HYDROGEN
Safety Resources

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Hydrogen Vehicle Tunnel Safety

Dr. Chris LaFleur, PE

Sandia National Laboratories
Codes and Standards Program Manager
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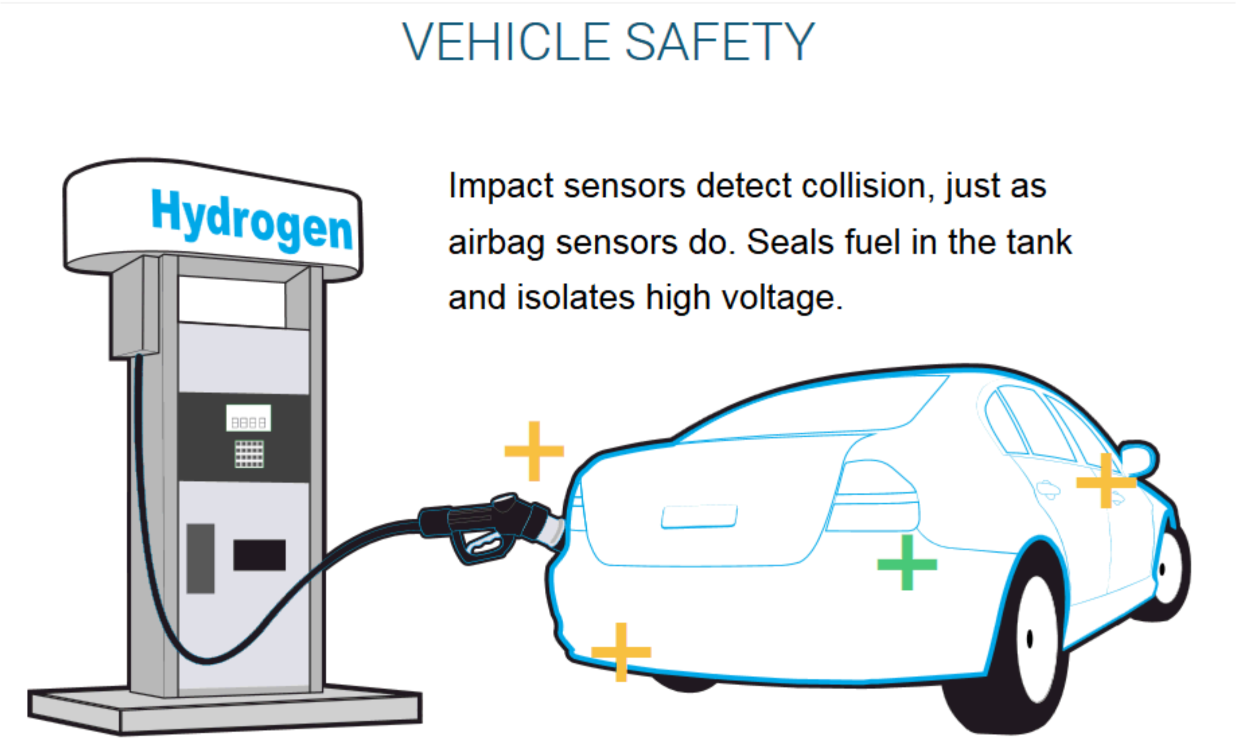
Outline

- Safety Issues Unique to Hydrogen FCEVs
  - High Voltage
  - Hydrogen Storage
  - Crash Safety
  - Tunnel Safety

