DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

49 CFR Part 571

[Docket No. NHTSA-2024-0006]

RIN 2127-AM40

Federal Motor Vehicle Safety Standards; Fuel System Integrity of Hydrogen Vehicles; Compressed Hydrogen Storage System Integrity; Incorporation by Reference

AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT).

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This notice proposes to establish two new Federal Motor Vehicle Safety Standards (FMVSS) specifying performance requirements for all motor vehicles that use hydrogen as a fuel source. The proposed standards are based on Global Technical Regulation (GTR) No. 13. FMVSS No. 307, “Fuel system integrity of hydrogen vehicles,” would specify requirements for the integrity of the fuel system in hydrogen vehicles during normal vehicle operations and after crashes. FMVSS No. 308, “Compressed hydrogen storage system integrity,” would specify requirements for the compressed hydrogen storage system to ensure the safe storage of hydrogen onboard vehicles. The two proposed standards would reduce deaths

and injuries that could occur as a result of fires due to hydrogen fuel leakages and/or explosion of the hydrogen storage system.

DATES: You should submit your comments early enough to be received not later than **[INSERT DATE 60 DAYS AFTER DATE OF PUBLICATION IN THE FEDERAL REGISTER]**. In compliance with the Paperwork Reduction Act, NHTSA is also seeking comment on a revision to an existing information collection. For additional information, see the Paperwork Reduction Act Section under the Regulatory Notices and Analyses section below. All comments relating to the information collection requirements should be submitted to NHTSA and to the Office of Management and Budget (OMB) at the address listed in the ADDRESSES section on or before [**INSERT DATE 60 DAYS AFTER DATE OF PUBLICATION IN THE FEDERAL REGISTER**].

PROPOSED EFFECTIVE DATE: [INSERT DATE 180 DAYS AFTER DATE OF PUBLICATION OF THE FINAL RULE IN THE FEDERAL REGISTER].

PROPOSED COMPLIANCE DATE: The September 1st that is two years subsequent to the publication of the final rule.

ADDRESSES: You may submit comments to the docket number identified in the heading of this document by any of the following methods:

- Federal eRulemaking Portal: Go to http://www.regulations.gov. Follow the online instructions for submitting comments.
- Mail: Docket Management Facility: U.S. Department of Transportation, 1200 New Jersey Avenue S.E., West Building Ground Floor, Room W12-140, Washington, D.C. 20590-0001.
- Hand Delivery or Courier: 1200 New Jersey Avenue S.E., West Building Ground Floor, Room W12-140, between 9 a.m. and 5 p.m. ET, Monday through Friday, except Federal holidays.
- Fax: 202-493-2251.

Instructions: All submissions must include the agency name and docket number. Note that all comments received will be posted without change to http://www.regulations.gov, including any personal information provided. Please see the Privacy Act discussion below. We will consider all comments received before the close of business on the comment closing date indicated above. To the extent possible, we will also consider comments filed after the closing date.

Docket: For access to the docket to read background documents or comments received, go to http://www.regulations.gov at any time or to 1200 New Jersey Avenue, S.E., West Building Ground Floor, Room W12-140, Washington, D.C. 20590, between 9 a.m. and 5 p.m., Monday through Friday, except Federal Holidays. Telephone: 202-366-9826.

Privacy Act: In accordance with 5 U.S.C. 553(c), DOT solicits comments from the public to better inform its decision-making process. DOT posts these comments, without edit, including any personal information the commenter provides, to www.regulations.gov, as described in the system of records notice (DOT/ALL-14 FDMS), which can be reviewed at www.transportation.gov/privacy. In order to facilitate comment tracking and response, we encourage commenters to provide their name, or the name of their organization; however, submission of names is completely optional. Whether or not commenters identify themselves, all timely comments will be fully considered.

Confidential Business Information: If you wish to submit any information under a claim of confidentiality, you should submit three copies of your complete submission, including the information you claim to be confidential business information, to the Chief Counsel, NHTSA, at the address given under FOR FURTHER INFORMATION CONTACT. In addition, you should submit two copies, from which you have deleted the claimed confidential business information, to the Docket at the address given above. When you send a comment containing information claimed to be confidential business information, you should include a cover letter setting forth the information specified in our confidential business information regulation (49 CFR Part 512).

SUPPLEMENTARY INFORMATION:

Table of Contents

I. Executive Summary

Vehicle manufacturers have continued to seek out renewable and clean alternative fuel sources to gasoline and diesel. Compressed hydrogen has emerged as a promising potential alternative because hydrogen is an abundant element in the atmosphere and does not produce tailpipe greenhouse gas emissions when used as a motor fuel. However, hydrogen must be compressed to high-pressures to be an efficient motor fuel, and is also highly flammable, similar to other motor fuels. NHTSA has already set regulations ensuring the safe containment of other motor vehicle fuels such as gasoline in FMVSS No. 301 and compressed natural gas in FMVSS No. 304, and the fuel integrity systems of those systems in FMVSS No. 301 and FMVSS No. 303, respectively. No such standards currently exist in the United States covering vehicles that operate on hydrogen. Accordingly, this document proposes two new Federal Motor Vehicle Safety Standards (FMVSSs) to address safety concerns relating to storage and use of hydrogen in motor vehicles, and to align the safety regulations of hydrogen vehicles with vehicles that operate using other fuel sources. This proposed rule was developed in concert with efforts to harmonize hydrogen vehicle standards with international partners through the Global Technical Regulation (GTR) process, and if adopted, would harmonize the FMVSSs with GTR No. 13, Hydrogen and Fuel Cell Vehicles.

This document proposes the creation of two new safety standards: FMVSS No. 307, "Fuel system integrity of hydrogen vehicles," and FMVSS No. 308, "Compressed hydrogen storage system integrity." FMVSS No. 307 would regulate the integrity of the fuel system in hydrogen vehicles during normal vehicle operations and after crashes. To this end, it includes performance requirements for the hydrogen fuel system to mitigate hazards associated with hydrogen leakage and discharge from the fuel system, as well as post-crash restrictions on hydrogen leakage, concentration in enclosed spaces, container displacement, and fire. FMVSS No. 308 would regulate the compressed hydrogen storage system (CHSS) itself, and would primarily include performance requirements that would ensure the CHSS is unlikely to leak or burst during use, as well as requirements intended to ensure that hydrogen is safely expelled from the container when it is exposed to a fire. FMVSS No. 308 also specifies performance requirements for different closure devices in the CHSS.

NHTSA is proposing that FMVSS Nos. 307 and 308 apply to all motor vehicle that use compressed hydrogen gas as a fuel source to propel the vehicle, regardless of the vehicle's gross vehicle weight rating (GVWR). However, while FMVSS No. 307 fuel system integrity requirements during normal vehicle operations would apply to both light vehicles (vehicles with a GVWR of 4,536 kg or less) and to heavy vehicles (vehicles with a GVWR greater than 4,536 kg), FMVSS No. 307 post-crash fuel system integrity requirements would only apply to compressed hydrogen fueled light vehicles and to all compressed hydrogen fueled school buses regardless of GVWR.

While the proposed safety standards are drafted in accordance with GTR No. 13, there are differences between some proposed requirements and test procedures and GTR No. 13. This document highlights these differences and provides reasons for these differences in relevant sections of the preamble, and seeks public comment.

II. Background

A. Hydrogen Fueled Vehicles

1. Hydrogen as a motor fuel

In the pursuit of sustainable, renewable, and clean transportation, vehicle manufacturers have continued to expand their pursuits of hydrogen as an alternative fuel source for automobiles. Unlike their gasoline or diesel counterparts, hydrogen-powered vehicles (hydrogen vehicles) do not produce carbon dioxide or other emissions. Furthermore, in contrast with battery electric vehicles, hydrogen vehicles do not require extended recharging from an external electrical source. These advantages, coupled with the relative abundance of hydrogen, make hydrogen vehicles an intriguing alternative to vehicles already offered in the market.

Hydrogen vehicles harness the chemical energy within hydrogen using one of two methodologies. The first technique is similar to conventional internal combustion engines (ICE) powered by petroleum products. Hydrogen can be burned in a combustion engine and the energy released from this process used to move pistons that provide mechanical power to the vehicle.

The second method utilizes a component called a fuel cell that converts the chemical energy in hydrogen into electricity. In this energy conversion process, hydrogen stored in the vehicle reacts with oxygen in the air to produce water and energy, in the form of electricity, which is then used to power the vehicle's mechanical operations. Hydrogen fuel cell vehicles (HFCVs), which are sometimes also referred to as fuel cell electric vehicles (FCEVs), are capable of continuous electrical generation so long as they have a steady supply of hydrogen fuel and oxygen.

One complicating factor of using hydrogen as a mobile fuel source is its relatively low energy density. Compared to gasoline, which has a mass density of 803 grams per liter at 15 °C, uncompressed hydrogen is extremely light, with a mass density of just 0.09 grams per liter at 15 °C, which means a vehicle operating on uncompressed hydrogen will have a significantly shorter range than a comparable gasoline-powered vehicle. To overcome this, hydrogen is compressed to a very high pressure of up to 70 megaPascals (MPa) while stored on a hydrogen vehicle.[1] Hydrogen compressed to 70 MPa at 15 °C has a volumetric energy density of 4.8 mega Joules per liter (MJ/L), which is similar in order of magnitude to gasoline's volumetric energy density of 32 MJ/L.[2,3]

While compressed hydrogen is an excellent fuel source due to its high energy density, its high storage pressure and wide limits of flammability (i.e., concentrations at which a mixture of fuel and air is flammable) raise safety concerns. Specifically, hydrogen is flammable at concentrations ranging from 4 to 75 percent, by volume.[4] By contrast, gasoline limits of flammability when mixed with air are from 1.0 to 7.6 percent, by volume.[5] The velocity at

---

[1] At atmospheric pressure and ambient temperature, hydrogen is in a gaseous state. The physical state of hydrogen can be changed from gas to liquid through compression and cryogenic cooling, so hydrogen can be stored in both compressed gaseous and liquid forms. However, hydrogen typically exists in gaseous form at essentially all normal usage and storage temperatures.

[2] *See* Patrick Molloy, "Run on Less with Hydrogen Fuel Cells." RMI, Oct. 2, 2019, https://rmi.org/run-on-less-with-hydrogen-fuel-cells/

[3] *See* Department of Energy Hydrogen and Fuel Cell Technologies Office, "Hydrogen Storage," https://www.energy.gov/eere/fuelcells/hydrogen-storage

[4] *See* Hydrogen Compared with Other Fuels, https://h2tools.org/bestpractices/hydrogen-compared-other-fuels

[5] *Id.*

which a hydrogen flame spreads at room temperature and atmospheric pressure is approximately 200 to 300 cm/s, whereas the velocity with which gasoline flames spread under the same conditions is approximately 40 cm/s.[6,7] These characteristics make hydrogen fuel sources more volatile than gasoline, and while NHTSA has existing FMVSS for gasoline vehicle fuel system integrity, no FMVSS yet apply to hydrogen storage and fuel systems. In particular, the safe use of hydrogen vehicles lies in preventing explosion of the hydrogen container(s) and preventing leaks from the container(s) and fuel system which could lead to fire. Given the greater flammability of compressed hydrogen, safety standards applicable to their fuel system integrity are not only reasonable, but necessary.

Despite the promise offered by hydrogen vehicles, they are still a diminutive fraction of the fleet. For model year 2022, there were two light hydrogen vehicle models offered for sale in the United States, whose sales by volume represented approximately 0.03% of the overall light vehicle fleet. There were no medium-or heavy-duty[8] hydrogen vehicles offered for sale in the U.S. during the 2022 model year;[9] however, manufacturers continue to state their intentions to explore hydrogen across all fleets.

2. Hydrogen vehicle systems

Hydrogen vehicles—both fuel cell and ICE—share the same basic structure. Hydrogen enters the vehicle through the fueling receptacle, is stored in the CHSS, and is released from the CHSS as needed to power either the combustion engine or fuel cell where the energy stored in hydrogen is converted into mechanical.[10] Figure-1 below shows an example of a hydrogen fuel

---

[6] *See* 6 Things to Remember about Hydrogen vs Natural Gas, https://www.powereng.com/library/6-things-to-remember-about-hydrogen-vs-natural-gas

[7] *See* Combustion fuels: density, ignition temperature and flame speed, https://thundersaidenergy.com/downloads/combustion-fuels-density-ignition-temperature-and-flame-speed/

[8] Medium-duty vehicles have a gross vehicle weight rating (GVWR) greater than 4,536 kg and less than or equal to 11,793 kg. Heavy-duty vehicles have a GVWR greater than 11,793 kg.

[9] Toyota has a commercial bus called the Sora that is currently sold in Japan and Europe.

[10] The chemical energy stored in the hydrogen fuel is converted into electric energy by the fuel cell, and the resulting electric energy is then be converted into mechanical energy by electric drive motor(s), thereby propelling the vehicle.

cell vehicle (HFCV).[11] A diagram of the main elements of a vehicle fuel system is shown in Figure-2.[12]

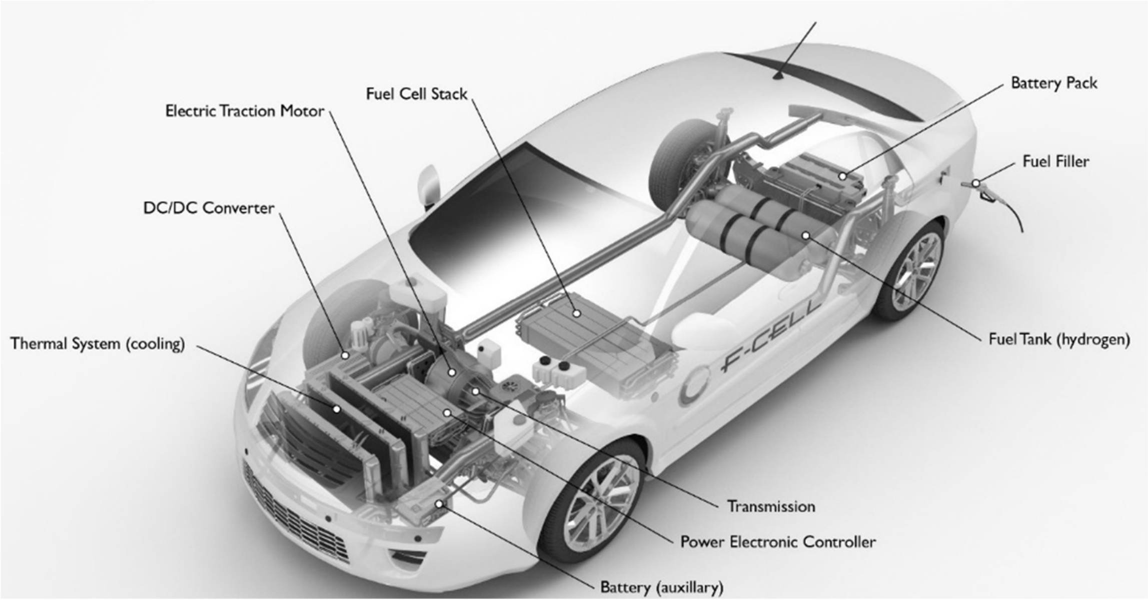

Figure-1: Example of a HFCV Design[13]

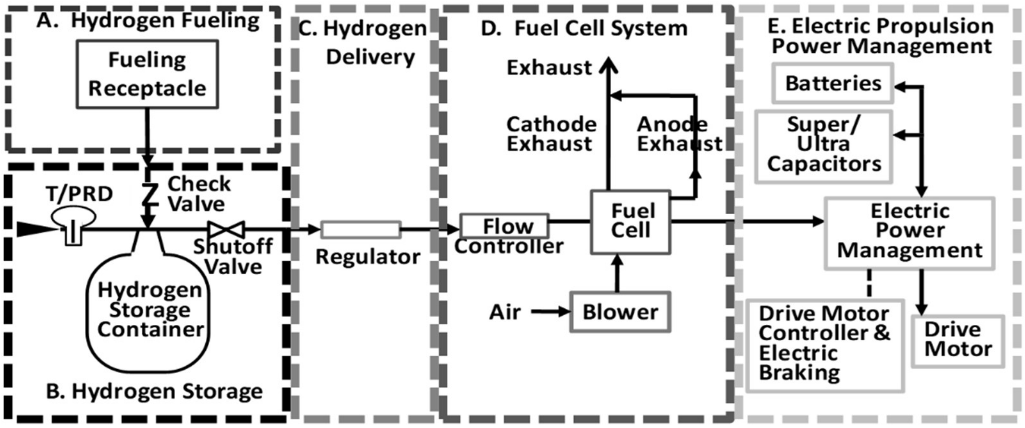

Figure-2: A schematic of a HFCV and its major systems

---

[11] Note that the vehicle depicted is a fuel cell vehicle. For a hydrogen ICE vehicle, the fuel cell would be replaced with a combustion engine.

