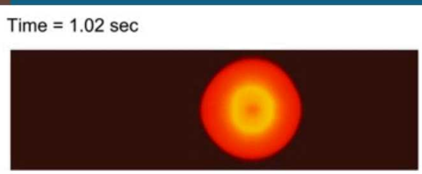
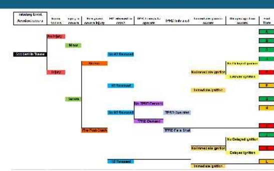
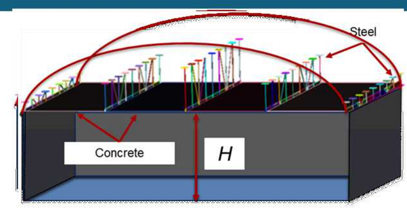
SAND2019-7181PE

Risk and Modeling of FCEVs in Tunnels







PRESENTED BY

Alice Muna & Brian Ehrhart

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SAND2019-XXXX

Risk and modeling of FCEV in tunnels

Objective: Provide the necessary information to authorities in the Northeast Corridor to determine if FCEVs will be permitted in tunnels

Comprehensive Risk Analysis

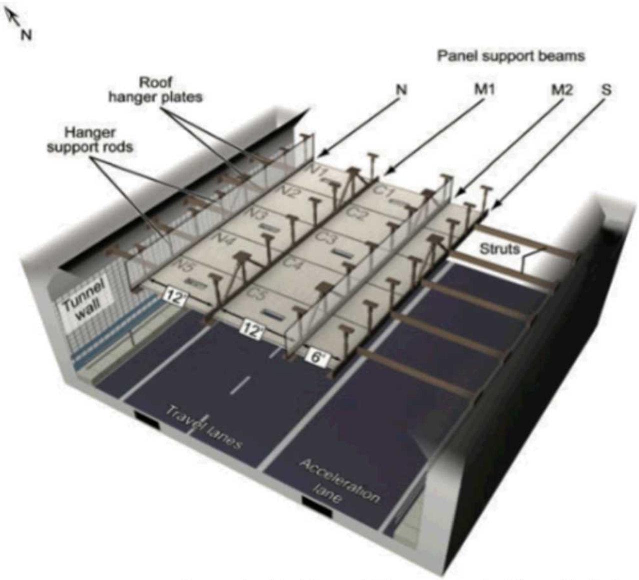
- What could happen, what are the consequences if it does happen, what are the chances of it happening
- Attempt to quantify the probabilities of each scenario

Evaluation of the Consequences, if uncertain

- Modeling and analysis of a Thermally Activated Pressure Relief Device (TPRD) release

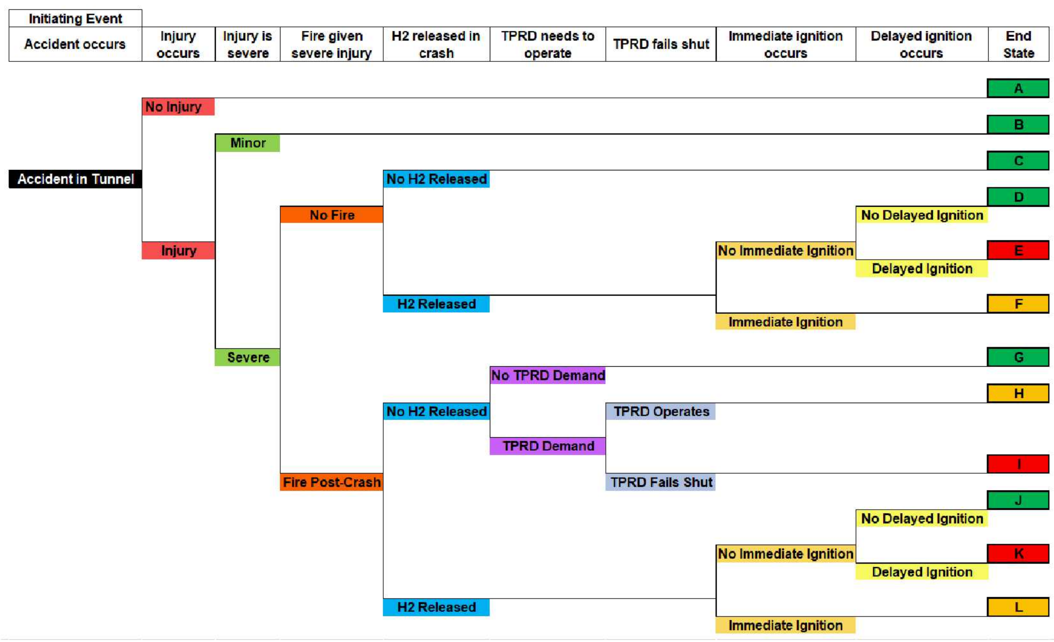
Listen to concerns of Authorities Having Jurisdiction (AHJ)

- Investigate and address each concern



Board, National Transportation Safety,(2007)

Tunnels safety study risk analysis



Event tree created to analyze the risk of an accident with a hydrogen fuel cell vehicle

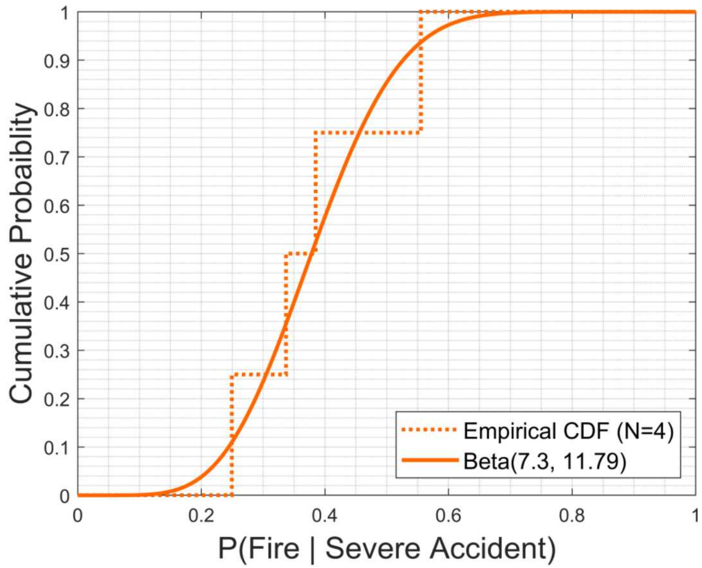
The event tree illustrates the chronological sequence of events involving the success and/or failures of system components

Ehrhart, Brian D., Brooks, Dusty M., Muna, Alice B., LaFleur, Chris, "Risk Assessment of Hydrogen Fuel Cell Vehicles in Tunnels," Accepted by Fire Technology Journal.

