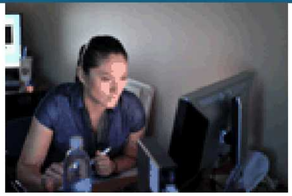
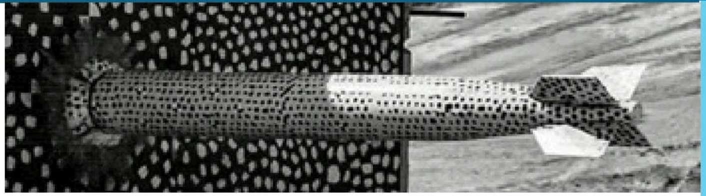
SAND2020-7488PE

Fire Risk for Emerging Technologies Capabilities





Chris LaFleur and Brian Ehrhart

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Industry Summaries

Improving Hydrogen Safety

Capability: *Provide scientific justification for code improvements by analyzing hydrogen safety risk through risk-informed and physics-based methods*

HyRAM

Quantitative risk assessment (QRA) methodology with frequency & probability data for hydrogen leaks

Fast-running models of hydrogen gas and flame behaviors

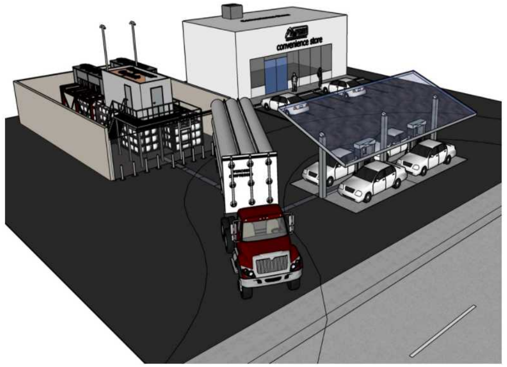
Free and Open Source

HYRAM HYDROGEN RISK ASSESSMENT MODELS

Infrastructure

Develop reference refueling station designs to stakeholders

Detailed designs, parts lists, cost estimates, and physical footprint for reference station designs

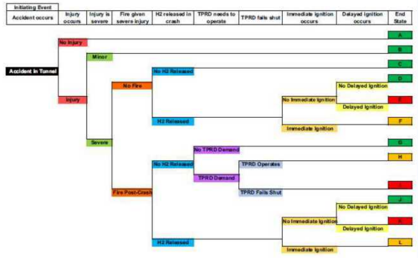


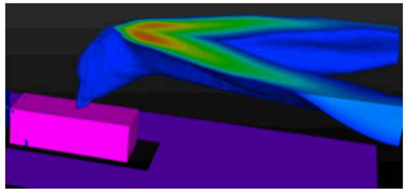
Risk and Hazard Analysis

Risk-significant hazards via HAZOP, Event Tree, FMEA

Probabilities estimated with statistical analysis and uncertainty quantification

High-fidelity and reduced-order modeling of physical hazards





Codes and Standards Participation

Committee membership and active participation in NFPA 2 and 55 codes

Committee Chair of NFPA 2

Also active in IEC and ICC

Improving Natural Gas Safety

Capability: *Provide scientific expertise to inform decision-makers by analyzing natural gas safety risk through risk-informed and physics-based methods*

LNG Rail Locomotives

DOT FRA project to assess hazards from LNG rail tender car

FMEA to identify failures from tender

HAZOP and Human Factors assessment of maintenance activities

Probability Class	Minor	Moderate	Critical
High	M	H	H
Medium	L	M	H
Low	L	L	M
	Severity Class		

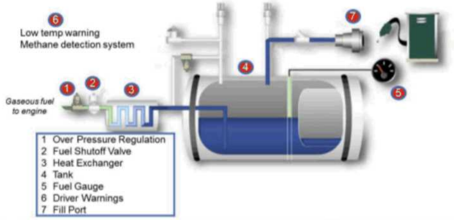
JRC2017-2275 (SAND2016-11209 C)

