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HyRAM model integration platform

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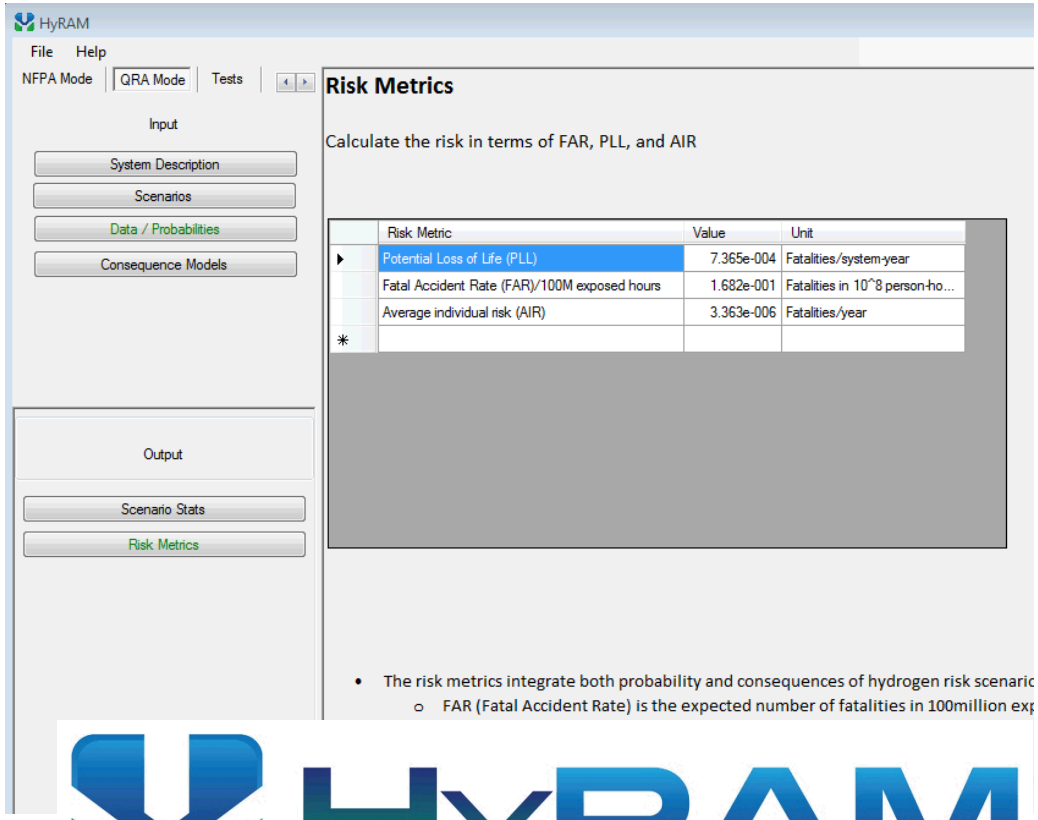
HyRAM* in one slide

- **Integration platform** for state-of-the-art hydrogen research
  - Modules to be developed by R&D community
- Software tool built to enable **industry-led** quantitative risk assessments (QRAs)
  - Puts the state-of-the-art R&D into the hands of H2 industry safety experts



HyRAM
HYDROGEN RISK ASSESSMENT MODELS

*HyRAM: Hydrogen Risk Assessment Models

QRA brings science, rigor, into decision-making

- **QRA used extensively in nuclear power, aviation, oil, gas**
- **Successful application of QRA in H2 codes & standards:**
  - Established GH2 separation distances (NFPA2 Ch. 7)
  - Calculated risk from indoor fueling (NFPA2 Ch. 10) and identified ambiguity in NFPA2 Ch. 10 requirements
  - Development of calculation approach for ISO TC197 safety distances
  - PB (Performance-based) compliance option (NFPA2 Ch. 5)
- **Additional areas of application for H2:**
  - Enclosures (NFPA2 Ch7 and ISO TC197)
  - Evaluate safety impact of different designs
  - Understand which components drive risk/reliabilty (and which ones don't)
  - Etc.

