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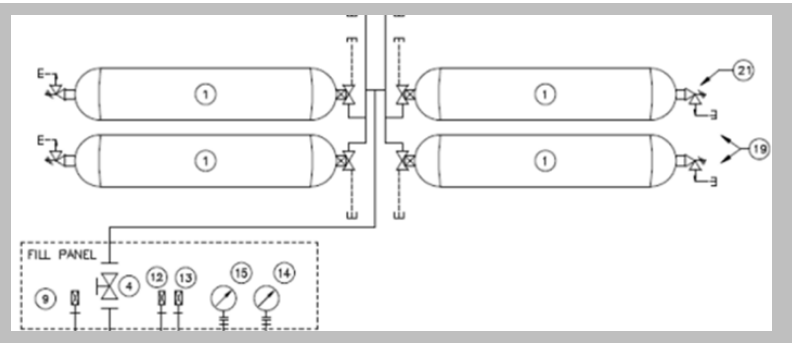

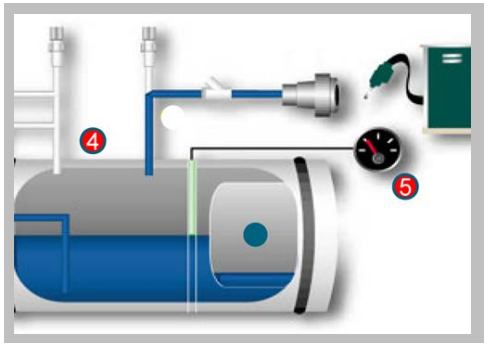

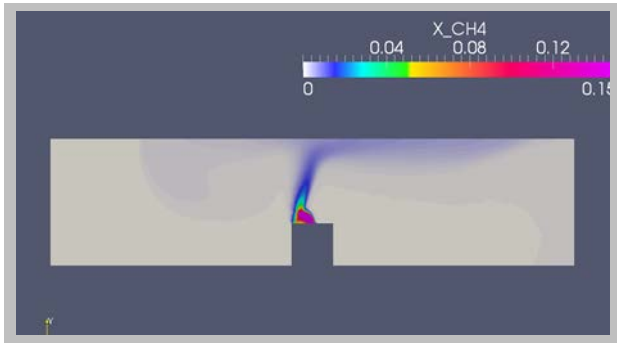

Risk-Informed LNG/CNG Maintenance Facility Codes and Standards

Project sponsored by DOE Clean Cities:

Technical & Analytical Assistance

Myra Blaylock, PhD

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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SAND NO SAND2016-10561 PE

Talk Objectives

Sandia National Laboratories

- Review Sandia work
  - Hazardous and Operability Study (HAZOP)
  - Best Practices to mitigate hazards
- Get feedback from NGVTF on Best Practices and Scenarios
  - myra.blaylock@sandia.gov
- New website: altfuels.sandia.gov
  - Reports, videos, links, information, these slides

