NHTSA's Hydrogen Fuel Cell Vehicle Safety Research Program

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Outline

- Hydrogen - FMVSS XXX?
- Global Technical Regulation Action Plan
- Safety Issues
- Alternative Approaches
- Research/Rulemaking Goals
- Research Tasks

GTR Action Plan

ECE/TRANS/WP.29/2007/41 (April 2007)

- Objective
  - Develop a global technical regulation for hydrogen/fuel cells
  - Attain equivalent levels of safety to conventional gasoline vehicles
  - Performance based and does not restrict future technologies
- Content:
  - Performance requirements for fuel containers
  - Electrical isolation
  - Maximum allowable hydrogen leakage

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

Alternate approaches to address fuel system crashworthiness

Hydrogen leakage limits based on FMVSS 303

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

Electrical integrity of high voltage fuel cell propulsion system

- Active fuel cell with hydrogen onboard vs.
- Inactive fuel cell, system “off”

High pressure container safety

- Cumulative life cycle and extreme use durability (SAE) vs. discrete testing
- Localized flame impingement test vs. engulfing bonfire

Issues Associated with Each Fueling Approach for Crash Testing

- High pressure hydrogen
  - + Electrical system is operational
  - + Worse case for leak rate
  - - Poses additional fire hazard in case of rupture or rapid release of hydrogen
- High pressure helium
  - + Consistent with FMVSS Nos. 301, 303
  - + Non-flammable
  - - Surrogate leak rate is slightly different
  - - Electrical system *is not* operational
- Low pressure hydrogen option
  - + Electrical system operational
  - - Must scale up leak rate to represent worse case at high pressure
  - +/- Cylinders more vulnerable to impact at low pressure

Research/Rulemaking goals

- Conduct research to assess all proposed alternatives
  - Confirm that selected alternative detects potential failure
- Prescribe additional requirements if results indicate safety need, e.g.:
  - Localized flame impingement test replaces bonfire test for hydrogen containers
  - Extend post-crash leakage measurement beyond 60 minutes to adjust for reduced flow rate of helium through same sized orifice

2009 - Research Tasks to Support Rulemaking/GTR Objectives

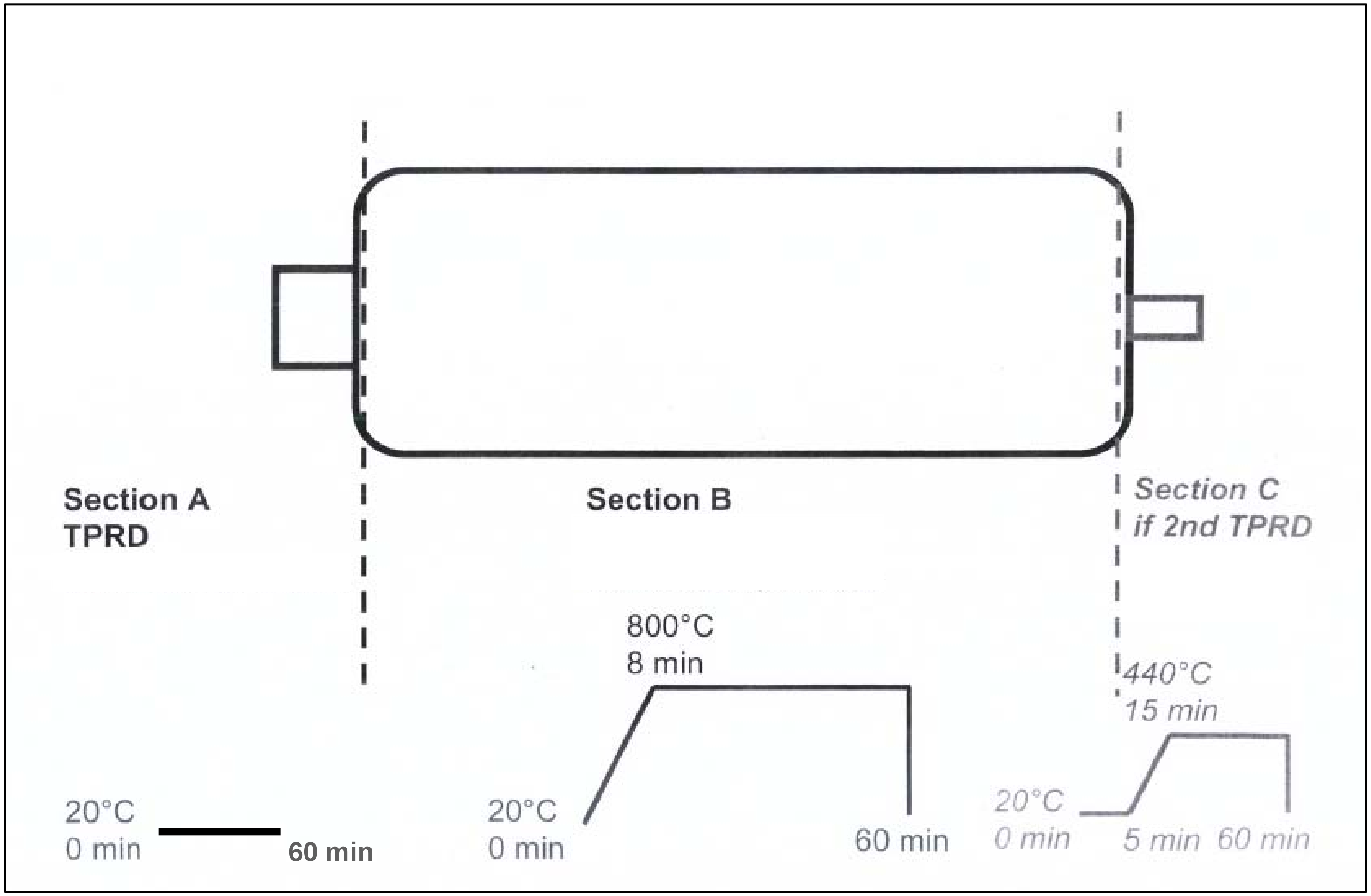
- 1. Localized fire testing - flame impingement on hydrogen storage cylinders
- 2. Cumulative cylinder life cycle testing
- 3. Comparative assessment of fueling options for crash testing
- 4. Fire safety of proposed leakage limits
- 5. Electrical isolation testing in the absence of hydrogen