Challenges for enabling H2 QRA

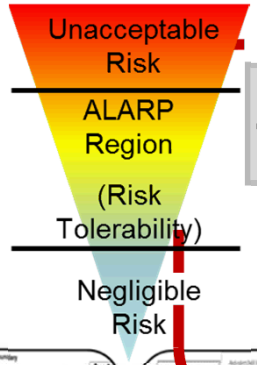
- **Challenge 1**: Short commercial history requires the use of both deterministic and probabilistic models for H2 QRA
  - Limited statistical data for H2-specific component performance, leak frequencies, gas and flame detection, ignition, harm
  - Evolving understanding of H2 physical behavior and consequences
- **Challenge 2**: Lack of user-friendly tools for doing this type of analysis
  - Lack of hydrogen-specific models in current QRA tools
  - Lack of integrated QRA capabilities in current H2 consequence tools

Scoping an industry-focused tool

- Sandia & HySafe workshop (June 2013) -- define user needs, goals
- Two distinct stakeholder groups.
  - **Users** – pilot the application of QRA toolkit for addressing specific industry questions.
    - High level, generic insights for C&S developers, regulators, etc.;
    - Detailed, site-specific QRA insights for system designers, insurers, authorities having jurisdiction (AHJs)
  - **Developers** – Improve the data and models being used within the toolkit.