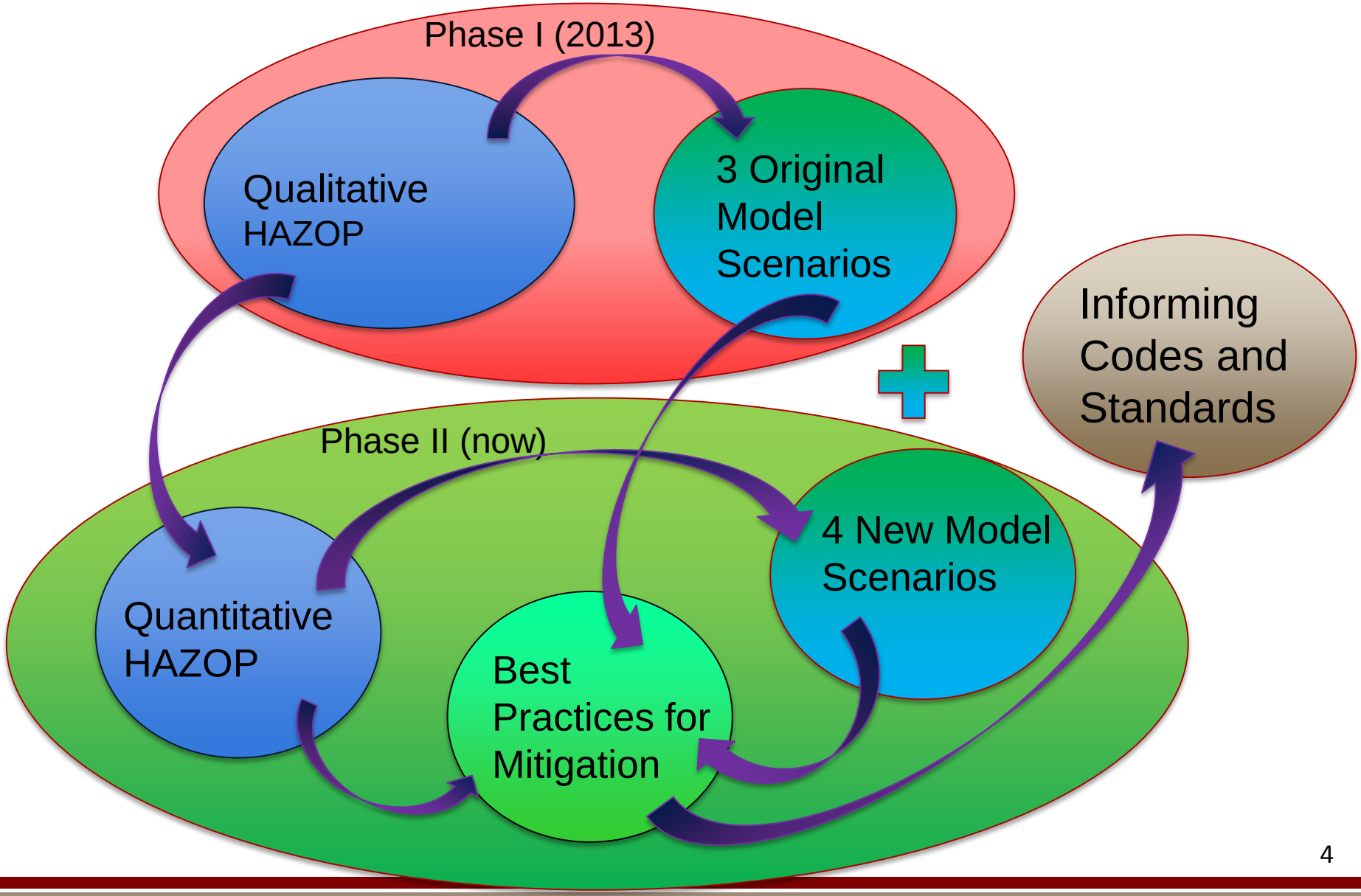
Project Motivation

- Improve **codes and standards** for gaseous fuel vehicle **maintenance facility** design and operation to reflect technology advancements

- Develop Risk-Informed guidelines for modification and construction of maintenance facilities using Quantitative Risk Assessment

Image: http://www.energyburrito.com/tag/natural-gas-vehicles/

Flow Chart


Phase I (2013)
Qualitative HAZOP
3 Original Model Scenarios
Informing Codes and Standards
Phase II (now)
Quantitative HAZOP
4 New Model Scenarios
Best Practices for Mitigation

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HAZOP and Model Recommendations

HAZOP Frequency

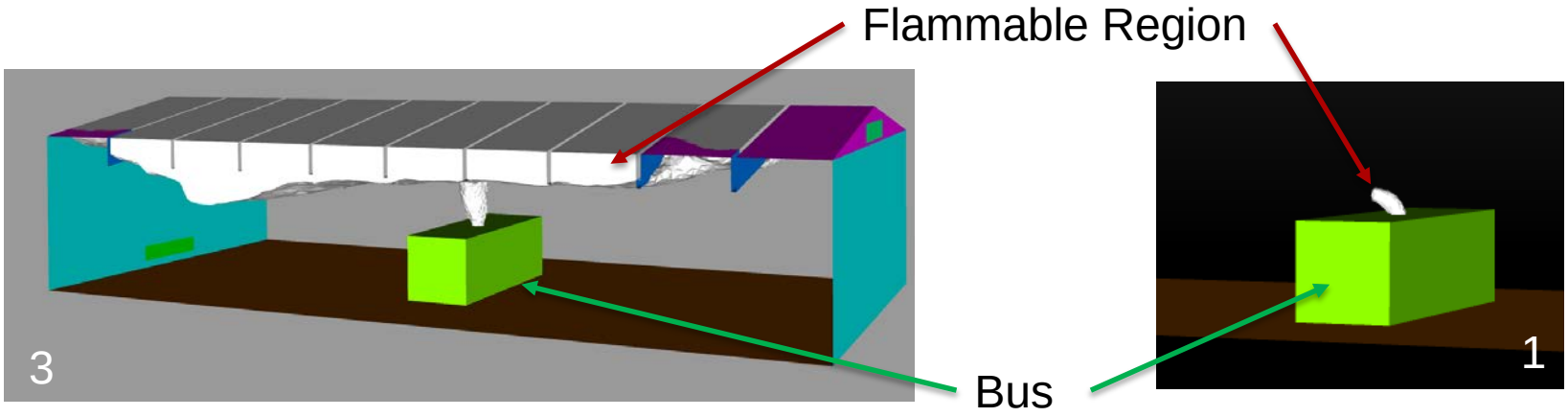
- Failure Definition – Unexpected or uncontrolled release of natural gas (liquid or gaseous phase)

Frequency Classifications for Release			
5	Intentional: Incident will occur on a set time frame		certain
4	Anticipated: Incidents that might occur several times during the lifetime of the facility	$f > 10^{-2}$/yr	1 in a 100 years
3	Unlikely: Events that are not anticipated to occur during the lifetime of the facility	10^{-4}/yr < f ≤ 10^{-2}/yr	
2	Extremely unlikely: Events that will probably not occur during the occur during the lifetime of the facility	10^{-6}/yr < f ≤ 10^{-4}/yr	
1	Beyond extremely unlikely: All other incidents	f ≤ 10^{-6}/yr	1 in a million years

HAZOP Consequence

- Consequence: How big is the release?

Consequence Classifications for Release	
3	Major (all contents of tank) release of natural gas (for CNG multiple cylinders)
2	Moderate release of natural gas (for CNG one cylinder)
1	Minor release of natural gas



HAZOP Escalation Factor

- Escalation : Assuming a release, what are the chances it will escalate? (i.e. Catch on fire)

Escalation Factor for Release		
4	Certain	Ignition is already present (+ faster release)
3	High	Faster release
2	Medium	Slow, large release
1	Low	Employee present

HAZOP Examples

Frequency	
5	Intentional
4	Anticipated
3	Unlikely
2	Extremely unlikely
1	Beyond extremely unlikely

Consequence	
3	Major
2	Moderate
1	Minor

Escalation Factor	
4-Certain	Ignition is already present (+ faster release)
3-High	Faster release
2-Medium	Slow, large release
1-Low	Employee present

Hazard Scenario	Causes	Description	Consequence	Frequency	Escalation	Rank
LNG: Overpressure of tank due to warming and proper operation of relief valve	Excessive hold time, insulation failure	Minor release of GNG	1	5	Low	5
CNG: Outlet or fitting on tank fails	Manufacturing defect, instillation or maintenance error	Potential catastrophic release of CNG	2	3	High	18

HAZOP Scenarios Selected for Further Analysis

HAZOP Scenario Number		Conse-quence	Frequency	Escalation Factor	Rank
1	External leakage from LNG regulator body	1	4	L	4
7	Overpressure of tank and proper operation of relief valve	1	5	L	5
12	Failure of LNG PRV to reclose after proper venting	3	4	H	36
14	Overpressure of cylinder due to external fire	3	2	H	18
15	Outlet or fitting on CNG cylinder fails	2	3	H	18
19	CNG PRD fails open below activation pressure	2	4	H	24
35 B	Leakage from CNG tubing	2	4	L	8
37	Human error or disregard for maintenance procedures	3	3	H	27

