HyRAM model integration platform
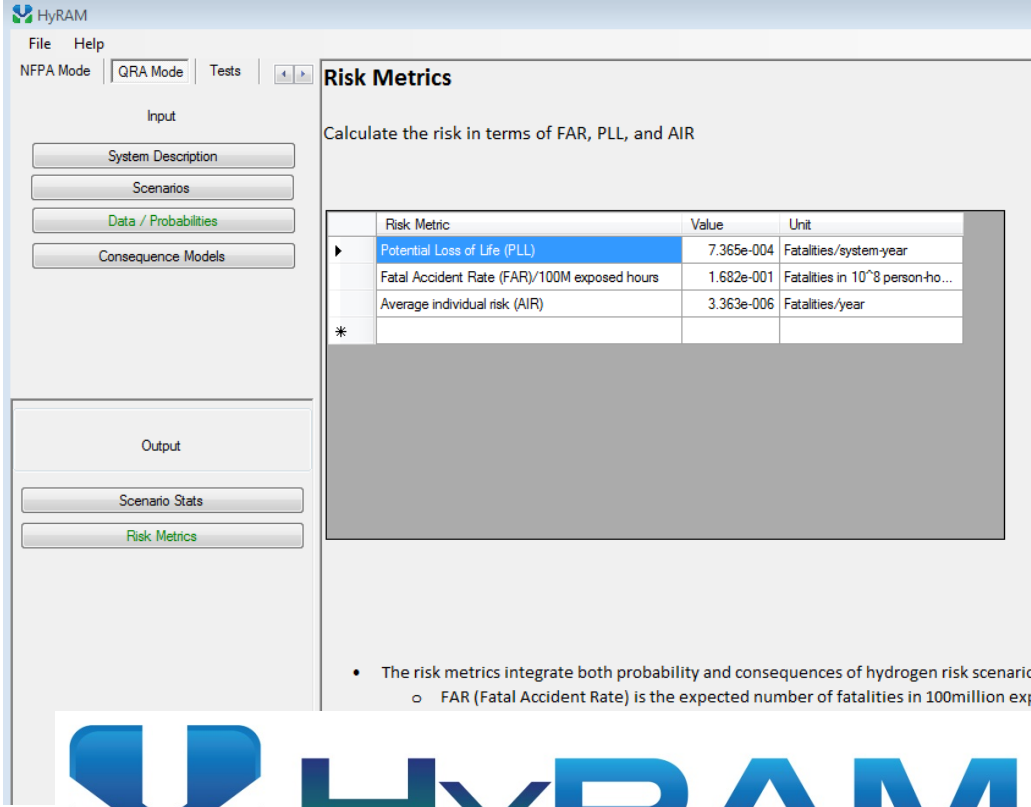
Katrina M. Groth, Ph.D.

Sandia National Laboratories, Albuquerque, NM, USA

2014 HySafe Research Priorities workshop
Washington DC, USA
10 November 2014

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

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.