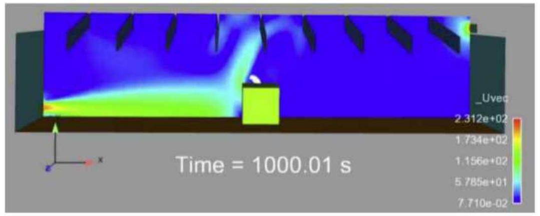
Natural Gas Vehicles

Code review of ventilation requirements to identify inconsistencies

HAZOP to identify risk-significant leak scenarios

CFD modeling to quantify NG leak behavior



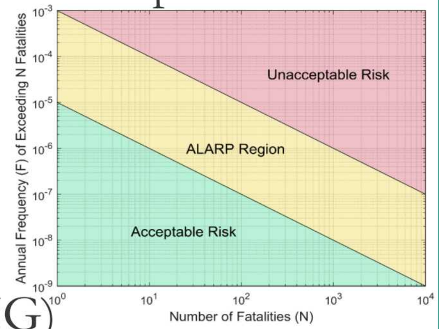


SAND2018-2945

Risk Acceptability Criteria

Comparison of fixed-facility and transportation risk calculation methods

Review and recommendations of risk acceptability criteria and recommendations for transportation of hazardous materials (especially CNG/LNG)

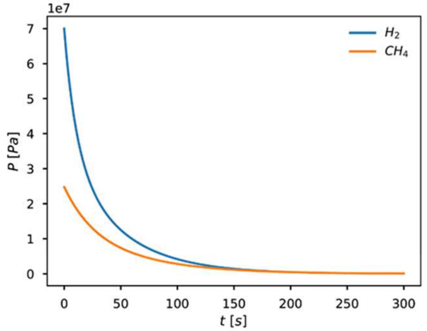


DOT/FRA/ORD-20/06 (SAND2020-2467 R)

Hydrogen/Natural Gas

Leverage existing HyRAM software and add capability to handle CNG and LNG risk and physics models

Hydrogen/natural gas blends assessed for release behavior



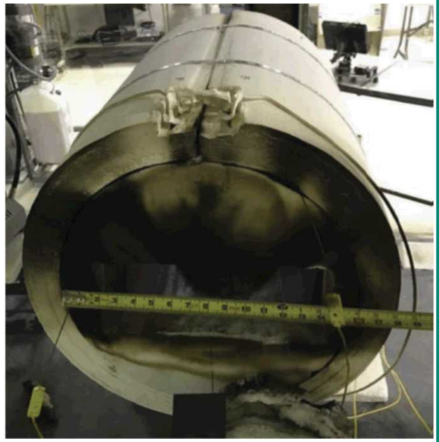
Improving Nuclear Power Plant Safety

Capability: *Support improvements to Fire PRA calculations and methodologies by assessing the effects of thermal environments on critical systems*

Fire Cable Testing

Experimental assessment of control cable signal response due to radiant heating

Significant variables identified through regression analysis of multiple cable types and signal loop designs

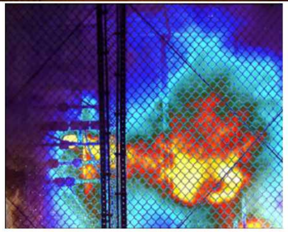


NUREG/CR-7244 (SAND2017-10346 R)

HEAF Characterization

High-speed video and particle data collected from HEAF event experiments

Modeling HEAF events will inform Zone of Influence for NPP Fire PRA calculations



Cable Fragility

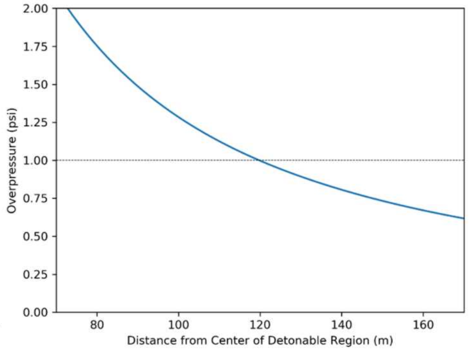
Provide preliminary model data and verify viability of the high heat flux ignition map methodology