Participation & iteration by both communities is necessary for success

QRA Process Overview

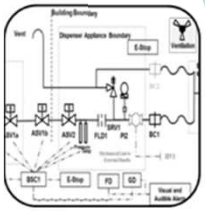


1. Set analysis goals

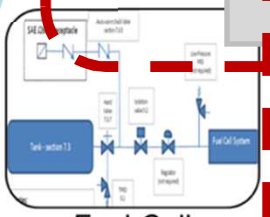
Before the Toolkit

QRA Process

2. System & hazard description



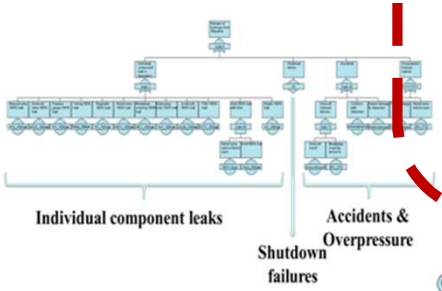
Dispenser



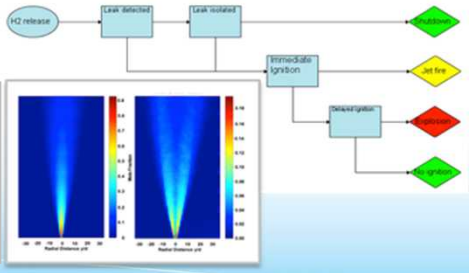
Fuel Cell

3. Cause analysis

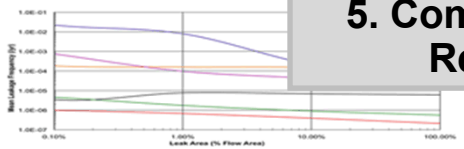
Focus of Toolkit



4. Consequence analysis

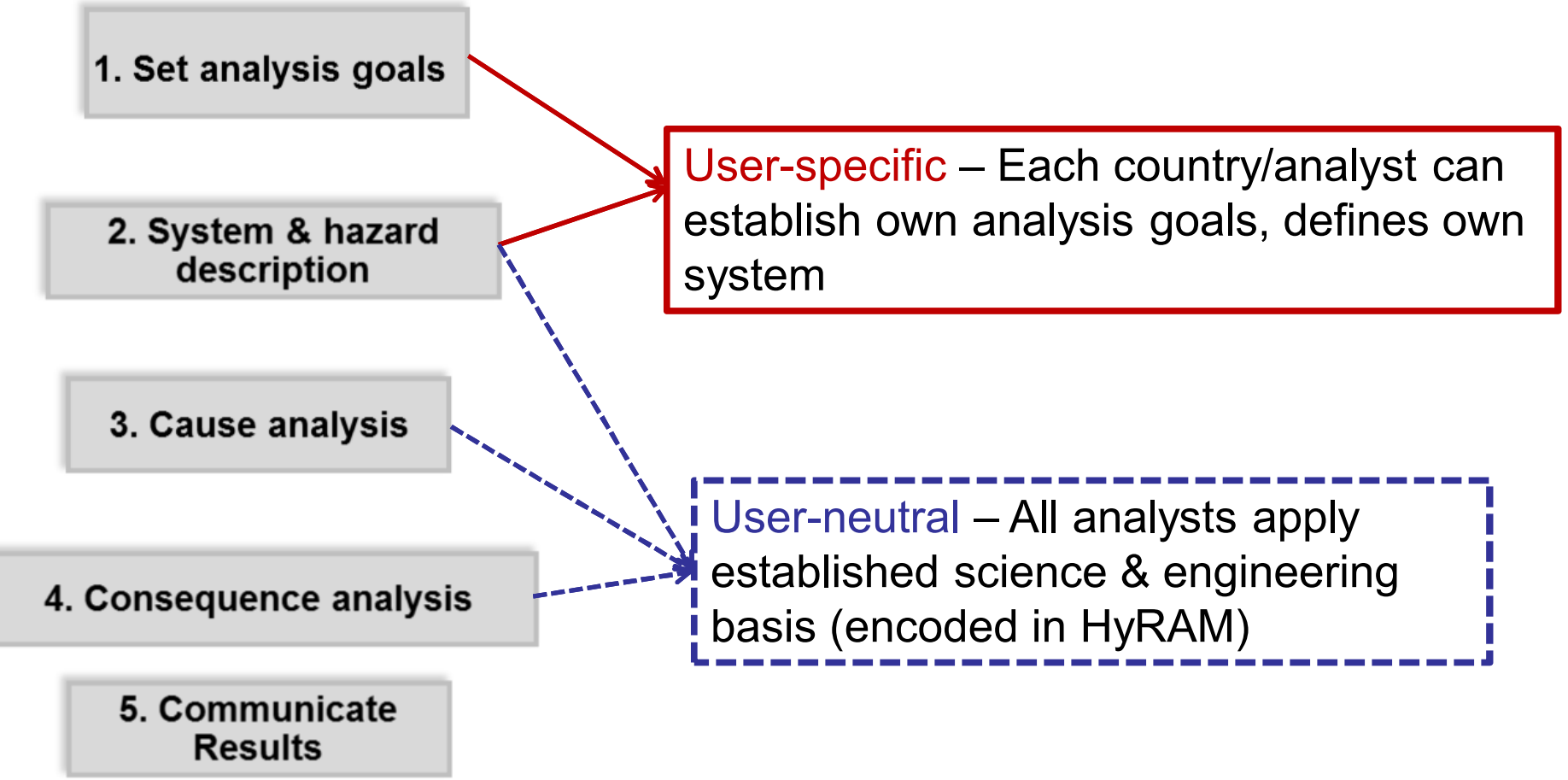


5. Communicate Results



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

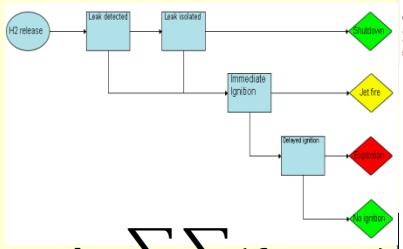
Philosophy


1. Set analysis goals
2. System & hazard description
3. Cause analysis
4. Consequence analysis
5. Communicate Results
User-specific – Each country/analyst can establish own analysis goals, defines own system
User-neutral – All analysts apply established science & engineering basis (encoded in HyRAM)

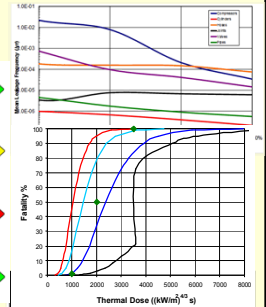
H2 researchers are filling gaps in models, tools, data

QRA method, data & models

- Hazards
- Accident sequences
- Release frequencies
- Ignition probabilities
- Harm/damage