Risk analysis used to identify possible scenarios and focus CFD modeling efforts on scenarios with highest risk

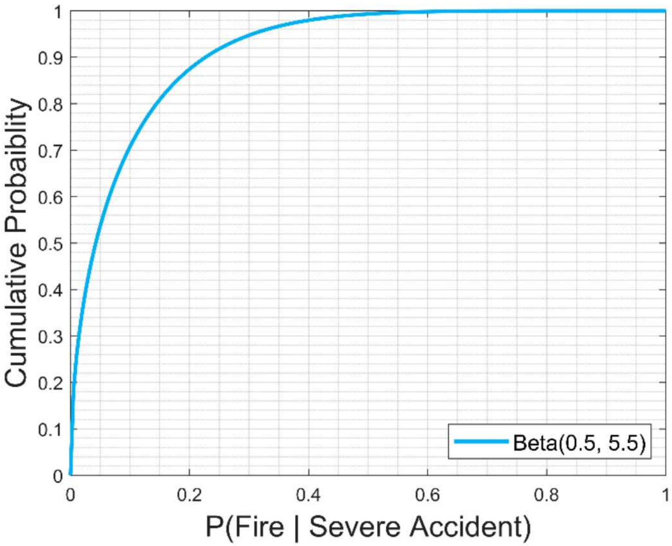
Uncertainty around scenario probabilities- examples

Probability that a fire occurs given severe accident



Year:	2006	2007	2008	2009
Average Severe Crash Rates	0.2045	0.1608	0.0913	0.1284
Average Fire Crash Rates	0.0510	0.0619	0.0507	0.0433

Probability of damage-induced H2 release

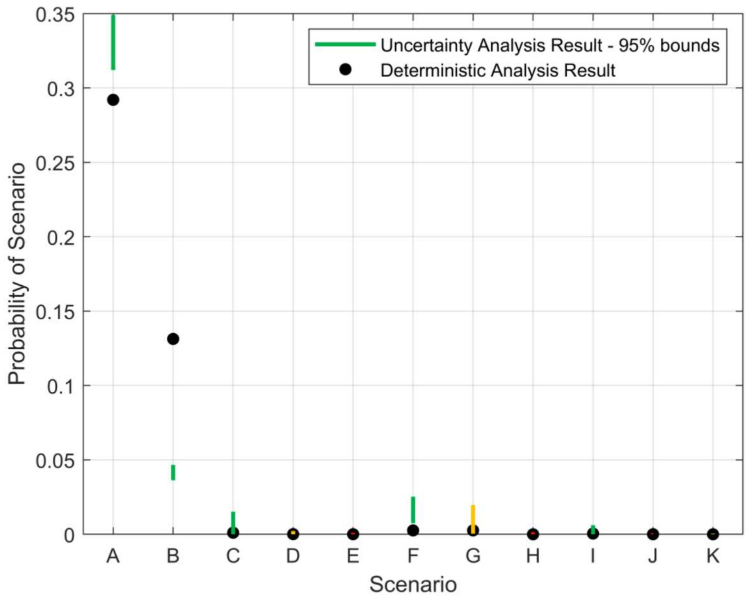


- Based on 5 experiments where no release occurred
- Beta distribution assumed along with Jeffrey's uninformed prior

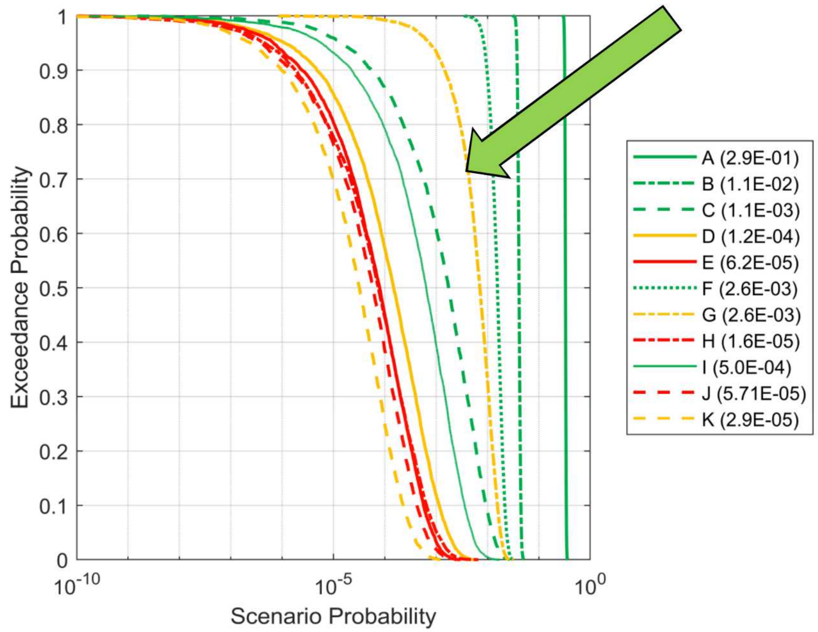
Calculation of uncertainty allows a more complete range of answers to be characterized

Uncertainty around scenario probabilities

Uncertainty Quantification on Deterministic Scenario Probabilities



Complimentary Cumulative Distribution Functions: Exceedance Probability Curves



Scenario G with the potential for increased consequence due to hydrogen will be analyzed further and modeled.