Thermal/electrical continuity monitoring was conducted to detect failure of the sample

Hydrogen Production

Consequence and likelihood assessment of theoretical H2 production facility at NPP

Overpressure calculations to ensure that key NPP facilities would be unharmed in event of hydrogen leak and explosion



Project Summaries

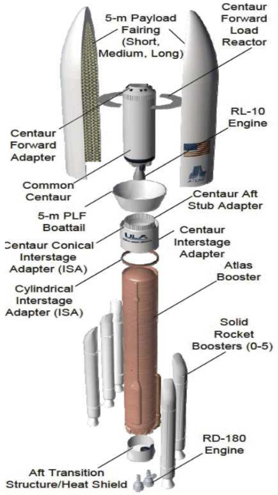
Fire and Thermal Modeling for the Mars 2020 Safety Analysis Report

Objective: *Analyze effects of launch accident propellant fire and thermal environments on radioactive materials used in space power systems*

Scope/Tasks

A launch accident can lead to significant physical and thermal insults to the Mars 2020 rover radioactive power source

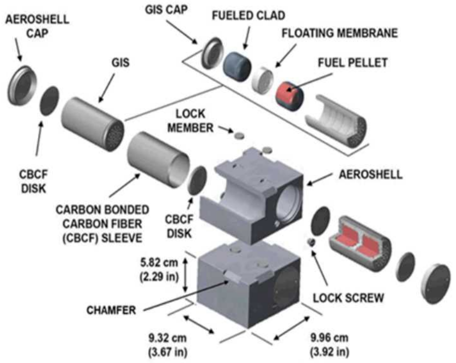
Thermal environments arise from the burning of liquid and solid rocket propellants



Results

Modeling codes developed to focus on different environments or scenarios

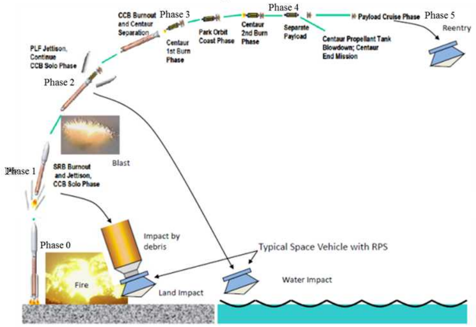
Fire environments alter radioactive particles via vaporization/condensation



Conclusions

Effects on mission risk are scenario-specific; particle sizes can increase and decrease based on the fire environment

Consequences vary based on the sizes of particles



Impacts

Approval required for all launches with nuclear payload

Fire and thermal modeling contribute to overall mission risk

[SAND2019-11148]

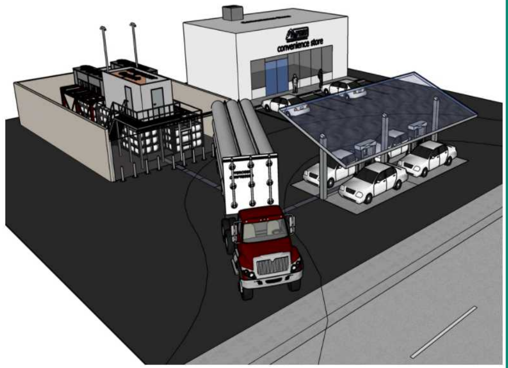
Hydrogen Refueling Reference Station Lot Size Analysis for Urban Sites (H2FIRST)

Objective: *Create compact gaseous and liquid hydrogen reference station designs appropriate for urban locations, enabled by design changes and near-term technology and fire code changes*

Scope/Tasks

Quantify physical footprint of generic theoretical hydrogen refueling station designs