$$\text{Risk} \sim \sum_{n} \sum_{j} (f_{nj} \cdot c_{nj})$$

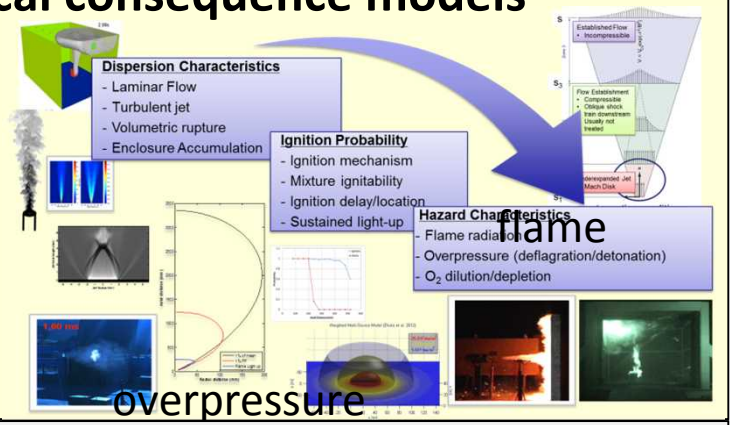


(kg/s)	Probability	Probability
<0.125	0.008	0.004
0.125 – 6.25	0.053	0.027

Reduced order physical consequence models

- GH2 release
- Ignition
- Reduced-order jet

  models
- Deflagration



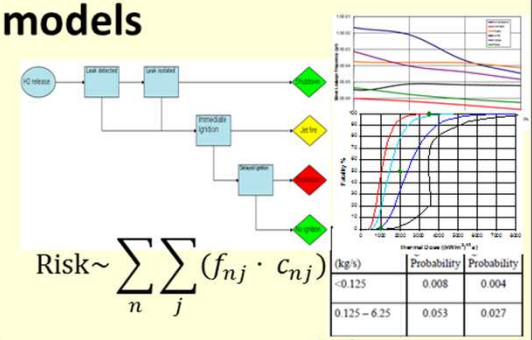
Outstanding gaps: System operating experience; component failure rates; Models for LH2 releases & cold gas plumes; ignition / flame light-up; Effect of barriers, detectors;

Sandia and HySafe are working to integrate those efforts

Objective: Facilitate H2 industry access to best science and engineering models to enable industry-lead QRAs

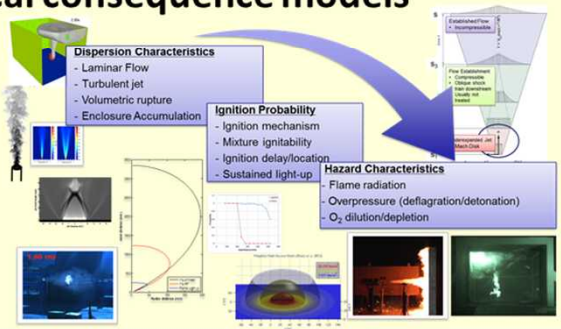
QRA method, data & models

- Hazards
- Accident sequences
- Release frequencies
- Ignition probabilities
- Harm/damage



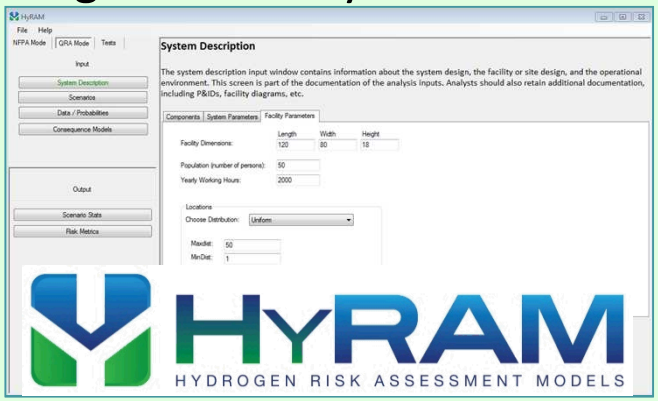
Reduced order physical consequence models

- GH2 release
- Ignition
- Reduced-order jet flame models
- Deflagration overpressure

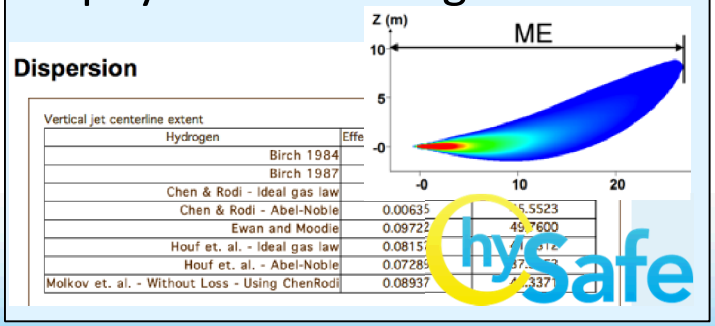


Outstanding gaps: System operating experience; component failure rates; Models for LH2 releases & cold gas plumes; ignition / flame light-up; Effect of barriers, detectors;

