Safety and Regulatory Structure for CNG/H2 Vehicles and Fuels in the United States

Compressed Natural Gas and Hydrogen Fuels: Lessons Learned for Safe Deployment of Vehicles Workshop

December 2009

Overview

- DOT/NHTSA Mission
- Federal Motor Vehicle Safety Standards (FMVSS)
- FMVSS covering alternative fuel vehicles
- Research supporting new/improved FMVSS for alternative fuel vehicles
- International Harmonization - Global Technical Regulations

Mission Statements

- DOT Mission Statement
  - Serve the United States by ensuring a safe transportation system that furthers our vital national interests and enhances the quality of life of the American people
    - Safety – Promote the public health and safety by working toward the elimination of transportation-related deaths and injuries

- NHTSA Mission Statement
  - To reduce deaths, injuries and economic losses resulting from motor vehicle crashes

NHTSA Congressional Authority

- NHTSA has congressional authority to establish Federal Motor Vehicle Safety Standards (FMVSS)
  - No person may manufacture or import a vehicle or item of equipment unless it complies with applicable FMVSS
  - Manufacturers must self-certify compliance
- FMVSS have the force of law

Requirements for FMVSS

- Must meet a safety need
- Objectively measurable compliance
- Performance-oriented (not design restrictive)
- Appropriate for each vehicle type

U.S. FMVSS 49 CFR Part 571

100 Series	**Crash Avoidance Standards**	Light systems, braking systems, rearview mirrors, controls & displays, tires, etc
200 Series	**Crashworthiness Standards**	Occupant protection, seating systems, advanced air bags, seat belt assemblies, child restraint systems, etc
300 Series	**Post-Crash Standards**	Fuel System Integrity, flammability of interior materials, component integrity

NHTSA's Standards for Fuel System Integrity

Standard 301	Fuel System Integrity
Standard 303	Compressed Natural Gas (CNG) System Integrity
Standard 304	CNG Container Integrity
Standard 305	Electric Vehicles

FMVSS 301; Fuel System Integrity (1967)

- Applies to vehicles with liquids fuel systems
- Vehicle crash tests:
  - 30 mph frontal rigid barrier
  - 33 mph side MDB
  - 50 mph rear MDB 70% overlap
- Benchmark for subsequent fuel system integrity standards for alternative fuel vehicles

Legislation Advancing CNG and Hydrogen Vehicle Safety Research

- Energy Policy Act of 1992
  - Required DOT to set safety standards for CNG conversion vehicles within 3 years

- FreedomCAR and Fuel Initiative of 2003
  - Promote the introduction hydrogen fuel cell vehicles

CNG Vehicles

- FMVSS 303; Fuel system integrity of compressed natural gas vehicles
  - Published April 1994
  - Analogous to FMVSS 301, allowable leakage limit is thermal energy equivalent to liquid fuel limit in front, side and rear crashes
- FMVSS 304; Compressed natural gas fuel container integrity
  - Published September 1994
  - Set additional life cycle requirements for CNG containers

Hydrogen Fuel Cell Vehicles

- Present
  - Hydrogen - FMVSS XXX?
  - Safety Issues
  - Research Tasks
  - Global Technical Regulation for hydrogen vehicles

Safety issues to be addressed under scope of research program

- Fuel system crashworthiness
  - Hydrogen leakage limits
  - Electrical integrity of high voltage fuel cell propulsion system
  - High pressure container safety
- Ensure a safety level consistent with gasoline, CNG, conventional electric hybrids
  - FMVSS Nos. 301, 303, 304, and 305
  - Identify unique fuel system safety hazards

Current voluntary standards offer alternate approaches to address fuel system crashworthiness

- Hydrogen leakage limits
  - Hydrogen vs. helium surrogate
  - High pressure vs. low pressure and scaling up

- High pressure container safety
  - Cumulative life cycle and extreme use durability (SAE) vs. discrete testing (i.e., FMVSS, CSA/NGV2, HGV2, ISO, EIHP, etc.)
  - Localized flame impingement (SAE) vs. bonfire (FMVSS, etc.)
  - Crash testing at high pressure (FMVSS No. 303) and/or low pressure (SAE,GM)