HAZOP Scenarios Selected for Further Analysis

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HAZOP Scenario Number		Heavy-Duty Vehicle Representative Facility Modeling Number (100' x 50' x 20')		Light-Duty Vehicle Representative Facility Modeling Number (60' x 40' x 20')	
1	External leakage from LNG regulator body	A/B	LNG blow-off	N/A	
7	Overpressure of LNG tank and proper operation of relief valve	A	LNG "Burping"/ "Weeping"	N/A	
12	Failure of LNG PRV to reclose after proper venting	G	(Modeling capabilities in development)	N/A	
14	Overpressure of cylinder due to external fire	F	Analytical Jet Fire (In development)	F	Analytical Jet Fire (In development)
15	Outlet or fitting on CNG cylinder fails	C	PRD failure for a CNG cylinder	E	PRD failure for a CNG cylinder
19	CNG PRD fails open below activation pressure	C	PRD failure for a CNG cylinder	E	PRD failure for a CNG cylinder
35B	Leakage from CNG tubing	B	CNG fuel system line cracking	D	CNG fuel system line cracking
37	Human error or disregard for maintenance procedures	All	Covered by other scenarios	All	Covered by other scenarios

Best Practices to Mitigate Hazards

Example - LNG “Burping” Release

Best Practices Example: LNG "Burping"

- Release Prevention Features
  - Design
  - Administrative
- Release Detection Method
- Release Mitigation Features
  - Design
  - Administrative
- Ignition Prevention Features
  - Design
  - Administrative
- Ignition Detection Method
- Ignition Mitigation Features
  - Design
  - Administrative

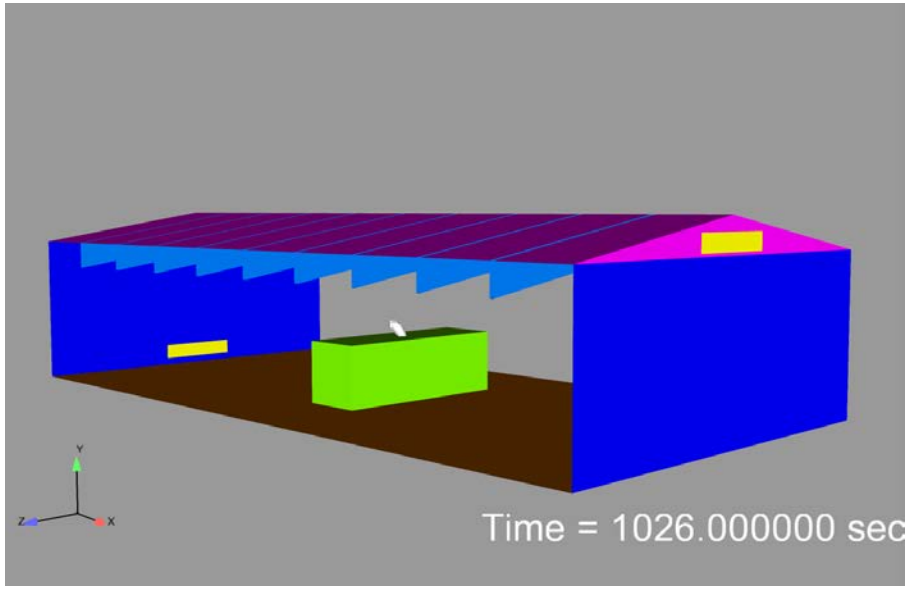
Best practices were reviewed across the event sequence of the LNG burp

Release Prevention Features	
Design	Administrative
	2 -Preventative Maintenance – purposefully reducing pressure outside 6 -Operator Training - hold times

Ignition Prevention Features	
Design	Administrative
Electrical classification areas - over vehicle (e.g. lights) Grounding & bonding of vehicle in bay	Prohibit smoking

Best Practices Example: LNG "Burping"

- Modeling results show no flammable concentration at the ceiling.
- Best practices can target specific consequences more strategically.
- They can also be applicable for facilities smaller or of a different layout than the maintenance garage modeled.



Best Practices Example: LNG "Burping"

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- Administrative Procedure: **Operate the vehicle engine periodically so that the hold time is not exceeded.**
  - This will maintain the LNG tank pressure below its seat pressure of 180 psig.
  - An administrative control to operate the vehicle(s) on a regular basis would reduce the frequency of release due to pressure buildup.
  - This best practice would **prevent** the release

Image: http://www.quora.com

Best Practices Example: LNG "Burping"

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- Administrative Procedure: **Check the vehicle's pressure gauge on a regular basis for pressure buildup.**
  - The pressure gauge for the tank shows when the tank is close to an overpressure buildup (and subsequent release through the PRV).
  - An administrative control to check the vehicle's pressure gauge on a regular basis would allow the operator to determine the best time to operate the vehicle engine.
  - This practice would **prevent** the release.

Image: http://www.pumptec.com

Best Practices Example: LNG "Burping"

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- Design: **Install a flexible vent hose to connect the PRV to the facility's exhaust system.**
  - If an LNG burp occurs, the LNG vapor would exhaust to the outside of the facility.
  - This would prevent any flammable buildup inside the maintenance facility.
  - This practice would **prevent the ignition** of the release. It would not prevent the release itself.