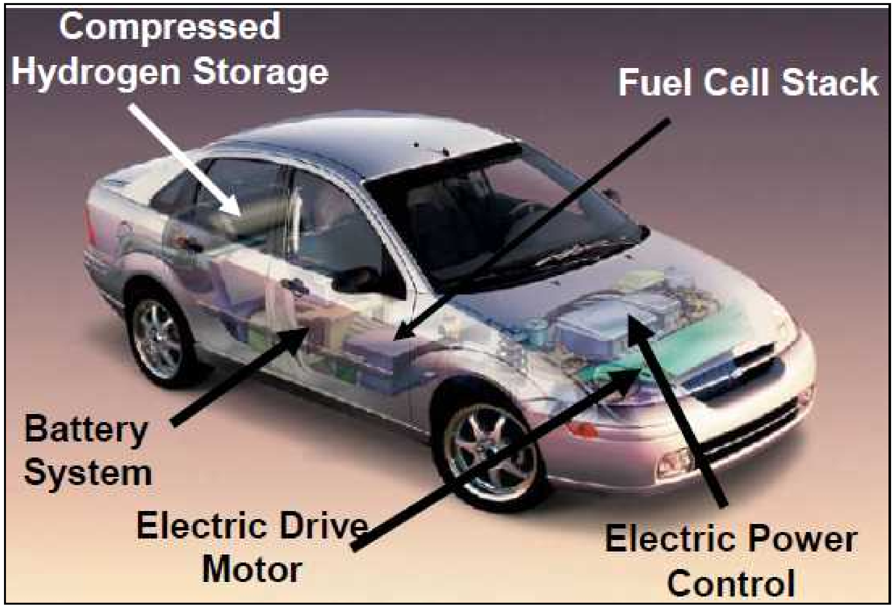


http://cafcp.org/cars#cars_safety

Fuel Cell Electric Vehicles (FCEVs)

Safety Issues Unique to Hydrogen FCEVs

- High Voltage Fuel Cell System
- Hydrogen Storage



Adapted from "Hydrogen Fuel Cell Vehicles – Overview of Safety Strategies", University of Ulster. International Short Course Series, May 2009. Sloane Solutions

High Voltage Vehicle Safety

- Fuel cell vehicle high-voltage systems are similar but not identical to hybrid and battery-electric vehicle systems
  - The fuel cell stack coolant loop is one key differentiator

Electrical Safety Strategy for EVs, HEVs & FCEVs

1. Insulation of high voltage parts
2. High voltage buses isolated from vehicle chassis
3. Fault tolerance
4. Post-crash electrical safety

Standards for High Voltage Vehicle Safety

SAE 1766	EV and HEV crash integrity testing
SAE J2578	General fuel cell vehicle safety
SAE J2344	EV and HEV crash integrity testing
ISO 6469-3	EV electrical safety
ISO 23273-3	FCV electrical safety

- Impact sensors de-activate high voltage

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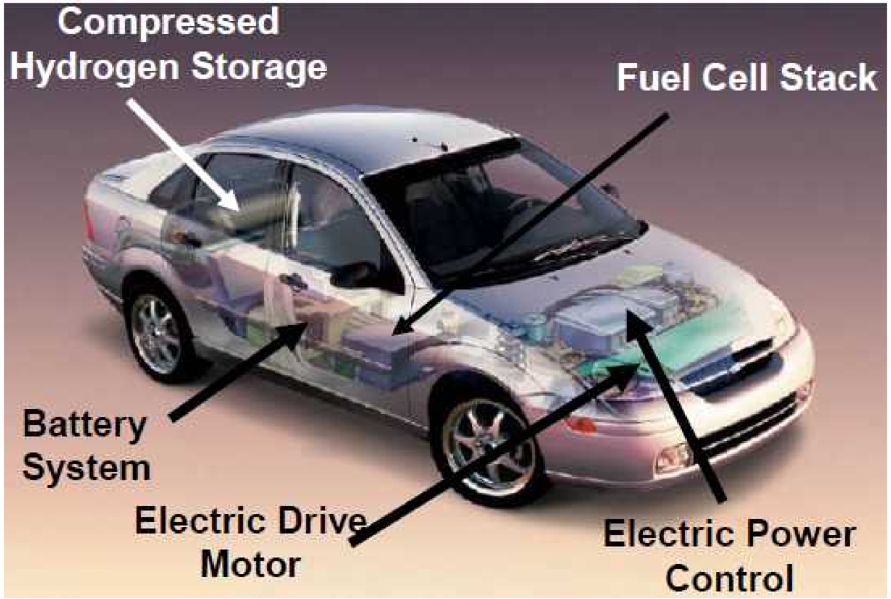