FY2009 - Research Tasks to Support Rulemaking/GTR Objectives

- 1. Localized fire testing - flame impingement on hydrogen storage cylinders
- 2. Cumulative cylinder life cycle testing
- 3. Comparative assessment of fueling options for crash testing
- 4. Fire safety of proposed leakage limits
- 5. Electrical isolation testing in the absence of hydrogen

1. Localized flame impingement on hydrogen storage cylinders

- FMVSS No. 304, Compressed natural gas fuel container integrity
  - Requires engulfing bonfire test
  - Cylinder must survive fire for 20 minutes or vent contents
- Localized flame impingement (SAE 2579)
  - Real world data indicates Type IV composite cylinders may not vent in localized fire
  - Lack of heat transfer to PRD
  - Composite loses structural integrity, resulting in catastrophic rupture
- Research Task:
  - Localized fire test procedure – Developed by Powertech under contract to Transport Canada using temp/propagation behavior ID'd in vehicle fire literature (OEM test data).
  - Powertech/NHTSA follow-on testing - Cylinders which have failed in real world fires will be used to test mitigation technologies
- Possible Outcome:
  - Requirement for localized flame test

Localized Fire Testing – NHTSA Follow-on Program

- Finding: The test developed for Transport Canada was not adaptable to evaluating the performance of various fire protection technologies – (purpose-built heat cradle specific to the diameter of the test article)

- Assess mitigation technologies
  - Coating systems that have intumescent properties
  - Heat wraps or shells
  - Heat detection systems that activate pressure relief devices

- A more versatile flame impingement test was developed based on an assessment of vehicle fire data
  - Temperature exceeding 900ºC
  - Duration of 30 minutes (duration of tire fire)
  - Fire length 250mm (standard bonfire is 1,650 mm in length)

Three Burner Unit for Protection System Evaluation

For the purposes of evaluating protective coating systems, used a fire source that heats a length of 0.45 m (about 18”) long, i.e. 3 “Tiger” torches in line (each torch approx 75mm diameter opening)

Localized Fire Testing – Methodology

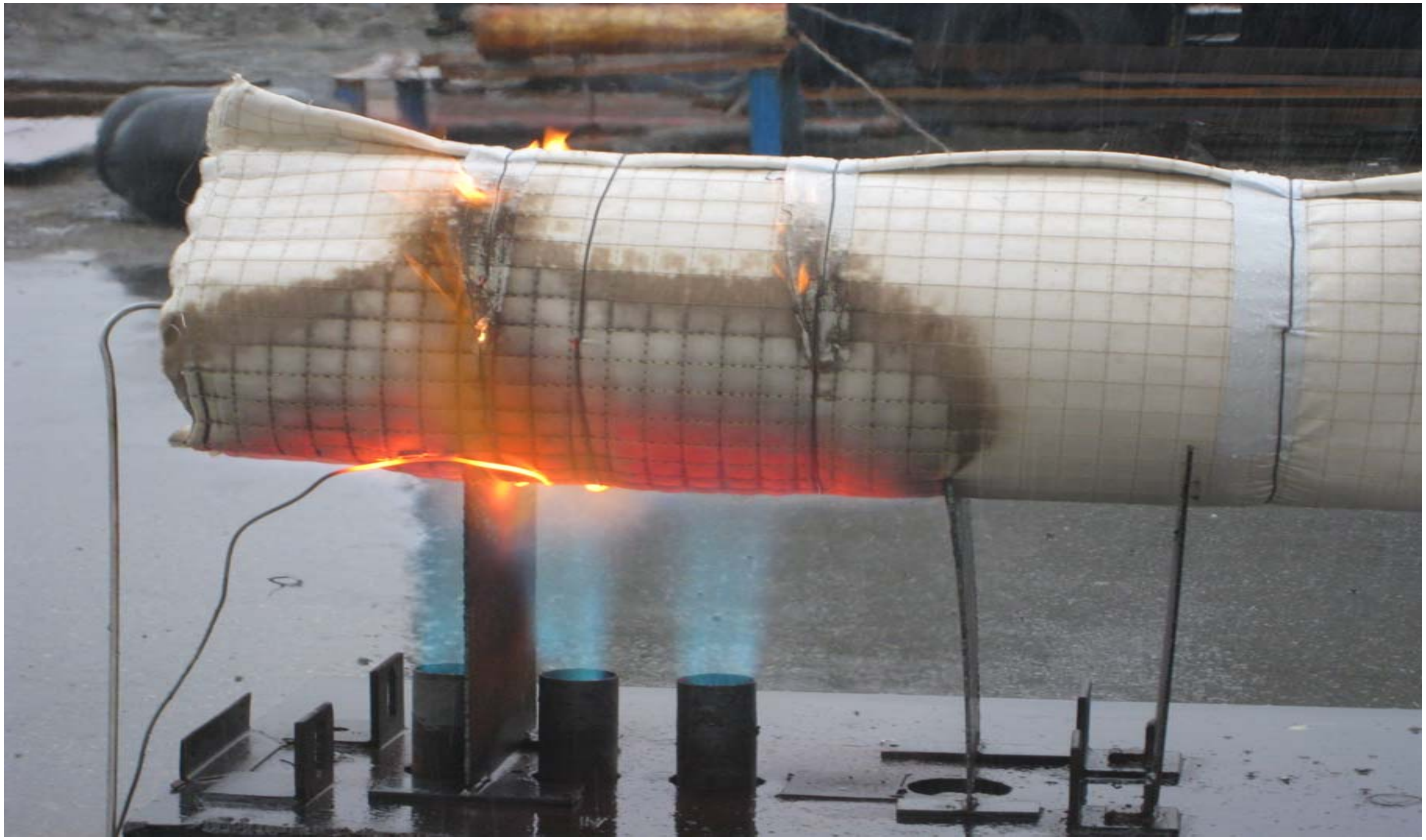
- Did screening tests involving tanks (held at low pressure) at 900ºC – 1000ºC for 5 - 10 minutes
  - Compared performance to baseline test on uncoated tanks