Image: http://www.auto-repair-manuals.com

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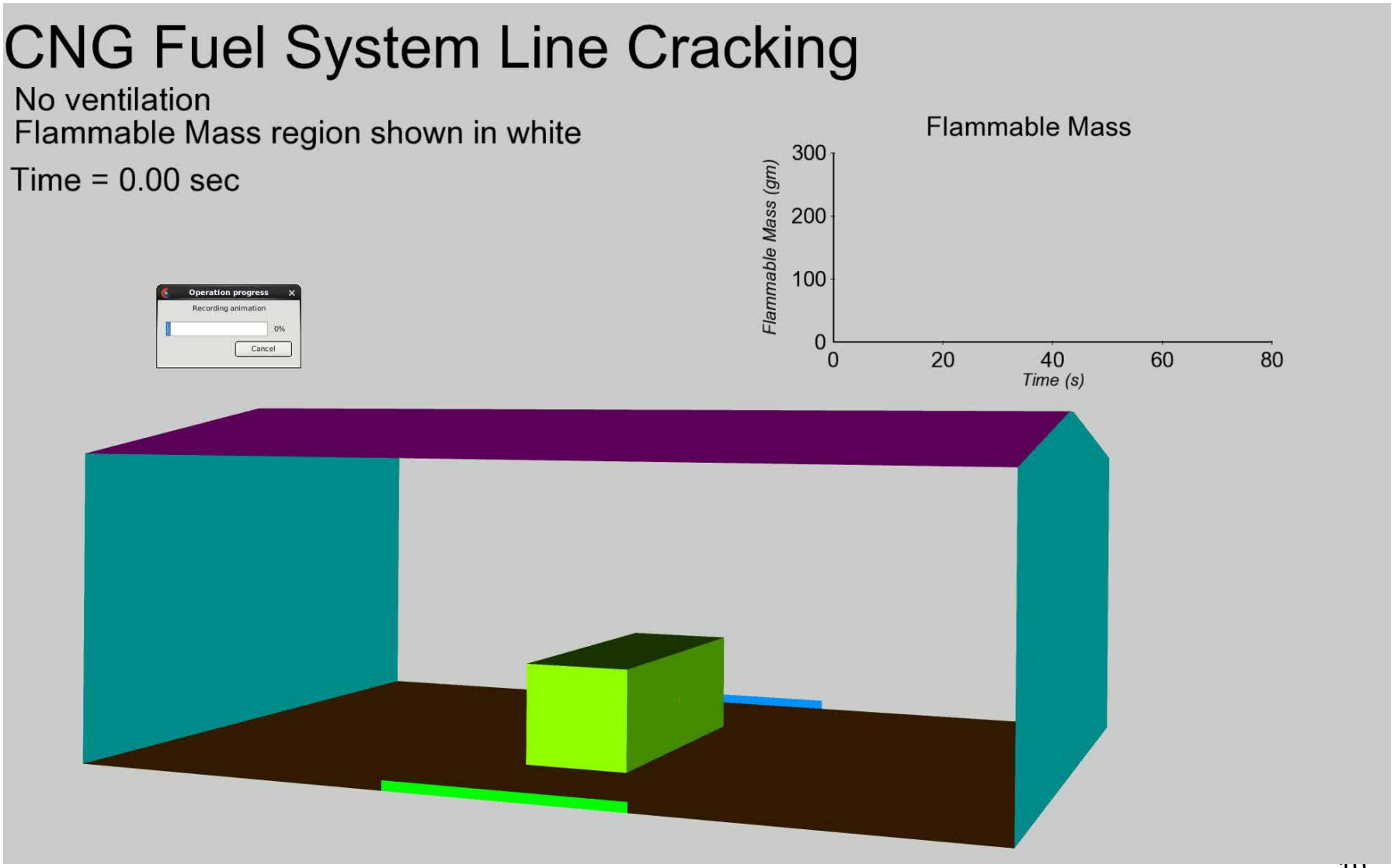
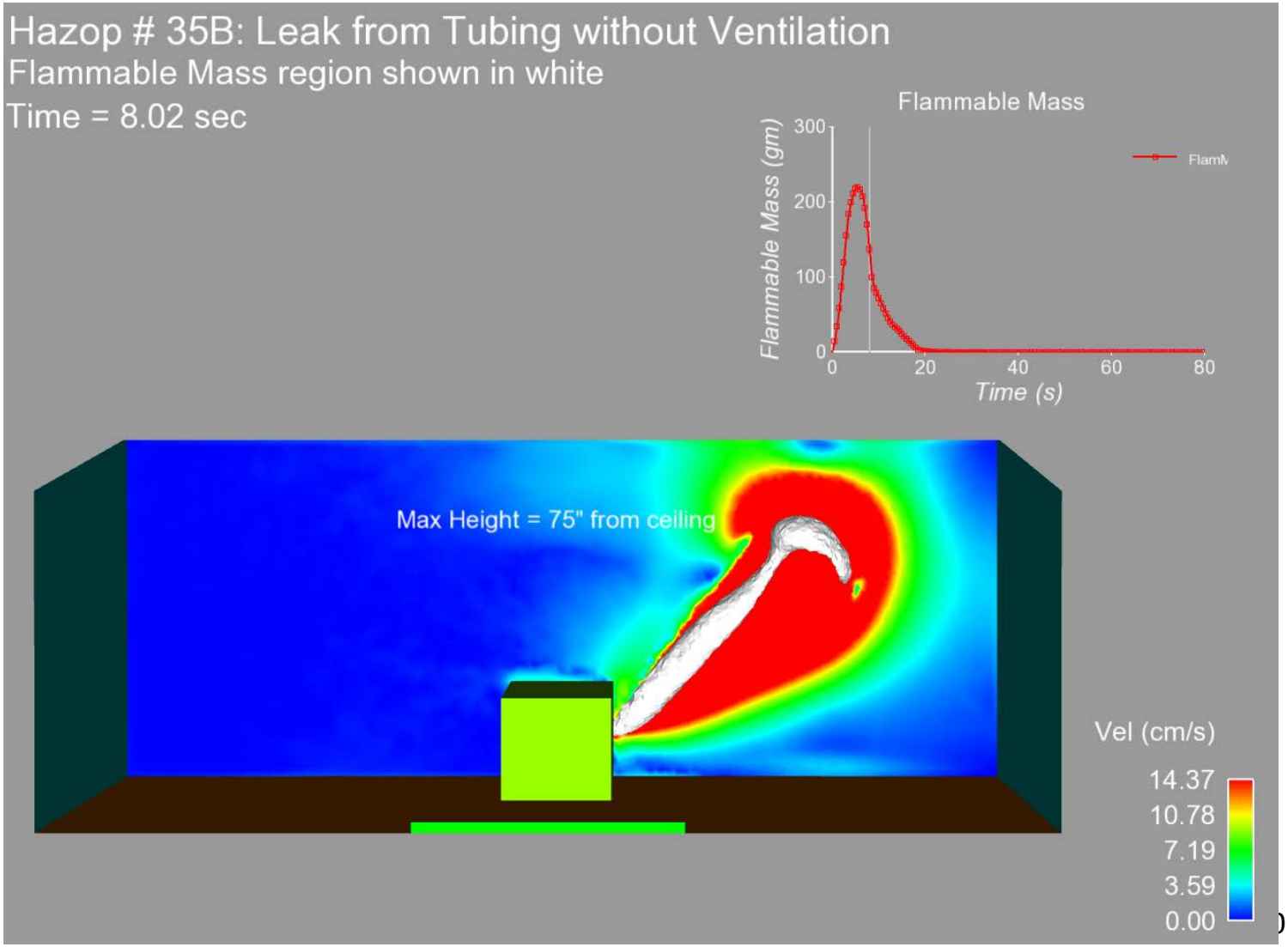
Other Modeling Work