[12] Figure-2 shows the main elements of a HFCV fuel system. In the case of a hydrogen ICE vehicle, the fuel cell system would be replaced by the ICE, and the electric propulsion management system would be replaced by the vehicle powertrain.

[13] For further information on HFCV design, *see* https://afdc.energy.gov/vehicles/fuel_cell.html, and https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work.

a. CHSS

During fueling, hydrogen is supplied from the fueling station to the vehicle through the vehicle's fueling receptacle. The hydrogen then flows to the CHSS for storage in the hydrogen container(s). The key functions of the CHSS are to receive compressed hydrogen through a check valve during fueling, contain the hydrogen until needed, and release hydrogen through an electrically activated shut-off valve to the hydrogen delivery system for use in powering the vehicle. The check valve prevents reverse flow in the vehicle fueling line. The shut-off valve between the storage container and the vehicle fuel delivery system controls the fuel flow out of the CHSS and automatically defaults to the closed fail-safe position when unpowered. In the event of a fire impinging on the CHSS, the TPRD provides a controlled release of hydrogen from the CHSS before the high temperature causes a hazardous burst of the container.

b. Hydrogen delivery

The hydrogen delivery system transfers hydrogen from the CHSS to the fuel cell system at the proper pressure and temperature for fuel cells to operate. This transfer process is accomplished through a series of flow control valves, pressure regulators, filters, piping, and heat exchangers.

c. Fuel cell system

The fuel cell system provides high-voltage electric power to the drive-train and vehicle batteries and capacitors. The fuel cell stack is the electricity-generating component of the fuel cell system. Individual fuel cells are electrically connected in series such that their combined voltage is between 300 and 600 Volts in direct current (VDC). Fuel cell stacks operate at high-voltage, which means a voltage greater than 60 VDC. The high voltage aspect of fuel cells are covered by FMVSS No. 305, "Electric-powered vehicles: electrolyte spillage and electrical shock protection," and are not considered in this proposal.

A typical fuel cell system includes a blower to feed air to the fuel cell system. Most of the hydrogen that is supplied to the fuel cell system is consumed within the fuel cells, but a tiny excess of hydrogen is required to ensure that there is no damage to the fuel cell from a lack of hydrogen, which can cause undesired chemical reactions that damage and degrade the fuel cell.[14] The excess hydrogen is either catalytically removed or vented to the atmosphere in accordance with the requirements discussed below. A fuel cell system also includes auxiliary components to remove heat. Most fuel cell systems are cooled by a mixture of glycol and water. Pumps circulate the coolant between the fuel cells and a radiator.

d. Electric propulsion and power management system

The electric power generated by the fuel cell system is supplied to the electric propulsion power management system where it is used to power the electric drive-train that propels the vehicle. The throttle position is used by the drive-train controllers to determine the amount of power to be sent to the drive wheels. Many HFCVs use batteries or ultra-capacitors to supplement the output of the fuel cells. These vehicles may also recapture energy during braking through regenerative braking, which recharges the batteries or ultra-capacitors and thereby maximizes efficiency.[15]

e. Hydrogen ICE vehicles

Hydrogen ICE vehicles have an ICE instead of a fuel cell system. The ICE engine burns hydrogen to generate mechanical energy to propel the vehicle. These vehicles use a mechanical propulsion system instead of an electric propulsion system.

B. Global Technical Regulation (GTR) No. 13

The proposed rule initiates the process of adopting Global Technical Regulation (GTR) No. 13 into the FMVSS. Based on GTR No. 13, this NPRM proposes requirements for the safe onboard storage and utilization of hydrogen in vehicles.

---

[14] A lack of hydrogen in a fuel cell, also known as hydrogen starvation, occurs when hydrogen fuel is exhausted at the fuel cell anode. This condition can lead to undesired chemical reactions occurring inside the fuel cell which can quickly degrade the fuel cell's catalyst and other components.

[15] The electric propulsion and power management system is covered by FMVSS No. 305, "Electric-powered vehicles: electrolyte spillage and electrical shock protection," and is not considered in this proposal.

1. Overview of the GTR process

The United States became the first signatory to the 1998 United Nations/Economic Commission for Europe (UNECE) agreement (1998 Agreement). The 1998 Agreement entered into force in 2000 and is administered by the World Forum for Harmonization of Vehicle Regulations working party (WP.29).[16] The 1998 Agreement established the development of global technical regulations (GTRs) regarding the safety, emissions, energy efficiency and theft prevention of wheeled vehicles, equipment and parts.

The 1998 Agreement contains procedures for establishing GTRs either through harmonizing existing regulations or developing new regulations. The GTR process provides NHTSA unique opportunities to enhance vehicle safety and improve government efficiency. It assists in developing the best safety practices from around the world, identifying and reducing unwarranted regulatory requirements, and leveraging scarce government resources for research and regulation. The process facilitates our effort to continuously improve and seek high levels of safety, particularly by helping us develop regulations that reflect a global consideration of current and anticipated technology and safety problems.

Contracting Parties who vote in favor of a GTR are obligated by the 1998 Agreement to "submit the technical Regulation to the process" used in the country to adopt the requirement into the agency's law or regulation.[17] In the U.S., that process usually commences with an NPRM or Advance NPRM (ANPRM). The 1998 Agreement does not obligate Contracting Parties to adopt the GTR after initiating this process.[18] The 1998 Agreement recognizes that governments have the right to determine whether the global technical regulations established under the Agreement are suitable for their own particular safety needs. Those needs vary from

---

[16] The World Forum was initially named the Working Party on the Construction of Vehicles, a subsidiary of the Inland Transport Committee. It was renamed to the World Forum in 2000.

[17] Article 7, 1998 Agreement, *available at* https://unece.org/text-1998-agreement.

[18] *Id*.

country to country due to differences in laws and in factors such as the traffic environment, vehicle fleet composition, driver characteristics and seat belt usage rates.

2. History of GTR No. 13

NHTSA began collaborating with the international community to develop a global technical regulation for hydrogen vehicles in the early 2000s. In 2005, WP.29 agreed to a proposal from Germany, Japan and the United States of America regarding how best to manage the development process for a hydrogen vehicle GTR. Pursuant to the proposal, the United States and Japan were designated co-chairs of an informal working group (IWG) to explore the safety aspects of hydrogen vehicles.

In June 2007, WP.29 adopted an action plan prepared by the co-sponsors to develop a GTR for compressed gaseous and liquefied hydrogen fuel vehicles. At the time, no hydrogen vehicles were commercially available. To allow for the advancement of hydrogen technologies, the co-sponsors' action plan split the GTR into two phases. Phase 1 would focus on developing a GTR for hydrogen vehicles based on current best practices. Phase 2 would commence subsequent to Phase 1, and supplement it by assessing any technological advancements and explore ways to harmonize vehicle crash tests to evaluate fuel system integrity.

The IWG evaluated existing research and design standards for the development of a hydrogen vehicle GTR. To the extent possible, the group avoided design specific requirements and considered requirements and specification that were supported by research and technically justified. The main areas of focus in Phase 1 were: performance requirements for hydrogen storage systems, high-pressure closures, pressure relief devices, and fuel lines; specifications on limits on hydrogen releases during normal vehicle operations and post-crash; and requirements for electrical isolation and protection against electric shock during normal vehicle operations and post-crash.

The draft GTR was recommended by the IWG at the December 2012 session, and GTR No. 13 for Hydrogen and Fuel Cell Vehicles was codified by WP.29 on June 27, 2013, after a 6-

year effort, with the United States voting in favor of the GTR. It specified safety-related performance requirements and test procedures with the purpose of minimizing human harm that may occur as a result of fire, burst, or explosion related to the hydrogen fuel system of vehicles, and/or from electric shock caused by a fuel cell vehicle's high voltage power train system.[19] The regulation consists of system performance requirements for compressed hydrogen storage systems (CHSS), CHSS closure devices, and the vehicle fuel delivery system. In Phase 1, the IWG purposefully did not harmonize crash tests and instead elected to have Contracting Parties use their own methodologies.

Phase 2 was adopted at the 190th Session of WP.29 on June 21, 2023.[20] Phase 2 accomplished several goals, including: broadening of the scope and application of GTR No. 13 to cover heavy-duty/commercial vehicles; harmonizing, clarifying, and expanding the requirements for thermal-pressure relief devices' direction in case of controlled release of hydrogen; strengthening test procedures for containers with pressures below 70 MPa, including comprehensive fire exposure tests; and extending the requirements to 25 years to more accurately capture the expected useful life of vehicles. The U.S. voted in favor of adopting Phase 2 and is proposing to adopt the changes made to GTR No. 13 by Phase 2 with this proposal.

III. Why is NHTSA Issuing this Proposal?

As a Contracting Party who voted in favor of GTR No. 13, the United States is obligated under the 1998 Agreement to "submit the technical Regulation to the process" used to adopt the requirement into the agency's law or regulation as a domestic standard. Today's proposal satisfies that obligation. In deciding whether to adopt a GTR as an FMVSS, we follow the procedural and substantive requirements for any other agency rulemaking, including the

---

[19] The electrical safety requirements in GTR No. 13 Phase 1 were incorporated into FMVSS No. 305. *See* 82 FR 44945.

[20] A copy of GTR No. 13 as updated by the Phase 2 amendments is available at: https://unece.org/sites/default/files/2023-07/ECE-TRANS-180-Add.13-Amend1e.pdf

Administrative Procedure Act, the National Traffic and Motor Vehicle Safety Act (Safety Act) (49 U.S.C. Chapter 301), Presidential executive orders, and DOT and NHTSA policies, procedures, and regulations.[21] Under 49 U.S.C. § 30111(a), FMVSSs must be practicable, meet the need for motor vehicle safety, and be stated in objective terms.[22] Section 30111(b) states that, when prescribing such standards, NHTSA must, among other things, consider all relevant, available motor vehicle safety information; consider whether a standard is reasonable, practicable, and appropriate for the types of motor vehicles or motor vehicle equipment for which it is prescribed; and consider the extent to which the standard will further the statutory purpose of reducing traffic crashes and associated deaths and injuries.

This proposal marks a substantial step in meeting those procedural and substantive requirements. The proposal serves as notice of our intention to adopt the requirements of GTR No. 13 as FMVSS Nos. 307 and 308 and provides an opportunity for the public to comment on the proposed requirements. In accordance with the APA, we seek comment on this proposal to help inform our decision-making, and will take all timely public comments into consideration when deciding whether (and if so, how) to proceed with a final rule, and the appropriateness of any potential modifications to the proposed performance standards that are appropriately within scope of the NPRM.

NHTSA tentatively finds that the proposed standards fulfill a clear, if not immediately present, need for motor vehicle safety. The purpose of FMVSS No. 307, “Fuel system integrity of hydrogen vehicles,” and FMVSS No. 308, “Compressed hydrogen storage system integrity,” is to reduce deaths and injuries in hydrogen-powered vehicles occurring from fires that result

---

[21] NHTSA’s policies in implementing the 1998 Agreement are published in 49 CFR Part 553, Appendix C, “Statement of Policy: Implementation of the United Nations/Economic Commission for Europe (UNECE) 1998 Agreement on Global Technical Regulations—Agency Policy Goals and Public Participation.” NHTSA’s paramount policy goal under the 1998 Agreement is to “[c]ontinuously improve safety and seek high levels of safety, particularly by developing and adopting new global technical regulations reflecting consideration of current and anticipated technology and safety problems.”

[22] “Motor vehicle safety” is defined in the Safety Act as “the performance of a motor vehicle or motor vehicle equipment in a way that protects the public against unreasonable risk of accidents occurring because of the design, construction, or performance of a motor vehicle, and against unreasonable risk of death or injury in an accident, and includes nonoperational safety of a motor vehicle.” 49 U.S.C. 30102(a)(8).

from leakage after motor vehicle crashes. Hydrogen is highly flammable, with an exceptionally wide limit of flammability in the air and a high burning velocity. If hydrogen leaks from the fuel system, the risk of fire in or near the vehicle is substantial and gravely impairs the safety of vehicle occupants and others within the vicinity of the vehicle.

Although the potential safety risk from hydrogen vehicles has not necessarily materialized, due to their current scarcity in the on-road fleet, NHTSA made the same determination about the safety need for fuel system and container integrity systems when it adopted FMVSS No. 301, *Fuel system integrity*, with the initial FMVSSs adopted in 1968,[23] and in 1994 when NHTSA adopted FMVSS No. 303, *Fuel system integrity of compressed natural gas vehicles*,[24] and FMVSS No. 304, *Compressed natural gas fuel container integrity*.[25] NHTSA faced a similar crossroads when developing FMVSS Nos. 303 and 304. Compressed Natural Gas (CNG) vehicles represented a very small portion of the total fleet size when NHTSA finalized the standards. The agency decided that the safety risk posed by CNG necessitated immediate action.[26] Members of the public shared a similar sentiment with the agency and urged quick action at that time to coalesce safety practices.[27] Today's proposal is the logical extension of NHTSA's existing standards that cover vehicles powered by other combustible fuel sources, except, for this NPRM, the agency has been able to draw on and benefit from the work of the international GTR No. 13 community in developing the proposed standards.

We tentatively find the proposed requirements in this NPRM to be practicable. Both automobile and hydrogen container manufacturers provided technical expertise to the IWG on test procedures and determining the boundaries of practicability of requirements during the development of GTR No. 13. Furthermore, GTR No. 13 incorporates a number of voluntary industry standards, which are discussed throughout this preamble, that have been demonstrated

---

[23] *See* 32 FR 2414 (1967).
[24] *See* 59 FR 19648 (1994).
[25] *See* 59 FR 49010 (1994).
[26] 58 FR 5323
[27] *See* 59 FR 19648, 19657.

as practicable. Given the industry input informing the GTR and that the GTR incorporates current technical standards now used in hydrogen vehicle safety designs, NHTSA believes that the proposed standards are practicable.

The 1998 Agreement provides flexibilities to propose alternative technical regulations as necessary to ensure compliance with a jurisdiction's specific legal and safety need requirements. As noted in the forthcoming sections, NHTSA is proposing several modifications to the requirements in GTR No. 13 to conform with the Safety Act requirements for FMVSS, clarify the wording of the regulation, and improve objectivity.

The agency believes that this proposed rule is timely. While hydrogen vehicles currently represent less than half a percent of the total sales of light vehicles and are still in the prototypical stage for heavier vehicles, there are several trends that may point to increased growth in the coming years. The slow adoption of hydrogen vehicles can be attributed to both the expense associated with developing a new powertrain and the lack of existing fueling infrastructure.[28] Recent Federal legislation and spending has renewed the country's focus on incentivizing clean vehicles. The Inflation Reduction Act (IRA) allotted billions towards the development of clean vehicles and the infrastructure to support them. Manufacturers can claim credits for building or retooling facilities to build hydrogen-powered vehicles under Qualifying Advanced energy project credit or can claim credits for each hydrogen vehicle produced pursuant to the Advanced manufacturing production credit.[29] Consumers who purchase hydrogen vehicles can qualify for a $7,500 tax credit, and commercial enterprises can claim up to $40,000 for hydrogen fuel cell vehicles.[30] Additionally, producers of clean hydrogen are also eligible for tax credits on a per-gallon basis.[31] This list of incentives is not exhaustive, and NHTSA

---

[28] *See*, *e.g.* S. Hardman, E. Shiu, R. Steinberger-Wilckens, and T. Turrentine., Barriers to the adoption of fuel cell vehicles: A qualitative investigation into early adopters attitudes, 95 Transportation Research Part A: Policy and Practice 166-82 (2017). https://www.sciencedirect.com/science/article/abs/pii/S0965856415302408#:~:text=FCVs%20have%20some%20specific%20challenges,and%20balance%20of%20plant%20components.

[29] *See* 26 U.S.C. 48C and 26 U.S.C. 45X, respectively.