- Promising materials then tested at full pressure at 900ºC – 1,000ºC for 30 minutes or until venting

- Evaluated the fire performance of the following:
  - Intumescent paints (on steel tank)
  - Intumescent coating (on carbon fiber tanks)
  - Insulating wraps (on carbon fiber tanks)
  - Heat detection systems (on carbon fiber tanks)

Intumescent Paint Coating on Carbon Fiber Composite Tank

Testing of Thermal Blanket Material –

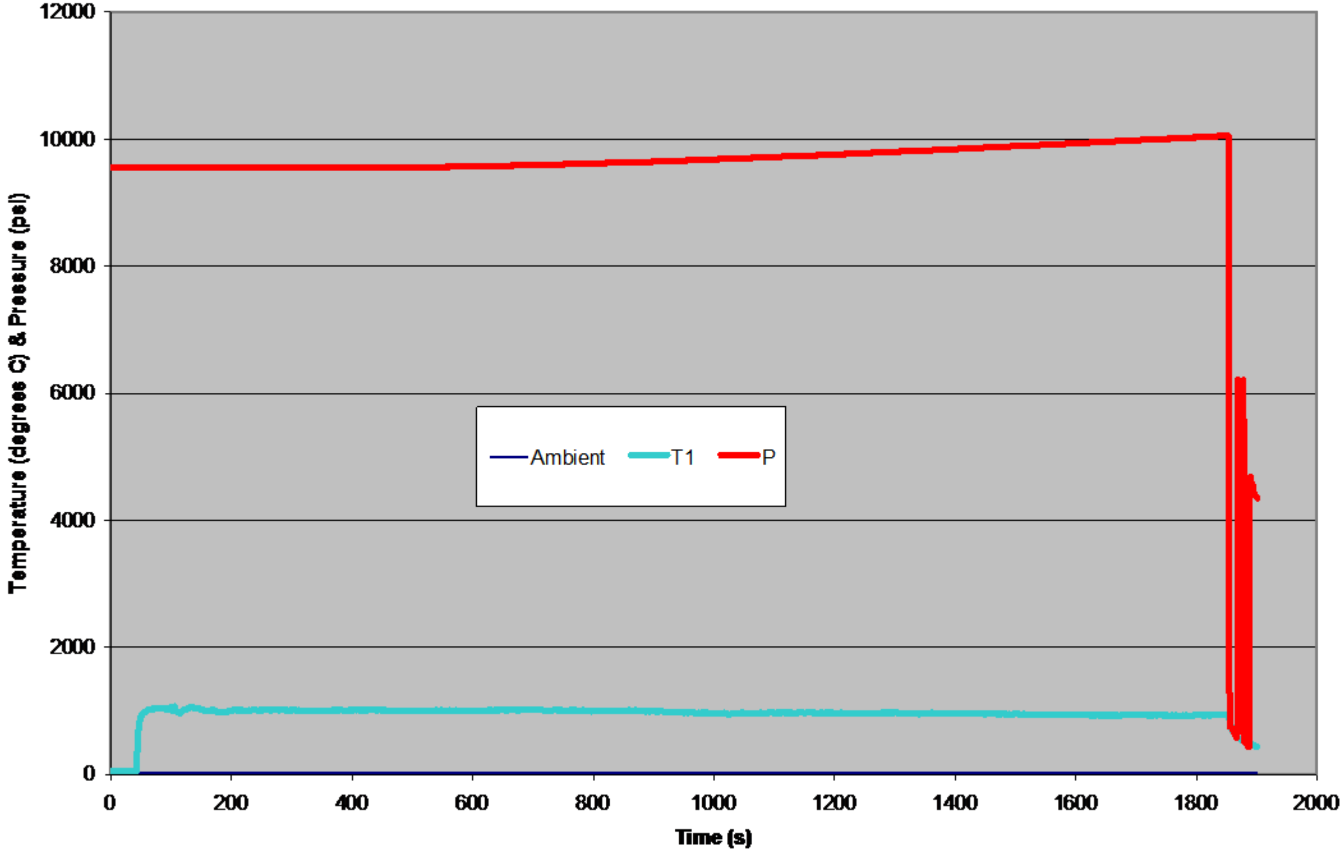


Sensing Technologies - Mechanical Activation Tube