#35B: Small Garage

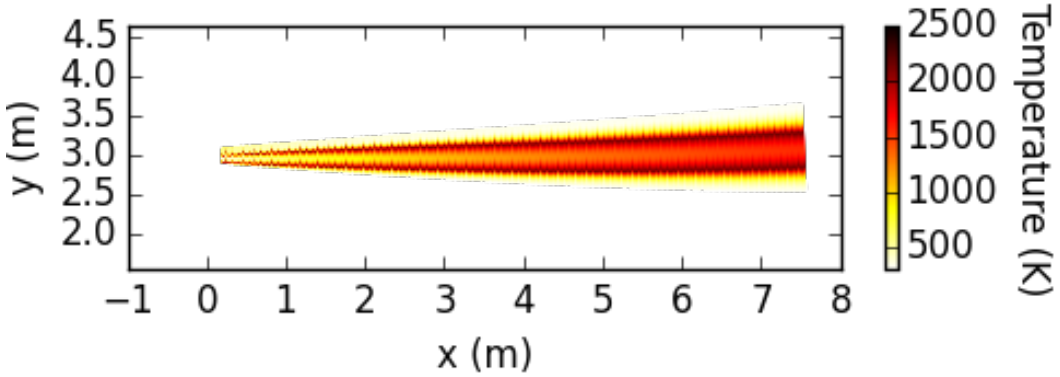


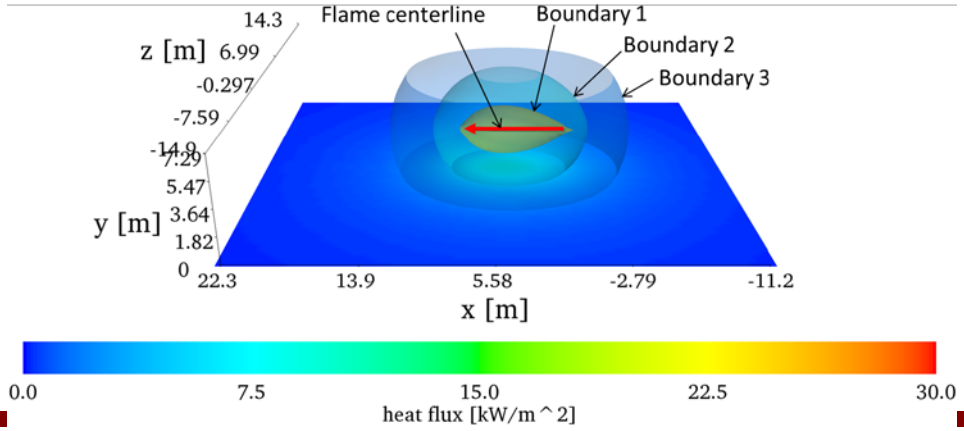
#35B: Small Garage



#14: Overpressure due to external fire

- 1D models
- Calculate jet plume length and heat flux





HAZOP Scenarios

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HAZOP Scenario Number		Consequence	Frequency	Escalation Factor	Rank
1	External leakage from LNG regulator body	1	4	L	4
7	Overpressure of tank and proper operation of relief valve	1	5	L	5
12	Failure of LNG PRV to reclose after proper venting				36
14	Overpressure of cylinder due to external fire	3	2	H	18
15	Outlet or fitting on CNG cylinder fails	2			18
19	CNG PRD fails open below activation pressure	2	4	H	24
35 B	Leakage from CNG tubing	3	4	L	12
37	Human error or disregard for maintenance procedures	3	3	H	27

What have you experienced?

What keeps you up at night?

What's Next?

- Potential Opportunities
  - HyRAM for NG: hyram.sandia.gov
  - Is NFPA 30A open to a risk based standard?
  - Experiments to validate models (LNG)
  - Cold LNG leak simulations
  - Ignited leak size and heat flux
  - Suggestions?

Thank you!

altfuels.sandia.gov

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Thank you!