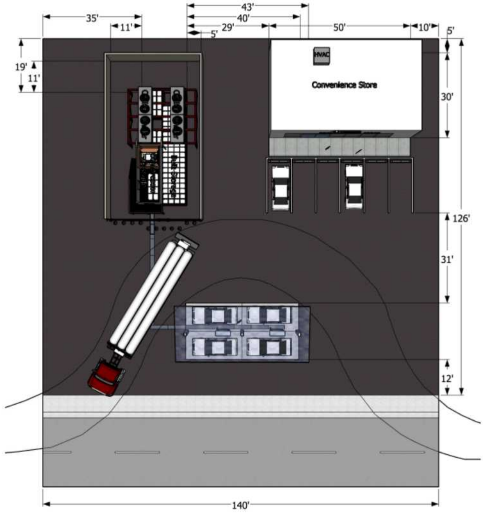
Compare differences in footprint for different design changes



Results

32 stations analyzed, 600 kg/day capacity with delivered gas, delivered liquid, or on-site electrolysis

Convenience store, traffic, parking, and delivery truck path had large impact on footprint

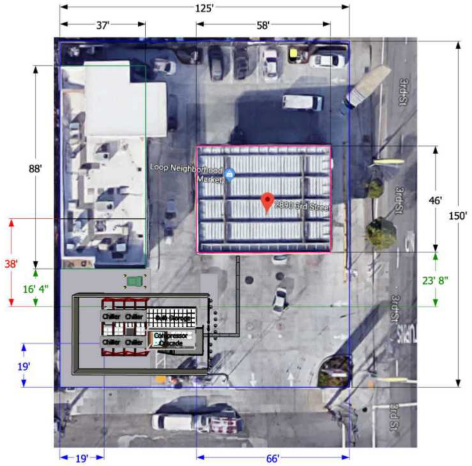


Conclusions

Footprint reduction leads to increased sites available

Largest footprint reductions may not be worth increased cost

Site-specific factors will affect station sites



Impacts

Identified issues and improved NFPA 2 code language for setback di calculation and systems with both liquid and gas

Identified future possibilities for footprint reductions

SAND2020-2796

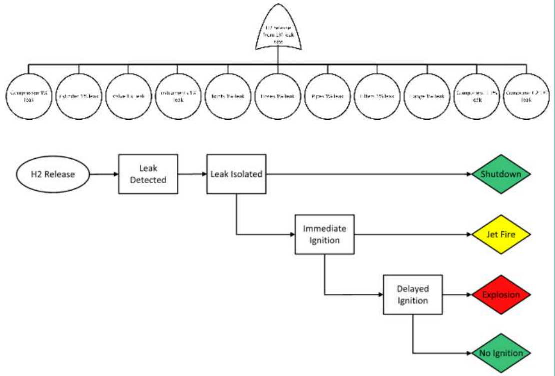
Hydrogen Risk Assessment Models 2.0: Open-source quantitative risk assessment framework (HyRAM)

Objective: *Put the R&D into the hands of the industry safety experts through a first-of-its-kind integration platform for state-of-the-art hydrogen safety models & data*

Core Functionality

Quantitative risk assessment (QRA) methodology with frequency & probability data for hydrogen leaks

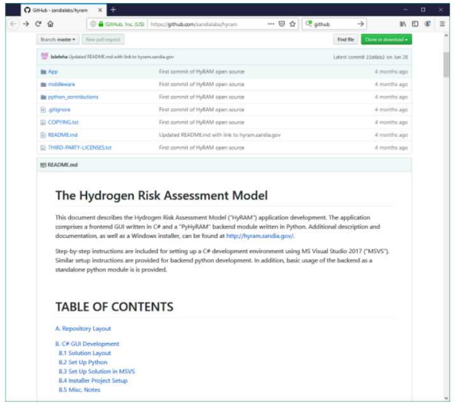
Fast-running models of hydrogen gas and flame behaviors



Free and Open Source

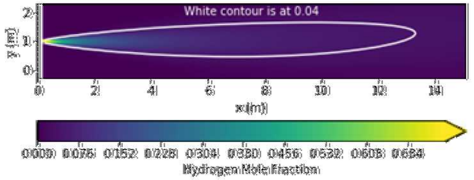
HyRAM 2.0 has Windows installer and Python source code