Shape Memory Alloy (SMA) contracts, activating piston in PRD

Quantum Tank – Stainless Steel Shell

Quantum Carbon Fiber Composite Tank with Metal Shell – 30 min @ >900 C



Localized Fire Test Program - Conclusions

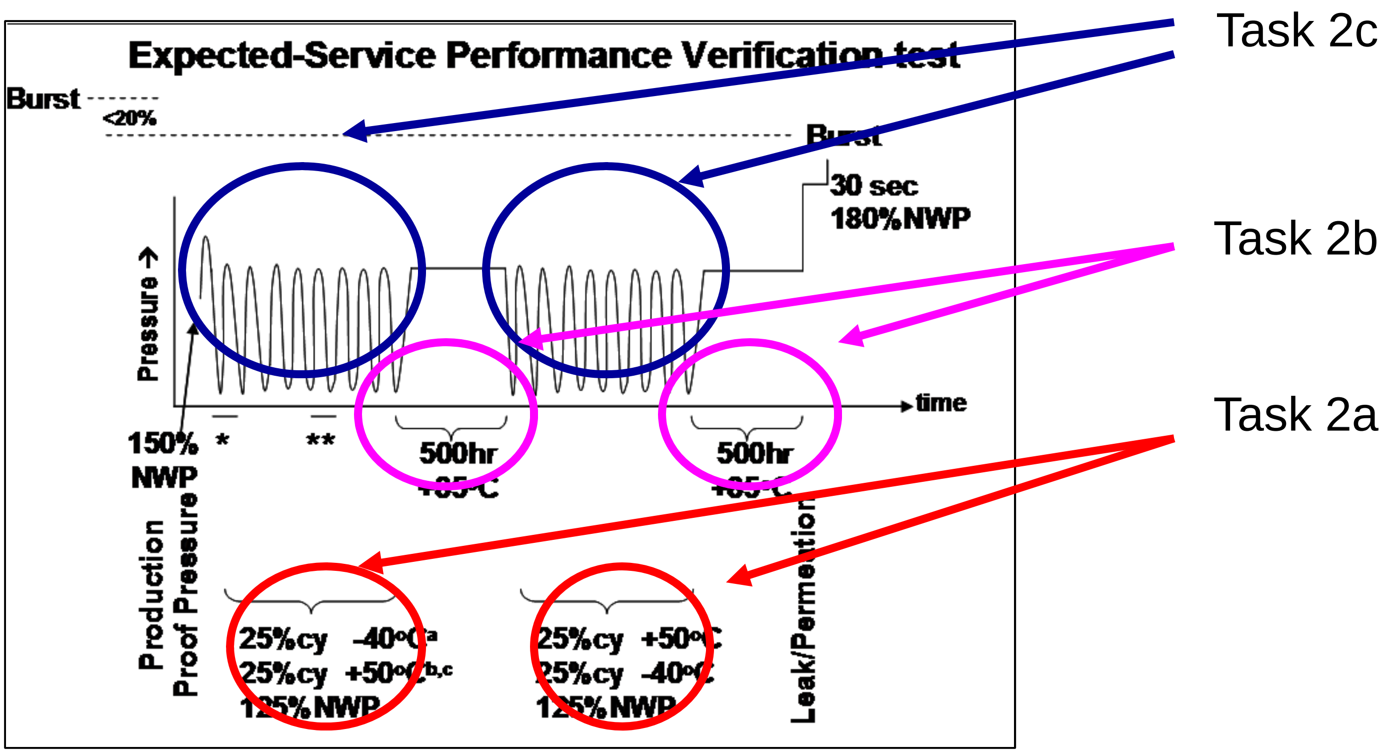
- Localized fire test procedure can be used to detect insufficient protections
- There are protective coating and wrap systems that work
- There are remote fire detection systems that work
- Test would be beneficial to CNG fuel systems as well

