System-Level Design and Verification Concepts for Hydrogen-Fueled Vehicles: Fireworthiness

by
R. Rhoads Stephenson
Motor Vehicle Fire Research Institute
www.mvfri.org
rodys@earthlink.net

MVFRI

Outline

- Vehicle Bonfire Test
- Hydrogen Storage Safety
- Keep the High Pressure in the Tank
- Pressure Relief Devices
- Active Pressure Relief Devices and Remote Defueling
- Hydrogen Releases Inside Buildings
- Hydrogen Underbody H_2 Release Experiments
- Incident Reporting

MVFRI

Vehicle Bonfire Test

- ECE R-34 Annex 5 applies to plastic fuel tanks
- Test full vehicle or vehicle “buck”
- Gasoline pool fire for 2 minutes
- No tank leakage

Vehicle Bonfire Test – Hydrogen Vehicle Fireworthiness

- 2 minute exposure of vehicle
- Continue test for 20-minutes total
  - tenability for occupants
  - Safe venting of H_2
- Safe hydrogen release OK – no burst or acceleration of fire
- Demonstration test planned soon

MVFRI

ECE R-34 Bonfire Test

MVFRI

Advantages

- System-Level
- Performance based
  - Hydrogen storage performance
  - Tenability of occupants
    - CO less than 1 %
    - Temperature at eye level less than 200 C
- Applies to any form of hydrogen storage

Extensions

- Could add underhood fire in frontal crash vehicle
- Could use same vehicles as crashed in FMVSS 301 or 303 (Fuel System Integrity)
  - Rear crash
  - Frontal crash
- Crashed vehicles will have real world deformations and torn seams

Hydrogen Storage Safety

- Many storage technologies involve high pressure
  - Compressed – up to 700 bar
  - Hydride – up to 100 bar
  - Liquid – low pressure
- 20 minute exposure to bonfire
  - Most tanks won't survive for 20 min
  - Thermally-actuated PRD must work
  - Safely vent – don't add to fire

MVFRI

Tank Burst Times

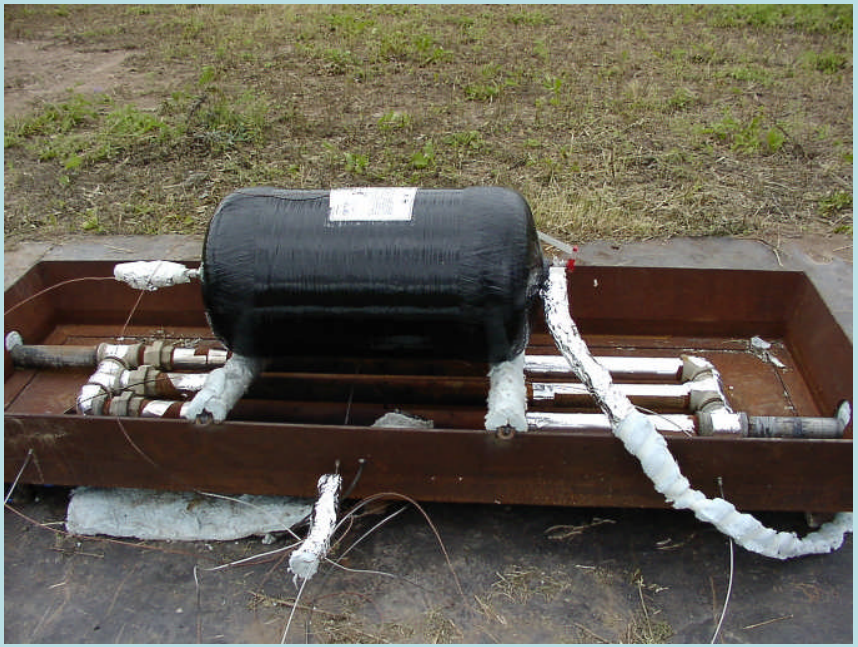
Sponsor	Tank Type	Volume (liters)	Pressure (MPa)	Burst time (sec.)
MVFRI	4	72	35	387
JARI	3	39	35	416
"	4	65	35	581
"	3	36	70	654
"	4	35	70	1281

MVFRI

Hydrogen Fuel Tank Test Setup

Instrumentation

- Tank internal temperature and pressure
- Exterior temperatures
- Blast pressures at 4 locations
- Visual and IR video