Crash Safety Requirement: Fuel Leakage Limit

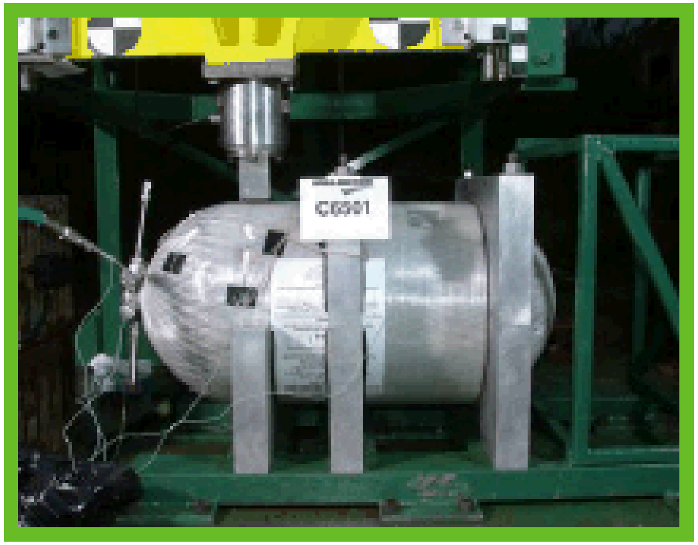
GTR 13 – International requirement limiting the amount of fuel allowed to leak in the 60 minutes after a vehicle crash

- Criterion based on the equivalent release of combustible energy as allowed by gasoline vehicles
- Equivalent energy contents:
  - 30 g/min gasoline leakage
  - 10.7 g/min hydrogen leakage
- In volumetric terms at normal temperature and pressure, the allowable hydrogen flow leakage is 118 NL/min.
- Ignition tests of hydrogen leaks ranging from 131 NL/min up to 1000 NL/min showed that the heat flux was not enough to damage the under floor area of the vehicle, release the vehicle hood, or injure a person standing 1 m from the vehicle

Crash Simulations & Testing

Component Simulation & Testing

Vehicle Simulation & Testing



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Component Simulation & Testing

Direct Safety

- On Tank
  - Main Shutoff Valve
  - Thermal Pressure Relief
  - Redundant Shutoff Valve
- Leak Detection

Indirect Safety

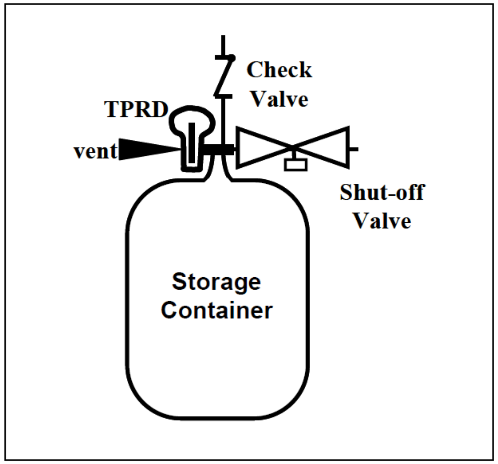
- Fuel Line Pressure Relief
- Protection Check Valves
- Defueling Orifice

Passive Safety

- Storage System Performance Verification
- Localized Fire Protection
- Crash Protection
- Fueling Check Valve

Standards for Components

- SAE J2579 – Fuel Systems in FC and other Hydrogen Vehicles
- ISO 15869 – Gaseous Hydrogen Land Vehicle Fuel Tanks
- UN-GTR 13 – Hydrogen and Fuel Cell Vehicles
- FMVSS 304 – CNG Fuel Container Integrity



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Component Simulation & Testing

GTR 13 provides the following performance qualification test requirements for:

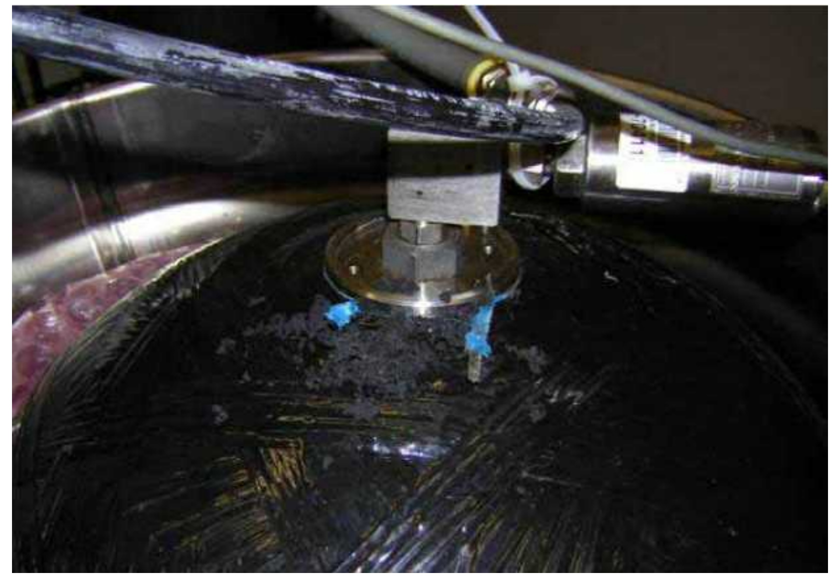
- Baseline metrics
- Performance durability
- Expected on-road performance
- Service terminating performance in fire
- Closure durability

