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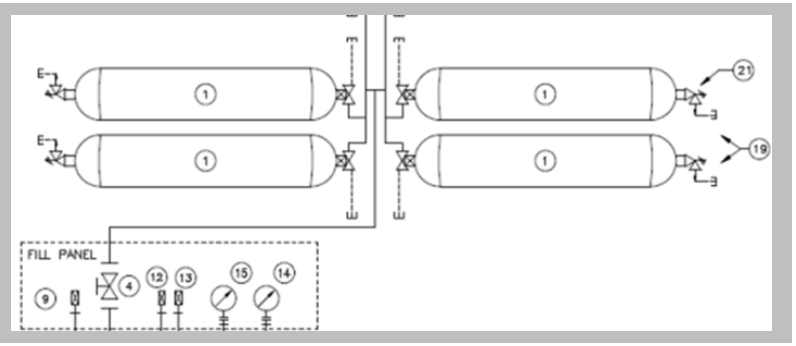


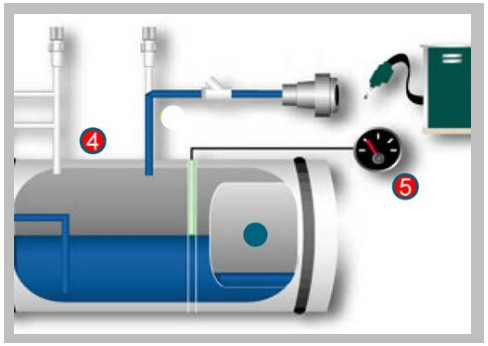

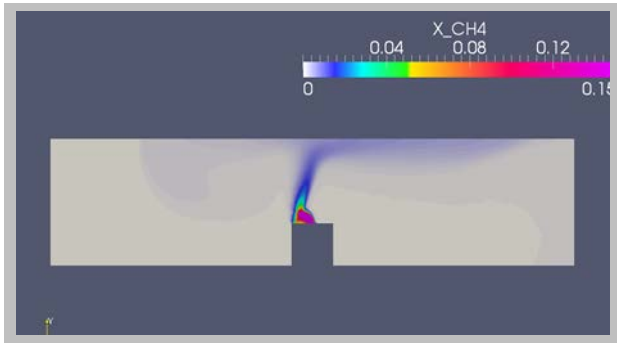


# Risk-Informed LNG/CNG Maintenance Facility Codes and Standards

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

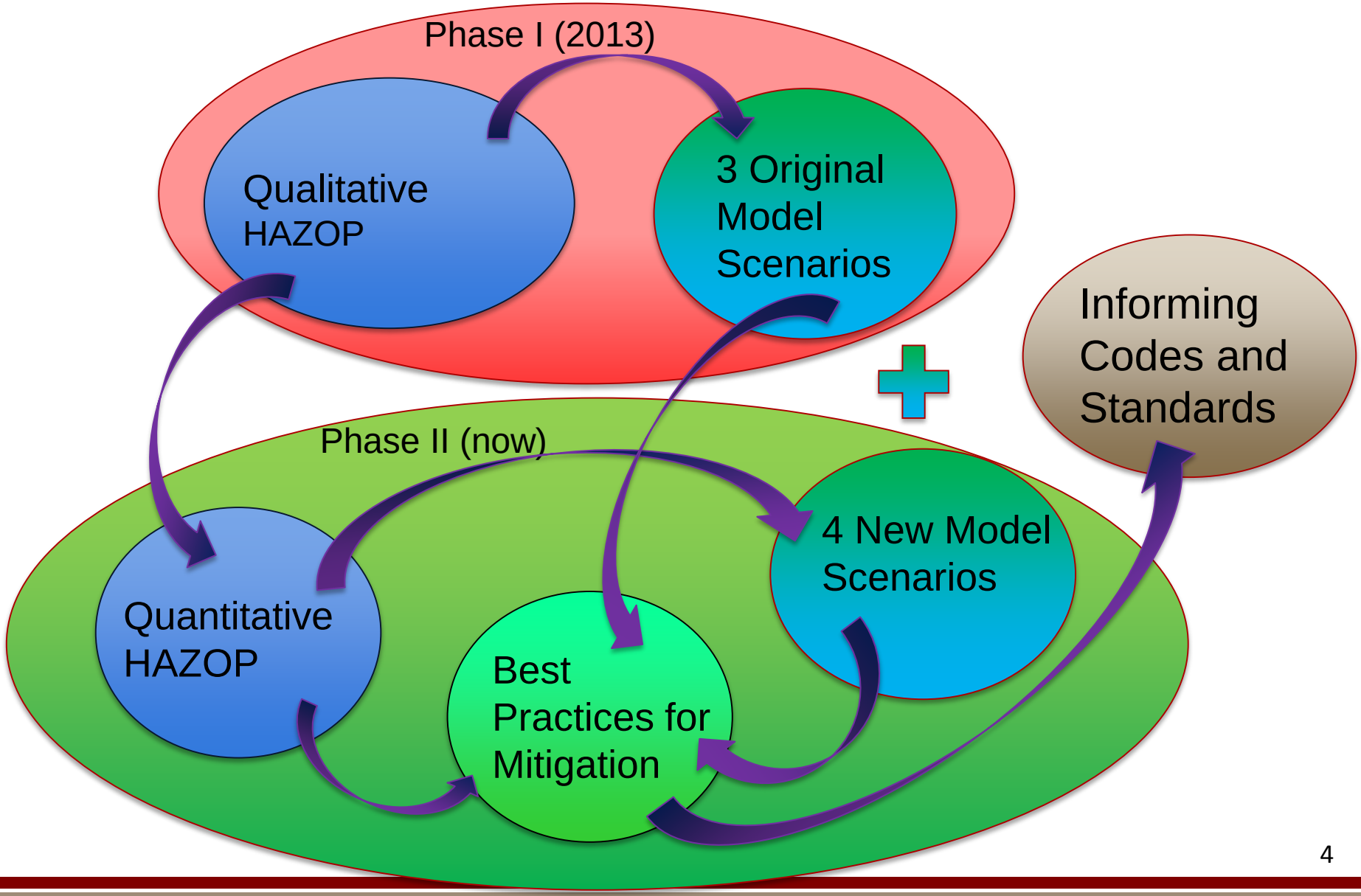