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

2. System & hazard description

3. Cause analysis

4. Consequence analysis

5. Communicate Results

Before the Toolkit

QRA Process

Focus of Toolkit
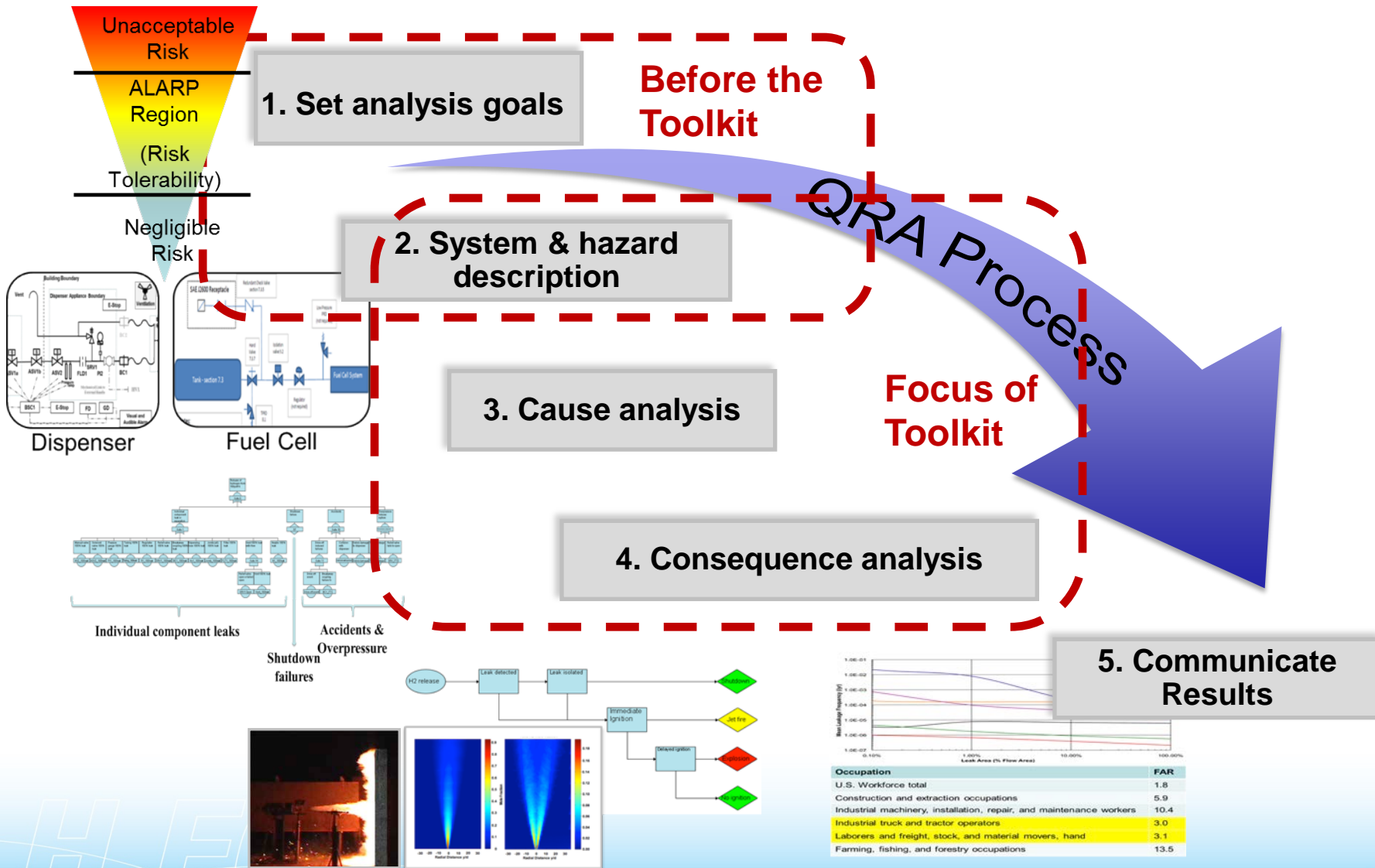
Philosophy

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

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

(kg/s)	Probability	Probability
<0.125	0.008	0.004
0.125 − 6.25	0.053	0.027
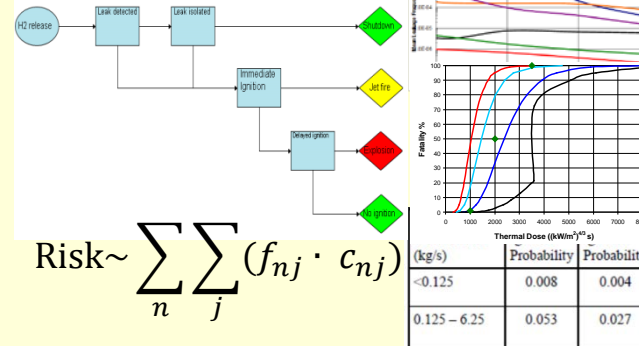
Reduced order physical consequence models