[30] *See* 26 U.S.C. 30D and 26 U.S.C. 45W, respectively.

[31] 26 U.S.C. 45Z.

recognizes that the collective efforts at both the federal and state level to incentive clean energy in the transportation industry are extensive and underline the importance of establishing safety standards presently, so that they are in place as the vehicles arrive in the marketplace.

Manufacturers continue to announce new forays into hydrogen vehicles, with some manufacturers citing the IRA as a catalyst for further development of hydrogen-powered vehicles.[32] Hyundai and Toyota, the only two manufacturers with hydrogen vehicles for sale currently in the United States, have announced plans to introduce more consumer hydrogen vehicle lines covering additional body styles and expand their hydrogen vehicle offerings.[33] Other manufacturers have announced plans to introduce their own hydrogen vehicle models,[34] and new entrants to the automotive market are testing prototypes and concept vehicles.[35] Manufacturers have also stated that they are exploring the viability of hydrogen heavy-duty vehicles.[36]

NHTSA faced a similar crossroads when developing FMVSS Nos. 303 and 304. Compressed Natural Gas (CNG) vehicles represented a very small portion of the total fleet size when NHTSA finalized the standards. The agency decided that the safety risk posed by keeping CNG at a high pressure necessitated an immediate action.[37] Members of the public have shared

---

[32] *See*, *e.g.* Elizabeth Sturcken, "Leading companies are using IRA tax credits for clean manufacturing and technology. Are you?" Environmental Defense Fund, June 7, 2023, https://business.edf.org/insights/leading-companies-are-using-ira-tax-credits-for-clean-manufacturing-and-technology-are-you/

[33] *See* Remeredzai J. Kuhadzai, "Toyota Hilux Hydrogen Fuel Cell Pickup Prototype Unveiled" https://cleantechnica.com/2023/01/11/toyota-starts-work-on-the-development-of-prototype-hydrogen-fuel-cell-toyota-hilux-pickup/ (Toyota plans to release the Helix only in Japan for the upcoming model year) and Toyota, "PACCAR and Toyota Expand Hydrogen Fuel Cell Truck Collaboration to Include Commercialization." May 2, 2023, https://pressroom.toyota.com/paccar-and-toyota-expand-hydrogen-fuel-cell-truck-collaboration-to-include-commercialization/; *see also* Michelle Thompson, "Hyundai hires new exec to help lead hydrogen initiatives." Repairer Driven News, June 29, 2023 https://www.repairerdrivennews.com/2023/06/29/hyundai-hires-new-exec-to-help-lead-hydrogen-initiatives/

[34] For example, *see* Ken Silverstein, "Electric Vehicles or Hydrogen Fuel Cell Cars? The Inflation Reduction Act Will Fuel Both." Forbes, Aug. 10, 2022, https://www.forbes.com/sites/kensilverstein/2022/08/10/electric-vehicles-or-hydrogen-fuel-cell-cars-the-inflation-reduction-act-will-fuel-both/?sh=2841d7634d01; *see also* Joey Capparella, "Hydrogen-Powered Honda CR-V to Be Built in the U.S. Starting in 2024." Car and Driver, Nov. 30, 2022

[35] *See,* Ezra Dyer, "Pininfarina Reveals Pura Vision SUV Concept." Car and Driver, Aug. 1, 2023, https://www.caranddriver.com/news/a44690183/pininfarina-pura-vision-suv-concept-revealed/

[36] *See* Rebecca Martineau, "Fast Flow Future for Heavy-Duty Hydrogen Trucks: Expanded Capabilities at NREL Demonstrate High-Flow-Rate Hydrogen Fueling for Heavy-Duty Applications." National Renewable Energy Laboratory, June 8, 2022, https://www.nrel.gov/news/program/2022/fast-flow-future-heavy-duty-hydrogen-trucks.html.

[37] 58 FR 5323

a similar sentiment with the agency and urged quick action to coalesce safety practices for hydrogen powered vehicles.[38]

We believe that the proposed standards would provide regulatory certainty for manufacturers. Given manufacturers' purported interest in expanding their hydrogen offerings and the IRA incentives reducing the comparative costs of hydrogen vehicles, adopting safety regulations now would provide manufacturers clarity on how to design new vehicle lines. Further, having hydrogen safety standards in place should assist in alleviating the trepidation consumers have of newer technologies, whereas a failure to adequately address safety concerns in the earliest stages of development could have a negative impact on the deployment of this new technology. Manufacturers have also informed NHTSA that they would like to see the agency coordinate and harmonize hydrogen standards with other nations.[39] This proposal would accomplish all of these tasks.

IV. Overview of Proposed Safety Standards

The safe use of compressed hydrogen in vehicles lies primarily in preventing explosion of the hydrogen container(s) and preventing fuel leaks which could lead to fire or explosion. The leakage of hydrogen from the fuel system during normal vehicle operations and post-crash can pose safety hazards (fire or explosion) to vehicle occupants and the surroundings. In order to address the fire and explosion hazards associated with hydrogen vehicles, NHTSA is proposing to set performance requirements for the CHSS and the overall fuel system that are generally consistent with GTR No. 13.

GTR No. 13, Section 5.1, "Compressed hydrogen storage system," specifies performance-based CHSS requirements which address documented on-road stress factors. These stress factors include those identified in CNG vehicle containers as well as those that are unique to containment of high-pressure hydrogen. These requirements were developed to demonstrate

---

[38] *See* 59 FR 19648, 19657.

[39] *See, e.g.* NHTSA-2004-18039-0020 at 17.

the CHSS's capability to perform critical functions throughout service, including fueling/defueling events, parking under extreme vehicle and environmental conditions, environmental exposures, and performance in fire without explosion.

GTR No. 13, Section 5.2, "Vehicle fuel system," includes performance requirements to prevent and mitigate hydrogen leak from the fuel system and to warn vehicle occupants in the event of hydrogen concentration in the vehicle above flammable limits during normal vehicle operations and post-crash.

Similar to how NHTSA originally established CNG standards, we are proposing to implement GTR No. 13 by establishing two new FMVSSs that would specify minimum performance standards for vehicles that use compressed hydrogen gas as a motor fuel.[40] FMVSS No. 308, "Compressed hydrogen storage system integrity," would set out requirements for CHSS integrity. FMVSS No. 307, "Fuel system integrity of hydrogen vehicles," would set out in-use and post-crash requirements for the overall fuel system, including the CHSS, hydrogen delivery system, and fuel cell.

NHTSA is proposing that FMVSS Nos. 307 and 308 apply to all hydrogen-powered vehicles. This is a departure from Phase 1 of GTR No. 13 which only applies to hydrogen powered light vehicles. As discussed below, the IWG of GTR No. 13 Phase 2 has expanded the applicability of the standard to hydrogen powered heavy vehicles. With the exception of crash tests for heavy vehicles, NHTSA finds that the technical standards in GTR No. 13 are practicable for heavy vehicles and address the same safety need found in light vehicles.

Note that, consistent with GTR No. 13, NHTSA is proposing that FMVSS No. 308 be a vehicle-level standard, rather than an equipment standard.[41] Some performance requirements and test procedures for the CHSS in FMVSS No. 308 are specific to the vehicle design and to its gross vehicle weight rating. NHTSA is aware this is a departure from FMVSS No. 304 that is an

---

[40] The standards proposed in this document would not apply to vehicles that use liquified hydrogen as a motor fuel.

[41] This is in contrast to FMVSS No. 304, *Compressed natural gas fuel container integrity*, which is an equipment standard.

equipment standard which applies to CNG containers sold as replacement parts for CNG vehicles. At this time, hydrogen vehicle manufacturers are strictly controlling the CHSS installed in their vehicles and replacement parts are obtained from the vehicle manufacturer (similar to electric vehicle batteries). NHTSA will monitor the deployment of hydrogen vehicles and how consumers are replacing parts of the fuel system. Since such data is lacking at this time, NHTSA is proposing FMVSS No. 308 as a vehicle standard, consistent with GTR No. 13. NHTSA will re-evaluate this decision based on comments received and on field data on hydrogen vehicle deployment, repair, and replacement parts. NHTSA seeks comment on whether FMVSS No. 308 should remain a vehicle standard, as well as whether FMVSS Nos. 307 and 308 should be combined into a single standard in the final rule.

A. FMVSS No. 308, "Compressed hydrogen storage system integrity"

FMVSS No. 308 would set out requirements for the performance of the CHSS and its subcomponents during normal use, with a particular focus on how the CHSS performs in a variety of incidents that a vehicle could experience during its lifetime operations and how well the component withstands usage.

NHTSA is proposing that FMVSS No. 308 only be a vehicle standard. As explained in more detail below, some of the proposed requirements are conditional on the vehicle type and characteristics. Without the knowledge of the relevant vehicle, some of the proposed CHSS standards cannot be tested. For these reasons, NHTSA does not intend that the proposed standard should extend to cover replacement parts, even though they would be considered motor vehicle equipment and still subject to NHTSA's safety defect authority, and replacement parts when installed may not take the vehicle out of compliance with the proposed new FMVSS No. 308, per 49 U.S.C. 30122. NHTSA seeks comment on this approach.

1. Compressed hydrogen storage system

The CHSS is defined to include all closure surfaces that provide primary containment of high-pressure hydrogen storage. The CHSS is defined to include the hydrogen container, check valve, shut-off valve and thermally-activated pressure relief device (TPRD), which are discussed in the sections below. Figure-3 illustrates a typical CHSS.

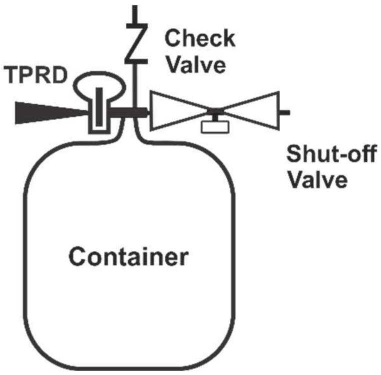

Figure-3: Typical CHSS

a. Hydrogen container

The hydrogen container is the main component of a CHSS. The hydrogen container stores hydrogen at extremely high pressure. On current hydrogen vehicles, hydrogen has typically been stored at a nominal working pressure (NWP) of 35 MPa or 70 MPa, at 15 °C. NWP means the gauge pressure that characterizes the normal operation of the system. Typically, the container is designed for a maximum allowable gas temperature of 85 °C. If the temperature of hydrogen stored at NWP is increased from 15 °C to 85 °C, then the pressure inside the container will rise to the maximum allowable pressure of 25 percent above NWP.[42] A container may consist of a single chamber or multiple permanently interconnected chambers. This allows designers flexibility in the overall shape of the CHSS.

Most containers used in hydrogen vehicles consist of two layers. The inner liner prevents gas leakage/permeation and is usually made of metal or thermoplastic polymer. The outer layer provides structural integrity and is usually made of metal or thermoset resin-impregnated fiber-

---

[42] This is based on data published in the NIST Chemistry WebBook, Standard Reference Database Number 69, Thermophysical Properties of Fluid Systems (isochoric properties for hydrogen), *available at* https://webbook.nist.gov/chemistry/fluid/

reinforced composite. For instance, Type 3 containers consist of a metal liner reinforced with resin impregnated continuous filament, and Type 4 containers consists of a non-metallic liner with resin-impregnated continuous filament.[43]

GTR No. 13 defines a container as "the pressure-bearing component on the vehicle that stores the primary volume of hydrogen fuel in a single chamber or in multiple permanently interconnected chambers." NHTSA is proposing a similar definition with the following modifications:

- Replace "the vehicle" with "a compressed hydrogen storage system" to clarify that the container is a subcomponent of the CHSS, and therefore a container cannot exist on its own without the other components of the CHSS.
- Remove the word "primary" because this introduces ambiguity regarding secondary or tertiary volumes of hydrogen.
- Add the word "continuous" to clarify that a container does not have any valves or other obstructions that may separate its different chambers.

Thus, NHTSA's proposed definition for "container" would be "pressure-bearing component of a compressed hydrogen storage system that stores a continuous volume of hydrogen fuel in a single chamber or in multiple permanently interconnected chambers." These changes are intended to clarify the definition and provide greater regulatory certainty as to what is considered part of the container. The changes do not alter the substantive requirements. NHTSA seeks comment on the proposed definition for the container.

b. Closure devices

---

[43] The American National Standard for Compressed Natural Gas Fuel Vehicle Containers (2007) classifies containers into Types 1 through 4 as follows:
Type 1 - Metal.
Type 2 - Resin impregnated continuous filament with metal liner with a minimum burst pressure of 125 percent of service pressure. This container is hoop-wrapped.
Type 3 - Resin impregnated continuous filament with metal liner. This container is full-wrapped.
Type 4 - Resin impregnated continuous filament with a non-metallic liner.

GTR No. 13 refers to closure devices as “primary” closure devices. This creates ambiguity about potential secondary or tertiary closure devices. As a result, NHTSA will refer simply to “closure devices.” NHTSA therefore proposes to define the term “closure devices” as “the check valve(s), shut-off valve(s) and thermally activated pressure relief device(s) that control the flow of hydrogen into and/or out of a CHSS,” so it will be clear what components are covered under the standard. NHTSA seeks comment on removal of the word “primary” and on the proposed definition for “closure devices.”

(1) TPRD

In the event of a fire, the TPRD provides a controlled release of hydrogen from the container before the high temperature from the fire weakens the container and causes a hazardous burst. TPRDs are designed to vent the entire hydrogen content of the container rapidly. These devices are designed to not be reset or reused once they have been activated.

(2) Check valve

During fueling, hydrogen enters the CHSS through a check valve. The check valve prevents back-flow of hydrogen into the fueling line or out of the fueling receptacle.

(3) Shut-off valve

A shut-off valve prevents the outflow of stored hydrogen from the container when the vehicle is not operating or when a fault is detected that requires isolation of the CHSS. In GTR No. 13, the shut-off valve is defined as “a valve between the container and the vehicle fuel system that must default to the ‘closed’ position when not connected to a power source.” NHTSA proposes adding the words “electrically activated” to the definition, so that a shut-off valve would be “an electrically activated valve between the container and the vehicle fuel system that must default to the ‘closed’ position when not connected to a power source.” NHTSA seeks comment on the proposed definition of shut-off valve.

(4) Container Attachments

The CHSS may include container attachments, which are non-pressure bearing parts attached to the container that provide additional support and/or protection to the container. Container attachments may only be removed with the use of tools for the purpose of maintenance and/or inspection. Container attachments include devices such as bump stops to mitigate impacts or shielding to mitigate surface damage to the container.

In the GTR No. 13 test procedures, container attachments are included in some tests. Importantly, in some cases, the container attachments provide protection to the container that improves test performance. Including container attachments for testing is discussed in the sections below where applicable and where the container attachments may affect test performance.

NHTSA proposes defining container attachments as "non-pressure bearing parts attached to the container that provide additional support and/or protection to the container and that may be removed only with the use of tools for the specific purpose of maintenance and/or inspection." NHTSA seeks comment on the proposed definition of container attachments. In this definition, the word "temporarily" has been removed from the GTR definition because anything that can be removed temporarily can also be removed permanently. For clarity, NHTSA has also shifted the order of some words relative to the definition in GTR No. 13.

2. General Requirements for the CHSS

NHTSA is proposing that the CHSS be required to include the functionality of a TPRD, shut-off valve, and check valve. These functions are required for the reasons stated above. However, NHTSA is aware of CNG vehicles that do not include check valves as part of their CNG storage system. In such CNG vehicles, the check valves are installed upstream between the fueling port and the CNG container, with additional valves to contain high pressure gas. NHTSA seeks comment on whether the check valves should be required as part of the CHSS.

The CHSS would be required to have an NWP of 70 MPa or less. This is because working pressures above 70 MPa are currently considered impractical and may pose a safety risk given current known technologies. The energy density of hydrogen does not increase significantly when pressurized above 70 MPa, so there is no significant improvement in hydrogen storage efficiency at pressures above 70 MPa. Pressures above 70 MPa, however, may present a greater safety hazard. As a result, NHTSA proposes that all CHSS must have an NWP less than or equal to 70 MPa. NHTSA seeks comment on this requirement, and specifically asks commenters to identify any technologies that can safely store hydrogen at pressures above 70 MPa.

