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

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Development of Fuel Cell Vehicles

	Prototype Vehicle	Demonstration Vehicle	Low Volume Production Vehicle	High Volume Production Vehicle
Number of Vehicles	≤ 10s	~100s	~1000s	~10,000 - 100,000
Challenge	<u>Learning vehicles</u>: •improve operation •experience fueling •improve reliability	<u>Demo vehicles</u>: • monitor operation • refine fueling • improve durability & efficiency & cost • establish repair/maintenance • feedback vehicle operation & driver experience	<u>Initial production</u>: • verify reliability, efficiency durability, cost • expand fueling infrastructure • monitor driver experience • feedback to next generation	
Public Standards & Regulations	<u>Develop best practices</u> -- product design -- product efficiency testing -- product safety testing -- refueling interface	<u>Refine public standards</u> -- fueling interface -- safety -- energy efficiency		
Government Role	•Support basic research •Support technology development	<u>Support deployment</u> (vehicles & infrastructure) deployment to monitor readiness, efficiency & cost <u>Develop regulations</u> -- safety . -- emissions		

Considerations in Development of Standards / Regulations

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

Vehicle Crash Tests are an example of Performance-Based Design Qualification Tests

- **Design guidelines versus Safety Design Qualification (Verification) Requirements**
  - **<u>Design Guidelines</u>**

    For use by engineeers developing storage systems

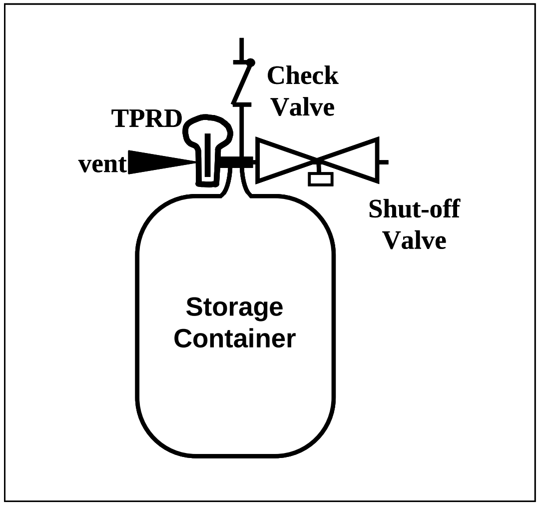
    Guidelines capture safety issues to be considered, FMEA, root cause analysis, environmental factors, safety strategy, material properties and test methods, analysis and simulation tools, performance requirements
  - **<u>Design Qualification</u>**

    For use by engineeers providing final safety qualification testing

    Test methods capture on-road extreme demand profiles in test conditions

    Verify safety in a vehicle context

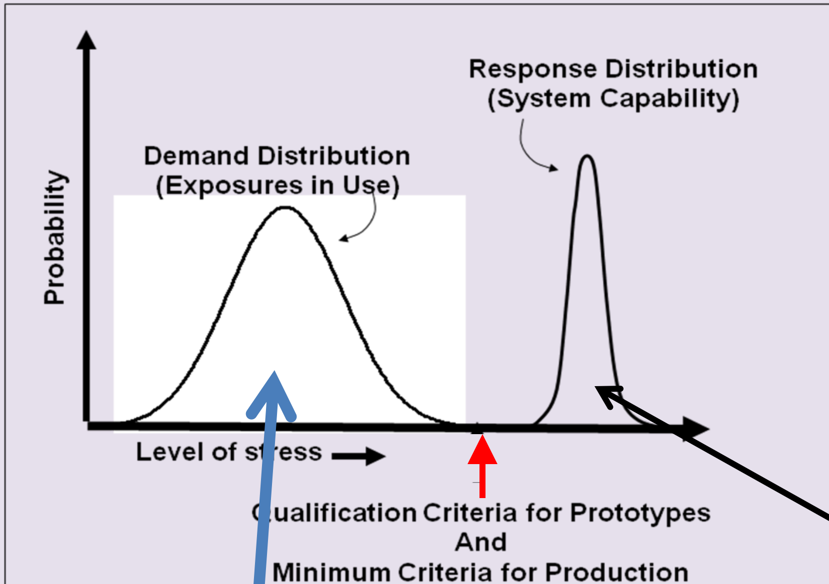
Compressed Hydrogen Storage System



Closures:

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

❖ On-road extreme demand profiles



Worst-Case On-Road Conditions for Storage

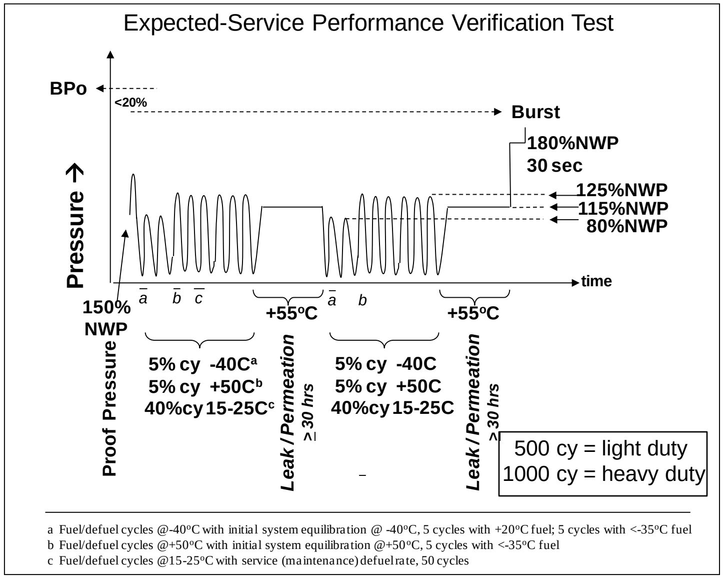
- 5500 cycles, -40C, +85C, 125%NWP & 150%NWP
- 25 years at NWP (Parking)
- In-use impacts (scratches & abrasions)
- Exposure to chemicals & impacts
- Localized & engulfing fire

Worst-Case Conditions = Test Conditions

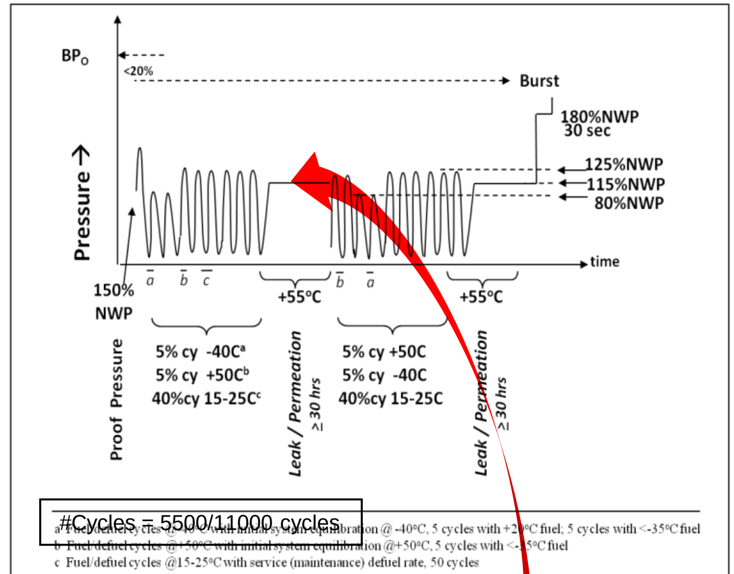
Responses:
Full function thruough life
No leak in service or crash
No rupture
Release in fire

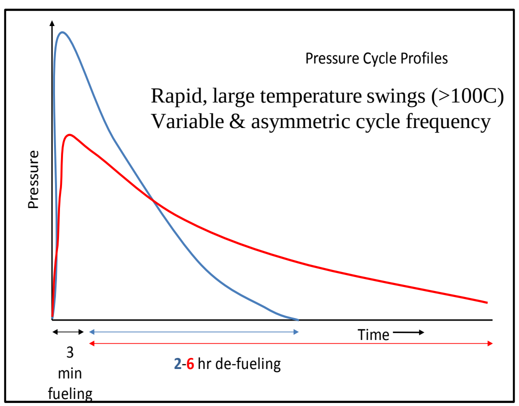
Demands:
Number of fueling/de-fueling pressure cycles
Duration of sustained pressure
Exposure to ambient temperature extremes
Exposure to chemicals (acids, bases, solvents)
Exposure to over-pressurizations (fueling station failures)