Verification Tests for Baseline Metrics

Initial Burst Pressure

FMVSS 304 Hydrogen Cylinders Following Burst Pressure Test

Initial Pressure Cycle Life



FMVSS 304 Pressure Cycle Test

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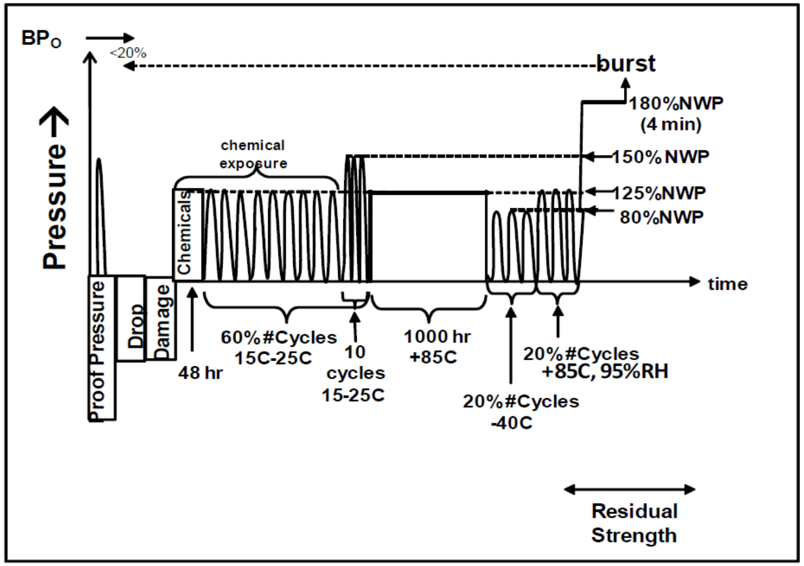
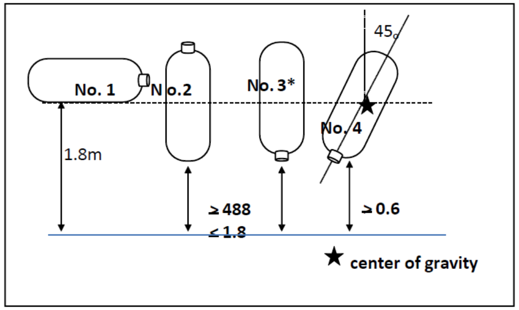
Verification Test for Performance Durability



GTR 13 Verification Test for Performance Durability



- Tests are applied **in series** to a single system
- Harsh Conditions
    - Proof Pressure Test
    - Drop (Impact) Test
    - Surface Damage Test
    - Chemical Exposure
    - High Temperature Static Pressure Test
    - Extreme Temperature Pressure Cycling
    - Residual Proof Pressure Test
    - Residual Strength Burst Test

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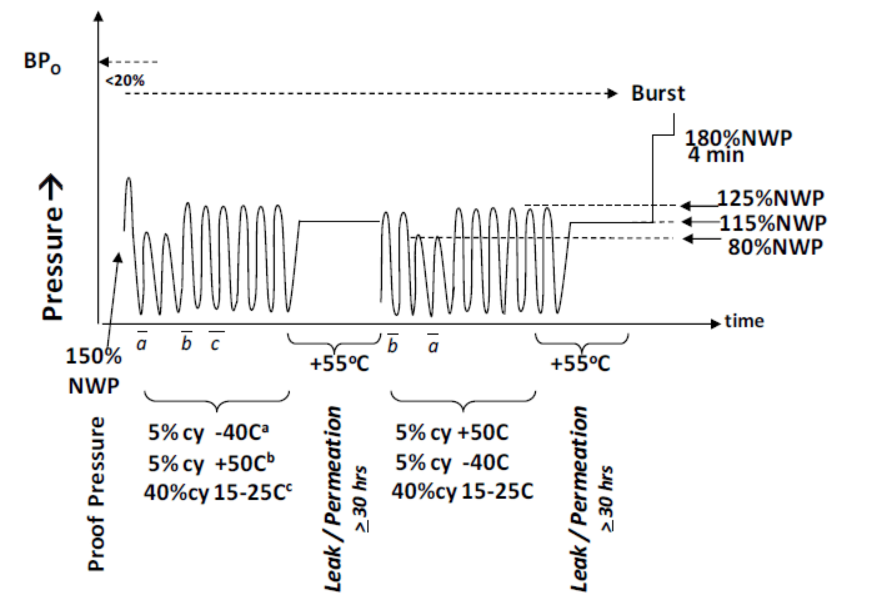
Verification Test for Expected On-Road Performance