Questions?

altfuels.sandia.gov

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Extra Slides

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HAZOP Scenarios for Further Anlysis

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HAZOP Scenario Number		Consequence	Frequency	Escalation Factor	Rank
1	External leakage from LNG regulator body	1	4	L	4
7	Overpressure of tank and proper operation of relief valve	1	5	L	5
12	Failure of LNG PRV to reclose after proper venting	3	4	H	36
14	Overpressure of cylinder due to external fire	3	2	H	18
15	Outlet or fitting on CNG cylinder fails	2	3	H	18
19	CNG PRD fails open below activation pressure	2	4	H	24
35 B	Leakage from CNG tubing	3	4	L	12
37	Human error or disregard for maintenance procedures	3	3	H	27

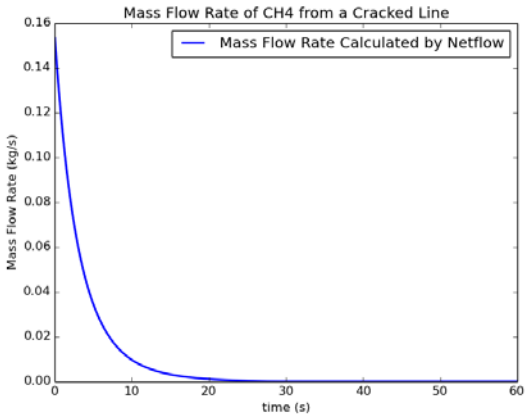
Next 8

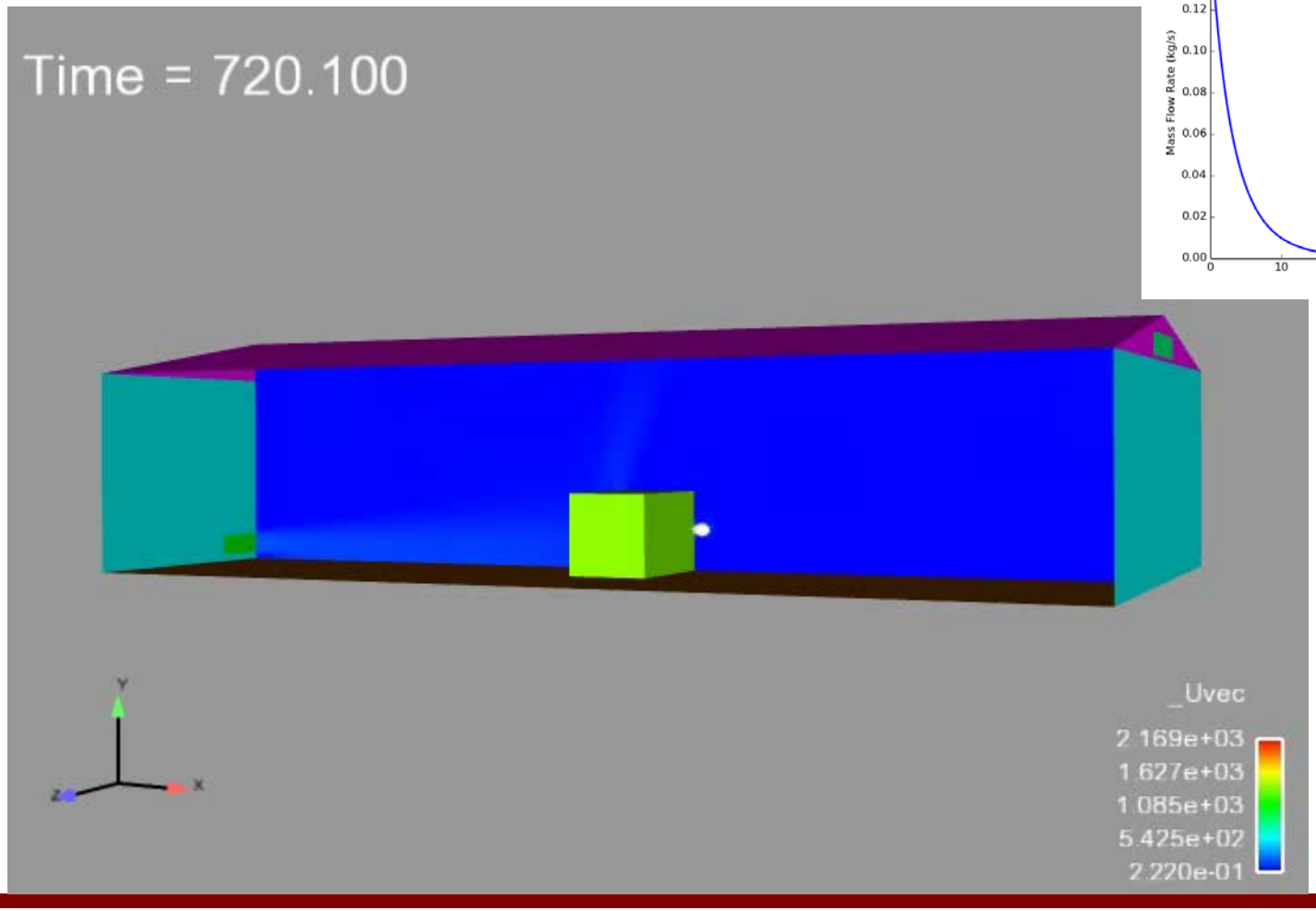
HAZOP Scenario			Conse-quence	Frequency	Escalation Factor	Rank
5	LNG-3 (Heat exchanger)	External leakage from heat exchanger due to defective materials, corrosion, etc.	2	3	M	12
4B	LNG-2 (Fuel Shutoff Valve	Valve fails to shut completely, or leaks external or in-process	3	2	M	12
6A	LNG-4 (LNG tank)	Overpressure of tank and failure of relief valve to open during a fire	3	1	C	12
8	LNG-4 (LNG tank)	Outlet or fitting on tank fails due to defect or installation error	3	2	M	12
	LNG-7 (Fill Port)	Release of GNG through fill port due to failure to check valve	3	2	M	12
13	CNG-1 (Cylinders)	Overpressurization of Cylinder due to External fire AND failure of PRD to operate	3	1	C	12
18	CNG-2 (Cylinder Solenoid Valve)	External leakage of CNG through body of solenoid or joint due to Mechanical damage, material failure, installation error	2	3	M	12
20	CNG-3 (Pressure Relief Device)	External leakage through PRD of CNG due to Mechanical defect, material defect, installation error, maintenance error	2	3	M	12