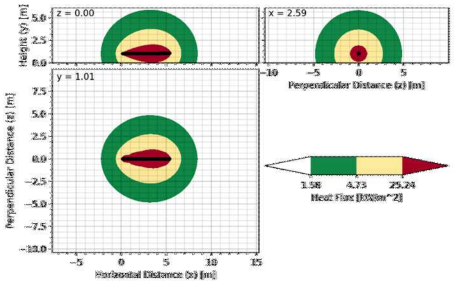
Open source, meaning users have access to the source code, can review or modify



Main Models

- System leak frequency
  Hazard heat flux location
- Ignition and fatality probabilities
- Density, tank blowdown
- Unignited jet dispersion
- Flame jet heat flux





Impacts

Hundreds of users in USA and internationally now able to perform independent risk assessments without supercomputer

Models and methodologies that justify code requirements now accessible to everyone

https://hyram.sandia.gov/

Risk Analysis and Modeling to Improve Hydrogen Fuel Cell Vehicle Repair Garages Codes and Standards (QAI CRADA)

Objective: *Analyze effects of ventilation requirements using risk assessment and simulations to better inform future codes and standards*

Scope/Tasks

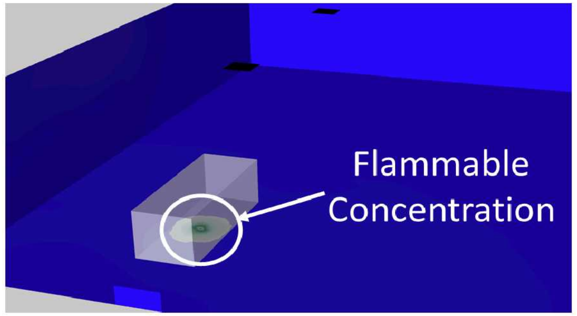
Analyze risk of maintenance operations for fuel cell vehicles

Simulate scenarios of interest from risk analysis using Sandia models of hydrogen release

Results

4 medium-risk scenarios identified using HAZOP

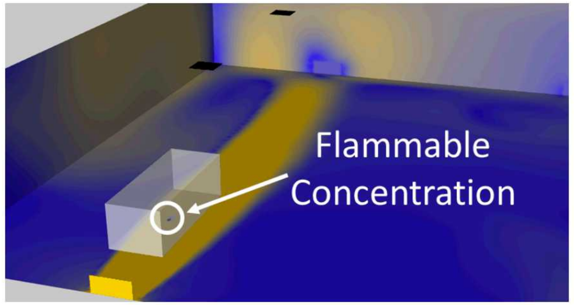
CFD modeling of main scenario of interest, which was leak from mid-pressure port while defueling the vehicle



Conclusions

A leak away from ventilation inlets had same maximum instantaneous flammable mass as no ventilation at all

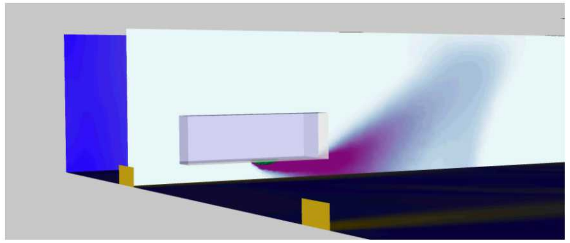
High-speed ventilation near leak significantly reduced instantaneous flammable mass



Impacts

Local ventilation near potential leak points may be more effective than expensive overhauls of facility ventilation overall

SAND2020-4221



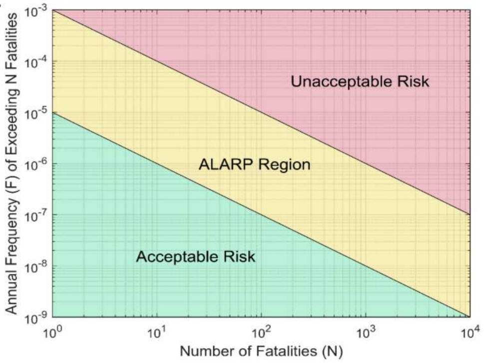
Evaluation of Risk Acceptance Criteria for Transporting Hazardous Materials (DOT FRA)