- Tests are applied **in series** to a single system
- Harsh Conditions
  - Proof pressure test
  - Ambient and extreme temperature gas pressure cycling test
  - Extreme temperature static gas pressure leak test
  - Residual proof pressure test
  - Residual strength burst test



a Fuel/defuel cycles @-40°C with initial system equilibration @ -40°C, 5 cycles with +20°C fuel; 5 cycles with <-35°C fuel
b Fuel/defuel cycles @+50°C with initial system equilibration @+50°C, 5 cycles with <-35°C fuel
c Fuel/defuel cycles @15-25°C with service (maintenance) defuelrate, 50 cycles

GTR 13 Verification Test for Expected On-Road Performance

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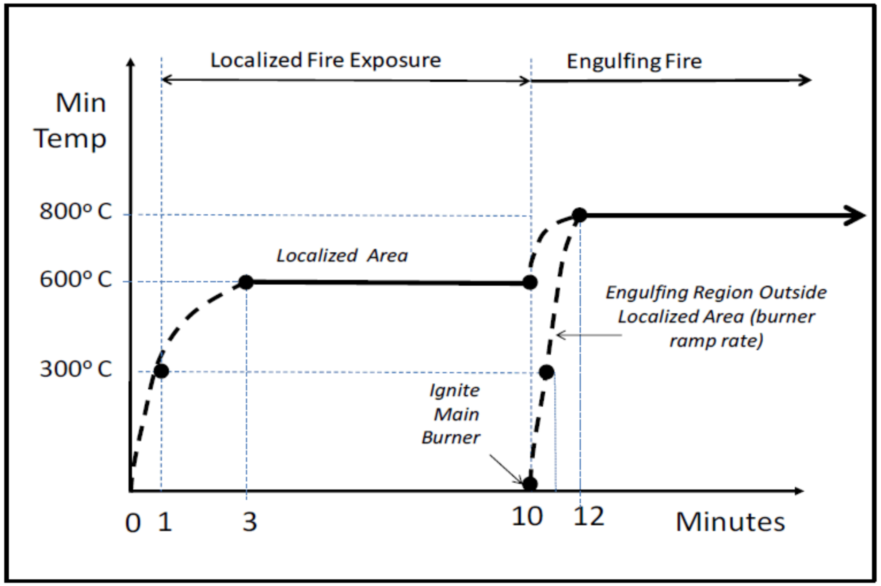
Verification Test for Service Terminating Performance in Fire



Temperature Profile of GTR 13 Fire Test

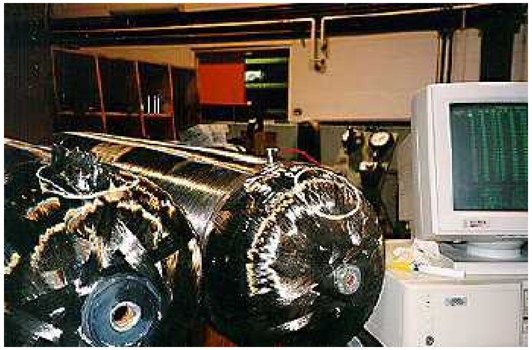
FMVSS 304 Hydrogen Cylinder Bonfire Test