- Improve **codes and standards** for gaseous fuel vehicle **maintenance facility** design and operation to reflect technology advancements

- 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

Sandia National Laboratories

# HAZOP and Model Recommendations

# HAZOP Frequency

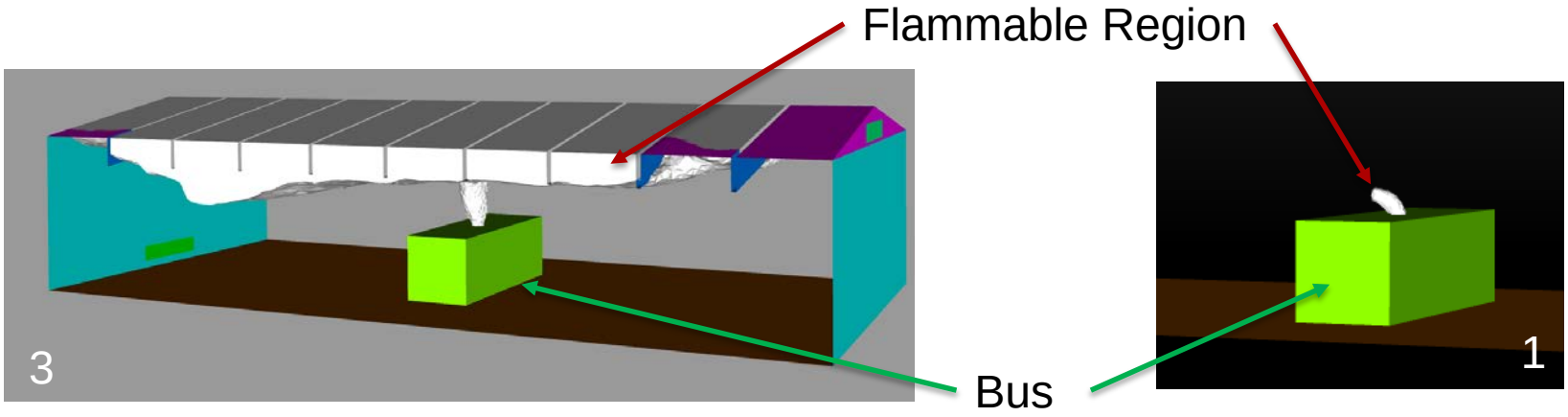
- Failure Definition – Unexpected or uncontrolled release of natural gas (liquid or gaseous phase)