GTR No. 13 provided contracting parties with the discretion to require that the closure devices be mounted directly on or within each container. The relevant safety concern is that the high-pressure lines required to connect remotely-located closure devices with the container could be susceptible to damage or leak. However, the definition of a container is sufficiently broad that it includes such lines as part of the container. These lines will be considered part of the permanently interconnected chambers storing the continuous volume of hydrogen. Thus, any lines connecting to closure devices are themselves part of the container and will be included in the extensive container performance testing discussed below. If a container (which includes any lines connecting to closure devices) can successfully complete the performance testing in FMVSS No. 308, then the risk of failure of the lines has been addressed. Therefore, NHTSA tentatively concludes that it is not necessary to specify that closure devices be mounted directly on or within each container. NHTSA is also concerned that such a specification would be design restrictive. NHTSA is aware of CNG fuel systems where the closure devices are neither on nor within each container, and there have been no reported safety issues with such systems. Therefore, NHTSA is not proposing to include a requirement for closure devices to be on or within each container, and would instead leave the location of closure devices to manufacturer discretion. NHTSA seeks comment on requiring closure devices to be mounted directly on or within each container.

3. Performance requirements for the CHSS

The CHSS would be required to meet specific performance requirements when subjected to the performance tests listed below. The performance tests and the respective performance requirements are discussed in detail in subsequent sections:

- Tests for baseline metrics
- Test for performance durability
- Test for expected on-road performance
- Test for service terminating performance in fire
- Tests for performance durability of closure devices

Several of these tests utilize a manufacturer-supplied value known as $\mathrm{BP_O}$. A container's $\mathrm{BP_O}$ is a design parameter specified by the manufacturer to establish the expected initial burst pressure of the container. It is NHTSA's understanding that $\mathrm{BP_O}$, associated with median or midpoint burst pressure for a batch of containers, can vary between batches of containers. Therefore, in order to facilitate compliance testing, NHTSA is proposing that manufacturers specify the $\mathrm{BP_O}$ associated with each container on the required container label (discussed below). NHTSA seeks comment on this labeling requirement, noting that it is not required by GTR No. 13.

4. Tests for baseline metrics

The container must be able to withstand high pressurization, as well as pressure cycling, which is a repeated pressurization and depressurization. Both of these stress factors occur during the service life of the vehicle as its fuel system is repeatedly depleted and refilled. Consistent with GTR No. 13, the proposed tests for baseline metrics would include two tests for the container: the baseline initial burst pressure test to evaluate resistance to burst at high pressure, and the baseline initial pressure cycle test to ensure the container is designed to leak before burst[44] and to evaluate its ability to withstand pressure cycling without burst and without leakage within its service life.

During the initial burst pressure test, the container must demonstrate that as the pressure is increased inside the container, the point of failure is above a minimum pressure level, discussed below. In other words, the container must demonstrate a minimum burst pressure. Burst pressure is defined as the highest pressure reached inside a container during a burst test which results in structural failure of the container and resultant fluid loss through the container, not including gaskets or seals. Burst pressure is determined by the baseline initial burst pressure test discussed below.

During the baseline initial pressure cycle test, the container must withstand pressure cycling that simulates repeated fueling and defueling by increasing the pressure inside the container to a high pressure level, then depressurizing it to low pressure, and repeating that process for a set number of cycles. The container must neither leak nor burst during an initial set of pressure cycles, and must not burst during a set number of pressure cycles beyond the initial set. These requirements are evaluated by the baseline pressure cycle life test discussed below.

The physical forces on the load-bearing components of a container are the same regardless of whether the pressure is being applied with hydraulic fluid, hydrogen gas, or any other medium. Therefore, for practicability and safety purposes both tests would be conducted using hydraulic fluid to exert pressure inside the container.[45] Hydraulic fluids, such as water or water with additives, are advantageous for these tests because they reduce the explosion risk associated with pneumatic pressurization. The explosion risk from pneumatic pressurization is high because compression of gas stores pressure-volume energy (PV energy), whereas during hydraulic pressurization with an incompressible fluid, PV energy is negligible. In addition, the

---

[44] Leak before burst design of high pressure containers is a common safety feature to ensure a leak will develop before a catastrophic burst will occur. A leak is a less severe failure mode compared to a catastrophic burst of the high pressure container.

[45] This is consistent with GTR No. 13.

incompressible nature of hydraulic fluids means that pressure cycles can be accomplished much faster than pneumatic pressurization cycles. This is important given the high number of cycles required for the baseline pressure cycle test. The use of hydrogen gas pneumatic pressure cycling does introduce stress factors beyond basic pressurization/depressurization, as discussed later, and these are addressed separately in the test for expected on-road performance. Given that hydraulic pressure cycling provides these benefits without compromising the safety or stringency of the proposed standards, hydraulic pressure cycling is used for these tests.

a. Baseline initial burst pressure

The baseline initial burst pressure test verifies that the initial burst pressure of a container is both above a minimum specified pressure level and is within 10 percent of the manufacturer specified BP_O. The requirement that the container tested must have a burst pressure within ±10 percent of BP_O is based on the need to control variability in container production. If a manufacturing process produces containers with highly variable initial burst pressures, there is a possibility of a container with a dangerously low burst pressure. NHTSA seeks comment on the safety need for specifying a limit on burst pressure variability in a batch and whether the 10 percent limit is appropriate; if commenters believe another limit is appropriate, they are asked to provide supporting data.

The minimum burst pressure, BP_{min}, in GTR No. 13 Phase 1 was set at 225 percent of NWP for carbon fiber composite containers, and 350 percent NWP for glass fiber composite containers. The value for carbon fiber composite containers was chosen to be a conservative starting point based on experience from CNG vehicles. GTR No. 13 Phase 1 made clear that the burst pressure requirement would be reviewed in Phase 2. The IWG of GTR No. 13 Phase 2 did review data on variability in initial burst pressure and end-of-life burst pressure (i.e. burst pressure after the test for performance durability, discussed in a later section), and determined that variation in burst pressure is actually low and that a minimum initial burst pressure of 200 percent NWP was appropriate for carbon fiber composite containers.[46] The GTR No. 13 Phase 2 IWG assessment also noted that manufacturers generally design containers to have burst pressures well above the required minimum burst pressure, to ensure that a container can meet the performance requirements of the test for performance durability. These findings suggest it is possible to lower the minimum burst pressure requirement to 200 percent of NWP without reducing safety, because manufacturers will generally be outperforming this requirement anyway.

Furthermore, a 200 percent minimum initial burst pressure can be supported when coupled with the following requirements from the proposed test for performance durability (which are discussed in the following section): [47]

- The container must withstand 180 percent NWP for 4 minutes at the end of the test for performance durability.
- The minimum burst pressure after the completion of the test for performance durability cannot be lower than 80 percent of BP_O.

In light of the variability in the minimum burst pressure and the need to meet the above two requirements at the end of the test for performance durability, NHTSA expects that manufacturers will ultimately design the container with an initial burst pressure well above 200 percent NWP.

Accordingly, NHTSA believes that proposing BP_{min} to 200 percent NWP, as set forth in GTR No. 13 Phase 2, meets the need for safety. Proposing the BP_{min} to 200 percent NWP facilitates hydrogen vehicle development without unnecessary overdesign of components.

---

[46] A study was conducted by the Japanese Automobile Research Institute which evaluated the variability of containers' initial burst pressure, as well as the variability in end-of-life burst pressure. The study concluded that variability among the containers was low, and therefore a minimum initial burst pressure of 200 percent NWP was acceptable and most consistent with the end-of-life burst pressure requirement.
See GTR No. 13 Phase 2 file GTR13-3-03: https://wiki.unece.org/download/attachments/58525915/GTR13-3-03%20Initial%20burst%20pressure%20requirement%20_3rd%20GTR13%20IWG_June2018.pdf?api=v2

[47] The tests conducted by the Japanese Automobile Research Institute showed that containers with burst pressure which met the BP_O ±10 percent requirement and subjected to the durability sequential tests, were able to withstand the end-of-life 180 percent NWP for four minutes and have an end-of-life burst pressure within -20 percent of BP_O, even if the minimum initial burst pressure is reduced to 200 percent NWP.

NHTSA seeks comment on the proposed BP_{min} of 200 percent NWP instead of the 225 percent NWP specified in GTR No. 13 Phase 1.

In the case of containers having glass-fiber as a primary constituent, consistent with GTR No. 13 Phase 2, NHTSA is proposing a higher BP_{min} of 350 percent of NWP because these containers are highly susceptible to stress rupture as compared to carbon fiber containers. Stress rupture is a failure mode that relates to the intrinsic failure probability of the individual fibers that overwrap the container for support. This failure mode can occur when the fibers are held under stress for long periods of time (such as in a continuously pressurized container).[48] The higher BP_{min} of 350 percent of NWP provides protection from the risk of stress rupture in containers having glass-fiber composite as a primary constituent. NHTSA seeks comment on this proposed requirement and how NHTSA can determine if a container has glass-fiber as a primary constituent. NHTSA seeks comment on appropriate criteria to determine the primary constituent in this context.

In the case of containers constructed of both glass and carbon fibers, NHTSA proposes to apply the requirements according to the primary constituent of the container as specified by the manufacturer. NHTSA proposes that the manufacturer shall specify upon request, in writing, and within five business days, the primary constituent of the container. NHTSA proposes that the burst pressure of the container, for which the manufacturer fails to specify upon request, in writing, and within five business days, the primary constituent of the container, must not be less than 350 percent of NWP. NHTSA seeks comment on this proposed requirement.

The test for performance durability, described below, includes a 1000 hour high-temperature (85 °C) static pressure test, which is designed to evaluate the container's resistance to stress rupture, in combination with other lifetime stress factors. Given that the high-temperature static pressure test is focused directly on evaluating stress rupture risk, and the test

---

[48] SAE Paper 2009-01-0012. Rationale for Performance-based Validation Testing of Compressed Hydrogen Storage by Christine S. Sloane, a*vailable at* https://www.sae.org/publications/technical-papers/content/2009-01-0012/.

for performance durability represents an overall worst-case lifetime of stress factors, regardless of fiber type, NHTSA seeks comment on whether the baseline initial burst pressure test even needs to be included in the standard's requirements.

GTR No. 13 specifies that the baseline initial burst pressure test (as well as the initial pressure cycle test described below) be conducted at ambient temperatures between 5 °C and 35 °C. The IWG of GTR No. 13 determined that container burst strength is not affected by using this range of ambient temperature between 5 °C and 35 °C.[49] This temperature range reduces test costs (thus improving the practicability of the proposed requirements) by enabling outdoor testing without special temperature controls. Extreme temperatures are addressed in later tests.

GTR No. 13 requires that the rate of pressurization be less than or equal to 1.4 MPa/s for pressures higher than 150 percent of the nominal working pressure. If the pressurization rate exceeds 0.35 MPa/s at pressures higher than 150 percent NWP, GTR No. 13 also requires that either the container is placed in series between the pressure source and the pressure measurement device, or that the time at the pressure above a target burst pressure exceeds 5 seconds. These requirements are designed to ensure that a pressure sensor will measure the pressure inside the container accurately. The pressurization rate limit ensures the pressure sensor will have enough time to read the pressure level as it rises. Placing the container in series between the pressure source and the pressure sensor ensures that the container will experience the pressure before the sensor, so there is no chance that the pressure sensor could read a pressure level that is not being experienced by the container. However, NHTSA is concerned that the second option that the time at the pressure above the target burst pressure exceeds 5 seconds is unclear and difficult to enforce. For example, it is not clear what pressure the "target burst pressure" is referring to since the pressure may be increasing continuously. Therefore, this option is not being proposed as an alternative and the container will simply be placed in series between the pressure source and the pressure measurement device. NHTSA seeks comment on this decision.

---

[49] *See* GTR No. 13, Part I, paragraph 81(d)(v).

b. Service life and number of cycles for the baseline initial pressure cycle test for containers on light and heavy vehicles

As discussed above, hydrogen is highly flammable, and therefore, hydrogen containers must not leak during their service life. While hydrogen leakage is a serious safety concern, leaking hydrogen will likely dissipate quickly into the atmosphere given its density, and may or may not ignite/explode, whereas, a hydrogen container burst involves an explosion by definition and is therefore a far worse, catastrophic failure mode that must be prevented under all circumstances regardless of service life. As a result, hydrogen containers are designed to leak before bursting beyond their service lives. This "leak before burst" safety feature is also followed for other high-pressure vehicle fuel containers such as vehicle CNG fuel containers. Systems are typically designed such that the occurrence of leakage should result in vehicle shut down and subsequent repair or removal of the container from service, thereby preventing a burst of the container from occurring.

The baseline pressure cycle test requirement is designed to provide an initial check for resistance to leak or burst due to pressure cycling during service, and a check that the container does in fact leak before burst after the container service life has been exceeded. Accordingly, the baseline initial pressure cycle test requires the container to (i) not leak or burst for a specified number of pressure cycles that are meant to represent maximum container service life, and (ii) leak before burst for a specified number of pressure cycles *beyond* the maximum service life. In the case of (i), the IWG of GTR No. 13 Phase 1 gave contracting parties the option of selecting either 5,500, 7,500, or 11,000 cycles as the expected maximum service life containers. In the case of (ii), the GTR explains that a greater number of pressure cycles (22,000) that far exceeds service life of containers is used to ensure that a container should leak before bursting during the expected service life.

GTR No. 13 provides several examples of the maximum number of empty-to-full fueling cycles for vehicles under extreme service. These examples are described below and summarized in Table-1.

- Sierra Research Report No. SR2004-09-04 for the California Air Resource Board (2004) reported on vehicle lifetime distance traveled by scrapped California vehicles, which all showed lifetime distances traveled below 350,000 miles. Based on these figures and 200 – 300 miles driven per full fueling, the maximum number of lifetime empty-to-full fuelings can be estimated as 1,200 – 1,800.
- Transport Canada reported that required emissions testing in British Columbia, Canada, in 2009 showed the five most extreme usage vehicles had odometer readings in the 500,000 – 600,000 miles range. Using the reported model year for each of these vehicles, this corresponds to less than 300 full fuelings per year, or less than one full fueling per day. Based on these figures and 200 – 300 miles driven per full fueling, the maximum number of empty-to-full fuelings can be estimated as 1,650 – 3,100.
- The New York City (NYC) taxicab fact book reports extreme usage of 200 miles in a shift and a maximum service life of five years.[50] Less than 10 percent of vehicles remain in service as long as five years. The average mileage per year is 72,000 for vehicles operating two shifts per day and seven days per week. There is no record of any vehicle remaining in high usage through-out the full 5-year service life. However, if a vehicle were projected to have fueled as often as 1.5 – 2 times per day and to have remained in service for the maximum 5-year NYC taxi service life, the maximum number of fuelings during the taxi service life would be 2,750 – 3,600.

---

[50] New York City taxicab fact book, Schaller Consulting (2006), http://www.schallerconsult.com/taxi/taxifb.pdf

- Transport Canada reported a survey of taxis operating in Toronto and Ottawa that showed common high usage of 20 hours per day, seven days per week with daily driving distances of 335 – 450 miles. Vehicle odometer readings were not reported. In the extreme worst-case, it might be projected that if a vehicle could remain at this high level of usage for seven years (the maximum reported taxi service life); then a maximum extreme driving distance of 870,000 – 1,200,000 miles is projected. Based on 200 – 300 miles driven per full fueling, the projected full-usage 15-year number of full fuelings could be 2,900 – 6,000.

Table-1: Expected vehicle usage data summary

Data source	Lifetime traveling distance (miles)	Distance per full-fueling (mile)	Number of lifetime empty-to-full filling
Sierra Research Report No. SR2004-09-04: California vehicles	350,000	200 – 300	1,200 – 1,800
Transport Canada: Vehicle fleet &Taxi	500,000 – 600,000	200 – 300	1,650 – 3,100
The New York City (NYC) taxicab fact book: Taxi usage	360,000 (5 year life)	N/A (Fueling frequency 1.5 – 2 times/day)	2750 – 3600 (5 year life)
Transport Canada: Taxi usage	870,000 – 1,200,000	200 – 300	2,900 – 6,000

Based on these examples, the IWG of GTR No. 13 Phase 1 set the minimum number of pressure cycles before leak at 5,500. The maximum number of cycles before leak was set at 11,000 cycles, which corresponds to a vehicle that remains in service with two full fuelings per day for 15 years (expected lifetime vehicle mileage of 2.2 – 3.3 million miles). The last example above shows it is possible for a high usage taxi to experience 6,000 fueling cycles during seven years of service. Taxi service is representative of the most demanding circumstances a light vehicle will experience, so this example is considered worst-case. Furthermore, such a vehicle could be subsequently resold and experience further fuelings beyond 6,000. As a result, the IWG of GTR No. 13 Phase 2 concluded that the choice of 5,500 cycles is not sufficient for containers on light vehicles. However, NHTSA concludes that the maximum choice of 11,000 cycles is too extreme for light vehicles. A vehicle traveling 2.2 – 3.3 million miles is unrealistic even for the most extreme service life for light vehicles. Accordingly, NHTSA proposes 7,500 as the number of cycles in the baseline initial pressure cycle test for which the container does not leak or burst. NHTSA believes that 7,500 pressure cycles is a reasonable representation of the maximum service life of a container, and notes that is greater than that presented in Table 1 for the Transport Canada taxi usage data.