Tank positioned in bonfire test rig

MVFRI

Burst Test

- 5000 psi tank burst

Burst Test Conclusions

- Temperature and pressure inside tank increased a negligible amount
  - Temperature up 20 C
  - Pressure up 200 psi (13 bar)
- Largest fragment (14 Kg) landed 80 meters (270 feet) away
- 43 psi overpressure at 2 m (6.3 feet)
- 6 psi overpressure at 6.5 m (21 feet)
- No damage (0.3 psi; 2.1 KPa) at 45 m (145 feet)

JARI Conclusions

- “The currently specified flame exposure test will not always represent a real vehicle fire”
- “Evaluation of safety through a flame exposure test on the actual vehicle is recommended to improve reliability”

(Source: “Improvement of Flame Exposure Test for High Pressure Hydrogen Cylinders to Achieve High Reliability and Accuracy,” Tamura et al, JARI, SAE paper 2006-01-0128, April 2006.)

Keep the High Pressure in the Tank

- Many vehicles will have multiple tanks
- High pressure tanks are inherently strong
- External plumbing and components outside the tank are more vulnerable in crashes
- “Best Engineering Practice” – Use in-tank regulator and keep the high pressure confined to the tank.

Pressure Relief Devices

- Most important fire safety device on the vehicle
- Thermal actuation required
- Many designs require pressure to open
- Do component level test at both 100% pressure and at 7 bar (100 psi)
- Must be extremely reliable – 10^{-8} per year

Active Pressure Relief Devices and Remote Defueling

- Normally closed pyrotechnic valve
- Solid tubing – no seals – no leaks
- Electronically controlled
- Allows earlier venting of H_2 from many signals
  - Crash deceleration
  - Air Bag deployment
  - Hydrogen leak
  - Fire & temperature – from many possible sensors

Advantages

- Don’t have to wait for fire to get to PRD
- Can protect against localized fires that do not heat the PRD
  - PRD is a point sensor
  - Burn wires and other sensors can sense a line or area
- Allows implementation of Remote Defueling
  - To protect emergency responders
  - Use remote controller with unique code for each vehicle (32 bit code is enough)

Hydrogen Releases Inside Buildings

- Residential or public parking garages
- PRD venting is a well known failure mode
- Single point failure
- Rapid release of H_2 from one tank or the whole vehicle in a few minutes
- High ventilation impractical – retrofit undesirable
- Hydrogen can explode
  - Easy ignition
  - Detonation is very hazardous
- Much more serious than with Natural Gas

Hydrogen Releases Inside Buildings (Con't)

- Desired PRD failure rate – 10^{-8} failures per year
  - Difficult to prove
- Solution: Put two PRDs in series
  - Four 9's reliability will become eight 9's
  - Upstream PRD keeps pressure off other PRD
  - Downstream PRD protects upstream PRD from corrosion, debris, and freezing water
- Two PRDs could be integrated into one housing

Vehicle Underbody H_2 Release Experiments

- 20 cubic feet/minute baseline (48 g/min)
  - Approximate flow into fuel cell at full power
  - Recommended by steering group for California Fuel Cell Partnership facility study (Parsons-Brinkerhoff)
- Also did 10 CFM for comparison
- Used popular SUV
- Two release points – along gasoline fuel lines
  - Left frame rail
  - Into the engine compartment

MVFRI

Vehicle Underbody H_2 Release Experiments (Jet)

- Ignited Jet Video

Vehicle Underbody H_2 Release Experiments (Jet)

- Conclusions
  - Low heat flux
  - Very low heating of components
  - Hard to ignite materials
  - Not very hazardous

Vehicle Underbody H_2 Release Experiments (Delayed Ignition)

- Releases of 1, 2, 4, …. up to 64 seconds
- Used “electric match” for ignition
- Almost all ignited
- Loud Bang
- Hood damage at 64 sec release
  - Minor
  - No ignition of vehicle components

Vehicle Underbody H_2 Release Experiments (Delayed Ignition)

- Delayed Ignition video

Incident Reporting

- Standards Development Organizations (SDO's) need real world feedback on how their standards are working
- Need incident reporting systems at SDO, National, and International levels
- Reporting should be required at vehicle and component level
- U.S DOE incident reporting now on line
  - www.h2incidents.org

MVFRI

Major Conclusions

- Vehicle level bonfire test (Fireworthiness) most appropriate
- PRD must be highly reliable
  - Suggest two PRDs in series
- Active PRD and remote defueling highly desirable
- Moderate hydrogen leaks are benign
- Incident data bases are important

Questions?

Please visit our website at:

www.mvfri.org