Scenario 3: CNG Vehicle Fuel System Line

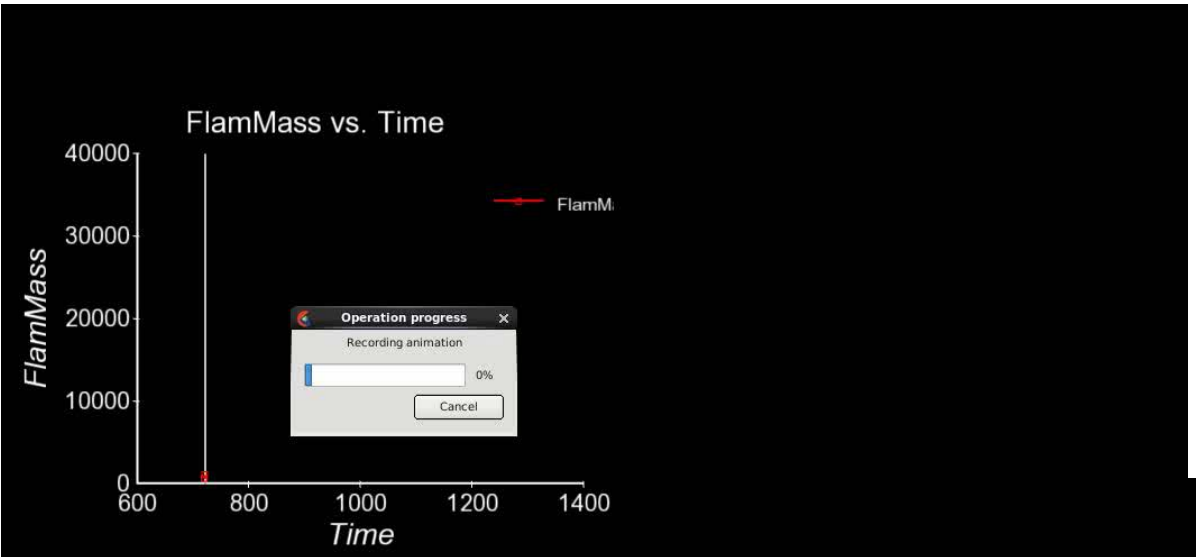
Cracking: 3.3 liters @ 248 bar; 3% area leak

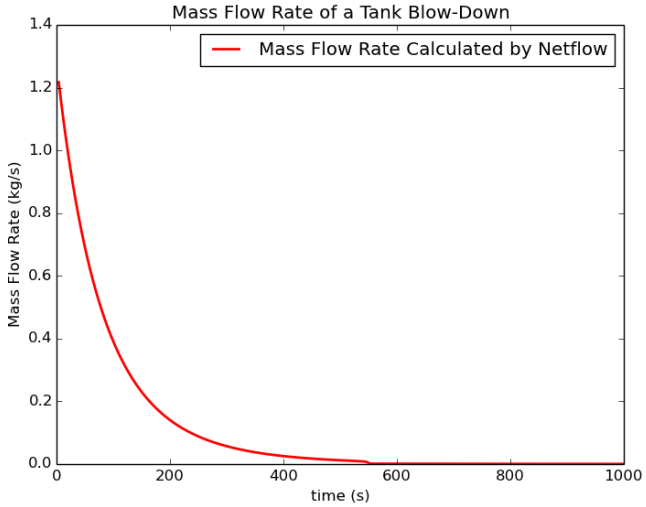
1.27 cm ID tubing

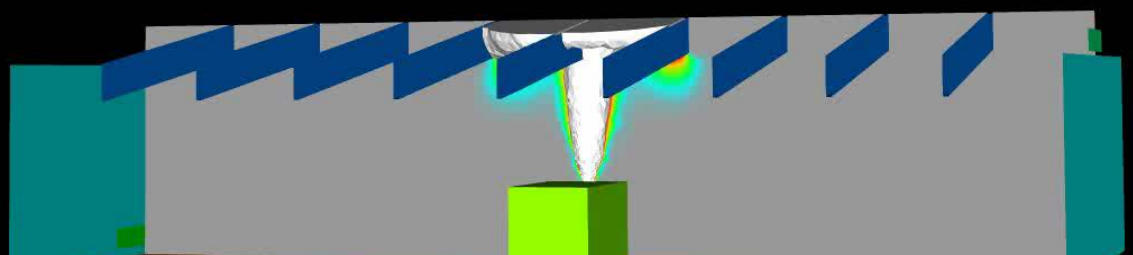


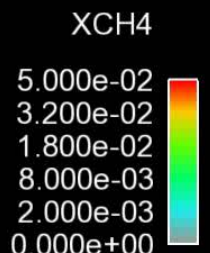


Scenario 4: Mechanical Failure PRD Release - 0.7 m^3 volume @ 250 bar from a 6.2 mm TPRD









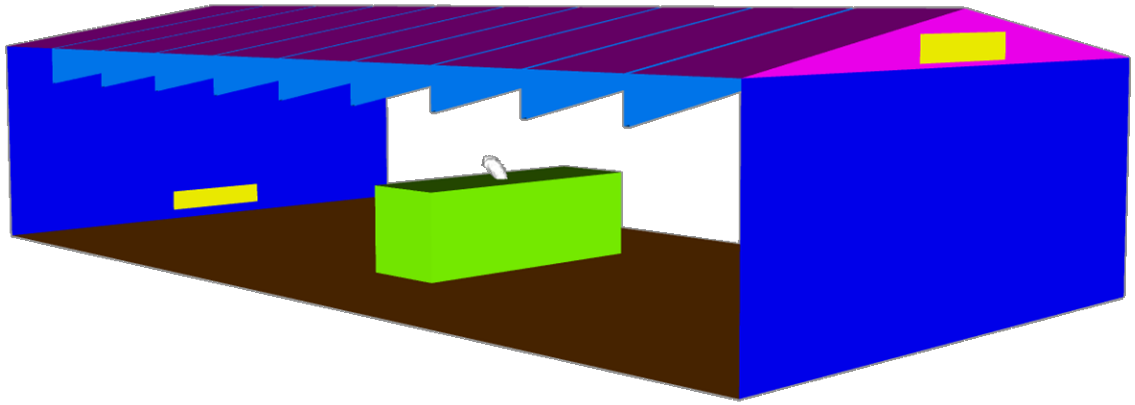
$$\Delta p_{max\ expansion} = 220\ kPa$$