As discussed above, the worst-case scenario is a container failure by burst. To ensure the container leaks before burst beyond the maximum service life, the container is pressure cycled beyond the 7,500 cycles (representing maximum service life) until leak occurs without burst or up to a maximum of 22,000 hydraulic pressure cycles. For vehicles with nominal on-road driving range of 300 miles per full-fueling, 22,000 hydraulic pressure cycles correspond to over 6 million miles, which is beyond extreme on-road vehicle lifetime range.

The analysis summarized above considered light vehicles with a service life of 15 years. When conducting their analysis, the IWG of GTR No. 13 Phase 1 had limited information available on lifetime vehicle mileage and fuelings. In addition, hydrogen vehicles were a new technology and there was very little field experience available to draw upon. As a result, the IWG of GTR No. 13 Phase 1 was conservative in setting the number of cycles for the baseline initial cycle test. In the analysis provided above, short periods of extreme service were extrapolated to a full 15-year service life. This is not a realistic assumption because vehicles generally cannot last in extreme service for a full 15 years.

To address this issue, the IWG of GTR No. 13 Phase 2 reviewed new data on the number of vehicle miles traveled. The analysis was also expanded to include heavy vehicles in addition to light vehicles.[51,52] The data shows that the number of cycles presented in GTR No. 13 for light vehicles correspond more appropriately to a 25-year service life.

For heavy vehicles, the new data on the number of vehicle miles traveled that was collected in Phase 2 indicates a higher number of cycles are required for a 25-year service life than that for light vehicles. This is consistent with the fact that heavy vehicles typically travel farther and remain in service longer than light vehicles. Consequently, for heavy vehicle containers, the IWG of GTR No. 13 Phase 2 set the number of pressure cycles representing maximum container service life at 11,000. In accordance with GTR No. 13 Phase 2, NHTSA proposes to require heavy vehicle containers to neither leak nor burst for 11,000 hydraulic pressure cycles, and also to leak without burst (or neither leak nor burst) beyond the 11,000 hydraulic pressure cycles up to a maximum of 22,000 pressure cycles. The proposed service life, number of hydraulic pressure cycles representing the maximum service life for which the container is required not to leak nor burst, and the number of pressure cycles beyond that representing maximum service life of the container for which the container is required to leak without burst or not leak nor burst at all is summarized in Table-2 for light and heavy vehicles.

---

[51] *See* GTR No. 13 Phase 2 file GTR13-11-12b: The number of cycles, https://wiki.unece.org/download/attachments/123666576/GTR13-9-07%20TF1%20OICA%20GTR13%20Baseline%20Initial%20Cycles.pdf?api=v2

[52] *See* GTR No. 13 Phase 2 file GTR13-9-07: Extension of the service life of the container to 25 years, https://wiki.unece.org/download/attachments/140706658/GTR13-11-12b%20TF1%20%20210927%20Estimation%20of%20VMT%20TF1-JAMA.pdf?api=v2

Table-2: Proposed Service Life and Number of Cycles in the Baseline Hydraulic Pressure Cycle Test for Light and Heavy Vehicles

Vehicle Type	Service Life	No. of cycles representing maximum service life for which the container does not leak nor burst	No. of cycles for which the container leaks without burst, or does not leak nor burst
Light	25 years	7,500	7,501 - 22,000
Heavy	25 years	11,000	11,001 - 22,000

NHTSA seeks comment on the proposed number of cycles in Table-2. NHTSA seeks any additional data available related to vehicle life, lifetime miles travelled, and number of lifetime fuel cycles.

c. Details of the baseline initial cycle test for containers on light and heavy vehicles

The low pressure during each cycle has been set at between 1 MPa to 2 MPa. This is selected to make the test easy to conduct. NHTSA seeks comment whether this low-pressure range is sufficiently wide for test lab efficiency. The high pressure of 125 percent NWP is selected because this is the peak pressure that typically occurs during fueling. Furthermore, this is the high pressure used in the ANSI NGV 2-2007, *Compressed Natural Gas Vehicle Fuel Containers*, ambient cycling test.[53]

GTR No. 13 requires three new containers to be tested during the baseline initial pressure cycle test. However, NHTSA does not believe three new containers need to be tested under the U.S. self-certification system where NHTSA buys and tests vehicles and equipment at the point of sale. Therefore, NHTSA has instead decided to base the value on the results of testing any one container for the baseline initial pressure cycle test. NHTSA seeks comment on this decision.

---

[53] ANSI NGV 2-2007, *Compressed Natural Gas Vehicle Fuel Containers*, 16.3 Ambient Cycling Test. https://webstore.ansi.org/standards/csa/ansingv22007

GTR No. 13's maximum hydraulic pressure cycle rate of 10 cycles/minute is based on the requirement in ANSI NGV 2-2007 for the ambient cycling test.[54] This pressure cycling rate is selected to allow for efficient compliance testing. Actual fueling cycles for hydrogen vehicles occur more slowly. For these reasons, the container manufacturer may specify a hydraulic pressure cycle profile that will prevent premature failure of the container due to test conditions outside of the container design envelope. Changing the hydraulic cycling profile does not change the stringency of the test or the safety of the container. However, the cycling profile can be important because testing NHTSA conducted resulted in a container failure attributed to a rapid defueling profile that was not representative of defueling rates during normal use.[55,56] NHTSA seeks comment on cycling profiles and whether the pressure cycling profile will significantly affect the test result. NHTSA seeks comment on more specifics of what manufacturers should be allowed to specify regarding an appropriate pressure cycling profile for testing their system.

A burst may be preceded by an instantaneous moment of leakage, especially if observed in slow motion. Therefore, NHTSA proposes a minimum time of 3 minutes to sustain a visible leak before the test can end successfully due to "leak before burst." NHTSA seeks comment on this additional requirement.

5. Test for performance durability

The container must withstand stress factors beyond basic pressurization and pressure cycling without leakage or burst. The container must demonstrate its durability by not leaking or bursting during a service life of pressure cycling that includes the application of external stress factors. The container must also withstand 180 percent NWP for four minutes[57] after the

---

[54] *Id.*

[55] DOT HS_812_988. Hydrogen Container Performance Testing, https://rosap.ntl.bts.gov/view/dot/62645.

[56] Details are provided in the technical document "Quantum GTR Pressure Cycle Discussion.pdf" submitted to the docket of this NPRM.

[57] The 180 percent NWP hold for 4 minutes is a simulation of a fueling station pressure regulation failure that results in over pressurization of the container. This test is conducted after all other external stresses have been applied to the container to simulate over-pressurization near the end-of-life of the container.

application of all the external stress factors and have a burst pressure that is at least 80 percent of its BP_O at the end of a service life that includes external stress factors. This requirement is evaluated by the test for performance durability. The test for performance durability uses the same service life described above for the tests for baseline metrics, along with external stress factors applied to the container.

A container is expected to encounter six types of external stress factors:

1. Impact (drop during installation and/or road wear)
2. Static high pressure from long-term parking
3. Over-pressurization from fueling and fueling station malfunction
4. Environmental exposures (chemicals and temperature/humidity)
5. Vehicle fire
6. Vehicle crash

The test for performance durability addresses the first four of these external stresses. Fire is addressed in a separate section for fire. Crash performance is addressed through crash testing in FMVSS No. 307. The test for performance durability is closely consistent with the industry standard SAE J2579_201806, *Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles*.[58]

Other than fire and vehicle crash, testing of the stresses compounded in a series is required.[59] This is because a container may experience all of these stresses during its service life, and the safety need for a hydrogen system remains an issue for the vehicle's entire service life. For example, a container that was dropped during installation could thereafter be exposed to road wear, long term parking, fueling stresses, and environmental exposures. Accordingly, the proposed test for performance durability arranges these external stresses in a sequential

---

[58] SAE J2579_201806. Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles. https://www.sae.org/standards/content/j2579_201806/

[59] This is in contrast to industry standards, wherein performance is evaluated after the application of a single stress factor in order to identify which stress factors cause failure.

application representing a severe in-service permutation of the stresses. The test sequence is as follows:

- Proof pressure test
- Drop test
- Surface damage test
- Chemical exposure test and ambient-temperature pressure cycling test
- High temperature static pressure test
- Extreme temperature pressure cycling test
- Residual pressure test
- Residual strength burst test

The test for performance durability is illustrated in Figure-4.

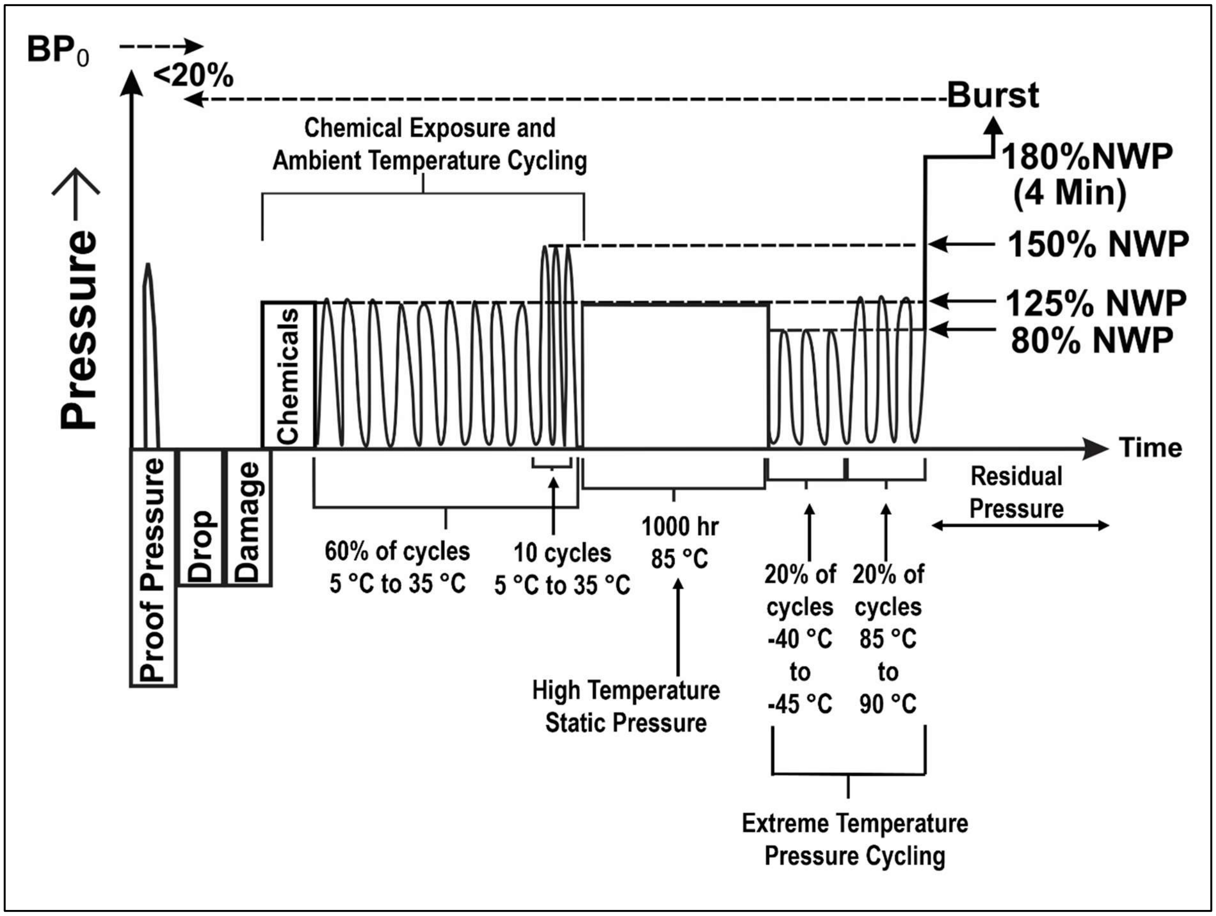

Figure-4: Illustration of the test for performance durability

For similar reasons as those explained above for the baseline tests, the cycling pressure force on containers is applied hydraulically with non-corrosive fluid such as water or a mixture of anti-freeze and water to prevent freezing. This allows for improved test lab safety and faster pressurization and depressurization rates which decreases the cost to conduct the tests.

a. Proof pressure test

The proof pressure test is typically done by the manufacturer before sale of the container. The proof pressure test is performed to confirm that the container will not leak nor burst due to a simple over-pressurization event to 150 percent NWP. The test pressure of 150 percent NWP is selected because fueling stations are expected to provide over-pressure protection of 150 percent NWP. A proof pressure test is a stress factor that can in some cases result in micro-cracks appearing in the container. Micro-cracks may weaken a tank's wall strength, causing the potential for leaks or a burst during the proof pressure test or the subsequent performance durability testing. Therefore, it is important that all containers experience proof pressure.

GTR No. 13 states that a container that has undergone a proof pressure test in manufacture is exempt from this test. However, NHTSA may not know whether a container has undergone the proof pressure test. As a result, NHTSA proposes that all containers will be subjected to the proof pressure test as part of the test for performance durability. In the event that a proof pressure test is conducted during manufacture and as part of the tests for performance durability, the container would experience two proof pressure tests. However, it is not expected that a second application will result in significantly more stress to the container than a single proof pressure test. NHTSA seeks comment on conducting the proof pressure test on all containers.

b. Drop test

The drop test is conducted to simulate dropping the container during handling or installation. Consistent with GTR No. 13, the unpressurized container may be dropped in any one of several orientations such as horizontal, vertical, or at a 45° angle. In the case of a non-cylindrical or asymmetric container, the horizontal and vertical axes may not be clear. In such cases, the container will be oriented using its center of gravity and the center of any of its shut-off valve interface locations. The two points will be aligned horizontally (i.e., perpendicular to gravity), vertically (i.e., parallel to gravity) or at a 45° angle relative to vertical. The center of gravity of an asymmetric container may not be easily identifiable, so NHTSA seeks comment on the appropriateness of using the center of gravity as a reference point for this compliance test and how to properly determine the center of gravity for a highly asymmetric container.

The surface onto which the container is dropped must be a smooth, horizontal, uniform, dry, concrete pad or other flooring type with equivalent hardness. The drop height of 1.8 meters is selected to represent a drop from a forklift during installation. The four possible drop orientations are illustrated in Figure-5 below.

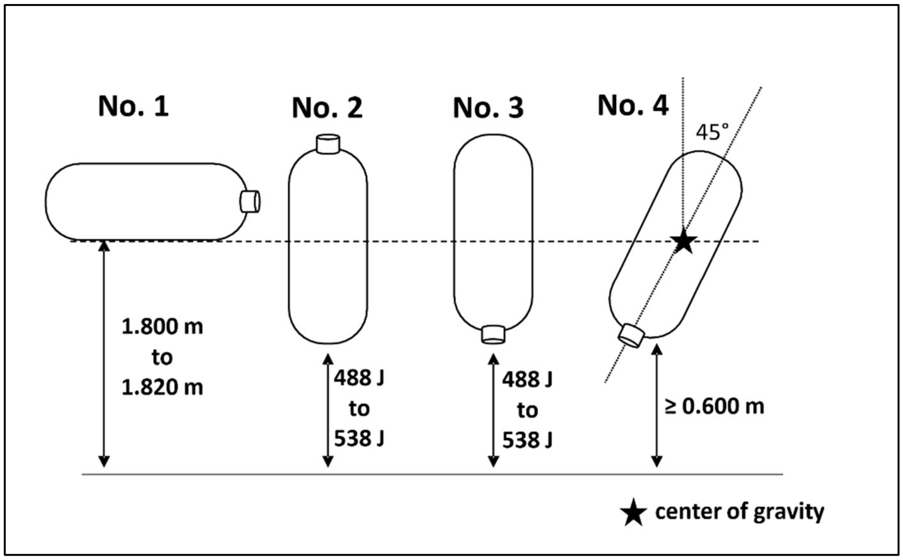

Figure-5: The four possible drop orientations

GTR No. 13 specifies a potential energy of at least 488 J during the vertical drops, along with a maximum drop height of 1.8 m, and a minimum drop height of 0.1 m. It is possible that a drop involving a very lightweight container could not simultaneously satisfy both the 488 J minimum energy and the 1.8 m maximum height. The IWG of GTR No. 13 Phase 2 resolved this conflict by specifying the vertical drop test potential energy of at least 488 J, with an overriding limitation that the drop height not exceed 1.8 m in any case. In the case of a lightweight container that would require a drop height over 1.8 m to reach 488 J of drop energy, the container should be dropped from 1.8 m, regardless of the potential energy. Similarly, a very heavy container could reach a potential energy[60] of 488 J while being less than 0.1 m above the drop surface. In this case, the container should be dropped from the 0.1 m minimum drop height.