Sandia: Integrated QRA algorithm & HyRAM toolkit

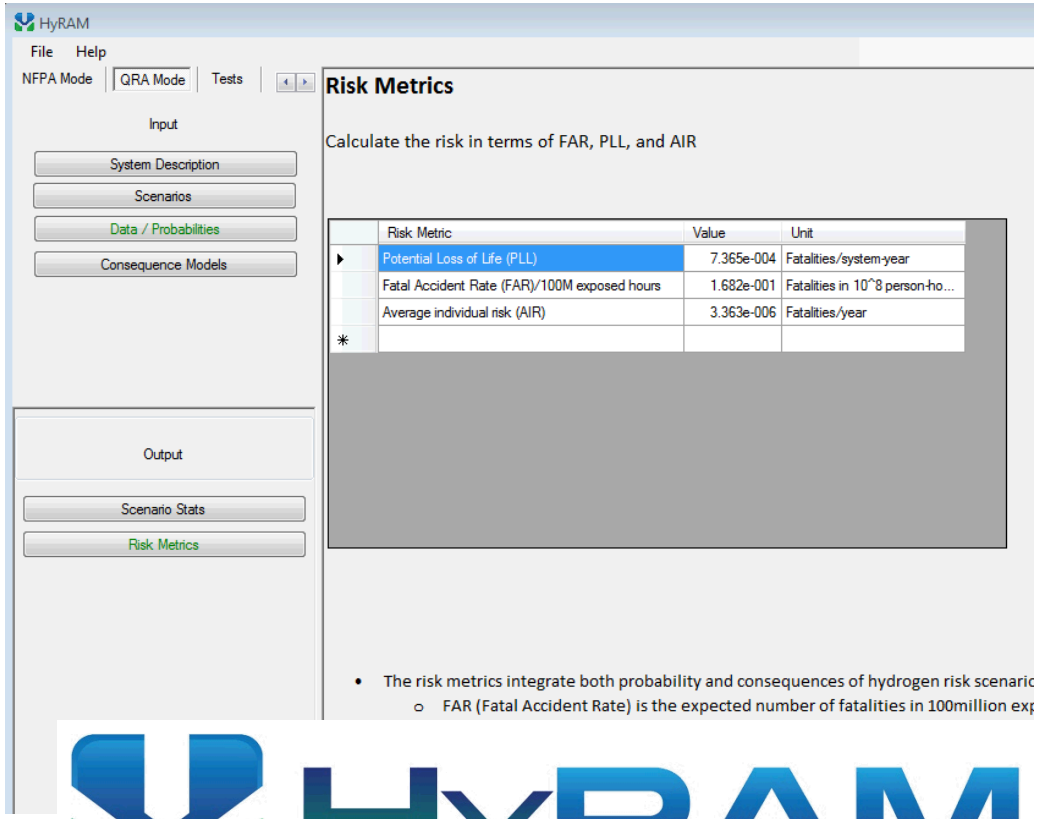


HySafe: Coordination of physical modeling & tools



HyRAM : Hydrogen Risk Assessment Models

- **Goal**: Develop tools to enable industry-led QRAs (Quantitative risk assessments)
  - Include best-available models for:
    - All relevant hazards (thermal, mechanical, toxicity)
    - Probabilistic models & data
    - H2 phenomena (gas release, ignition, heat flux, overpressure)
  - GUIs and generic assumptions
  - Flexible software architecture to enable improvements as H2 science, data and models improve



HyRAM
HYDROGEN RISK ASSESSMENT MODELS

Metrics [currently] supported in HyRAM

Calculates 3 risk metrics:

- **FAR (Fatal Accident Rate)**
  - Expected number of fatalities per 100million exposed hours
- **AIR (Average Individual Risk)**
  - Expected number of fatalities per exposed individual
- **PLL (Potential Loss of Life)**
  - Expected number of fatalities per dispenser-year.