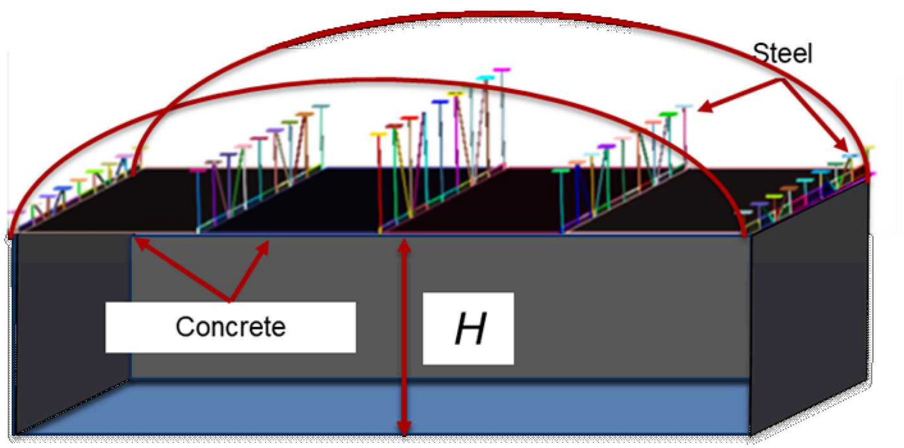
Modeling Multiple Tunnels

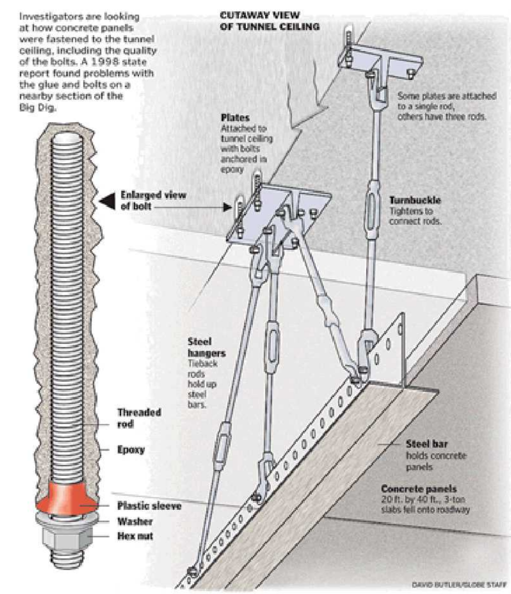
TPRD release scenario (G)

- Gasoline from other vehicle ignites, external fire engulfs FCEV, activates the TPRD
- H_2 immediately ignited and a jet fire results aimed toward tunnel ceiling
- A 125-liter, 70 MPA tank with a TPRD orifice of 2.25 mm is analyzed with a blowdown of approximately 300 sec

Analyzed CANA, Sumner & Ted Williams Tunnels to quantify:

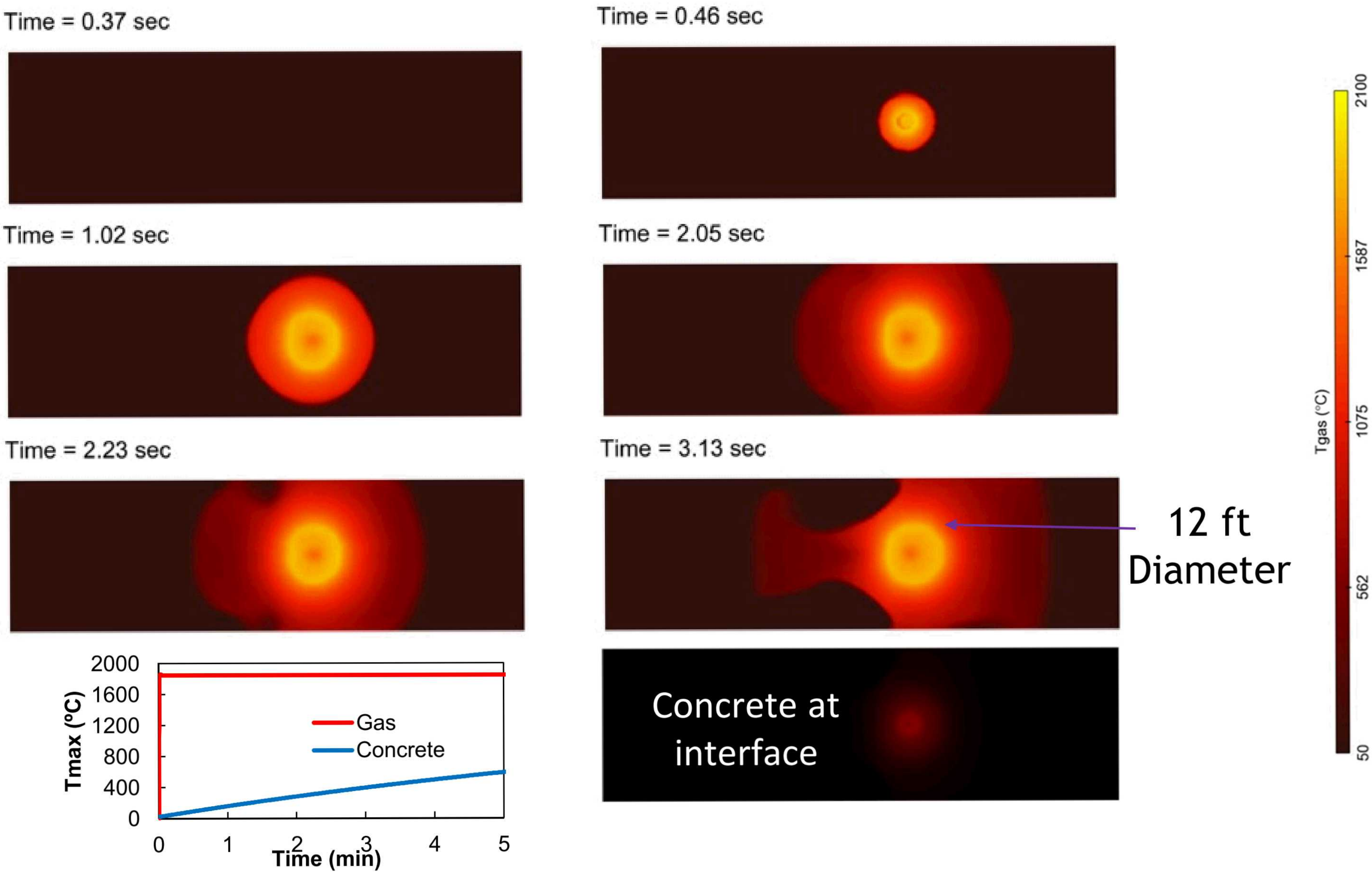
- Distortion of steel frames supporting concrete panels
- Impact on capacity of epoxy anchors under anticipated heat
- Potential for spalling of concrete tunnel roof slab and ceiling panels