- GH2 release
- Ignition
- Reduced-order jet

    models
- Deflagration

Dispersion Characteristics
- Laminar Flow
- Turbulent jet
- Volumetric rupture
- Enclosure Accumulation

Ignition Probability
- Ignition mechanism
- Mixture ignitability
- Ignition delay/location
- Sustained light-up

Hazard Characteristics
- Flame radiation
- Overpressure (deflagration/detonation)
- O₂ dilution/depletion

flame

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 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

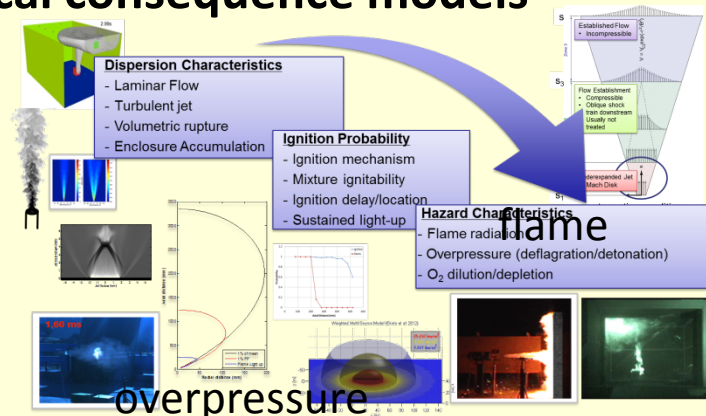- Hazards
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Reduced order physical consequence models

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

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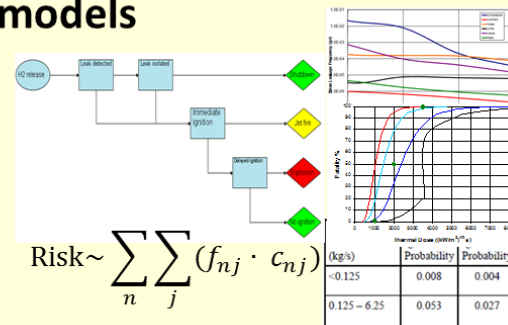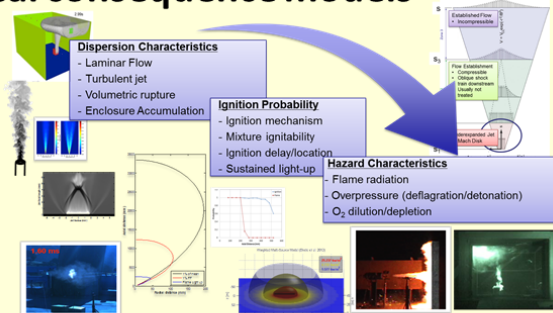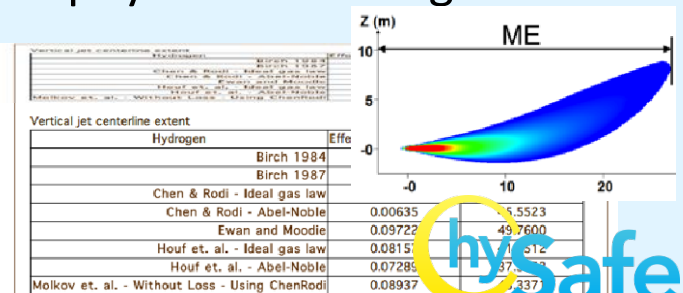- O₂ dilution/depletion