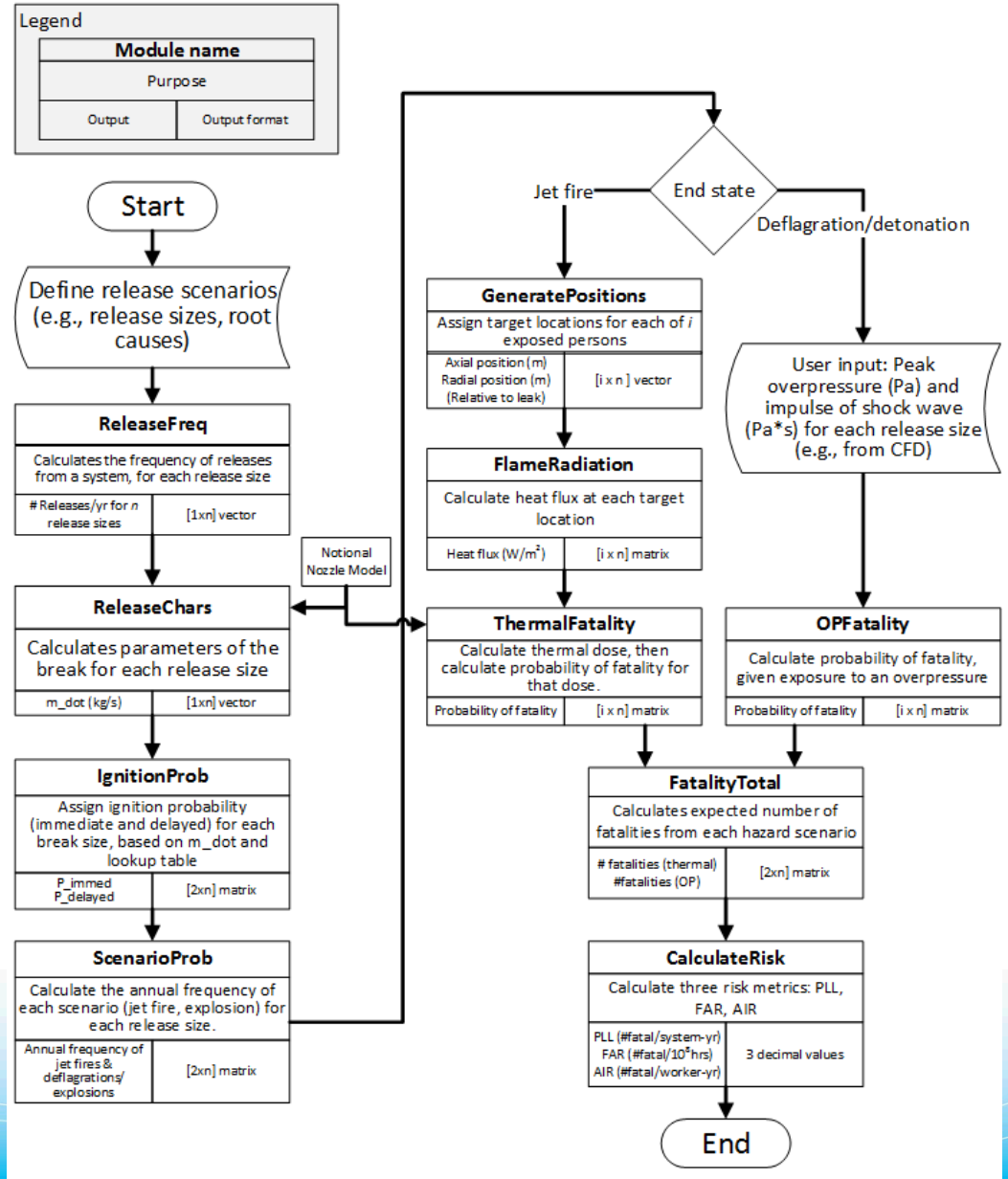
And physical behavior of:

- **Hydrogen jets**
  - Width, velocity, density, …
- **Jet fires**
  - Flame length, heat flux, …
- **Deflagrations** (coming soon)
  - Ignitable volume, overpressure, …

HyRAM toolkit modules (current and planned)

- .NET software framework (Windows) with planned HTML interface;
  - C# and Python

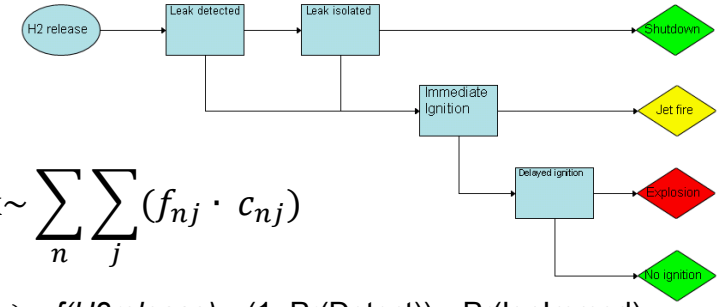
- Integrates best available probabilistic and deterministic models for:
  - Component failure
  - Ignition occurrence
  - Gas release
  - Gas dispersion
  - Jet flames
  - Deflagration / detonation
  - Harm to humans and structures



Modules: Cause & harm models (currently)

Accident sequences

- Hazards considered: Thermal effects (jet fire), overpressure (explosion/deflagration)



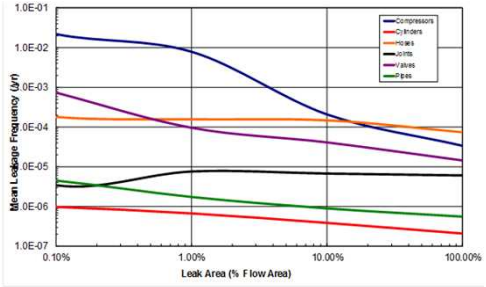
$$\text{Risk} \sim \sum_n \sum_j (f_{nj} \cdot c_{nj})$$

