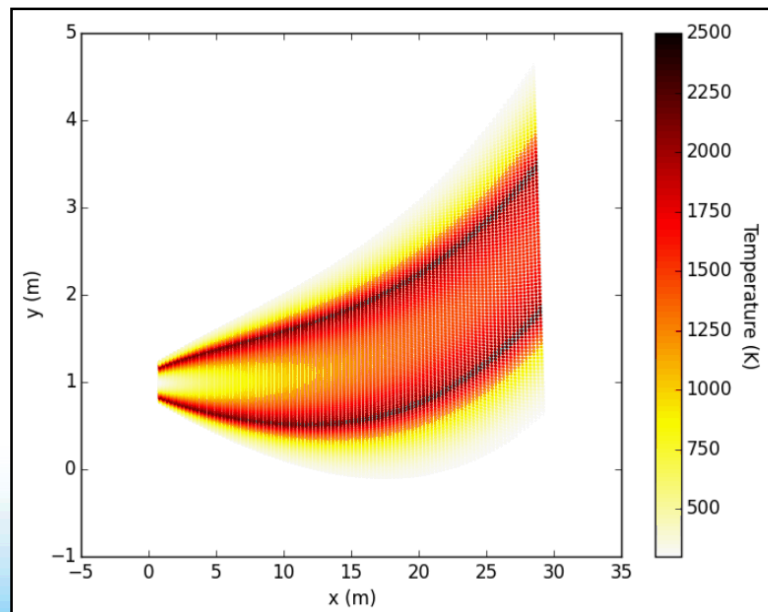
Input

- Leak size and known conditions.



Output

- Shows flame temperature at different distances -- direct analog to original safety distance work.



Example HyRAM calculation: Full QRA

Allows credit for mitigations that reduce likelihood of events & provides system-specific risk-reduction insight

Input

- System description (components, parameters, facility description)

Components | System Parameters | Facility Parameters

Piping | Vehicles

Variable	Value	Unit
Pipe Outer Diameter	0.375	Inch
Pipe Wall Thickness	0.065	Inch
Internal Temperatu		
Internal Pressure		
External Temperatu		
External Pressure		

Components | System Parameters | Facility Parameters

Component	Count	Unit
# Compressors	0	...
# Cylinders	0	...
# Valves	5	...
# Instruments	3	...
# Joints	35	...
# Hoses	1	...

Facility | Occupants

Input Details | Distribution

Variable	Value
Population (Number of persons)	50
Working hours per year	2000

Output

- Total system risk
  - Enables comparisons, e.g. risk with vs. without gas detection

Risk Metric	Value	Unit
Potential Loss of Life (PLL)	4.500e-04	Fatalities/system-year
Fatal Accident Rate (FAR)/100M exposed hours	0.1027	Fatalities in 10^8 person-ho...
Average individual risk (AIR)	2.055e-06	Fatalities/year

Risk Metric	Value	Unit
Potential Loss of Life (PLL)	5.000e-04	Fatalities/system-year
Fatal Accident Rate (FAR)/100M exposed hours	0.1141	Fatalities in 10^8 person-ho...
Average individual risk (AIR)	2.283e-06	Fatalities/year

- Insight into risk drivers: scenario frequency & risk ranking

Scenario	End State Type	Avg. Events/Year	PLL Contribution
0.01pct Release	No Ignition	0.03448206	0.00%
0.1pct Release	No Ignition	0.00495318	0.00%
1pct Release	No Ignition	0.00148741	0.00%
10pct Release	No Ignition	0.00116683	0.00%
100pct Release	No Ignition	0.00071471	0.00%
0.01pct Release	Jet fire	0.00025097	0.00 %
0.01pct Release	Explosion	0.00012448	0.01 %
100pct Release	Jet fire	0.00003669	0.00 %
0.1pct Release	Jet fire	0.00003605	0.00 %
0.1pct Release	Explosion	0.00001788	0.00 %
100pct Release	Explosion	0.00001770	95.15 %
1pct Release	Jet fire	0.00001083	0.00 %
10pct Release	Jet fire	0.00000849	0.00 %
1pct Release	Explosion	0.00000537	0.03 %
10pct Release	Explosion	0.00000421	4.81 %