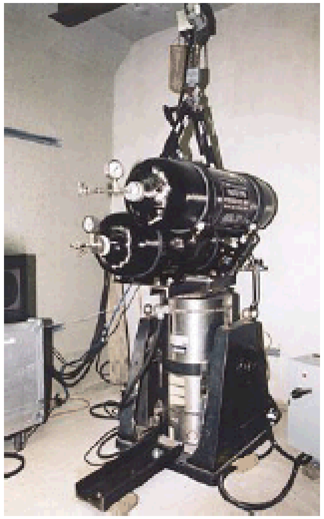
Adapted from "Hydrogen Fuel Cell Vehicles – Overview of Safety Strategies", University of Ulster. International Short Course Series, May 2009. Sloane Solutions

Verification Test for Closure Durability

TPRD Requirements

- Pressure cycling
- Accelerated life
- Temperature cycling
- Salt corrosion resistance
- Vehicle environment
- Stress corrosion
- Drop and vibration test
- Leak test
- Bench top activation test
- Flow rate test





Check Valve and Automatic Shut-off Valve Qualification Requirements

- Hydrostatic strength
- Leak
- Extreme temperature pressure cycling
- Salt corrosion
- Vehicle environment
- Atmospheric exposure
- Electrical
- Vibration
- Stress corrosion cracking
- Pre-cooled hydrogen exposure

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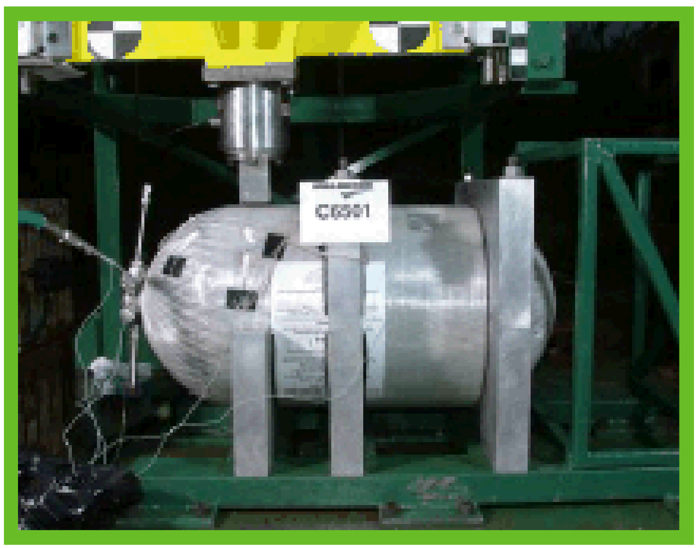
Crash Simulations & Testing