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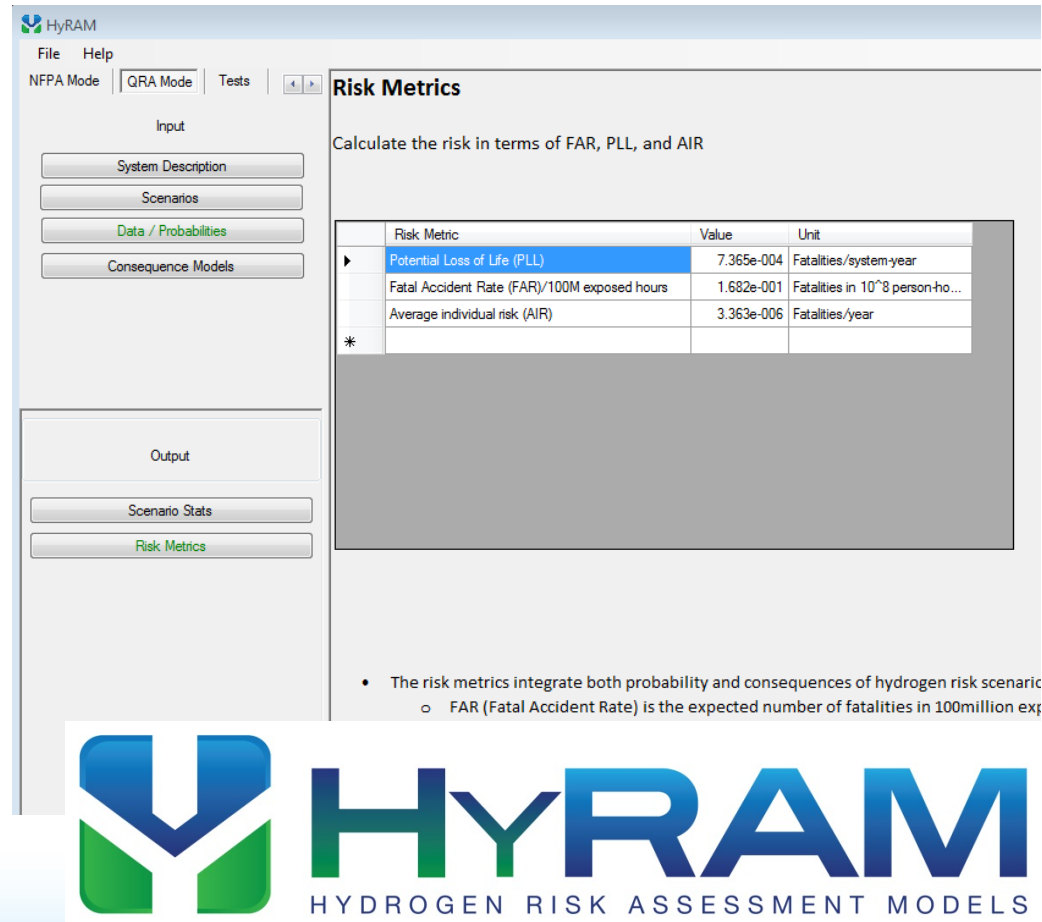
Sandia: Integrated QRA algorithm & HyRAM toolkit

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

HySafe: Coordination of physical modeling & tools

Vertical jet centerline extent

Hydrogen		
Birch 1984		
Birch 1987		
Chen & Rodi - Ideal gas law		
Chen & Rodi - Abel-Noble	0.00635	5.5523
Ewan and Moodie	0.09722	49.7600
Houf et. al. - Ideal gas law	0.08157	
Houf et. al. - Abel-Noble	0.07289	
Molkov et. al. - Without Loss - Using ChenRodi	0.08937	