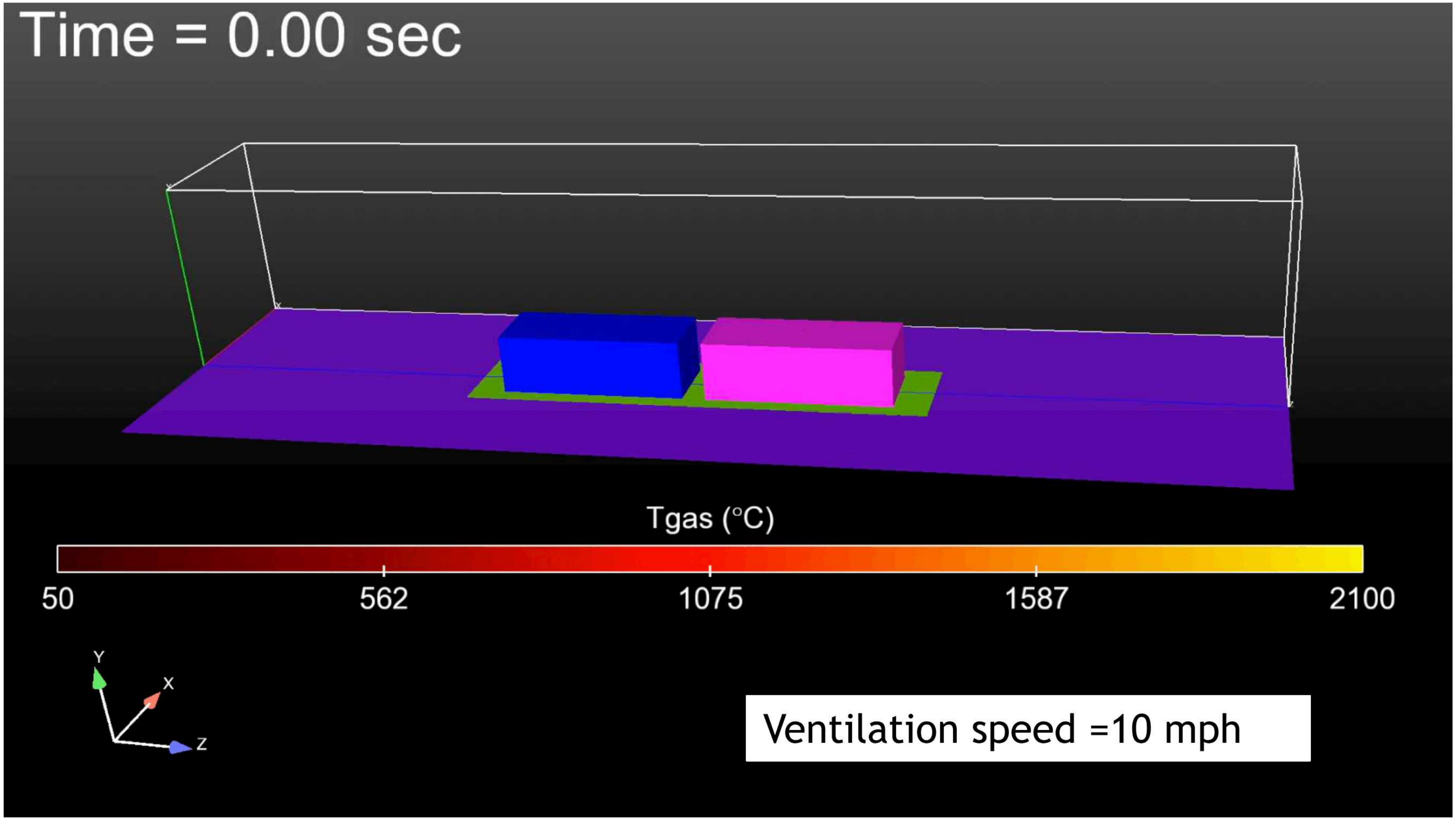


Board, National Transportation Safety,(2007)

Accomplishments: CANA Tunnel CFD, No Ventilation



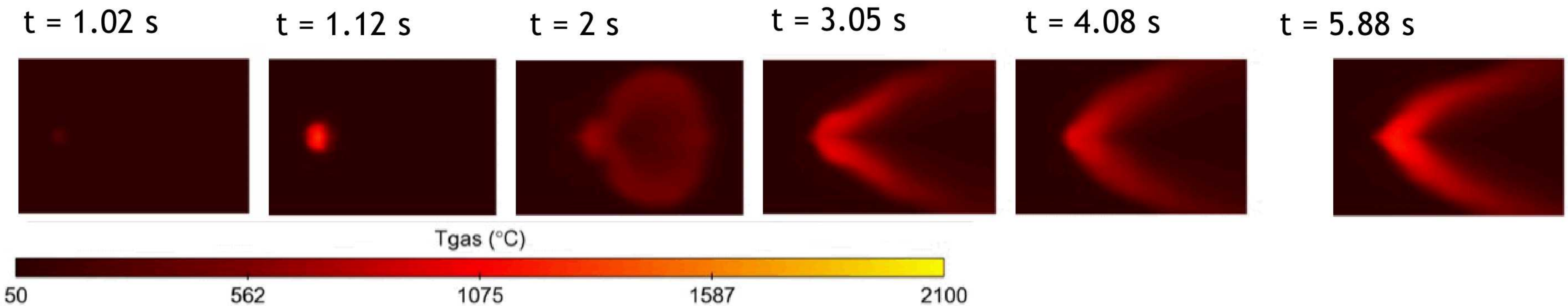
Accomplishments: CANA Tunnel H_2 Jet Flame CFD Model – Gas Temperature With Ventilation