2. Cumulative cylinder life cycle testing

- Generate simulated real-world life cycle data which is lacking
  - SAE TIR 2579 specifies expected service and durability test procedures. (pneumatic gas cycling, parking, extreme temperature, flaw, chemical tolerance, burst)
  - Japan considering similar requirements in new standard, JARI 001 upgrade.
- Research Task:
  - Conduct life cycle testing on representative hydrogen storage systems, vary test conditions to represent different service conditions
- Possible Outcome:
  - Requirement for pneumatic rather than hydraulic pressure cycling test (FMVSS No. 304)
  - Requirement for post pressure-cycle burst strength

Test matrix evaluates test temperatures, cycling count, parking performance

- What number of cycles simulates full service life?
- Are any observed failures realistic of service conditions?
- What temperature conditions are reasonable without inducing unrealistic failures?



3. Comparative assessment of fueling options for crash testing

- Fueling options advocated by industry
  - High pressure hydrogen (SAE)
  - High pressure helium (SAE, Japan)
  - Low pressure hydrogen (SAE, GM)

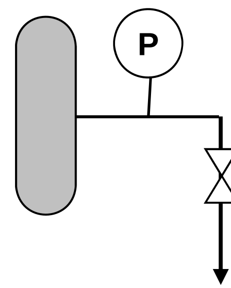
- Research task:
  - Conduct testing to compare container vulnerability to impact at high and low pressure fill
  - Conduct leakage tests using hydrogen and helium at high to low pressure fill for a range of cylinder sizes

- Possible Outcome:
  - Selection of most appropriate fill option for assessing pass/fail leakage and fuel system vulnerability per FMVSS crash conditions

Technical Approach

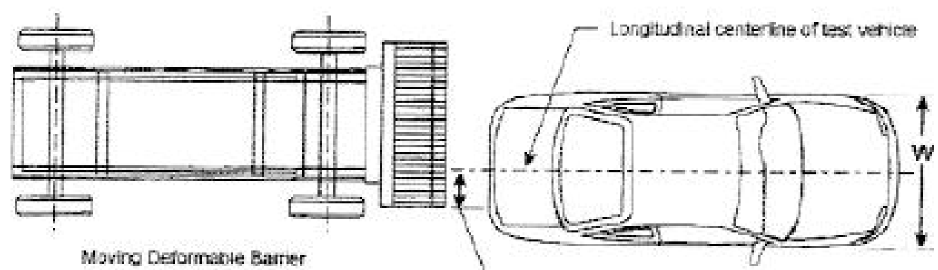
- **Task 3a: Drop weight impact tests**
  - **Various internal pressures,**
  - **Container wall thicknesses (by service pressure),**
  - **Impact orientation (simulated front, rear, and side crashes)**

  To find the most vulnerable conditions.