Component Simulation & Testing → Vehicle Simulation & Testing



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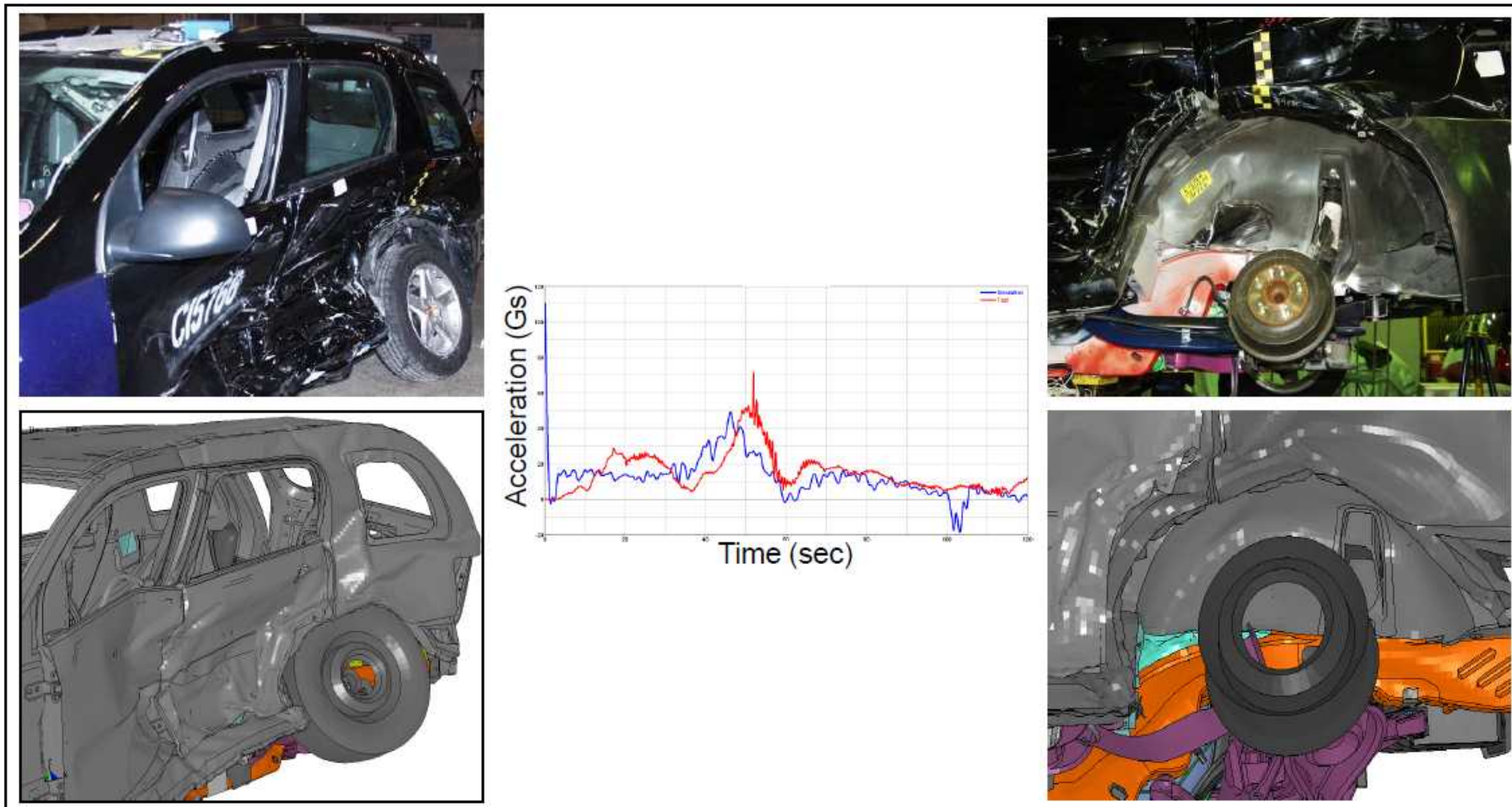
Prototype Vehicle Simulation & Testing

FCEV Crashworthiness – FMVSS 208 Barrier Test

FCEV Crashworthiness- Car to Car Impact

50 mph Angle Car to Car Impact- Confirmation of Crash Simulations with Crash Testing



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Tunnel-Specific Requirements (NFPA 502)

- Tunnel structural performance is required to withstand a fire temperature exposure defined by the RWS curve
- Credible hydrogen release scenarios can be compared to this curve