| 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

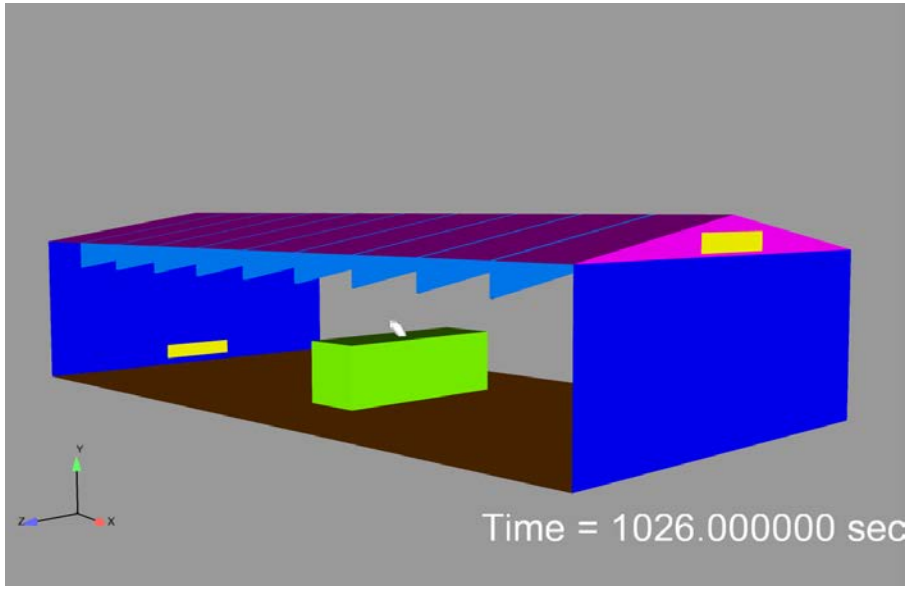
Best practices were reviewed across the event sequence of the LNG burp

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

| Ignition Prevention Features | |
|---|---|
| Design | Administrative |
| Electrical classification areas - over vehicle (e.g. lights)<br>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"

Sandia National Laboratories

- 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"