hySafe

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

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
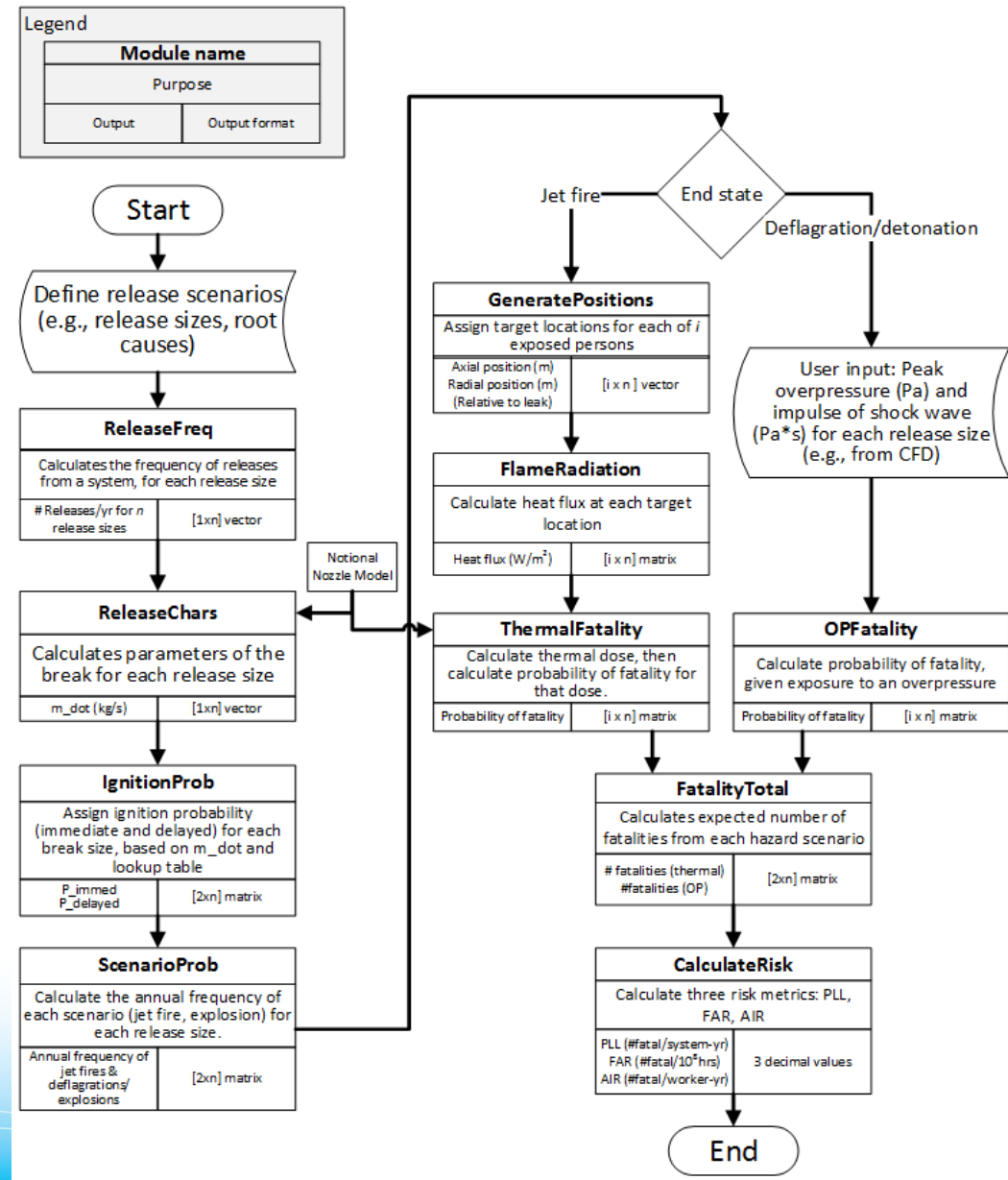
Modules: Cause & harm models (currently)