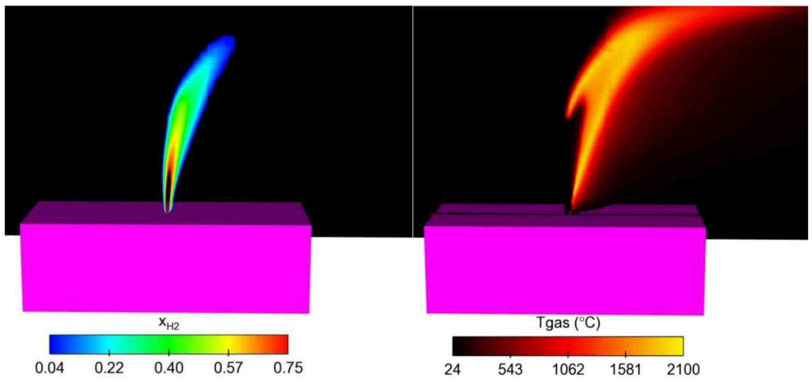


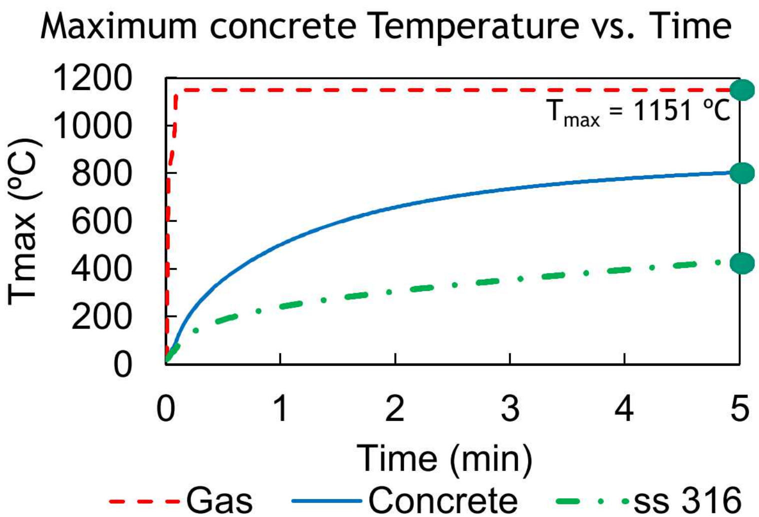
Accomplishments: CANA Tunnel CFD with Ventilation

Flame does not reach ceiling, but hot gas mixture does.

The separation of the jet at the ceiling interface is caused by a counter-rotating vortex pair generated by the jet in crossflow







Accomplishments: Tunnel Results

- Potential for **explosive spalling**:
  - Modeling showed that conditions are present that may result in localized spalling in the area where the hydrogen jet flame impinges the ceiling
  - Steel deflection is minimal
  - Note that the hydrogen heat release rate was over-predicted, so the temperature observed should be lower
- Effect of heat on the **epoxy**:
  - Maximum temperature at epoxy/bolt location is ambient, well below failure point of 90 ^{o}C, even under the worst case, conservative condition
- Effect of heat on the **steel support structure**:
  - Maximum temperature of steel hangers exposed directly to the hydrogen jet flame is 706 ^{o}C after 5 minutes of impingement for the case with no ventilation
- Analysis focused on short duration H_2 jet flame. Hydrocarbon fuel/vehicle fire would be a longer duration and resulting heat was not analyzed and may result in spalling concrete
  - Only the hydrogen fire was analyzed because it posed a new hazard

Thank you!

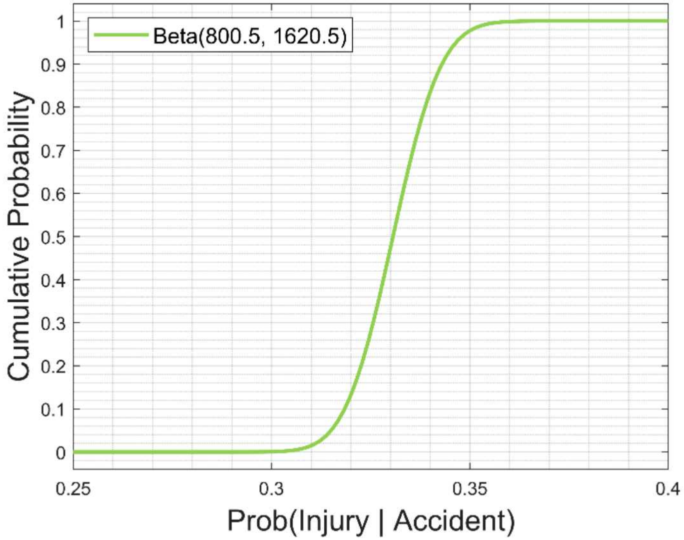
Questions? Feedback?

Brian Ehrhart bdehrha@sandia.gov

Alice Muna amuna@sandia.gov

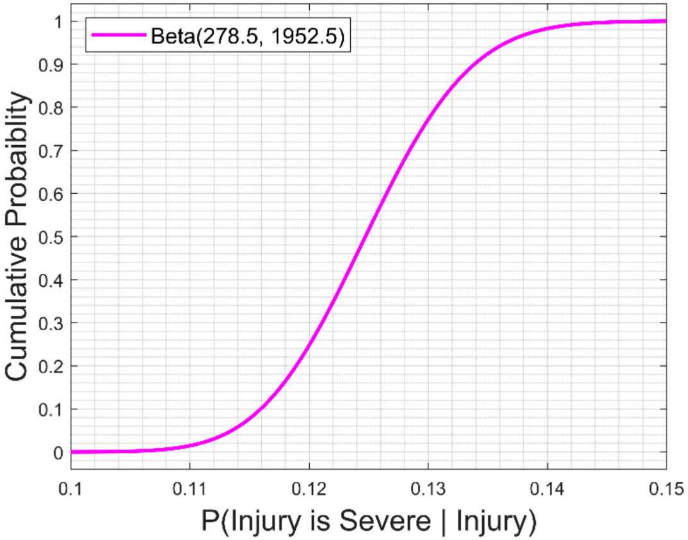
Uncertainty around scenario probabilities