Sandia National Laboratories

- 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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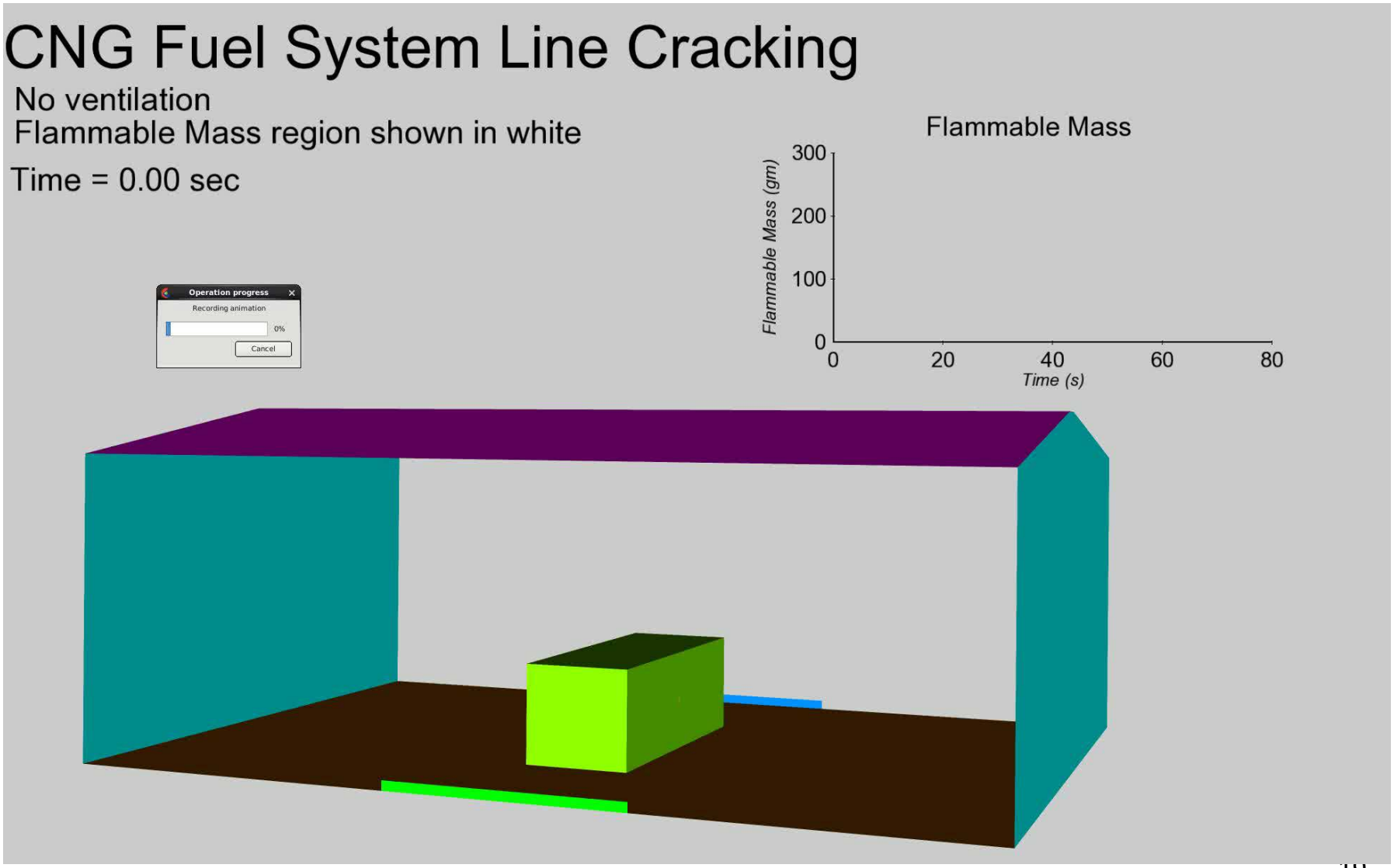
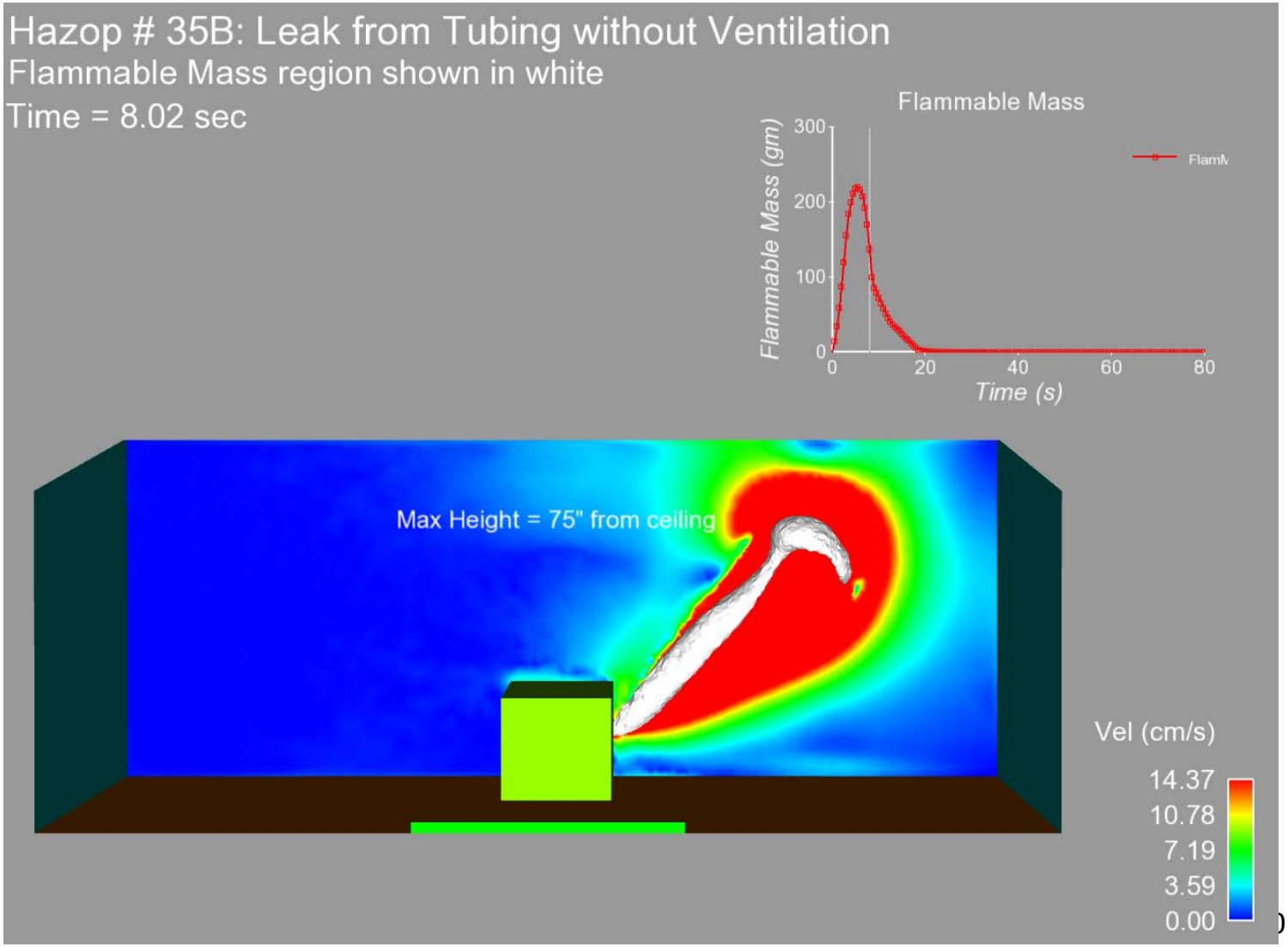
# Other Modeling Work