For the angled drop, the container is dropped from any angle between 40° and 50° from the vertical orientation with the center of any shut-off valve interface location downward. However, if the lowest point of the container is closer to the ground than 0.6 m, the drop angle is changed such that the lowest point of the container is 0.6 m above the ground and the center of gravity is 1.8 m above the surface onto which it is dropped. This may result in a drop angle greater than 50° from the vertical orientation.

The drop test is conducted with an unpressurized container because the risk of dropping is primarily aftermarket during vehicle repair where a new storage system, or an older system removed during vehicle service, is dropped from a forklift during handling. Additionally, drop testing conducted by NHTSA under various conditions indicated that an unpressurized container is more susceptible to damage in the drop test than a pressurized container.[61]

The drop test is a test in which container attachments may improve performance by protecting the container when it impacts the ground. Consistent with GTR No. 13, the drop test is conducted on the container with any associated container attachments. NHTSA seeks comment on including container attachments for the drop test.

It is possible that the container could experience damage from the drop test that prevents continuing with the remainder of the tests for performance durability. To address this possibility,

---

[60] Potential energy is calculated as the product of container mass, gravitational acceleration, and the height from the center of gravity of the container to the surface onto which the container is dropped.

[61] DOT HS_812_988. Hydrogen Container Performance Testing, https://rosap.ntl.bts.gov/view/dot/62645.

NHTSA proposes that if any damage to the container following the drop test prevents further testing of the container, the container is considered to have failed the tests for performance durability and no further testing is conducted.

c. Surface damage test

The surface damage test applies cuts and impacts to the surface of the container. The cuts on the surface simulate abrasions that can occur due to container mounting hardware or straps. The impacts simulate on-road impacts, such as flying gravel. The surface damage test consists of two linear cuts and five pendulum impacts.

The linear cuts are created with a saw. The first cut is 0.75 millimeters to 1.25 millimeters deep and 200 to 205 millimeters long. The second cut is 1.25 millimeters to 1.75 millimeters deep and 25 millimeters to 28 millimeters long. The second cut is only applied if the container is to be affixed to the vehicle by compressing its composite surface.

GTR No. 13 allowed all-metal containers to be exempt from the linear cuts because (1) metal is scratch resistant compared to non-metal, and (2) metal containers can be so thin that the cuts would fully penetrate the container. NHTSA's proposal includes this exemption, but NHTSA seeks comment on whether another objective and practicable procedure exists for evaluating surface abrasions that could apply to all containers, such as, for example, the application of a defined cutting force to the container surface.

The impacts are created with a pendulum impactor consisting of a pyramid with equilateral faces and square base, and with the summit and edges being rounded to a radius of 3 mm. The impact of the pendulum occurs with a nominal impact energy of 30 J. Prior to the impacts, the container is preconditioned at -40 °C to simulate a worst-case temperature environment. The temperature of -40 °C was selected based on industry standards.[62] We note

---

[62] SAE J2579_201806. Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles.

that weather records show temperatures of -40 °C can occur in northern locations of the United States.[63]

The surface damage test is a test in which container attachments may improve performance by shielding the container from the impacts. For containers with container attachments, GTR No. 13 specifies that if the container surface is accessible, then the test is conducted on the container surface. However, NHTSA is concerned that determining whether the container surface is accessible is subjective, because “accessible” is not defined in the GTR and could have many potential meanings. Therefore, NHTSA is not proposing a specification involving the accessibility of the container surface. Instead, NHTSA proposes that if the container attachments can be removed using a process specified by the manufacturer, they will be removed and not included for the surface damage test nor for the remaining portions of the test for performance durability. Testing the container without its container attachments is representative of a situation in which installation personnel remove the container attachments and fail to re-install them before the container enters service. Container attachments that cannot be removed are included for the test. NHTSA seeks comment on including container attachments for the surface damage test.

In accordance with GTR No. 13, NHTSA proposes specifying the pendulum impacts “on the side opposite from the saw cuts.” For containers with multiple permanently interconnected chambers, GTR No. 13 specifies applying the pendulum impacts to a different chamber to that where the saw cuts were made. However, the agency is not proposing this distinction for pendulum impact location for containers with multiple permanently interconnected chambers because NHTSA is concerned that it may be less stringent (and thus, potentially less protective of safety) than when impacts are to the same chamber where the cuts were applied. NHTSA seeks comment on whether applying the impacts to the opposite side of the same chamber that received the saw cuts may be more stringent than applying the impacts to a separate chamber,

---

[63] Canadian Climate Normals, https://climate.weather.gc.ca/climate_normals/index_e.html

and whether including the specification as written in GTR No. 13 would reduce stringency for containers with multiple permanently interconnected chambers relative to containers with a single chamber.

d. Chemical exposure and ambient pressure cycling test

Consistent with GTR No. 13, the chemical exposure test exposes the container to a range of chemicals that might be encountered in on-road service:

- Sulfuric acid at 19 percent in water to simulate battery acid.
- Sodium hydroxide at 25 percent in water to simulate lye.
- Methanol at 5 percent in gasoline to simulate fueling station fluids.
- Ammonium nitrate at 28 percent in water to simulate fertilizer.
- Methanol at 50 percent in water to simulate windshield-washer fluid.

A pad of glass wool saturated with one of the chemicals listed above is applied to each of the pendulum impact locations from the surface damage test. This is done to simulate each chemical exposure in an area where on-road damage has degraded the container's protective coating. The chemicals are applied with glass wool fibers to keep them in place and reduce evaporation.

After the chemical exposures are in place, pressure cycling commences. The test for performance durability uses the same number of cycles as required by the baseline initial cycle test before leakage. This is a total of 7,500 cycles for light vehicles or 11,000 cycles for heavy vehicles. Of the total cycles, 60 percent are conducted with the chemical exposures in place, and at ambient temperature (5 °C to 35 °C). All but the final 10 of these chemical exposure cycles are conducted from low pressure of 2 MPa to high pressure of 125 percent NWP, as in the baseline initial pressure cycle test. These cycles simulate extended vehicle use after impact damage and exposure to chemicals.

The final 10 chemical exposure cycles are conducted to a high pressure of 150 percent NWP to simulate fueling station over-pressurization. After completing chemical exposure cycles, the chemical exposure pads are removed, and the exposed areas are washed with water to remove excess chemicals.

The chemical exposure test is a test in which container attachments may improve performance by shielding the container from the chemical exposures. Container attachments will be included in the chemical exposure test unless they were removed prior to the surface damage test. NHTSA seeks comment on including container attachments for the chemical exposure test.

e. High temperature static pressure test

Consistent with GTR No. 13, the high temperature static pressure test involves holding the container for 1000 hours at 85 °C and 125 percent NWP. This test simulates an extended exposure to high static pressure and temperature, which is a condition that could occur in the case of a vehicle parked for an extended period of time. The primary risk associated with prolonged parking at high pressure and temperature is stress rupture. However, the stress rupture condition cannot be directly replicated because the relevant time period is years to decades. Alternatively, experimental data on the tensile stress failure of strands representative of those used in container composite wrapping showed that: [64,65]

- For the glass fiber composite strands, the probability of failure for 25 years under tensile stress of 100 percent NWP is equivalent to 1000 hours under a tensile stress of 125 percent NWP.
- The time to failure increased when the load was reduced.
- Carbon fiber composite strands showed greater resistance to stress rupture than glass fiber composite strands in that a small reduction in the applied load resulted in a greater increase in time to failure for the carbon fiber composite strands than for the glass fiber composite strands.

---

[64] SAE Paper 2009-01-0012. Rationale for Performance-based Validation Testing of Compressed Hydrogen Storage by Christine S. Sloane.

[65] Christine S. Sloane, Hydrogen Storage technology - Materials and Applications, edited by Lennie Klebanoff, Section III-12 with Figure 12.6 Glass fiber composite strands.

- For carbon fiber composite strands, the probability of failure for 25 years under tensile stress of 100 percent NWP is approximately equivalent to 500 hours under tensile stress of 125 percent NWP.

An elevated temperature of 85 °C is applied to account for heat-accelerated deterioration. The temperature of 85 °C represents an extreme under-hood temperature for a dark/black-colored vehicle parked outside on asphalt in direct sunlight in 50 °C ambient conditions.[66] Including the extreme temperature condition of 85 °C in the high temperature static pressure test ensures that the container can sustain exposure to 85 °C for 1000 hours under tensile stress of 125 NWP without experiencing stress rupture.

f. Extreme temperature pressure cycling test

Consistent with GTR No. 13, the extreme temperature pressure cycling test involves pressure cycling at extreme temperatures and simulates operation (fueling and defueling) in extreme temperature conditions. As mentioned above, the test for performance durability uses the same number of cycles as required by the baseline initial cycle test before leakage. This is a total of 7,500 cycles for light vehicles or 11,000 cycles for heavy vehicles. The extreme temperature pressure cycling test consists of 40 percent of these total cycles, of which half (20 percent of the total) are conducted at -40 °C and the other half are conducted at 85 °C. The cold temperature -40 °C is selected to simulate a worst-case extreme cold environment as explained above for the surface damage test, and the hot temperature of 85 °C is selected for the same reasons discussed above for the high temperature static pressure test. During the cold pressure cycling, the maximum cycling pressure is only 80 percent NWP. This is because fueling pressures do not reach 100 percent NWP when fueling in extreme cold because as temperature decreases, pressure also decreases. During the hot pressure cycling, the maximum cycling pressure is 125 percent NWP for the reasons discussed above for the baseline initial pressure cycle test.

---

[66] SAE J2579_201806. Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles.

During the extreme temperature pressure cycling test, the relative humidity is maintained above 80 percent to represent high humidity that may foreseeably be encountered in the U.S. Humidity is known to degrade some materials due to the presence of moisture in humid air. Therefore, it is important to include the stress factor of humidity in the test for performance durability.

g. Residual pressure test

Consistent with GTR No. 3, the residual pressure test requires pressurizing the container to 180 percent NWP and holding this pressure for 4 minutes. The 180 percent NWP hold for 4 minutes is a simulation of a fueling station pressure regulation failure that results in over-pressurization of the container. This test is conducted after all other external stresses have been applied to the container to simulate over-pressurization near the end of life of the container.[67,68]

h. Residual strength burst test

Consistent with GTR No. 13, the residual strength burst test involves subjecting the end-of-life container to a burst test identical to the baseline initial burst pressure test. The burst pressure at the end of the durability test is required to be at least 80 percent of the BP_O specified on the container label. This effectively controls the burst pressure degradation rate throughout an extreme service life. Controlling degradation rate is important because, for example, a container starting with a very high BP_O, say 400 percent NWP, but then declining to 180 percent NWP indicates a high degradation rate. NHTSA is concerned that if such a container were to be kept in service beyond its intended service life, the high degradation rate could continue and lead to a high risk of burst. Therefore, the residual burst strength must be at least 80 percent of BP_O. This concept is similar to the requirements for seat belt webbing in FMVSS No. 209 where both minimum breaking strength after abrasion (S4.2d) as well as maximum degradation rate after exposure to light and micro-organisms (S4.2e and S4.2f) are controlled.

---

[67] SAE J2579_201806. Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles. Appendix H

[68] Christine S. Sloane, Hydrogen Storage technology - Materials and Applications, edited by Lennie Klebanoff, Section III-12 with Figure 12.6 Glass fiber composite strands

6. Test for expected on-road performance

For ensuring safe operations, the CHSS must contain hydrogen without leakage or burst. The expected on-road performance test ensures the CHSS is able to effectively contain hydrogen without leakage or burst. Consistent with GTR No. 13, the test for expected on-road performance uses on-road operating conditions including fueling and defueling the container at different ambient conditions with hydrogen gas at low and high temperatures. The test also includes a static high-pressure hold during which the CHSS is evaluated for hydrogen leakage and/or permeation of hydrogen from the CHSS. The container of the CHSS must withstand 180% NWP hold for 4 minutes and have a burst pressure that is at least 80 percent of its BP_O at the end of the test for expected on-road performance. The test for expected on-road performance is closely consistent with the industry standard SAE J2579_201806.[69]

While the test for performance durability evaluates the durability of the container when exposed to external stress factors combined with hydraulic pressure cycling, the test for expected on-road performance does not evaluate durability and instead focuses on pneumatic hydrogen fueling exposure, along with extreme temperature conditions. When fueling, hydrogen gas increases its temperature due to the Joule Thomson effect.[70] As a result, pneumatic testing with hydrogen gas creates rapid temperature swings within the CHSS that do not occur during hydraulic cycling. Pneumatic testing also can result in hydrogen diffusion into materials, which can have deleterious chemical effects such as hydrogen embrittlement.[71] Due to these unique stress factors, a pneumatic test using hydrogen gas is an effective method for evaluating the susceptibility of the CHSS to hydrogen permeation and leakage.

Again, consistent with GTR No. 13, the test for expected on-road performance starts with a proof pressure test pressurizing the container with hydrogen to 150 percent NWP. This is

---

[69] SAE J2579_201806. Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles.

[70] For more information, *see* https://www.britannica.com/science/Joule-Thomson-effect

[71] For more information, *see* https://www.sciencedirect.com/topics/engineering/hydrogen-embrittlement#:~:text=3.7%20Hydrogen%20Embrittlement-,Hydrogen%20embrittlement%20(HE)%20refers%20to%20mechanical%20damage%20of%20a%20metal,when%20hydrogen%20atoms%20are%20generated.

followed by a total of 500 pressure cycles at various environmental conditions. The 500 cycles are broken up into stages for low temperature cycling, high temperature cycling, and ambient temperature cycling. Table-3 shows the number of cycles during each stage, along with other applicable conditions. After the first 250 cycles, the CHSS is held at high pressure and temperature for up to 500 hours while it is evaluated for leakage and/or permeation. After the completion of all 500 cycles, the CHSS is again held at high pressure and temperature for 500 hours and evaluated for leakage and/or permeation.

Following this second leakage/permeation evaluation, the container is pressurized with hydraulic fluid to 180% NWP and held for 4 minutes. The container then undergoes a residual strength burst test in a similar manner as that described for the test for performance durability. Similar to the test for performance durability, the container's residual burst pressure must be at least 80 percent of BP_O. A visual schematic of the test is shown in Figure-6 below.

Table-3: Summary of the test for expected on-road performance.