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 test temp/time profile

- (vs. FMVSS 304, engulfing bonfire 430° C – vent or survive 20 minutes)



NHTSA follow-on study objectives

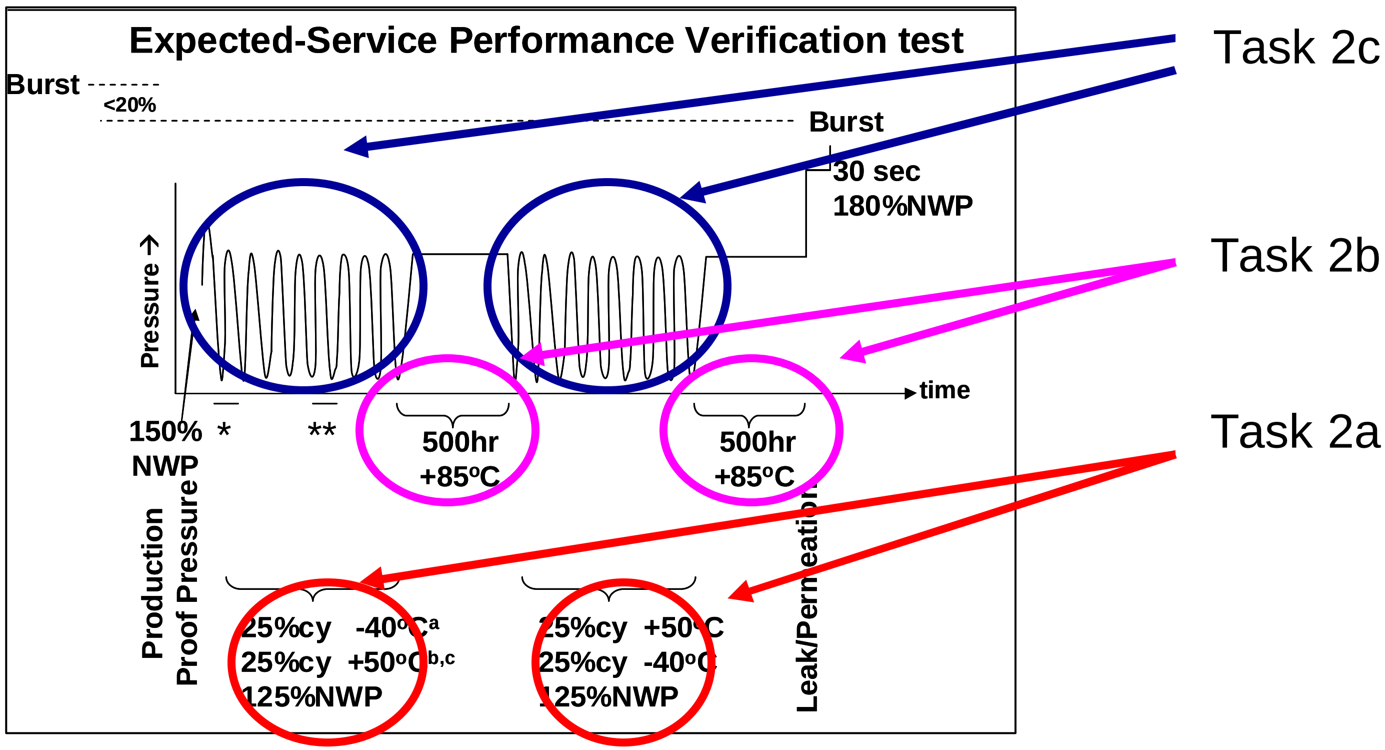
- DOT-NHTSA contract to continue localized fire studies
- Objectives:
  - Evaluate fire resistance of various coatings and insulating materials (includes testing on pressurized tanks)
  - Evaluate the use of remote heat sensing technologies to activate PRDs
  - Perform localized fire tests on tanks from an OEM fuel system currently protected using a proprietary insulating coating
  - Provide recommendations for standards regarding fire test requirements