1. Pneumatic sequence (H_2 gas is fluid)

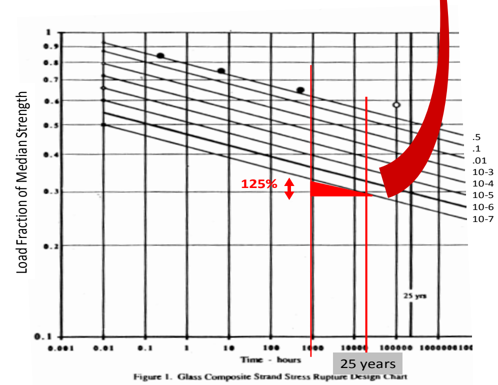


2. Hydraulic sequence (liquid is fluid)





3. Fire Test



4. Control of Production Variability

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

-- 3 vessels tested in design qualification --burst pressure ± 10%

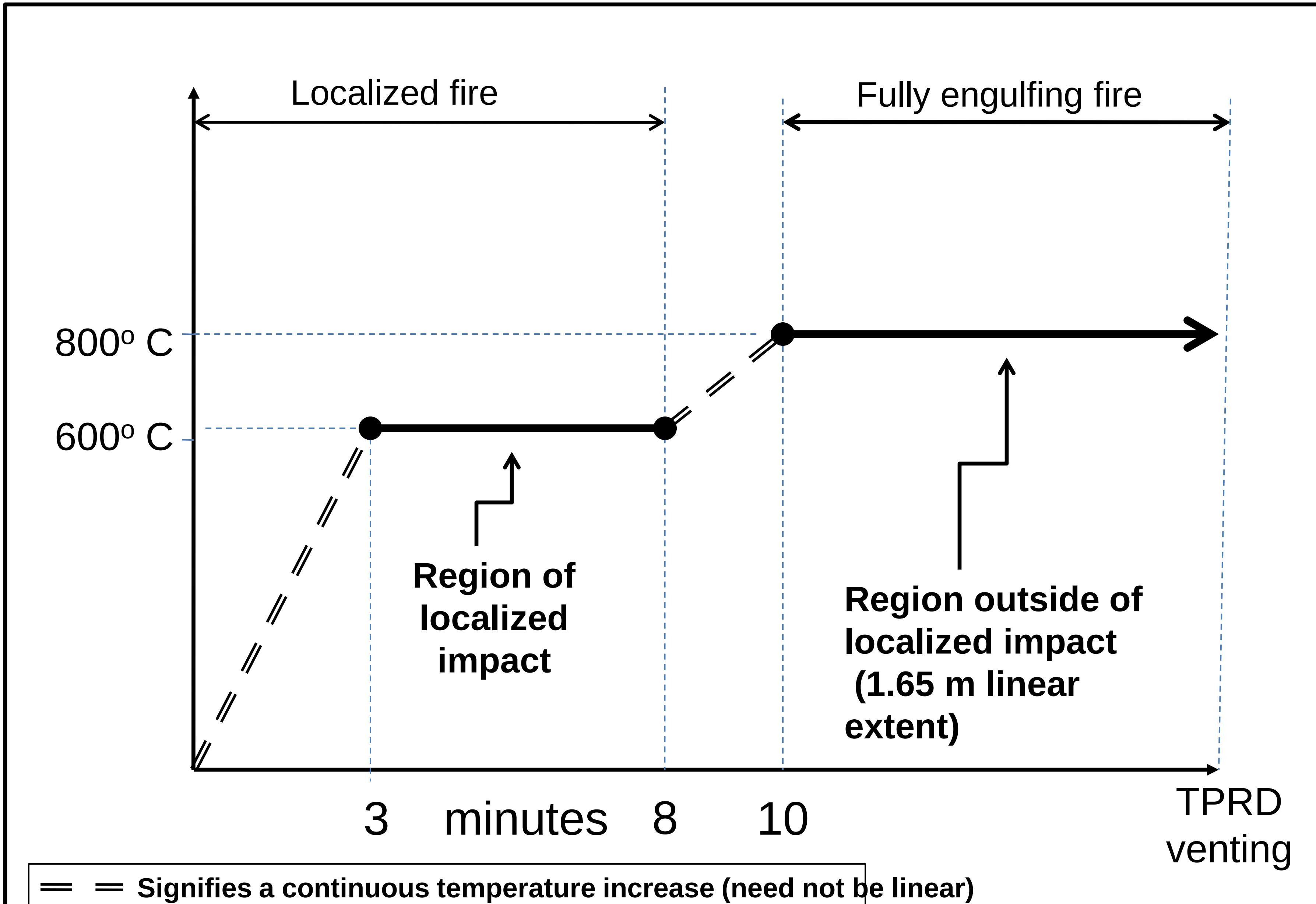
-- periodic (batch) testing during production

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



Open Issues
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Material Compatibility for High Pressure Hydrogen (Embrittlement Resistance)

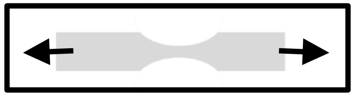
❖ unrestricted (all tank designs) qualification

- **Accepted Steel alloys**:
  UNS# S31603 (equivalents include SUS316L, AISI316L, AISI316 and DIN1.4435); all must have ≥ 12% nickel composition and ≤ 0.1% magnetic phases by volume.
  No welds
- **Accepted Aluminum alloys**:
  A6061-T6, A6061-T62, A6061-T651 and A6061-T6511.
  No welds

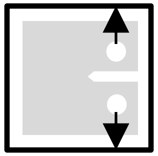
- **Acceptance of additional alloys**:

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