# #35B: Small Garage

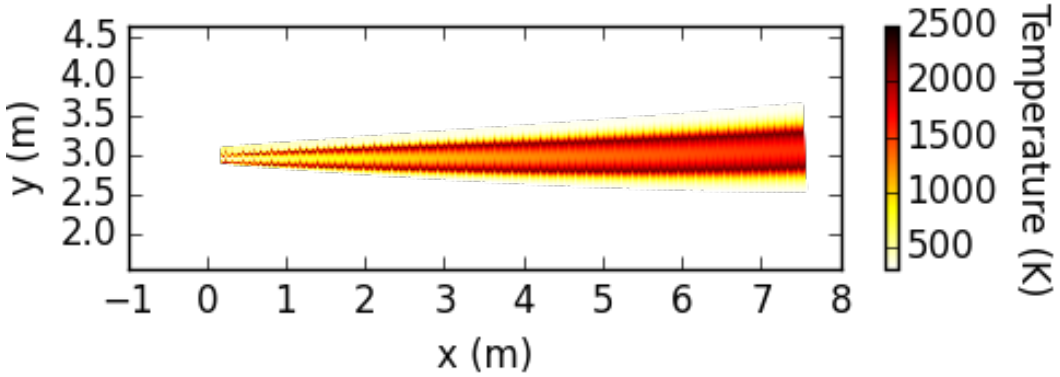


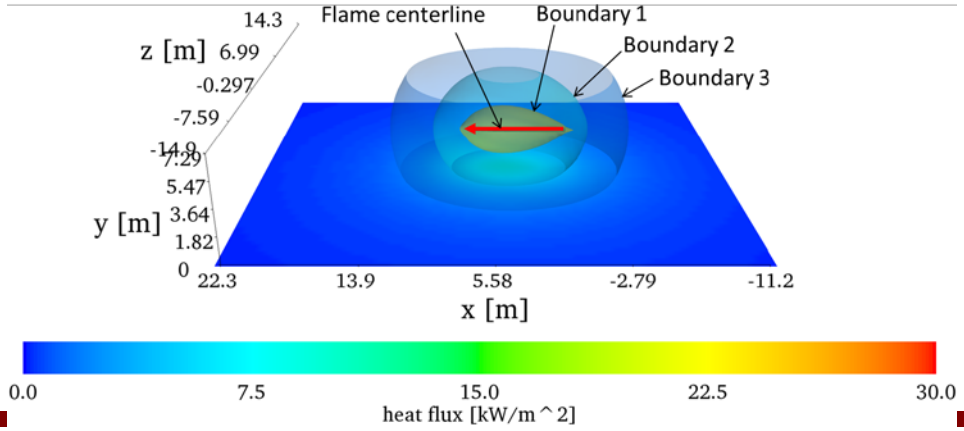
# #35B: Small Garage



# #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

Myra.Blaylock@sandia.gov

Sandia National Laboratories

Thank you!

Questions?

altfuels.sandia.gov

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# Extra Slides

Sandia National Laboratories

# 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 |
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| **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 |