Objective: *Recommend safety/risk assessment criteria for use in FRA's review of applications for the use of LNG as a locomotive fuel or cargo*

Scope/Tasks

Review the applicability of fixed-facility risk assessment methodology to hazmat transportation

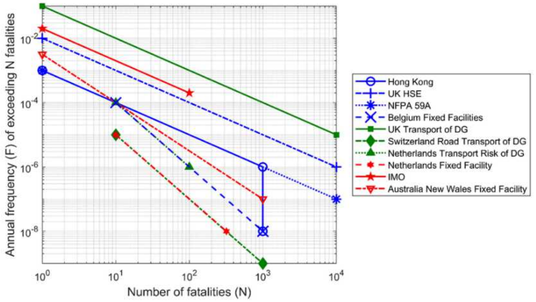
Assess risk acceptability criteria applicable to hazmat transportation from the literature



Results

Different calculation methods and different applicability for individual and societal risk

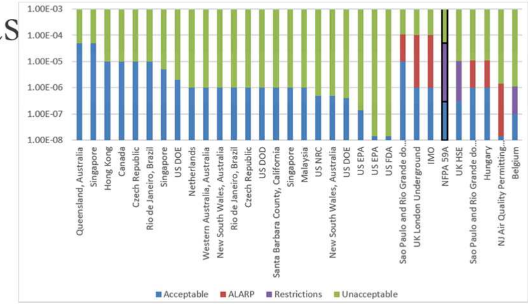
Different locales and industries treat risk acceptability differently, literature search conducted on many relevant examples



Conclusions

Transportation QRA fundamentally the same as fixed facility, but differences in calculation of probabilities and hazard locations

Recommended criteria adapted from NFPA 59A



Impacts

Recent interest in shipping natural gas by rail has led to permit requests to FRA/PHMSA

Natural gas locomotives being explored for reduced emissions

https://railroads.dot.gov/elibrary/evaluation-risk-acceptance-criteria-transporting-hazardous-materials

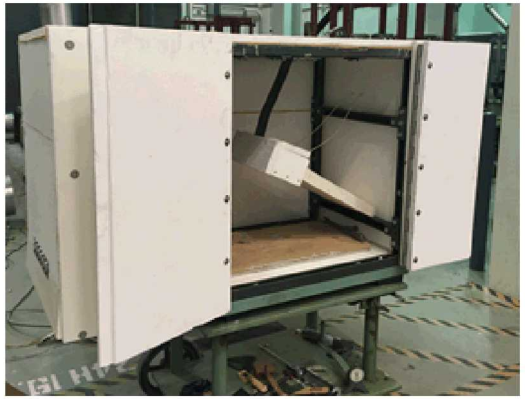
Evaluation of Flammability for Vertical Wood Flooring (New Mexico Wood Floor Company– Small Business Program)

Objective: *Test flame spread of end-grain wood flooring/siding as best as possible to testing standard to comply with IBC and NFPA 1 requirements.*

Scope/Tasks

Perform ASTM E84 Steiner Tunnel Test on wood siding samples

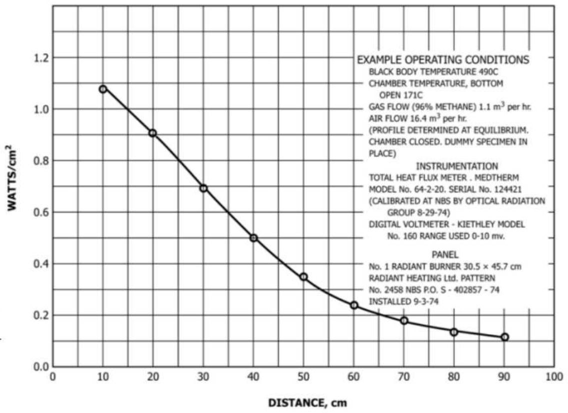
Conduct ASTM E648/ NFPA 253 Critical radiant heat flux tests