- **Task 3b: Simulated Leak and pressure drop**
  - **Pressure drop rate vs. mass flow rate**
  - **Hydrogen and helium**

  To specify pass/fail criteria



- **Task 3c: Full Scale Vehicle Crashes**
  - **Forward, side, and rear crashes**
  - **Retrofit CNG vehicles with hydrogen containers**

  conduct NHTSA front, side and rear, crash tests to verify tasks 3a and 3b

4. Post-Crash Hydrogen Leakage Limits/Fire Safety Research

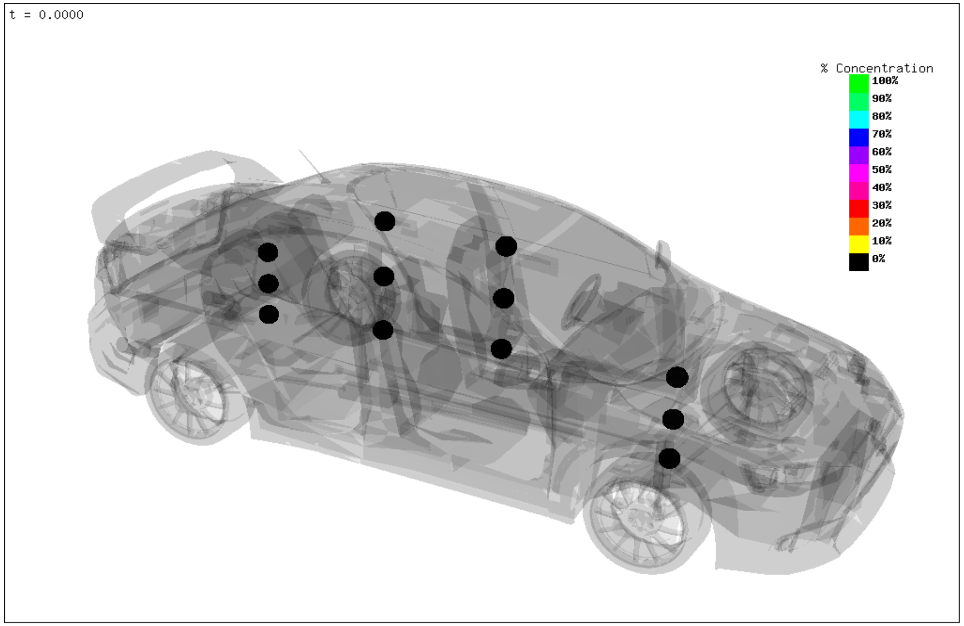
- Research Task:
  - Conduct testing to verify the fire safety of proposed pass/fail hydrogen leakage limits
  - Determine hydrogen concentrations in vehicles as a function of leakage rate, test ignition of hydrogen at fixed concentration levels, conduct ignition tests in uncrashed and crashed vehicles.
- Outcome:
  - Confirmation of the fire safety of proposed leakage limits (118 – 130 NL/min), which are currently based on the thermal energy equivalent to gasoline

Technical Approach

- Conduct analysis and experiments to characterize:
  - Accumulation of combustible mixture of H2 in engine, passenger, and trunk compartments resulting from a H2 fuel system leak;
  - Heat flux and overpressure of different mixtures of H2 burning in air at concentration levels ranging from:
    - Lower flammability limit: 4%;
    - Stoichiometric ratio: 30%; and
    - Upper flammability limit: 75%
  - Combustion threats to humans from heat flux and overpressure resulting from H2 ignition and combustion.

Task 4a: Conduct Leak Rate vs. H_2 Concentration Tests on Intact Automobiles

- H_2 sampling locations:
  - 3 sensors in engine compartment;
  - 3 each in front and back of passenger compartment;
  - 3 in trunk compartment.
  - Positioned @ 10%, 50% & 90% of vertical dimension in compartment



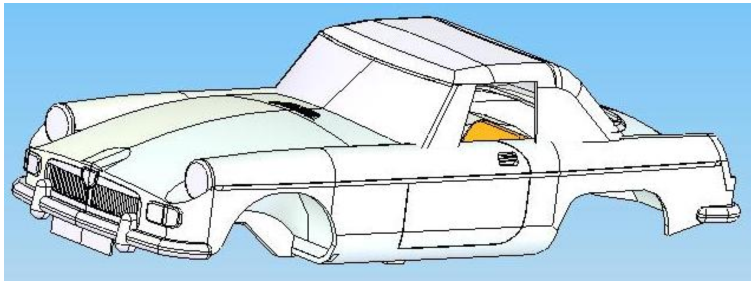
Task 4a (Cont.)