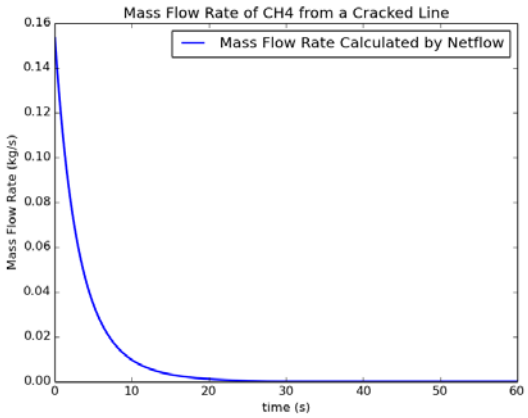
# Next 8

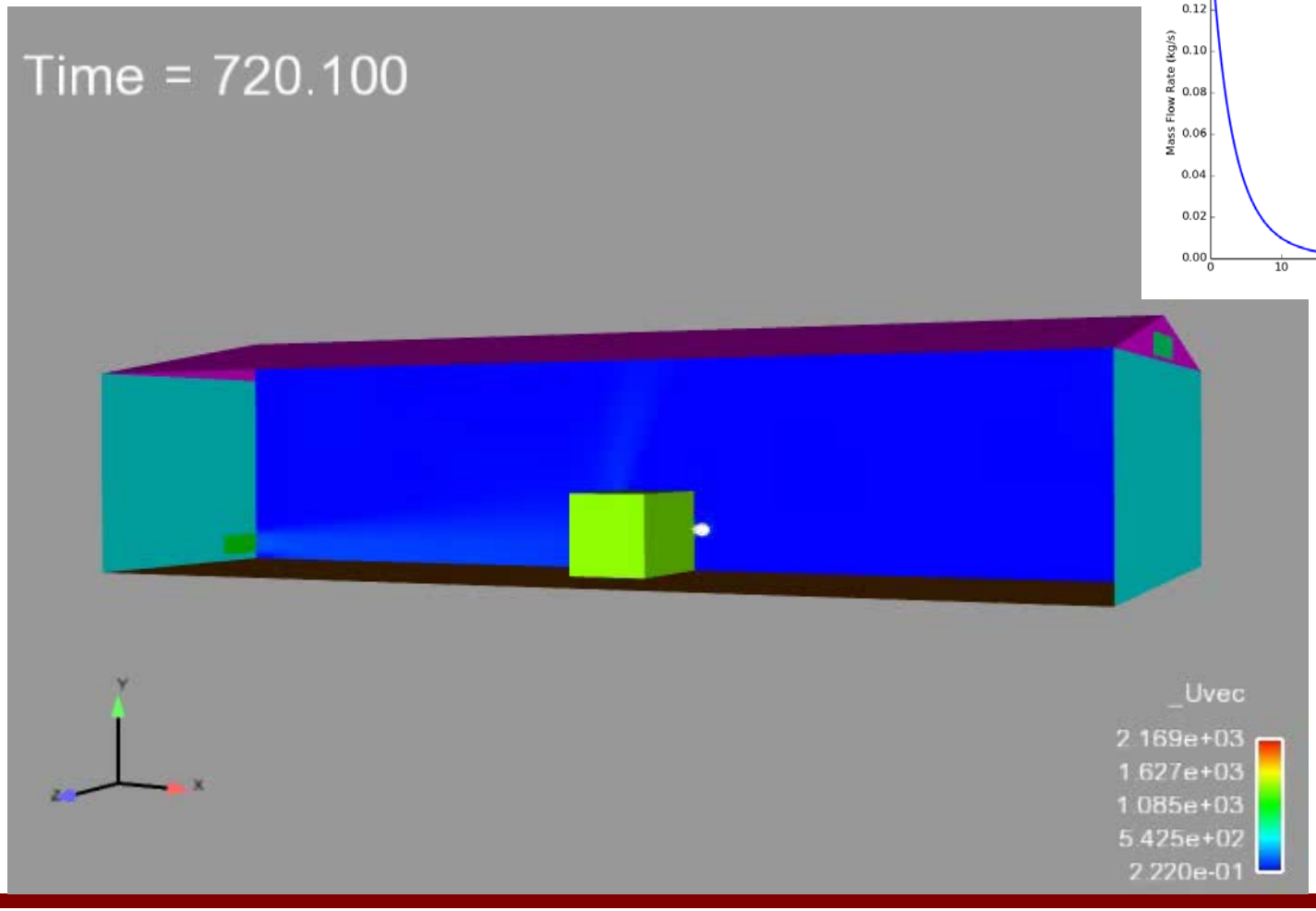
| HAZOP Scenario | | | Conse-quence | Frequency | Escalation Factor | Rank |
|---|---|---|---|---|---|---|
| 5 | LNG-3 (Heat exchanger) | External leakage from heat exchanger due to defective materials, corrosion, etc. | 2 | 3 | M | 12 |
| 4B | LNG-2 (Fuel Shutoff Valve | Valve fails to shut completely, 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