Probability of injury given an accident



	Total Number of Accidents	Total Number of Injuries
Z-L Ma et al. (via Bassan)	116	35
Caliendo	2304	765

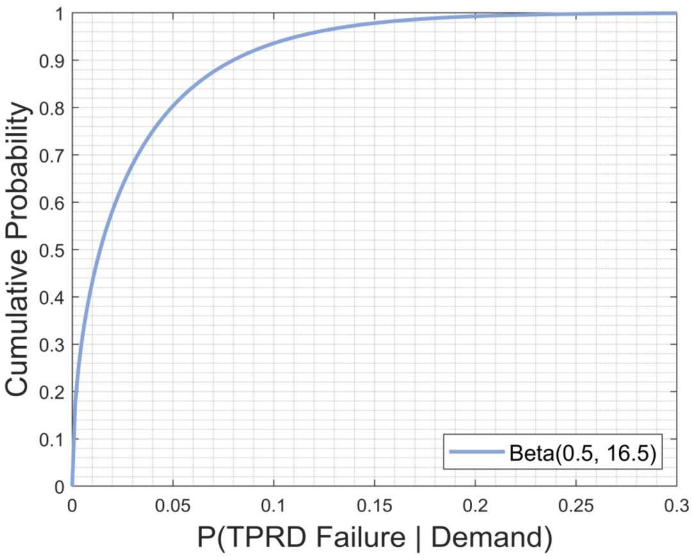
Probability that an accident is severe given that an injury occurred



	Total Number of Injuries	Severe Injury (or fatality)
Amunsden	562	97
Amunsden	1130	125
Z-L Ma et al.	35	11
Meng Qu	503	45

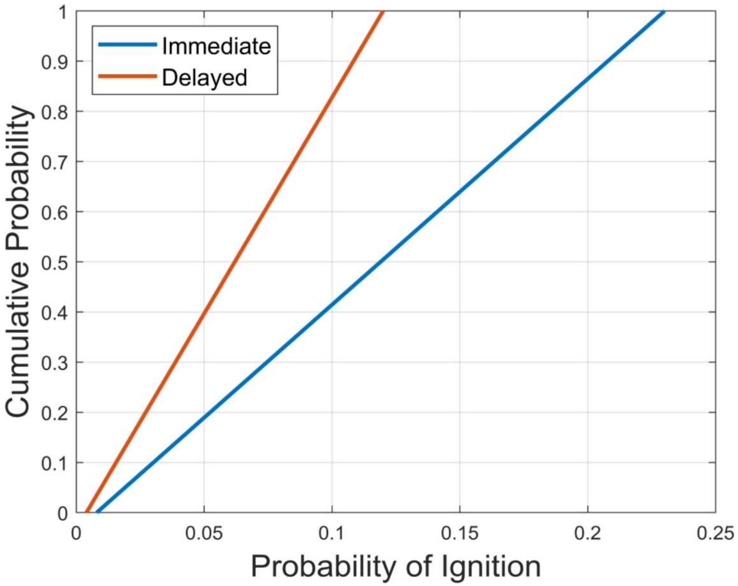
Uncertainty around scenario probabilities

Uncertainty of TPRD failure to operate



- Bayesian approach with informed prior
- Choice of an informed prior leads to a lower estimated probability of failure, but overall range where most of the distribution lies is similar to that obtained with a Jeffrey's prior

Probability of H2 ignition

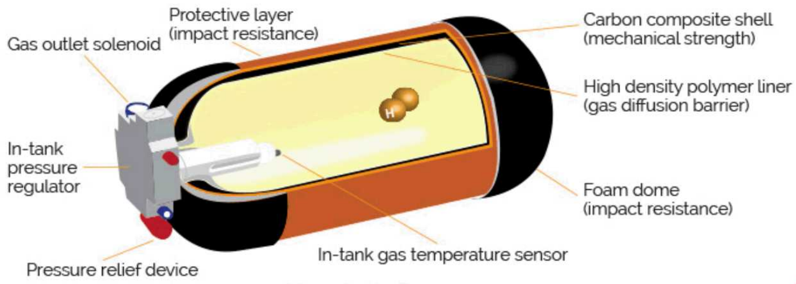


- Due to wide range of ignition probability values, a uniform distribution between the lowest and highest values was chosen

Velocity of H_2 Tank Blowdown

Valve orifice diameter was adjusted due to mesh co

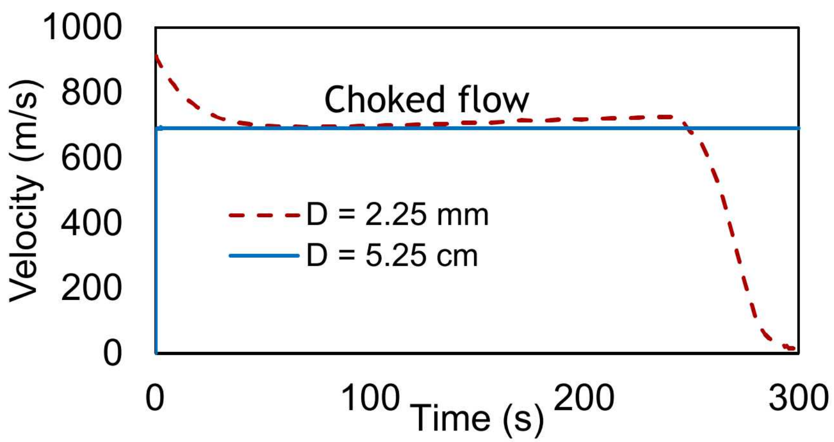
- Actual valve diameter 2.25 mm → CFD orifice diamet
- Same mass flow rate by adjusting velocity under-predict the ceiling