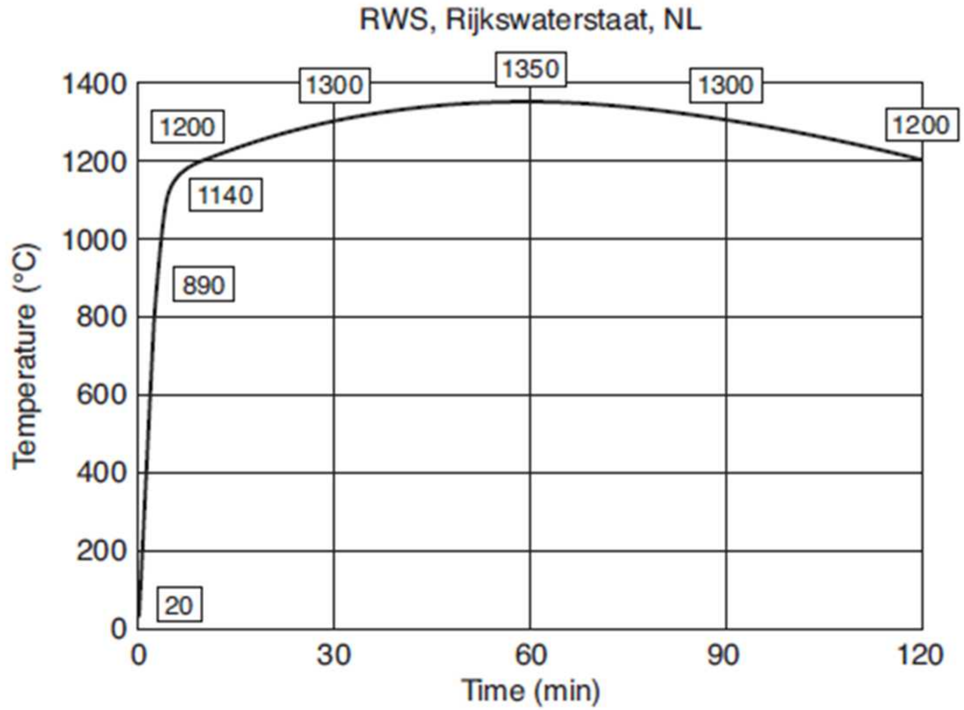

FIGURE A.7.3.2(a) RWS Time–Temperature Curve.

Risk Analysis Basis

What Can Happen?	How Likely is it?	What are the Consequences?	Notes
A FCEV is involved in a crash in a tunnel	This will change over time as more FCEVs are on the road, but because we want to examine this risk, we assume this will happen	Various crash scenarios ranging from no damage to severe	The tank is expected to survive intact, holding pressure and without leaking.
Crash resulting in an external fire	Highway data exists to quantify this likelihood	External fire could cause TPRD to vent hydrogen. The ignited venting hydrogen would create a 2 MW jet fire lasting 5 minutes for a full 5 kg tank. The GTR requires this weakly radiating jet fire be pointed at the ground.	NFPA 502 requires tunnels withstand the RWS (Rijkswaterstaat) time-temperature curve exposure of 120 minutes with no collapse and no spalling. Also NFPA 502 provides specific temperature exposure limits for structural members.
Crash significant enough to result in a hydrogen release	FMVSS 301 and 303 provide crash test requirements to evaluate crashworthiness of vehicles. GTR #13 provides test requirements for the pressure tanks surpassing those described in FMVSS No. 304 for CNG.	A fuel line break is most likely. This is downstream of the pressure regulator, limiting released hydrogen to <100 psi. Tanks are expected to survive intact, and hold pressure post-crash	The storage system will detect leaks from fuel line and activate a solenoid to shut down the leak almost immediately, resulting in a very small quantity of hydrogen released. NHTSA Reports: DOT-HS-812-112 Crashworthiness Research of Prototype Hydrogen Fuel Cell Vehicles 2015 and DOT-HS-811-150 Compressed Hydrogen Cylinder Research and testing in Accordance with FMVSS 304 2009.
Released hydrogen could be diluted by tunnel ventilation	Larger ventilation capacities increase this likelihood.	No ignition of hydrogen due to dilution below the flammable limit.	Existing tunnel ventilation rates and solenoid shut off valve response times are known.
Released hydrogen could ignite immediately	TPRD vented hydrogen into a fire will ignite immediately. Note: a TPRD will only release when engulfed in a fire.	A jet fire from the fuel line break or vent tube which is aimed at the ground. This will create a 2 MW flame with low radiating energy lasting ~5 min. for a 5 kg tank.	Hydrogen jet fire models are available and can be compared to RWS time-temp curve
Released hydrogen could have delayed ignition	This is a function of the size of the flammable range of hydrogen released and distance to possible ignition sources	The consequence depends on the amount of hydrogen released and ventilation rate of tunnel which acts to dilute the concentration of hydrogen	Computer simulations and CFD models can be run. However, the credibility of this scenario is very limited given the robust tank and vehicle crashworthiness requirements noted.

University of Sheffield Study

Assessment of the impact of jet flame hazard from hydrogen cars in road tunnels was published in 2008

- Prior to the GTR requirements limiting post-crash hydrogen release rates
  - Jet flames of 0.05 kg/s and 0.25 kg/s for 60 sec and 12 sec duration were calculated as 6 MW and 30 MW fires
  - These rates are far above the GTR allowed leakage
- Prior to pressure tank and vehicle crash testing conducted to date

- Today's vehicles analogous scenario
  - 5 kg tank with pressure regulator that limited the release time to 5 minutes
  - Average release rate = 0.017 kg/s
  - Results in 2 MW fire

Wu. Y., 3rd International Symposium on Tunnel Safety and Security, 12 – 14, March, 2008

Backup

CNG Vehicle Crash Photos

The Civic was crushed to the “B” pillar behind the driver’s seat.


The driver walked away. There was no leak or rupture of the natural gas fuel tank or system.