Stage of Test	*No. of cycles*	*Ambient Conditions*	*Fuel Delivery Temperature*	*Pressurization medium*
Pneumatic proof pressure test to 150% NWP	not appliable	5.0 °C to 35.0 °C	-40.0 °C to -33.0 °C	*Hydrogen gas*
Low temperature cycling	5	-30.0 °C to -25.0 °C	15.0 °C to 25.0 °C	*Hydrogen gas*
Low temperature cycling	20	-30.0 °C to -25.0 °C	-40.0 °C to -33.0 °C	*Hydrogen gas*
High temperature cycling	25	50.0 °C to 55.0 °C 80% to 100% relative humidity	-40.0 °C to -33.0 °C	*Hydrogen gas*
Ambient temperature cycling	200	5.0 °C to 35.0 °C	-40.0 °C to -33.0 °C	*Hydrogen gas*
Static pressure for up to 500 hours with leak/permeation evaluation	not appliable	55.0 °C to 60.0 °C	not appliable	*Hydrogen gas*

High temperature cycling	25	50.0 °C to 55.0 °C, 80% to 100% relative humidity	-40.0 °C to -33.0 °C	*Hydrogen gas*
Low temperature cycling	25	-30.0 °C to -25.0 °C	-40.0 °C to -33.0 °C	*Hydrogen gas*
Ambient temperature cycling	200	5.0 °C to 35.0 °C	-40.0 °C to -33.0 °C	*Hydrogen gas*
Static pressure for up to 500 hours with leak/permeation evaluation	not appliable	55.0 °C to 60.0 °C	not appliable	*Hydrogen gas*
Residual pressure test	not applicable	not applicable	not applicable	Hydraulic fluid
Burst test	not applicable	not applicable	not applicable	Hydraulic fluid

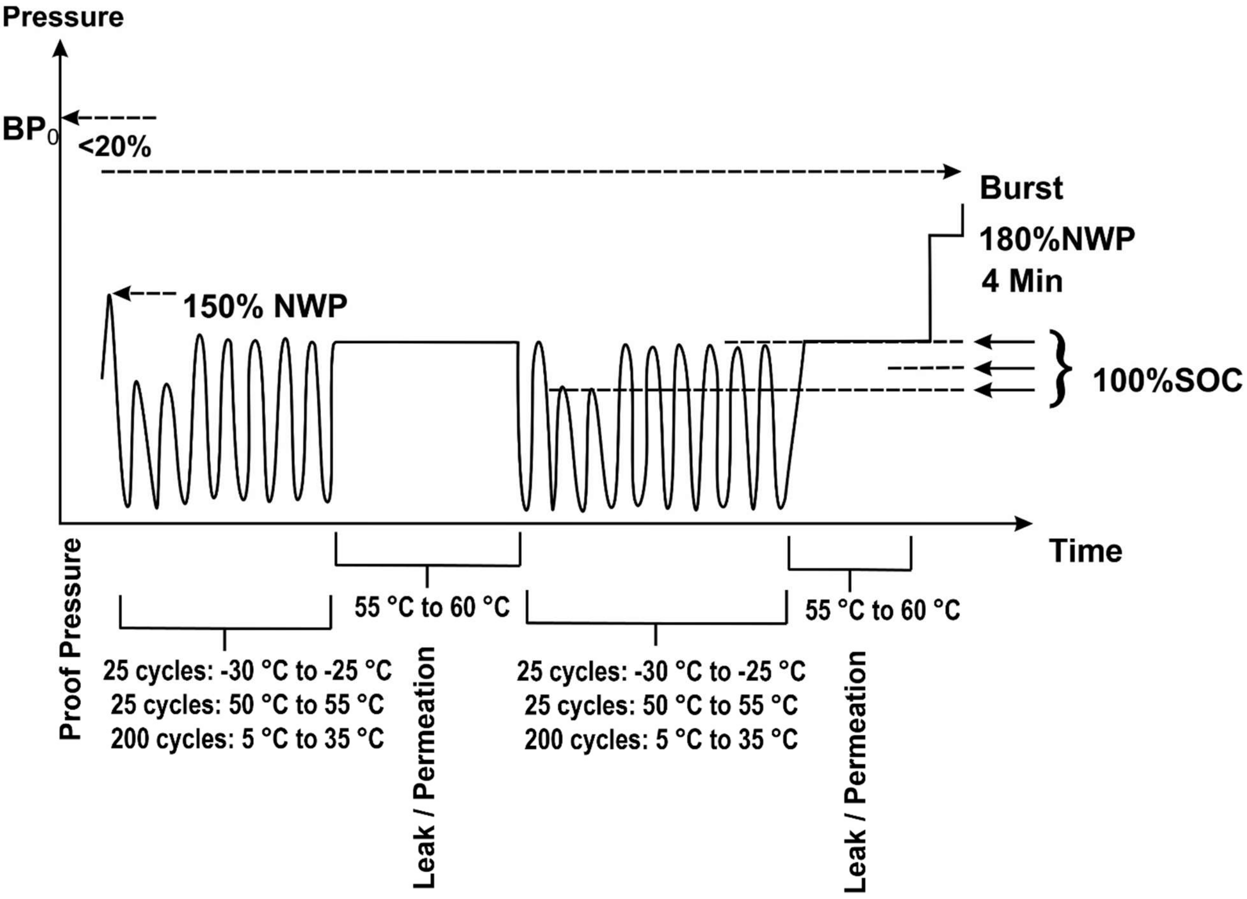

Figure-6: Illustration of the test for expected on-road performance.

a. Proof pressure test

The proof pressure test is conducted in the same manner and for the same reasons discussed above for the test for performance durability. However, in this test, the container is pressurized to 150 percent NWP using hydrogen gas which has been pre-cooled to -40.0 °C to -33.0 °C. This is the temperature range to which hydrogen fueling stations typically pre-cool hydrogen to offset the hydrogen's temperature increase during fueling.

b. Ambient and extreme temperature gas pressure cycling test

The expected lifetime fueling exposure consists of 500 fuel cycles from 2 MPa to 125 percent NWP (empty-to-full) under a variety of ambient fueling temperatures. The number 500 is obtained through a calculation of expected vehicle lifetime driving range divided by driving range per full-fueling. This calculation and the data source is summarized in Table-4.

Table-4: Maximum number of full fueling/defueling cycles

	Expected vehicle lifetime driving range	**Expected vehicle driving range per full-fueling**	**Expected worst-case number of full-fueling**
Data source	Sierra Research Report No. SR 2004-09-04, September 22, 2004	2006-2007 market data of high volume passenger vehicle manufacturers in Europe, Japan, North America	
Calculation	250,000 km (155,000 miles)	483 km (300 miles)	**500**

Some vehicles may exceed 500 fuel cycles if partial fueling occurs in the vehicle lifetime. However, the stress of full fueling exceeds the stress of partial fueling because of the higher pressure and temperature change during full-fueling. NHTSA believes that, as a result, 500 full-fueling cycles should provide robust demonstration of leak-free fueling capability.

The industry standard SAE J2601_202005 *Fueling protocols for light duty gaseous hydrogen surface vehicles* establishes industry-wide fueling protocols for the fueling of hydrogen into passenger vehicles. The guidelines include:[72]

1. The maximum pressure within the vehicle fuel system is 125 percent NWP
2. Gas temperature within the vehicle fuel system is less than or equal to 85 °C
3. Fuel flow rate at dispenser nozzle is less than or equal to 60 g/s
4. The dispenser is capable of dispensing fuel at temperatures between -40 °C and -33 °C

These guidelines are applied at hydrogen fueling stations when fueling hydrogen vehicles. During the ambient and extreme temperature gas pressure cycling test, the rate of pressurization must be greater than or equal to the ramp rate specified by a table of ramp rates based on SAE J2601_202005, according to the CHSS volume, the ambient conditions, and the fuel delivery temperature. If the required ambient temperature is not available in the table, the closest ramp rate value or a linearly interpolated value is used. This ensures that the fueling cycles are similar to those that would occur during on-road service. Table-5 shows the ramp rates based on SAEJ2601_202005, for different CHSS volume, the ambient conditions, and the fuel delivery temperature. GTR No. 13 specifies that the pressure ramp rate shall be decreased if the measured internal temperature in the container exceeds 85 °C.

---

[72] SAE J2601_202005. Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles. https://www.sae.org/standards/content/j2601_202005/

Table-5: Pressure ramp rates for the test for expected on-road performance

CHSS VOLUME (L)	*CHSS Pressurization Rate (MPa/min)*			
	50.0 °C to 55.0 °C Ambient Conditions -33.0 °C to -40.0 °C Fuel Delivery Temperature	*5.0 °C to 35.0 °C Ambient Conditions -33.0 °C to -40.0 °C Fuel Delivery Temperature*	-30.0 °C to -25.0 °C *Ambient Conditions -33.0 °C to -40.0 °C Fuel Delivery Temperature*	-30.0 °C to -25.0 °C *Ambient Conditions* 15.0 °C to 25.0 °C *Fuel Delivery Temperature*
50	7.6	19.9	28.5	13.1
100	7.6	19.9	28.5	7.7
174	7.6	19.9	19.9	5.2
250	7.6	19.9	19.9	4.1
300	7.6	16.5	16.5	3.6
400	7.6	12.4	12.4	2.9
500	7.6	9.9	9.9	2.3
600	7.6	8.3	8.3	2.1
700	7.1	7.1	7.1	1.9
1000	5.0	5.0	5.0	1.4
1500	3.3	3.3	3.3	1.0
2000	2.5	2.5	2.5	0.7
2500	2.0	2.0	2.0	0.5

Extreme environmental temperatures around the world are summarized in Table-6. To ensure safety in extremely hot conditions, some fueling pressure cycles are conducted at 50 °C. To ensure safety in extremely cold conditions, consistent with GTR No. 13 Phase 2 amendments, some fueling pressure cycles are conducted at -25 °C. The temperature -25 °C is used instead of -40 °C because testing at -40 °C is impractical during the test for expected on-road performance. Specifically, a test apparatus must operate at well below -40 °C in order to maintain the temperature surrounding the CHSS at -40 °C. In addition, at -40 °C, test laboratories encounter difficulties such as freezing valves and failing o-ring seals. This can significantly increase test cost. Furthermore, testing conducted by NHTSA found that, for the test for expected on-road performance, testing at -25 °C yields the same results as testing at -40 °C.[73] This change does not compromise the safety intent of the test because in-tank gas temperatures will reach -40 °C due to gas expansion during depressurization. In addition, pressure cycling under the extreme cold condition of -40 °Cis tested separately during the test for performance durability. Therefore, -25 °C is proposed as the extreme cold temperature for the test for expected on-road performance, which is consistent with the Phase 2 amendment to GTR No. 13. In summary, NHTSA is proposing 50 °C for the high temperature pressure cycles and -25 °C for the cold temperature pressure cycles.

Table-6: Extreme environmental temperatures around the world

Data source: Environment Canada 1971-2000			
Temperature	**Areas that occurs**	**Frequency of sustained exposure to this temperature (year)**	**Extremes of ambient environmental temperature used for this test**
Around 50 °C	desert areas of lower latitude countries	5 percent	**50 °C**
Less or equal to -40 °C	countries north of the 45th parallel	5 percent	**-40 °C**
Less than -30 °C	countries north of the 45th parallel	5 percent of vehicle life	

As described above, hydrogen fueling stations typically pre-cool hydrogen to between -40°C and -33°C. However, a fueling station failure could result in the fueling station delivering

---

[73] DOT HS_811_832. Cumulative Fuel System Life Cycle and Durability Testing of Hydrogen Containers,https://www.nhtsa.gov/sites/nhtsa.gov/files/811832.pdf

hydrogen at ambient temperature. This would lead to very high temperatures inside the CHSS after a full fueling. To account for this risk, the first 5 cycles in the ambient and extreme temperature gas pressure cycling test are conducted with hydrogen fuel at between 15 °C and 25°C, as opposed to the pre-cooled hydrogen between -40°C and -33°C which is used for the remaining 495 cycles.

All pressure cycles are performed to 100 percent state-of-charge (SOC). SOC is defined by the ratio of hydrogen density at a given temperature and pressure to hydrogen density at NWP and 15 °C.[74] Specifying 100 percent SOC ensures an equivalent quantity of hydrogen in the CHSS regardless of the resulting temperature and pressure. For example, 100 percent NWP at 15 °C corresponds to 80 percent NWP at -40 °C. In either case, however, the CHSS is at 100 percent SOC (fully fueled).

The first 10 cycles (cold cycles) are performed with the CHSS stabilized with the external air temperature surrounding the CHSS at -25 °C at the beginning of the cycle. This ensures there is no residual heat present from the previous fueling cycle and maximizes the severity of the cold external temperature. However, the process to equilibrate a storage system is time-consuming. As a result, the next 15 cycles are performed with an external air temperature surrounding the CHSS of -25 °C, but without CHSS equilibration to the external temperature.

The next 25 cycles are performed with an external temperature of 50 °C. For the first 5 of these cycles, the CHSS is stabilized with the external air temperature surrounding the CHSS at the at the beginning of the cycle. At this point, the external temperature to the system is at its hottest, and the CHSS pressure is at its minimum. The fueling process will then progressively heat the contents of the CHSS until full (100 percent SOC). At this point, the CHSS reaches its hottest possible interior temperature. In addition, these 25 cycles are performed with the relative humidity over 80 percent surrounding the CHSS. This adds the stress of excessive humidity

---

[74] Since the hydrogen gas density varies nonlinearly with temperature and pressure, a table is provided in the regulatory text for hydrogen density at different pressures and temperatures.

which is common in extreme hot climates. Specifically, the high humidity keeps a thin film of water on surfaces where dissimilar metals may be in contact, such as valve to tank interfaces or valve body to valve connection interfaces. This water film adds the necessary conduction path to effect galvanic corrosion. Galvanic corrosion can cause pitting and other forms of metal loss which can degrade the strength of materials and impact sealing surfaces. Therefore, it is important to include the stress factor of humidity in the test for expected on-road performance

The next 200 cycles are performed with ambient external temperature of (5 °C to 35 °C). This represents a normal ambient temperature. After these 200 cycles (at a total cycle count of 250), the extreme temperature static gas pressure leak/permeation test is performed. This test is discussed in the next section. However, after the completion of the permeation test, pressure cycling continues for an additional 250 cycles.

The first 25 of these additional cycles (cycle count 251-275) are performed with the extreme hot external temperature of 50 °C. The next 25 cycles (cycle count 276-300) are performed with the extreme cold temperature -25 °C. In this series, the order of extreme hot and cold cycles is switched. This accounts for compounding stress from transitioning from hot cycling to cold cycling, as opposed to the previous series, which transitioned from cold to hot. The final 200 cycles (cycle count 301-500) are performed with ambient external temperature of 5 °C to 35 °C. After the completion of cycling, the extreme temperature static gas pressure leak/permeation test is performed for a second time.

GTR No. 13 states that if system controls that are active in vehicle service prevent the pressure from dropping below a specified pressure, the test cycles during the ambient and extreme temperature gas pressure cycling test must not go below that specified pressure. In addition, GTR No. 13 states that if devices and/or controls are used in the intended vehicle application to prevent an extreme internal temperature, the test may be conducted with these devices and/or controls in place. However, NHTSA’s approach to testing involves the agency independently purchasing (on the open market) and then testing vehicles. With this approach, NHTSA has no way of determining what system controls and/or devices are active in the vehicle, because this information is typically proprietary and is not publicly available. As a result, all cycles would be performed with an initial pressure of between 1 MPa and 2 MPa and extreme internal temperatures will not be prevented during cycling. Furthermore, and importantly for safety, this is a condition that could occur in the event the system controls and/or devices fail in service.

c. Extreme temperature static gas pressure leak/permeation test

Leak and permeation are risk factors for fire hazards, particularly when parking in confined spaces such as garages. The extreme temperature static gas pressure leak/permeation test is designed to simulate extended parking in a confined space under an elevated temperature. In these conditions, hydrogen can leak or permeate from the CHSS and slowly accumulate in the surrounding air. During the extreme temperature static gas pressure leak/permeation test, the pressurized CHSS at 100% SOC is held at 55 °C for a period of up to 500 hours. Any hydrogen leakage and/or permeation from the CHSS cannot exceed the limit of 46 milliliter/hour (mL/h) per liter of CHSS water capacity. This limit is discussed below. The test may end before 500 hours if three consecutive hydrogen permeation rates separated by at least 12 hours are within 10 percent of the prior rate because this indicates a permeation steady state has been reached. NHTSA seeks comment on how to accurately measure or otherwise determine the permeation rate from the CHSS.