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)

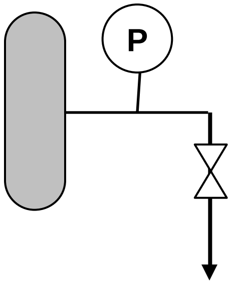
- Research task:
  - Conduct testing to compare container vulnerability to impact at high and low pressure fill
  - Conduct leakage tests using hydrogen and helium at high to low pressure fill for a range of cylinder sizes

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

Technical Approach

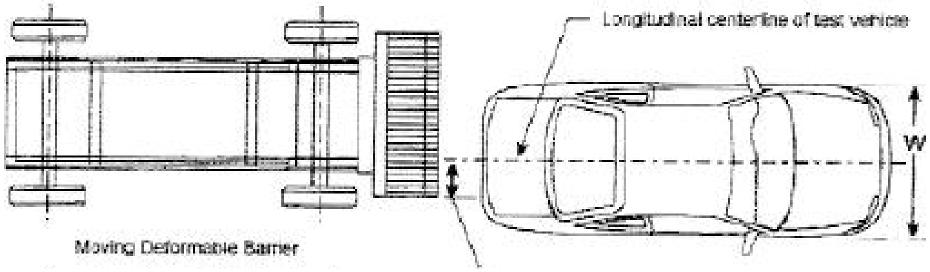
- **Task 3a: Drop weight impact tests**
  - **Various internal pressures,**
  - **Container wall thicknesses (by service pressure),**
  - **Impact orientation (simulated front, rear, and side crashes)**

  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%
  - Assess 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:

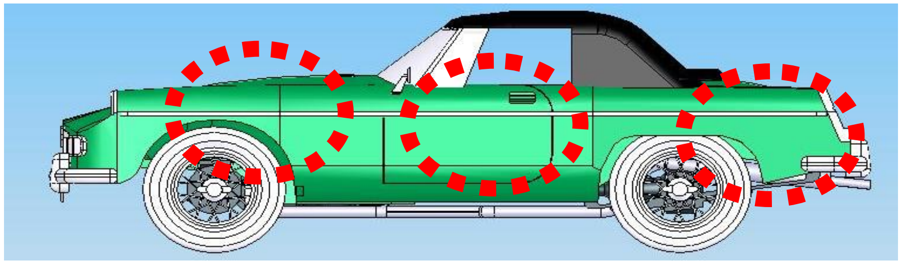
  3 sensors in engine compartment;

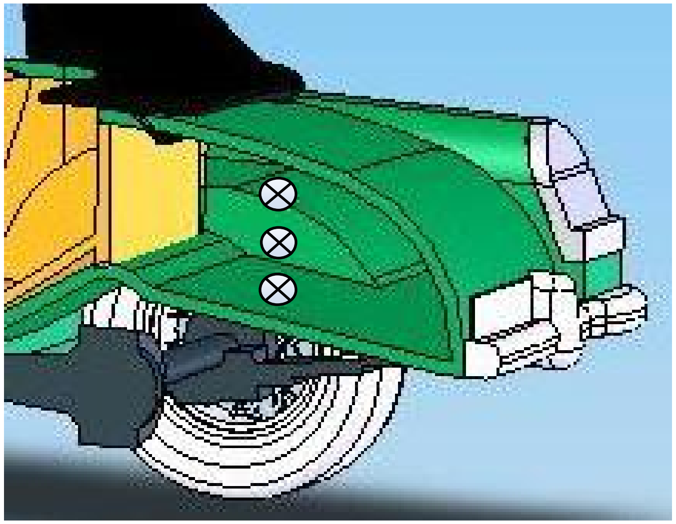
  3 each in front and back of passenger compartment;

  3 in trunk compartment.