Accident sequences

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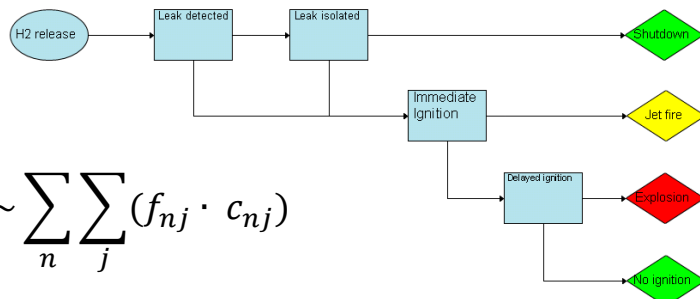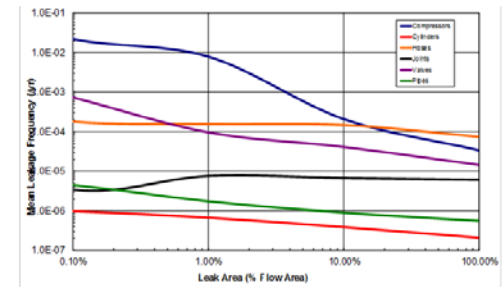

$$\text{Risk} \sim \sum_n \sum_j (f_{nj} \cdot c_{nj})$$

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

Release frequency

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

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

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
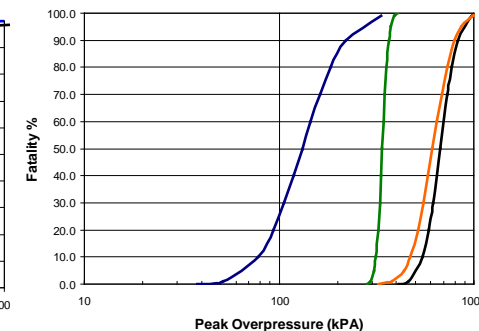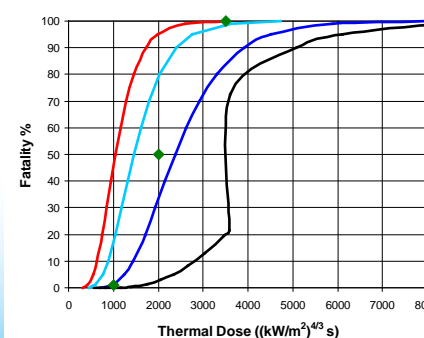
Modules: Behavior & Consequence (currently)

Release Characteristics
- H$_2$ jet integral model developed & validated
- Source models developed for LH2 & choked flow inputs
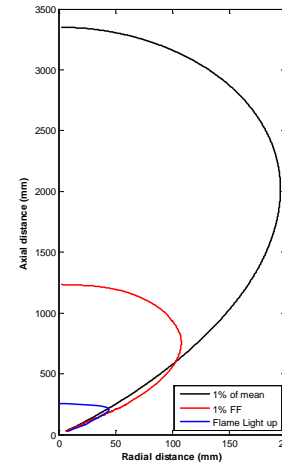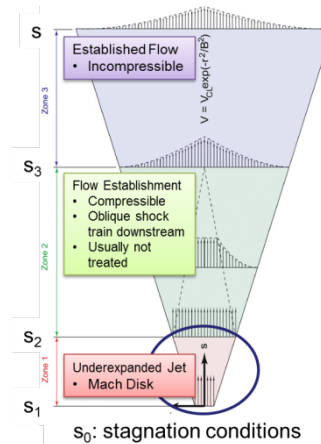
Ignition/Flame Light-up (*pending addition*)
- Flammability Factor verified for ignition prediction
- Light-up boundaries identified
- Next: sustained flame prediction

Flame Radiation
- Flame integral model developed
- Multi-source models significantly improve heat flux prediction
- Surface reflection can be a major potential heat flux contributor
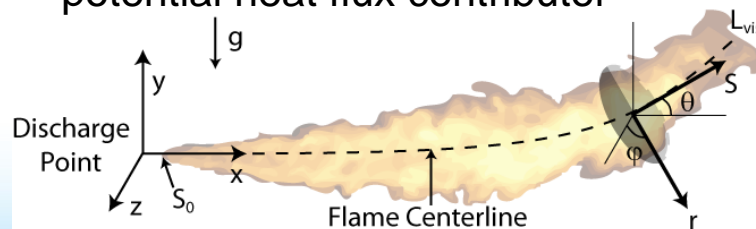
Deflagration within Enclosures
- Ventilated deflagration overpressure explored experimentally and computationally
- Current QRA module requires CFD results.
- Engineering model framework pending