$f(\text{JetFire}) = f(\text{H2release}) * (1-\text{Pr(Detect)}) * \text{Pr(IgnImmed)}$

Release frequency

- Expected annual leak freq. for each component type -- Data developed from limited H2 data combined w/ data from other industries.

$$f(H2release) = \sum_{i=9\ comps} n_i * E(f(Leak)_i) + E(Pr(accidents)) * n_{demands}$$



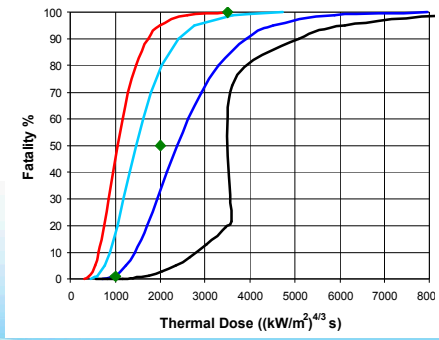
Ignition probability

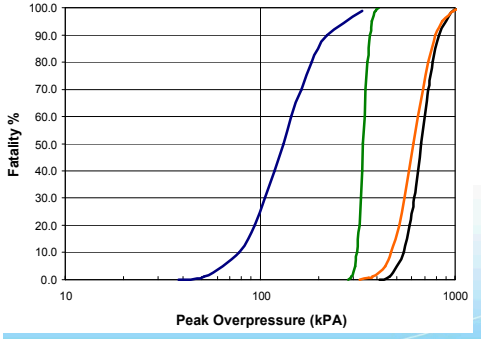
- Extrapolated from methane ignition probabilities
- Flow rate calculated using *Release Characteristics* module

Hydrogen Release Rate (kg/s)	Immediate Ignition Probability	Delayed Ignition Probability
<0.125	0.008	0.004
0.125 – 6.25	0.053	0.027
>6.25	0.23	0.12

Harm models

- Probability of fatality from exposure to heat flux and overpressures – multiple options

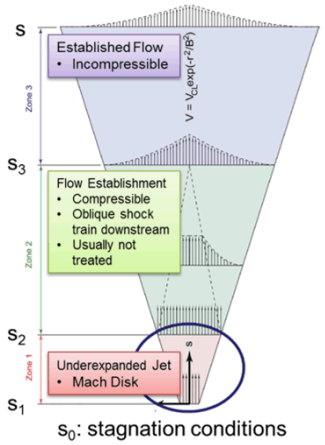


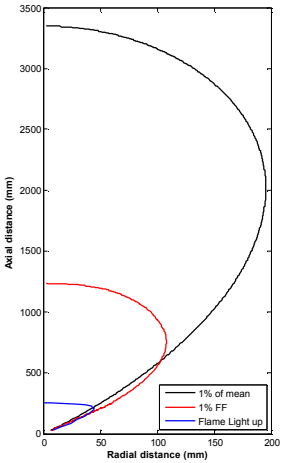


Modules: Behavior & Consequence (currently)

Release Characteristics

- H_2 jet integral model developed & validated
- Source models developed for LH2 & choked flow inputs



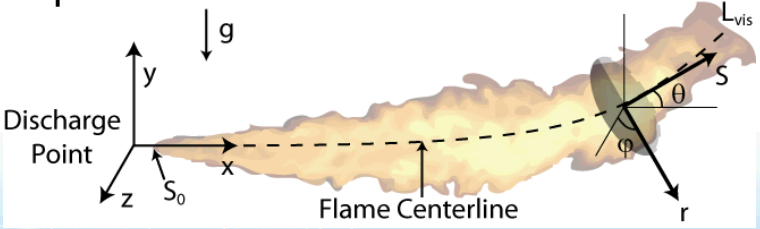


Ignition/Flame Light-up (*pending addition*)

- Flammability Factor verified for ignition prediction
- Light-up boundaries identified
- Next: sustained flame prediction

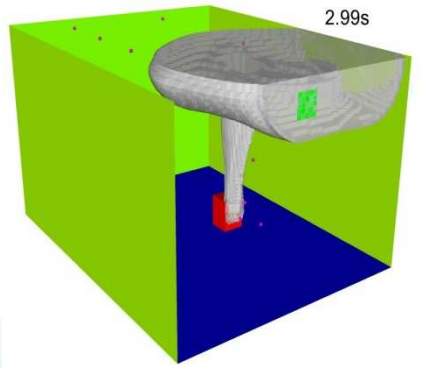
Flame Radiation

- Flame integral model developed
- Multi-source models significantly improve heat flux prediction
- Surface reflection can be a major potential heat flux contributor