Report at altfuels.sandia.gov

Natural Gas Vehicle Maintenance Garage

Sandia National Laboratories

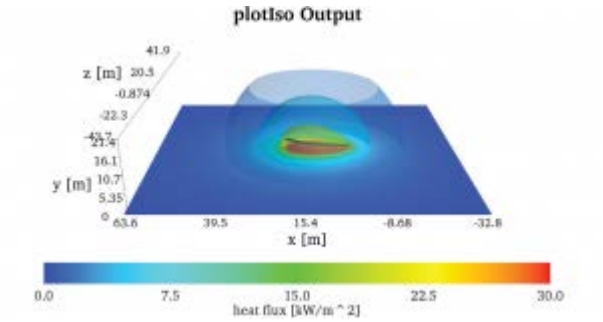
- Dimensions: 100’ x 50’ m x 20’ ; 1:6 roof pitch (60 x 40 x 20)
- Layouts w/ and w/o horizontal support beams investigated:
  - 9 beams (6” x 42”) spaced 10’ & parallel to the roof pitch
- Two vents were used for air circulation
  - Inlet near the floor — outlet along roof of opposite side-wall
  - Vent area for both vents was 2’ x 10’
  - Ventilation rate set to 5 air changes/hour (~2 m/s w/ current vent sizing)
  - Simulations were run with and without ventilation
- NGV modeled as a cuboid
  (8’ x 8’ x 24’)

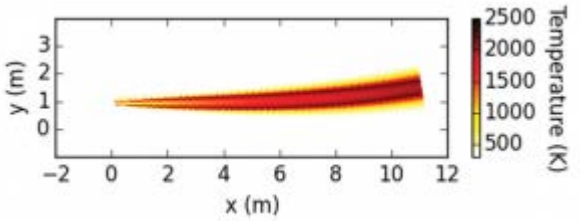


HyRAM
HYDROGEN RISK ASSESSMENT MODELS

Sandia National Laboratories

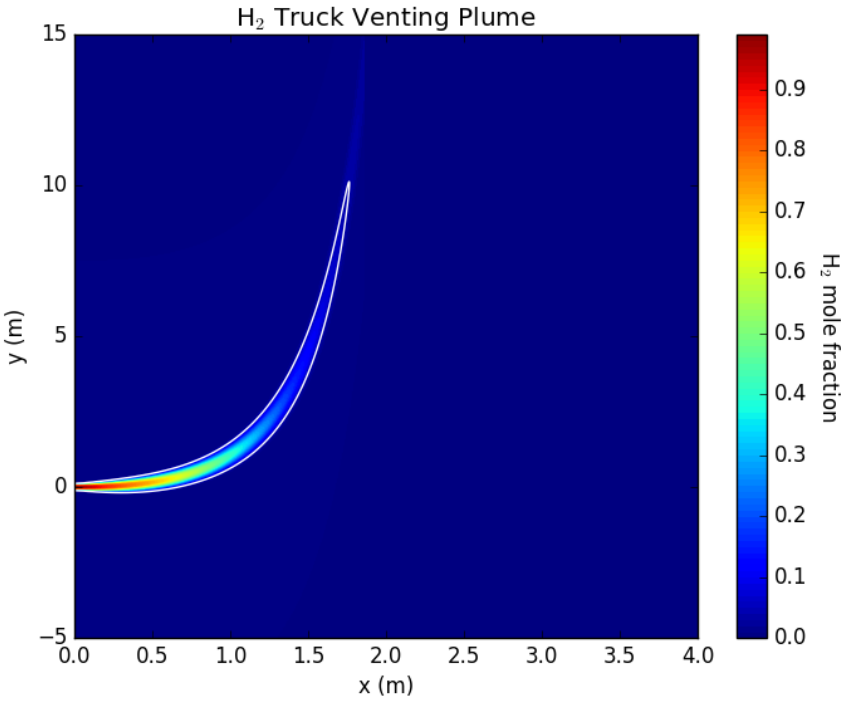
- Hydrogen Risk Assessment Model
  hyram.sandia.gov
- Generic data for gaseous hydrogen (GH2) systems:
  component leak frequencies, ignition probability; modifiable by users
- Models of GH2 physical effects for consequence modeling
  - Release characteristics (plumes, accumulation)
  - Flame properties (jet fires, deflagration within enclosures)
- Probabilistic models for human harm from thermal and overpressure hazards
- Fast running: to accommodate rapid iteration
- Calculates common risk metrics for user-defined systems: FAR, AIR, PLL; frequency of fires





“Cold Plume” Capabilities For LNG

- Modeling leaks from a two-phase container is possible
  - From the top: gaseous region
  - From the bottom: liquid region
- Can use this to get rough calculations of plume characteristics
- Two phase flow through pipes is still in development



HAZOP Modeling Scenarios

Modeling Scenario	Scenario Description	Garage Details	Tank/Leak Volume	Tank Pressure	Leak Size	HAZOP Scenarios
A	LNG Blow-Off	Heavy Duty: 100'x50'x20' with a 1:6 pitched roof	1.7% of 700 liters = 2.3 kg	248 bar	Diameter = 6.2mm	1,7
B	CNG Fuel System Line Cracking	Heavy Duty: 100'x50'x20' with a 1:6 pitched roof	3.3 liters	248 bar	3.8 mm^2 3% of tubing size	35B
C	PRD Failure for a CNG Cylinder	Heavy Duty: 100'x50'x20' with a 1:6 pitched roof	700 liters	248 bar	Diameter = 6.2mm	15,19
D	CNG Fuel System Line Cracking	Light Duty: 60'x40'x20'with a pitched roof	3.3 liters	248 bar	3.8 mm^2 3% of tubing size	35B
E	PRD Failure for a CNG Cylinder	Light Duty: 60'x40'x20'with a pitched roof	700 liters	248 bar	Diameter = 6.2mm	15,19
F	Overpressure of CNG cylinder due to external fire	No Garage: 1D analysis only	700 liters	248 bar	Diameter = 6.2mm	14