Next steps for the HyRAM toolkit:

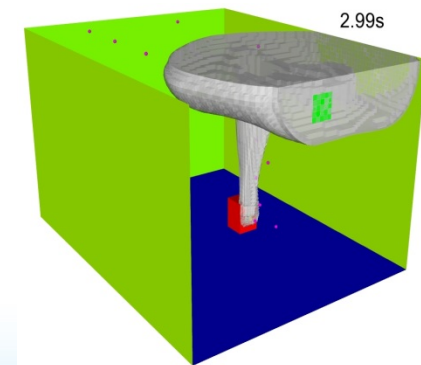- Initial working prototype (HyRAM 1.0alpha) – user testing beginning ~Feb 2015.

- 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.

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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
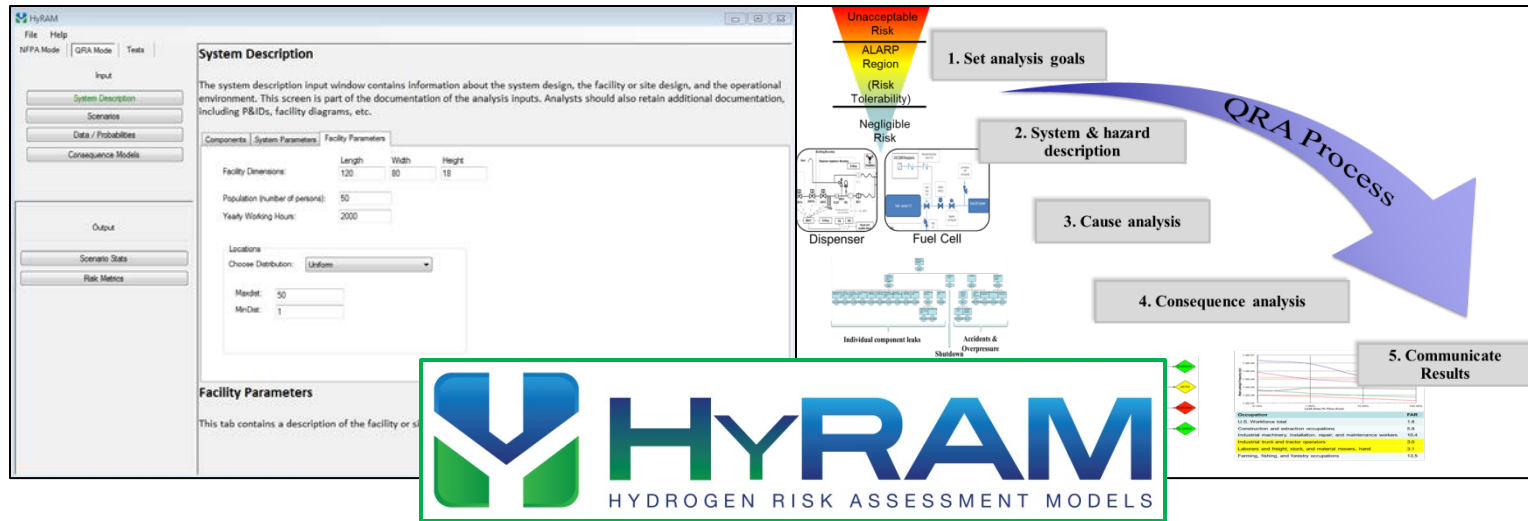
Thank you!

Katrina Groth

Sandia National Laboratories

kgroth@sandia.gov

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