- Six leak locations
  - Four originating directly from H2 tank
  - Straight up, straight down, 45° forward and backwards (reflected off pavement along auto centerline)
  - One directly into the passenger compartment
  - One directly into the trunk compartment

- Determine safe-minimum and safe-maximum leak rates that avoid atmosphere becoming flammable:
  - 118 and 131 L/min baselines; iterate by halving and doubling to reach min/max

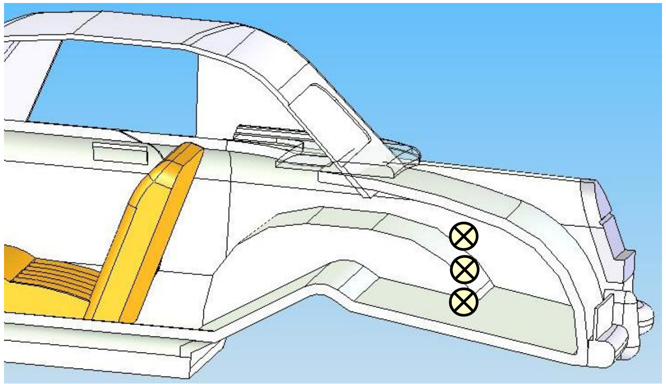
Task 4b: Conduct Ignition and Combustion Tests on Simulated Automobile Compartments

- 3 clear-plastic compartments approximating:
  - - engine, passenger, trunk geometries and volumes
  - - H_2 sensor locations same as Task 4a



- Leak rates/concentrations from Task 4a
  - - 3 ignition times
    - at stoichiometric and lowest and highest obtainable concentrations
  - - 3 igniter locations
    - 10%, 50%, 90% vertical height
  - - 1 pressure and 1 heat flux sensor at a minimum

⊗ = igniter locations (10%, 50%, 90%)



- Data sought:
  - Severity of overpressure and thermal threats posed by combustion

Task 4c: Conduct Full-Scale Leak, Ignition and Fire Tests on Intact and Crashed Automobiles

- 1 intact and 3 crashed automobiles (from NHTSA's compliance test program)
- For each vehicle: 3 leak locations, one each directly into engine, passenger and trunk compartment
- Leak rates from Task 4a
- 3 ignition times at stoichiometric and lowest and highest obtainable concentrations
- 3 igniter locations 10%, 50%, 90% vertical height
- Paired pressure and heat flux sensor suite locations:
  - Front and back seat; chest and head levels
  - Engine and trunk compartment
  - Outside automobile: front, back, and sides
- Data sought: Severity of overpressure and thermal threats posed by combustion

FY 2010 Plans

- As of September 2009, all tasks fully funded
- Most tasks will be completed in 2011
- Opportunity to conduct additional crash tests of OEM HFCV's in 2010, dependent upon additional funding
- Initiating research to assess aging issues in CNG vehicles (refueling rupture, fire exposure)
- Initiating research to assess li-ion battery safety

Hydrogen Fueled Vehicle Global Technical Regulation

Nha Nguyen

Office of International Policy and Harmonization

Harmonization of Vehicle Regulations

- NHTSA participates in international harmonization activities under the United Nations World Forum for the Harmonization of Vehicle Regulations (WP.29) and the 1998 Global Agreement
  - 30 contracting parties, including: Canada, China, the EC, India, Japan, and South Africa.
  - International development of Global Technical Regulations (GTRs) under the Agreement is guided by three governing principles:
    - Data-driven & science-based
    - Performance-based
    - Transparent

Hydrogen Fueled Vehicle Global Technical Regulation (GTR)

- Develop in 2 phases:
  - Phase 1 (2011): Develop a performance-based GTR based on a component level, subsystems, and whole vehicle crash test approach. For crash testing, each contracting party will maintain its existing national crash tests but GTR will set a maximum allowable level of hydrogen leakage.
  - Phase 2: Assess future technologies and discuss how to harmonize crash test requirements for HFV regarding whole vehicle crash testing.

GTR - Phase 1

- Fuel Storage system (70% completion)
  - Material qualification
  - Hydraulic and pneumatic cycling testing
  - Storage system production qualification
- Fuel system (80% completion)
  - In-use: fuel leakage mitigation
  - post crash: maximum allowable leakage limit
- Electrical Safety (50% completion)
  - In-use and post crash

Thank you!

- Questions?