Results

Measurements of flame spread and smoke development index were made

Critical radiant heat flux at flameout was determined based on measured heat flux-distance curve



Conclusions

Test results are proprietary

Impacts

Test results can be provided to Authority Having Jurisdiction to determine that product meets the fire test requirements

Small business can determine if their product will pass tests at standards lab and save limited funding

Characterization and Modeling of High Energy Arc Faults (NRC)

Objective: *Understand the dynamics of a HEAF event, characterize the source term of the arc (heat transfer), and develop a model to determine the appropriate probabilistic risk assessment methodology*

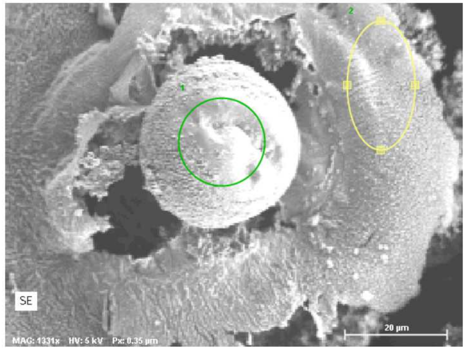
Scope/Tasks

Collect image and particle data from HEAF event experiments

Create model to characterize heat transport from HEAF events in nuclear power plants

Results

Particle morphology analyzed from full-scale experiments

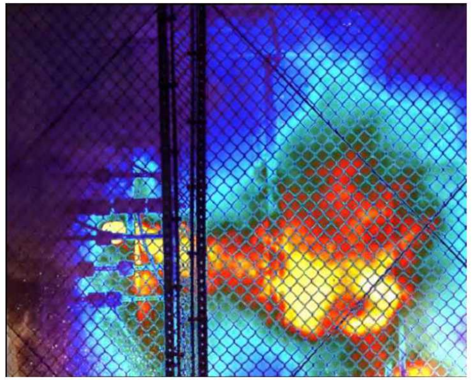


High-speed video provided spatial and temporal data as well as unique in-depth view of equipment breach dynamics

Conclusions

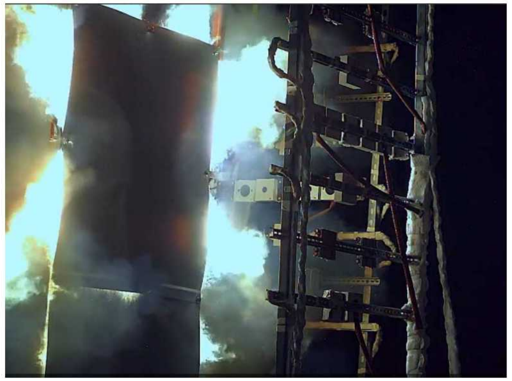
HEAF consequences are highly dependent on arc duration and conductor material.

Aluminum HEAF events are more energetic than copper.



Impacts

Modeling key HEAF events will allow Zone of Influence to be developed in the Fire Probabilistic Risk Assessment methodology



Evaluation of Cable Fragility in High Heat Flux Events (NRC-RES)

Objective: *Determine target cable failure criteria for HEAF events involving high heat flux, short duration exposures*

Scope/Tasks

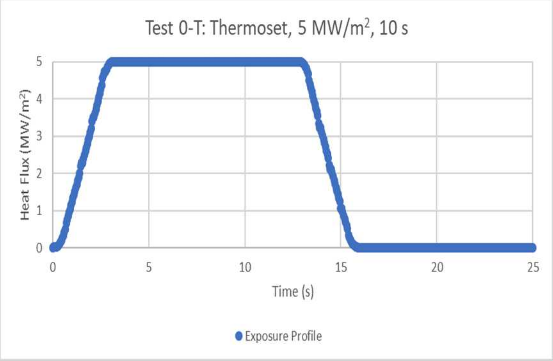
Provide preliminary model data and verify viability of the high heat flux ignition map methodology

Use Solar Furnace to expose cables to high heat fluxes (5 MW/m^2) for durations similar to arc incidents in nuclear power plants

Results

Phase 0 tests showed spontaneous transient ignition for all heat fluxes

No cables remained burning after incident heat flux was removed



Conclusions

Ignition as the failure criteria for cables may not be feasible. Sustained versus transient ignition will be investigated in subsequent testing.

