Test Protocol for Hydrogen Storage Systems in SAE J2579 and GTR Requirements and Its Effects on Type 3 and 4 Containers

27 September 2010

International Technical Forum on Hydrogen –Natural Gas Blend fuel

Beijing, China

Chris Sloane
Sloane Solutions
### Development of Fuel Cell Vehicles

<table>
<thead>
<tr>
<th>Number of Vehicles</th>
<th>Challenge</th>
<th>Public Standards &amp; Regulations</th>
<th>Government Role</th>
</tr>
</thead>
</table>
| *Prototype Vehicle* | *Learning vehicles:*  
- improve operation  
- experience fueling  
- improve reliability | *Develop best practices*  
- product design  
- product efficiency testing  
- product safety testing  
- refueling interface | *Support basic research*  
*Support technology development* |
| *Demonstration Vehicle* | *Demo vehicles:*  
- monitor operation  
- refine fueling  
- improve durability & efficiency & cost  
- establish repair/maintenance  
- feedback vehicle operation & driver experience | *Refine public standards*  
- fueling interface  
- safety  
- energy efficiency | *Support deployment (vehicles & infrastructure)*  
*Deployment to monitor readiness, efficiency & cost* |
| *Low Volume Production Vehicle* | *Initial production:*  
- verify reliability, efficiency durability, cost  
- expand fueling infrastructure  
- monitor driver experience  
- feedback to next generation |  | *Develop regulations*  
- safety  
- emissions |
| *High Volume Production Vehicle* | ~10,000 - 100,000 | | |
Considerations in Development of Standards / Regulations

- **Performance-based versus Prescriptive**
  - **Performance-based:**
    - demonstrate capability to perform under on-road conditions
    - demonstrate safe performance under extreme conditions
    - rapid technology advancement
  - **Prescriptive:**
    - test for known failure modes of earlier technologies
    - project performance under extreme conditions
    - delayed technology advancement

- **Design guidelines versus Safety Design Qualification (Verification) Requirements**
  - **Design Guidelines**
    For use by engineers developing storage systems
    Guidelines capture safety issues to be considered, FMEA, root cause analysis, environmental factors, safety strategy, material properties and test methods, analysis and simulation tools, performance requirements
  - **Design Qualification**
    For use by engineers providing final safety qualification testing
    Test methods capture on-road extreme demand profiles in test conditions
    Verify safety in a vehicle context

Vehicle Crash Tests are an example of Performance-Based Design Qualification Tests
Compressed Hydrogen Storage System

Closures:
- TPRD = thermally activated pressure relief device
- Check valve – prevents reverse flow in fueling line
- Shut-off Valve – automatic fail-safe closure valve
Worst-Case Conditions = Test Conditions

Demands:
- Number of fueling/de-fueling pressure cycles
- Duration of sustained pressure
- Exposure to ambient temperature extremes
- Exposure to chemicals (acids, bases, solvents)
- Exposure to over-pressurizations (fueling station failures)

Responses:
- Full function through life
- No leak in service or crash
- No rupture
- Release in fire

Worst-Case On-Road Conditions for Storage
- 5500 cycles, -40C, +85C, 125%NWP & 150%NWP
- 25 years at NWP (Parking)
- In-use impacts (scratches & abrasions)
- Exposure to chemicals & impacts
- Localized & engulfing fire
1. Pneumatic sequence (H₂ gas is fluid)

Expected-Service Performance Verification Test

- 5% cy -40°C
- 5% cy +50°C
- 40% cy 15-25°C
- 180% NWP
- 30 sec
- 150% NWP

2. Hydraulic sequence (liquid is fluid)

- 180% NWP
- 30 sec
- 125% NWP
- 115% NWP
- 80% NWP

3. Fire Test

- 3 vessels tested in design qualification
- Leak-Before-Burst

4. Control of Production Variability

- 3 vessels tested in design qualification
- Burst pressure ± 10%
- Periodic (batch) testing during production
Open Issues in Development of the Safety Design Qualification Requirements for Compressed Hydrogen Storage

- Fire test – localized fire test
  -- engulfing fire test

- Hydrogen embrittlement
Proposed Localized Fire Design Qualification Test

Localized fire

800°C

600°C

Region outside of localized impact (1.65 m linear extent)

Region of localized impact

TPRD venting

3 minutes 8 10

Signifies a continuous temperature increase (need not be linear)
Open Issues in Development of the Safety Design Qualification Requirements For Compressed Hydrogen Storage

• Fire test – localized fire test -- engulfing fire test

• Hydrogen embrittlement
Material Compatibility for High Pressure Hydrogen (Embrittlement Resistance)

- **unrestricted (all tank designs) qualification**

- **Accepted Steel alloys:**
  UNS# S31603 (equivalents include SUS316L, AISI316L, AISI316 and DIN1.4435); all must have $\geq 12\%$ nickel composition and $\leq 0.1\%$ magnetic phases by volume.
  No welds

- **Accepted Aluminum alloys:**
  A6061-T6, A6061-T62, A6061-T651 and A6061-T6511.
  No welds

- **Acceptance of additional alloys:**
  1. Slow Strain Rate Test
  2. Fatigue Life Test
  3. Fatigue Crack Growth Test

**OR**

- **design-restricted qualification**

5500 125\%NWP cycles with H2, no leak; 11000 cycles, no rupture; hydraulic qualification modified for H2 crack acceleration