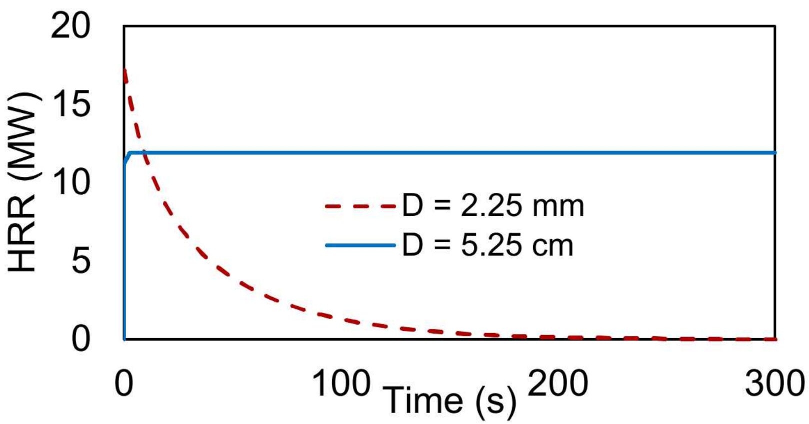


https://cafcp.org/emergency-responders

- Modeled: 700 m/s over 5 minutes
  - Will over-predict amount of mass released, but captures momentum and flame length
  - Heat release rate is also over-predicted,

$$HRR = \dot{m}_0 \Delta H_c$$

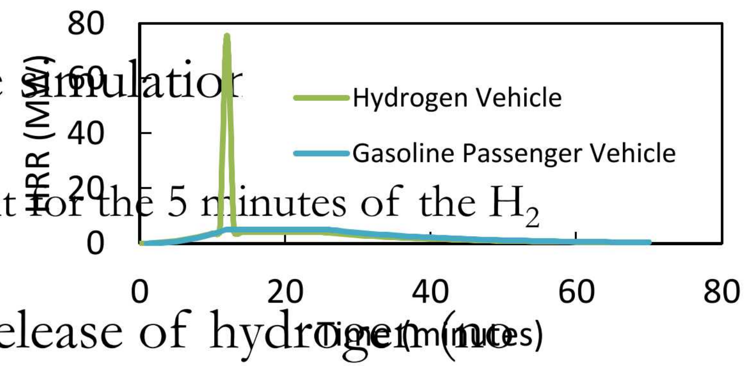




Important Conservative Assumptions

Only one fuel can be burned at a time in the simulation

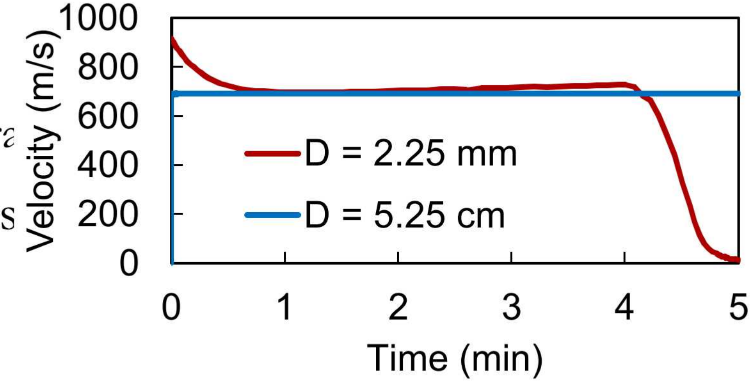
- Simulations include only hydrogen jet flame
- Heat Release Rate (HRR) from hydrogen is constant for the 5 minutes of the H_2 release

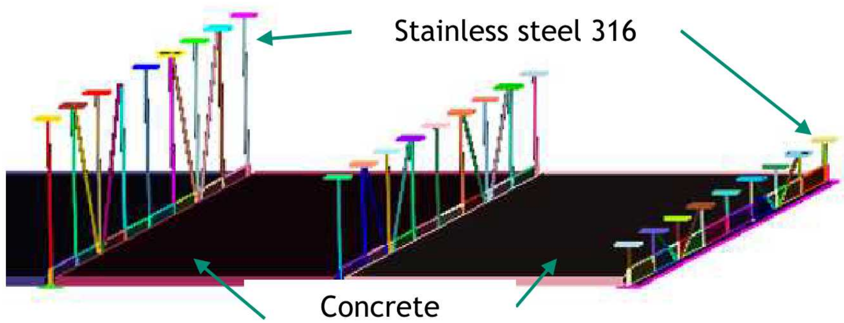


Constant choked velocity was used for the release of hydrogen (no blowdown over time)

- Blowdown would last 5 minutes
- Ensured worst case flame heat release rate and dura