Deflagration within Enclosures

- Ventilated deflagration overpressure explored experimentally and computationally
- Current QRA module requires CFD results.
- Engineering model framework pending



Next steps for the HyRAM toolkit:

- Initial working prototype (HyRAM 1.0alpha) – user testing beginning ~Feb 2015.
- Extending algorithm scope with Sandia models
  - 2015: Add recent Sandia models: accumulation, overpressure
  - 2016: Traditional QRA interface options (Fault Trees, Event Trees)
  - 2017: Cryogenic behavior
- Interface with international data & model selection/development work to expand science base of HyRAM
  - 2015: Code interface manual and algorithm manuals
- Long-term:
  - Transfer of toolkit to third party (HySafe?) for maintenance, hosting, ongoing support via “community owned” model.

Major HyRAM needs from HySafe

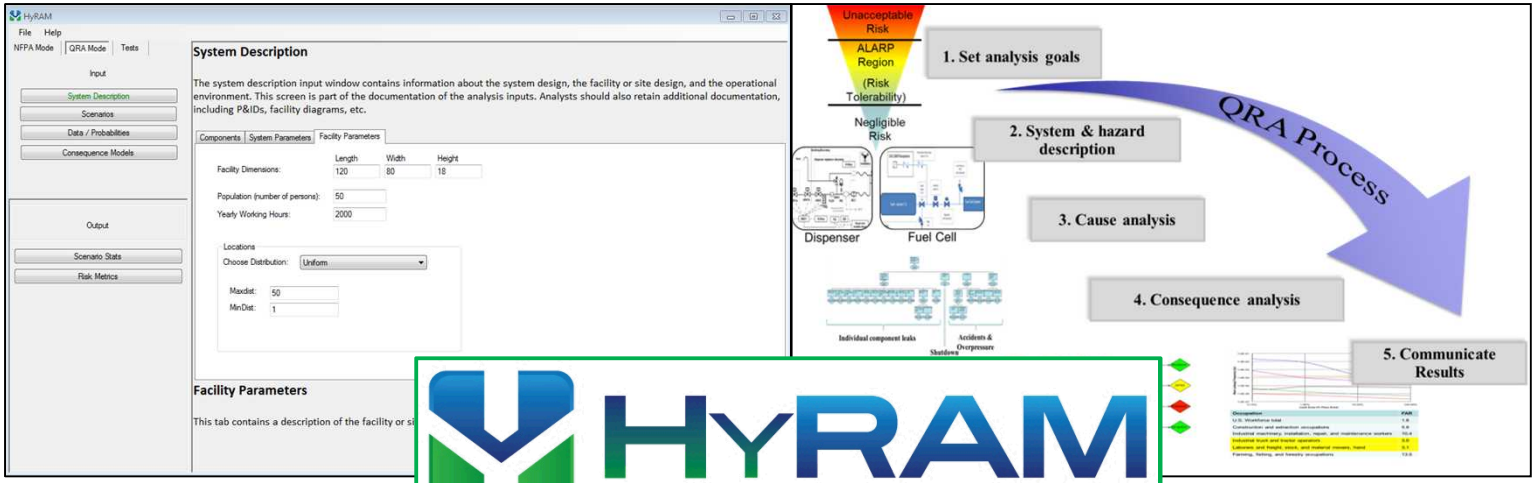
- **In one sentence: Models, data, validation & community engagement**
- Specifically:
  - Engagement with partners to refine QRA approach, standardize, review & adopt models (international and domestic, research and application)
  - Behavior models specifically developed & validated for application to hydrogen fuel cell problems
    - Developed as standalone C#, Python modules.
  - Lab-scale experiments, full-scale experiments, simulation for behavior models
  - H2 data for improving credibility of probabilistic event models (e.g., release frequencies, harm)
  - Validation activities to enhance credibility of behavior models and data originating from non-fuel-cell applications.

Summary

- **HyRAM is an integration platform** for state-of-the-art science & engineering models **to facilitate industry-led QRA.**
  - H2 industry has strong desire to use risk-informed decision making
  - Industry needs tools, and they need to be user-friendly, coordinated, and credible.

- Current state:
  - HyRAM 1.0alpha is almost ready for user testing
  - Additional Sandia models being added over next years

- Major needs:
  - **Models, data, validation and community engagement**
  - Ongoing efforts to identify robust data and models for toolkit
  - "Community ownership" model



Thank you!

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