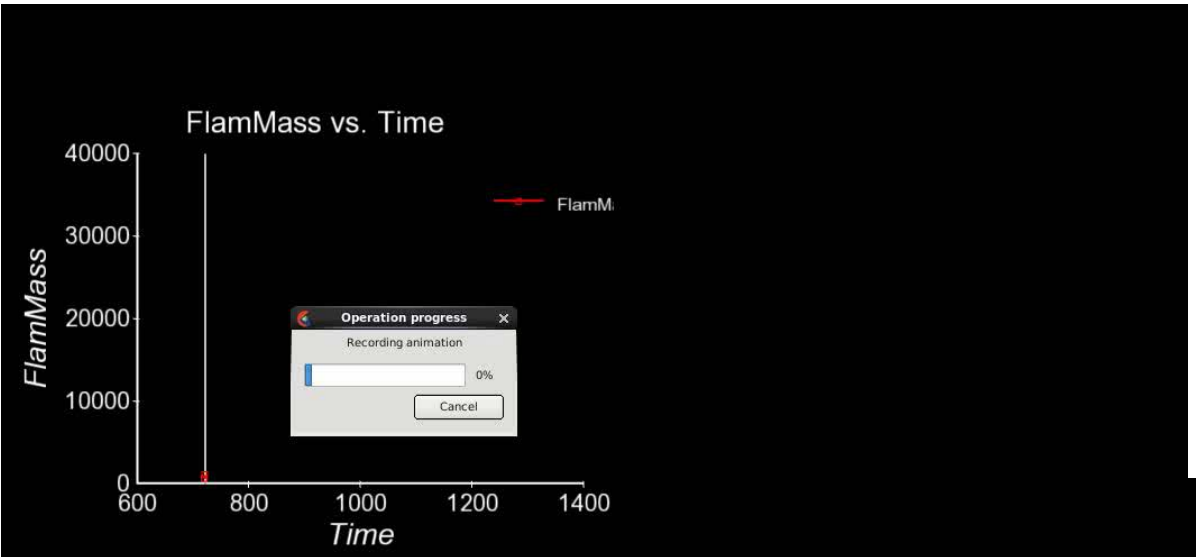
**Cracking:** 3.3 liters @ 248 bar; 3% area leak