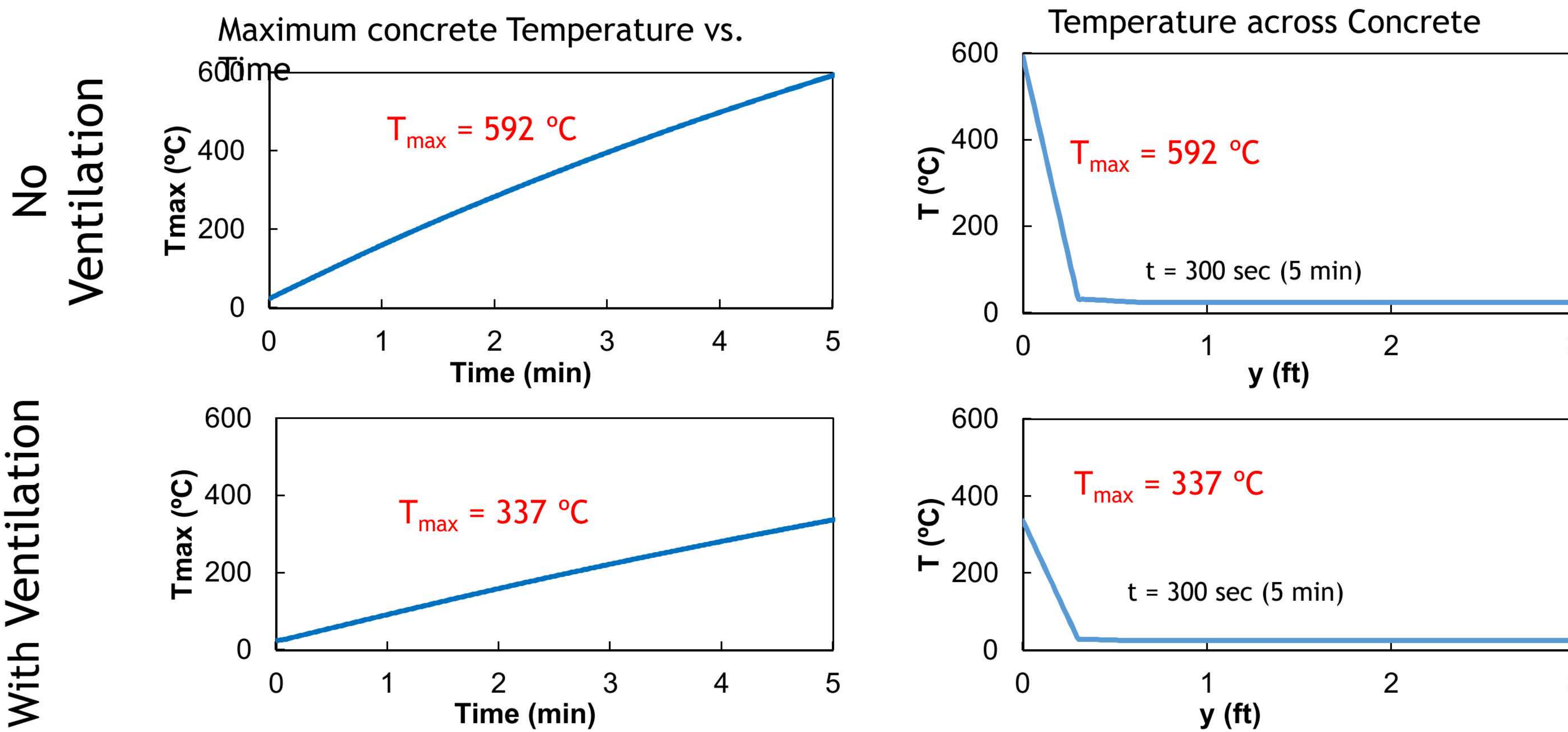
The flame was located directly under the shortes
the worst case





Accomplishments: Heat Transfer Model Predicts Temperatures Throughout Concrete Panels

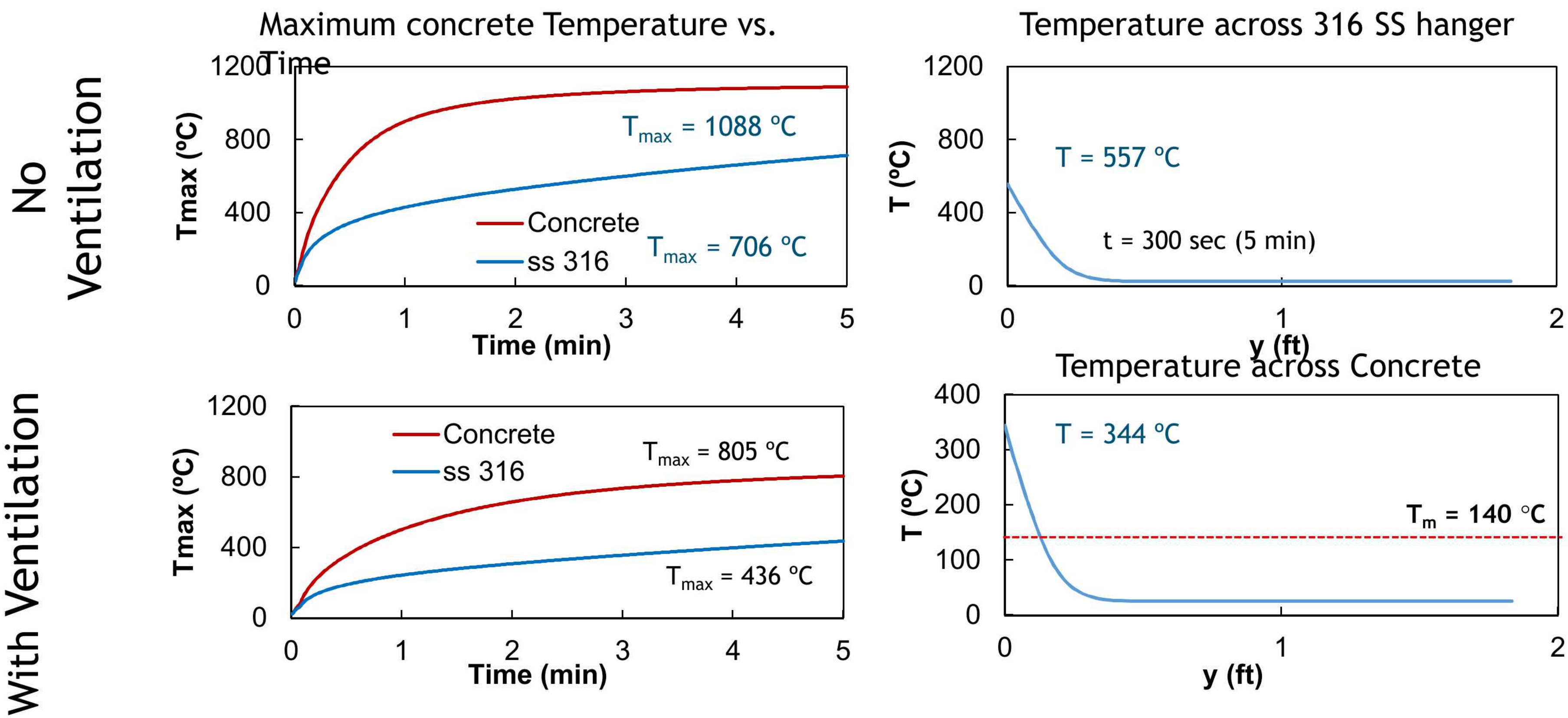
CANA Tunnel



It is much less likely to have explosive spalling when tunnel ventilation is operating

Accomplishments: Effects on Structural Elements Predicted

TW Tunnel



The epoxy will not reach the failure temperature of 90 °C