Impacts

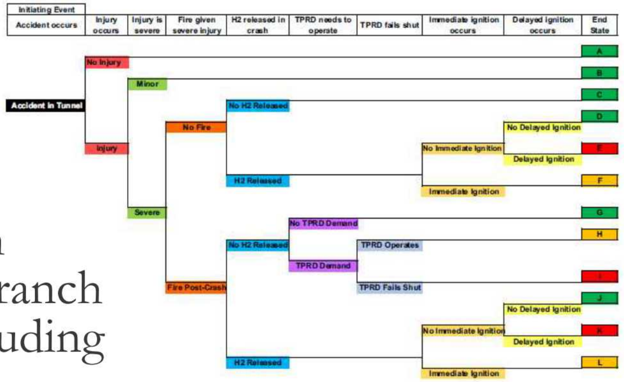
Cable failure heat flux and temperature data will be used to create revised zone of influence distances in the Fire PRA methodology for high energy arc faults for both copper and aluminum conductors

Risk Assessment of Hydrogen Fuel Cell Electric Vehicles in Tunnels (DOE HFTO)

Objective: *Perform risk analysis to identify potential crash scenarios and provide a quantitative calculation for the probability of each scenario occurring, with a qualitative categorization of possible consequences.*

Scope/Tasks

Construct event sequence diagram



Estimate probability distributions for each event and calculate branch line probabilities including uncertainty

Results

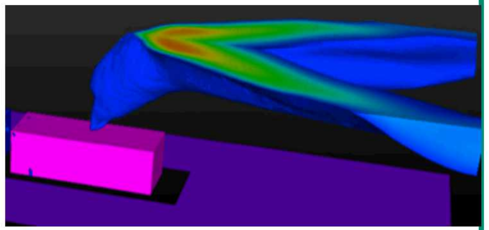
Values for the conditional probability of each scenario given a crash with a single FCEV in a tunnel were calculated

Scenario	Probability 95% bounds	Probability median estimate	Median frequency[a]	Severity
A	[6.5E−01, 6.9E−01]	6.7E−01	2.3E−01	No effect
B	[2.7E−01, 3.1E−01]	2.9E−01	1.0E−01	No effect
C	[1.3E−02, 3.3E−02]	2.4E−02	7.9E−03	No effect
D	[1.9E−06, 8.3E−03]	8.7E−04	2.8E−04	No effect
E	[8.8E−08, 6.5E−04]	4.4E−05	1.4E−05	Overpressure
F	[1.9E−07, 1.4E−03]	9.5E−05	3.1E−05	Jet flame
G	[3.3E−04, 1.8E−02]	6.5E−03	2.1E−03	No effect
H	[3.1E−04, 1.8E−02]	6.3E−03	2.0E−03	Jet flame
I	[1.1E−07, 1.3E−03]	6.7E−05	2.3E−05	Overpressure
J	[1.1E−06, 5.2E−03]	5.2E−04	1.7E−04	No effect
K	[5.1E−08, 4.1E−04]	2.6E−05	8.6E−06	Overpressure
L	[1.1E−07, 8.8E−04]	5.7E−05	1.9E−05	Jet flame

Conclusions

Most likely consequence of a crash is no additional hazard from hydrogen fuel (98.1–99.9% probability)

Most likely H2 ignition scenario is jet flame from pressure relief device due to hydrocarbon fire (0.03–1.8% probability)



Impacts

Very low probability scenarios quantified

Utilized in discussions with authorities in key markets to allow fuel cell vehicles in tunnels

https://doi.org/10.1007/s10694-019-00910-z