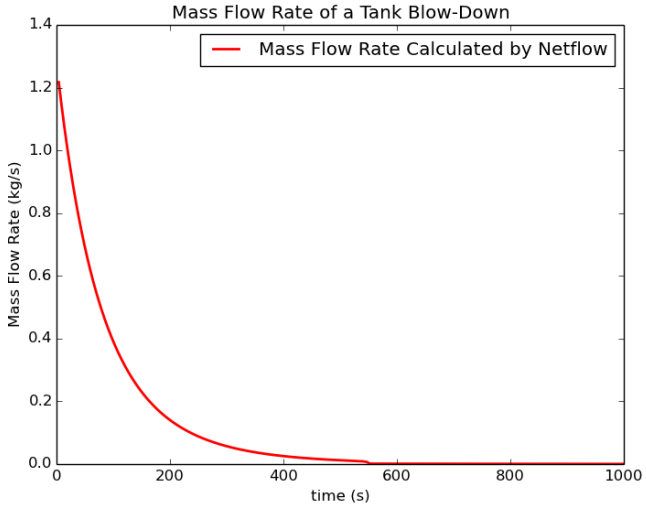
1.27 cm ID tubing

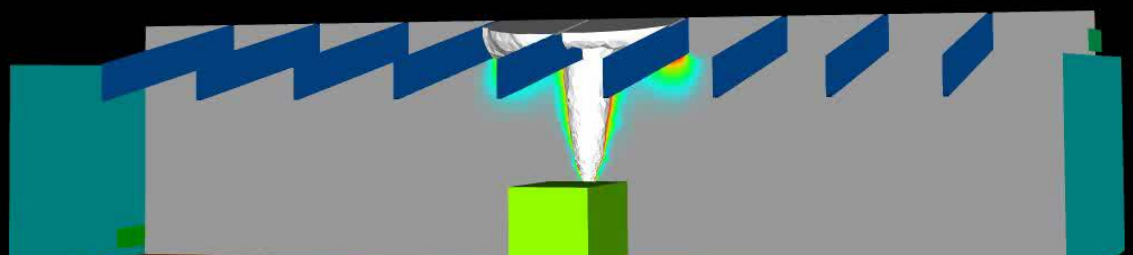


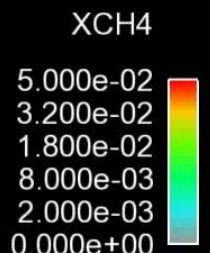



# Scenario 4: Mechanical Failure PRD Release - 0.7 $m^3$ volume @ 250 bar from a 6.2 mm TPRD





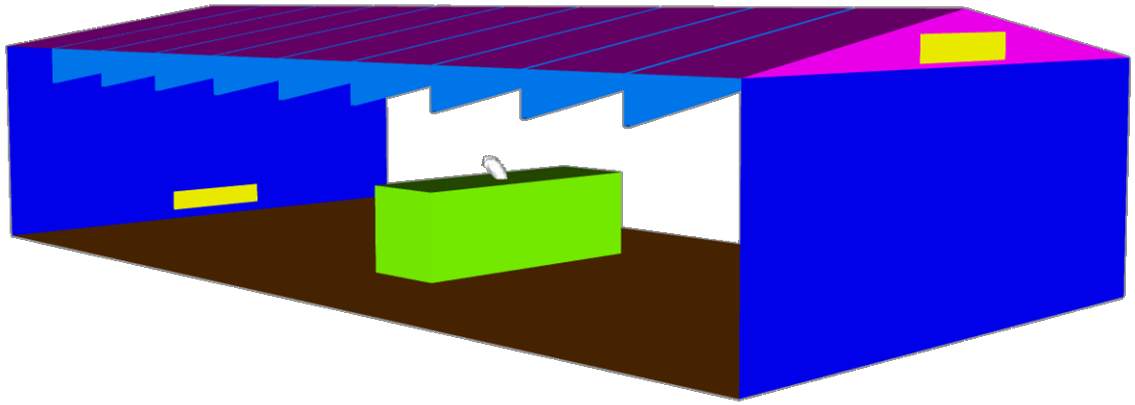

$$\Delta p_{max\ expansion} = 220\ kPa$$

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

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- 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