  - Positioned @ 10%, 50% & 90% of vertical dimension in compartment

⊗ = sensor locations (10%, 50%, 90%)





Task 4a (Cont.)

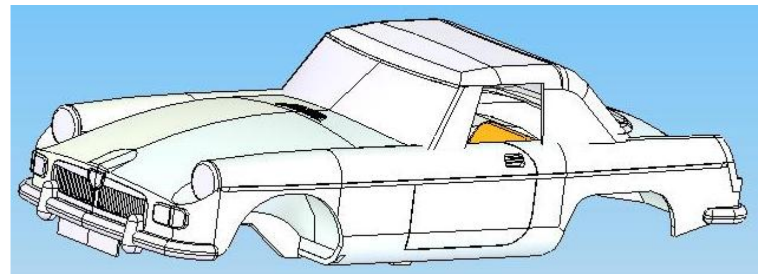
- Six leak locations
  - Four originating directly from H2 tank
  - Straight up, straight down, 45° forward and backwards (reflected off pavement along auto centerline)
  - One directly into the passenger compartment
  - One directly into the trunk compartment

- 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

- Measurement duration:
  - Time to maximum H2 concentration steady-state or depletion of H2 supply (full tank storage volume)
  - Time to return to minimum H2 concentration steady-state

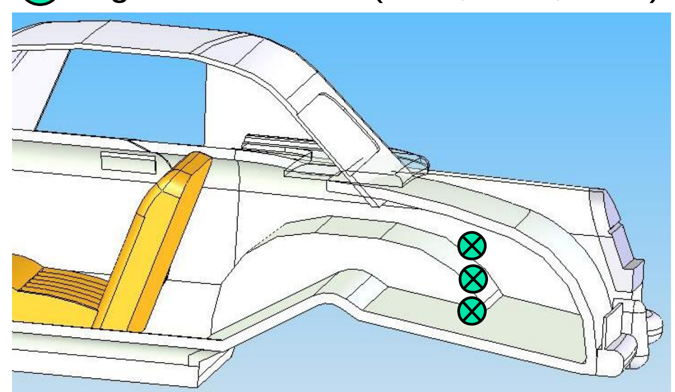
Task 4b: Conduct Ignition and Combustion Tests on Simulated Automobile Compartments

- 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

5. Electrical isolation testing in the absence of hydrogen

- Fuel cell produces no voltage when crash test is conducted using helium surrogate
  - NPRM FMVSS 305 sets electrical isolation limits for high voltage sources (batteries and fuel cells) post-crash, but does not specify test procedure for testing isolation of the high voltage fuel cell system in a deactivated state
  - SAE 2578 - Measure isolation by applying test voltage from an external source (megohmmeter)
- Research Task:
  - Conduct isolation testing with no hydrogen present, using megohmmeter
- Possible Outcome:
  - Confirm that testing can be conducted with the megohmmeter, without inducing damage to the vehicle propulsion circuit

Electrical Isolation Test Procedure Development and Verification

- In cooperation with two HFCV manufacturers:
  - Conduct research utilizing OEM vehicles to determine whether electrical isolation testing using a megohmmeter (megger) is feasible when crash testing HFCVs with high pressure helium on board and the fuel cell in a stopped state.
  - Produce and validate an electrical isolation test procedure utilizing a megger that includes recommended test points and safety precautions.

Other Recent Related Activities

- FMEA of compressed hydrogen vehicle
  - Used this study to identify and rank the hazards addressed in this research effort
- Comparative assessment of post-crash electrical isolation testing options for HFCV's
  - Low pressure or offboard hydrogen source, 4% hydrogen in helium, megger
- Assessment of recent published research regarding HFCV fuel system integrity
  - Using this study to identify gaps and/or redundancy in research areas
- Destructive testing of type 3 and 4 Hydrogen storage cylinders (SwRI)

Thank you!

- Questions?