The leak/permeation limit is characterized by the many possible combinations of vehicles and garages, and the associated test conditions. The leak/permeation limit is defined to restrict the hydrogen concentration from reaching 25 percent lower flammability limit (LFL) by volume. The LFL of hydrogen is lowest concentration of hydrogen in which a hydrogen gas mixture is flammable. National and international standard bodies (such as National Fire Protection

Association [NFPA] and IEC) recognize 4 percent hydrogen by volume in air as the LFL.[75] The conservative 25 percent LFL limit accounts for concentration non-homogeneities and is equivalent to 1 percent hydrogen concentration in air.[76,77]

Worst case ventilation in structures where hydrogen vehicles can be parked is expected to be at or below 0.18 air changes per hour, but the exact design value is highly dependent on the type and location of structures in which the vehicles are parked. In the case of light passenger vehicles, an extremely low air exchange rate (of 0.03 volumetric air changes per hour) has been measured in “tight” wood frame structures (with plastic vapor barriers, weather-stripping on the doors, and no vents) that are sheltered from wind and are very hot (55 °C) with little daily temperature swings that can cause density-driven infiltration. The resulting discharge limit for a light vehicle that tightly fits into a garage of 30.4 cubic meters (m^3) with 0.03 volumetric air exchange per hour is 150 mL/minute (at 115 percent NWP for full fill at 55°C), corresponding to no more than 1 percent hydrogen concentration in air.

In order to determine the leak/permeation limit for the expected on-road performance test, consistent with GTR No. 13, the vehicle-level 150 mL/min leak/permeation limit is expressed in terms of allowable leak/permeation for each container in the storage system at 55 °C and 115 percent NWP. This corresponds to 46 mL/hour(h)/Liter(L)-water-capacity for each container in the storage system.[78] The use of this limit is applicable to light vehicles that are smaller or larger than the base described above. If, for example, the total water capacity of the

---

[75] *See* Gases - Explosion and Flammability Concentration Limits. https://www.engineeringtoolbox.com/explosive-concentration-limits-d_423.html

[76] Data for hydrogen dispersion behavior, garage and vehicle scenarios, including garage sizes, air exchange rates and temperatures, and the calculation methodology are found in the following reference prepared as part of the European Network of Excellence HySafe: P. Adams, A. Bengaouer, B. Cariteau, V. Molkov, A.G. Venetsanos, "Allowable hydrogen permeation rate from road vehicles," https://h2tools.org/sites/default/files/2019-08/paper_-_part_1.pdf

[77] NFPA 30A-2015, Code for Motor Fuel Dispensing Facilities and Repair Garages, 7.4.7.1, https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=30A

[78] Data for hydrogen dispersion behavior, garage and vehicle scenarios, including garage sizes, air exchange rates and temperatures, and the calculation methodology are found in the following reference prepared as part of the European Network of Excellence HySafe: P. Adams, A. Bengaouer, B. Cariteau, V. Molkov, A.G. Venetsanos, "Allowable hydrogen permeation rate from road vehicles," https://h2tools.org/sites/default/files/2019-08/paper_-_part_1.pdf

light vehicle storage system is 330 L (or less) and the garage size is 50 m^3, then the 46 mL/h/L-water-capacity requirement results in a steady-state hydrogen concentration of no more than 1 percent. This can be shown by calculating the allowable discharge from the light vehicle based on the requirement of 46 mL/h/L per container volume capacity (that is, 46 mL/h/L x 330L / (60 min/h) = 253 mL/min) which is similar to the allowable discharge based on the garage size of 50 m^3 with an air exchange rate of 0.03 volumetric air exchanges per hour (that is, 150 mL/min x 50 m^3 / 30.4 m^3 = 247 mL/min). Since both results are essentially the same, the hydrogen concentration in the garage is not expected to exceed 1 percent for light vehicles with storage systems of 330L (or less) in 50 m^3 garages.

Since the discharge limit has been found to be reasonably scalable depending on the vehicle size, the discharge limit for alternative vehicle sizes in tight-fitting garages with 0.03 volumetric air exchanges per hour can be determined from the 150 mL/minute discharge limit computed above using a scaling factor R computed as:

$$R = (V_{width}+1)\ (V_{height}+0.5)\ (V_{length}+1)/\ 30.4$$

where V_{length}, V_{width}, and V_{height} are the dimensions of the vehicle in meters,

Similarly, the use of 46 mL/h/L-water-capacity requirement for storage system containers is also scalable to larger medium-duty and heavy-duty vehicles. Figure-7 shows the required volumetric air exchange rate that would result in less than 25 percent LFL of hydrogen by volume in garages of various sized vehicles equipped with CHSS that have no more than a 46 mL/L/H permeation rate. Examples of current or currently-planned hydrogen vehicles shown in Figure-7 indicate that the required ventilation rate for garages of large vehicles (buses and tractor-trailers) is lower than that of small vehicles (passenger cars). Light hydrogen vehicles which can possibly be parked in tight garages (with as low as 0.03 volumetric air changes per hour) are required to have permeation/leak rate less than of 46 mL/hour(h)/Liter(L)-water-capacity for each container in the vehicle's CHSS.[79] Even though medium-duty and heavy-duty vehicles are not expected to be parked in such "tight" garages as is the case with light vehicles, in order to better meet the safety need, we conservatively assume an equivalent rate of 0.03 volumetric air exchanges for garages of these vehicles. While it is foreseeable that medium-duty and heavy-duty vehicles may be parked in more open (naturally-ventilated) or mechanically-ventilated spaces, the 46 mL/h/L-water-capacity requirement for storage system containers provides a safety margin in the event of mechanical ventilation failures.

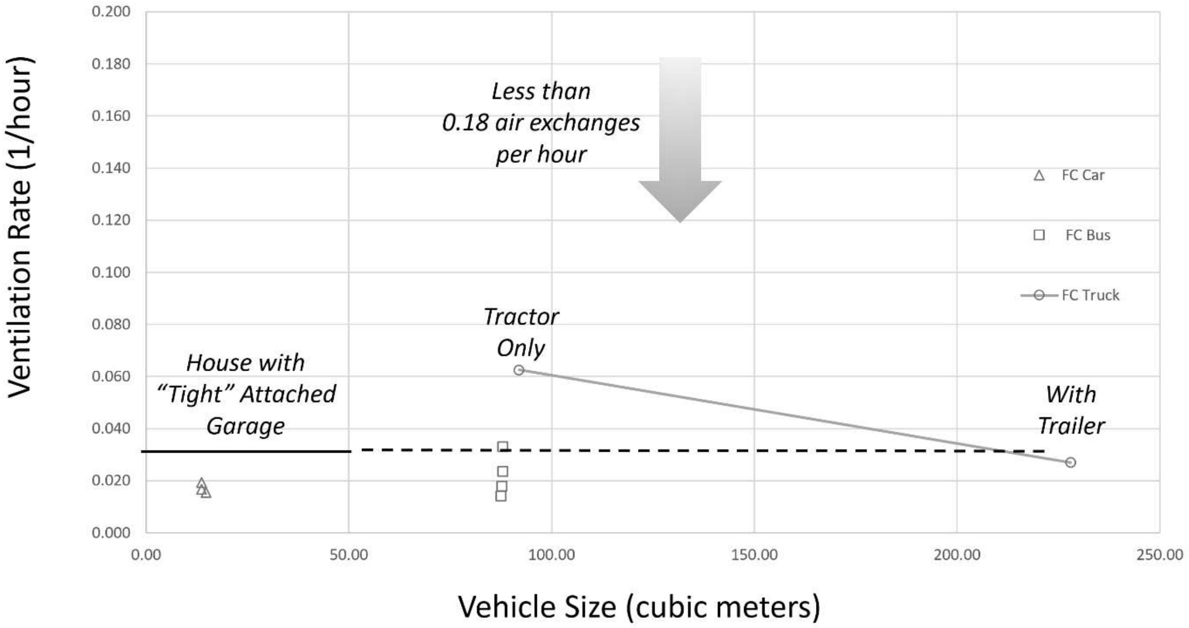

Figure-7: Required Volumetric Air Exchange Rate (Ventilation Rate) of Enclosed Space Surrounding a Hydrogen Vehicle that Results in Less than 25 Percent Lower Flammability Limit of Hydrogen by Volume.

In addition to the required leak/permeation limit discussed above, GTR No. 13 also includes a localized leak requirement. This requirement is based on the SAE technical paper

---

[79] This leak/permeation limit for each container ensures that the hydrogen concentration is lower than 25 percent of the lower flammability limit (LFL) by volume and the hydrogen concentration in air is less than 1 percent.

2008-01-0726, *Flame Quenching Limits of Hydrogen Leaks*.[80] This paper states that the lowest possible flammable flow for hydrogen is about 0.005 milligrams per second (mg/s) (3.6 normal millilitres per minute (NmL/min)).[81] As a result, if a hydrogen permeation rate over 0.005 mg/s is detected, a localized leak test ensures that the hydrogen is not all emanating from the same localized area of the container. This leak test is conducted as a bubble test. In a bubble test, a surfactant solution is applied across the CHSS and the tester observes for the formation of bubbles in the solution resulting from any leaks. If bubbles are detected, the test lab estimates the leak rate based on the average size of the bubbles and the number of bubbles generated per unit of time.

However, NHTSA is concerned that this requirement would not meet the Safety Act requirement for FMVSSs to be objective, due to the subjective estimation of bubble sizes. Therefore, the localized leak requirement has not been included in FMVSS No. 308. Furthermore, NHTSA believes that the primary safety risk of accumulating hydrogen is already addressed by the overall permeation limit of 46 mL/h/L-water-capacity. NHTSA seeks comment on not including the localize leak requirement during the extreme temperature static gas pressure leak/permeation test. If commenters believe it should be included, NHTSA requests that they explain (1) how they believe it could be made more objective and (2) how specifically it would add to the standard's ability to meet the safety need.

d. Residual pressure test & residual strength burst test

The residual pressure test and residual strength burst test are conducted in the same manner and for the same reasons discussed above for the test for performance durability.

7. Test for service terminating performance in fire

---

[80] SAE Technical report 2008-01-0726. Flame Quenching Limits of Hydrogen Leaks. Figure 3 to Figure 9. https://www.sae.org/publications/technical-papers/content/2008-01-0726/

[81] A normal milliliter, also known as a standard cubic centimeter, represents the volume a gas would occupy at standard temperature (0 °C) and standard pressure (1 atmosphere).

Vehicle fire presents a severe risk to the safe containment of hydrogen. Fire can rapidly degrade the container while simultaneously increasing the pressure inside the container. To avoid the possibility of burst, CHSS should be designed to vent their pressurized contents when exposed to fire. Under the proposed standard, the CHSS must vent its pressurized hydrogen during the test for service terminating performance in fire, discussed below, which simulates a vehicle fire. The CHSS must expel its contents (high pressure hydrogen gas) in a controlled manner through its TPRD(s) without the occurrence of burst.

A comprehensive examination of CNG container in-service failures between 2000 and 2008 showed that the majority of fire incidents occurred on storage systems that did not utilize properly designed TPRDs.[82] The in-service failures resulted when TPRDs did not respond to protect the container due to the lack of adequate heat exposure on the TPRDs, while a small "localized" fire degraded the container wall elsewhere, eventually causing the container to burst. Prior to GTR. No. 13, localized fire exposure had not been addressed in regulations or industry standards. The test for service terminating performance in fire addresses both localized and engulfing fires with two respective test stages.

The test for service terminating performance in fire evaluates the CHSS. It is possible that vehicle manufacturers may add additional fire protection features as part of overall vehicle design, and GTR No. 13 includes the option of conducting CHSS fire testing with vehicle shields, panels, wraps, structural elements, and other features as specified by the manufacturer. However, adding vehicle-level protection features is not practical for testing. Furthermore, NHTSA believes that it is important for safety that the CHSS itself can withstand fire and safely vent in the event its shielding is compromised – for example, if a crash damages the shielding, and the shielding was an integral part of the CHSS's ability to withstand fire, then the CHSS should be able to vent properly before it explodes. As a result, vehicle-level protection measures

---

[82] SAE Technical Paper 2011-01-0251. Establishing Localized Fire Test Methods and Progressing Safety Standards for FCVs and Hydrogen Vehicles.
https://www.sae.org/publications/technical-papers/content/2011-01-0251/

are not evaluated by the test for service terminating performance in fire. However, if a CHSS includes container attachments, these attachments are included in the fire test. NHTSA seeks comment on excluding vehicle-specific shielding and on including container attachments as part of the fire test, particularly in the case of container attachments which can be removed using a process specified by the manufacturer.

The fire test temperature targets set forth in GTR No. 13 are based on vehicle fire experiments conducted by the Japanese Automobile Research Institute (JARI).[83] Some key findings from these vehicle-level fire experiments are as follows:

- About 30 to 50 percent of the JARI vehicle fires resulted in a "localized" fire. In these cases, the data indicated the container could have been locally degraded before TPRDs would have activated.
- Thermal gravimetric analysis (TGA) indicated that composite container materials begin to degrade rapidly at 300 °C.
- While the vehicle fires often lasted 30-60 minutes, the period of localized fire container degradation lasted less than 10 minutes.
- Peak temperatures on the test containers' surfaces reached 700 °C during the localized fire stages.
- The rise in peak temperature near the end of the localized fire period often indicated the transition to an engulfing fire.
- Peak temperatures on the test containers' surfaces reached 1000 °C during the engulfing fire stage.

Based upon these experiments, temperature limits were defined in GTR No. 13 to characterize the thermal exposure during the localized and engulfing fire stages:

---

[83] *Id*.

- The minimum container surface temperature during the localized fire stage for the side of the container facing the fire was set to 450 °C to create a challenging but realistic thermal condition.
- The maximum container surface temperature during the localized fire stage for the side of the container facing the fire and for the sides of the container was set to 700 °C.
- The minimum container surface temperature during the engulfing fire stage on the side of the container facing the fire was set to 600 °C, because this was the lowest value observed for this side of the container during the engulfing fire stage.
- A maximum temperature limit on the bottom of the container during the engulfing stage was not necessary as the temperature is naturally limited.

The updates to the fire test by the IWG of GTR No. 13 Phase 2 focused on improving the repeatability and reproducibility across test laboratories. Two significant improvements to the fire test are (1) the use of a pre-test checkout procedure and (2) basic burner specifications. The pre-test checkout requires conducting a preliminary fire exposure on a standardized steel container to verify that specified fire temperatures can be achieved for the localized and engulfing fire segments of the test prior to conducting the fire test on a CHSS. During this pre-test checkout, the fuel flow is adjusted to achieve fire temperatures within the limits given in Table-7 as measured on the surface of the pre-test steel container. The use of a pre-test steel container instead of an actual CHSS improves the accuracy and repeatability of the test because it avoids possible container material degradation that could affect the temperature measurements.

Table-7: Pre-test checkout temperature requirements

Fire Stage	*Temperature Range on Bottom of Pre-test Container*	*Temperature Range on Sides of*	*Temperature Range on Top of Pre-test Container*

		Pre-test Container	
Localized	450 °C to 700 °C	less than 750 °C	less than 300 °C
Engulfing	Average temperatures of the pre-test container surface measured at the three bottom locations must be greater than 600 °C	Not applicable	Average temperatures of the pre-test container surface measured at the three top locations must be at least 100 °C, and when greater than 750 °C, must also be less than the average temperatures of the pre-test container surface measured at the three bottom locations

In addition to temperature requirements, GTR No. 13 also specifies required heat release rates per unit area (HRR/A) during the localized and engulfing fire stages. The HRR/A is calculated using the lower heating value (LHV) of the fuel, which is measured in megajoules of energy released per kilogram of fuel consumed. To obtain HRR/A, the fuel flow rate is multiplied by LHV and then divided by the burner area. GTR No. 13 specifies a standardized calculation for burner area. NHTSA has considered the specification for HRR/A and determined that it could result in over-specification of the test parameters, potentially making it very difficult to conduct the test. In addition, NHTSA believes that the detailed temperature specifications for the pre-test container during the pre-test checkout are sufficient to ensure repeatability and reproducibility of the test.[84] Therefore, NHTSA is not proposing specifications for HRR/A. NHTSA seeks comment on this decision.

The dimensions of the pre-test steel container for the pre-test checkout are similar to those of the containers from the JARI vehicle fire tests. The standard pre-test steel container is fabricated from 12-inch Schedule 40 NPS pipe along with end caps. The diameter of this pipe is 12 inches (304 mm), while the length is:

- at least 800 mm
- not greater than 1.65 m
- greater than or equal to the length of the CHSS to be tested, unless the CHSS is greater than 1.65 m

The pre-test steel container is instrumented with thermocouples in the same manner as the containers in the JARI vehicle fire tests and mounted above the burner in the same manner as the CHSS to be fire tested. Thermocouples are located along the cylindrical section of the pre-test container at the bottom surface exposed to the burner flame, mid-height along the left and right side of the cylindrical surface, and top surface opposite the direct exposure to the burner flame. Example thermocouple locations are shown below in Figure-8.

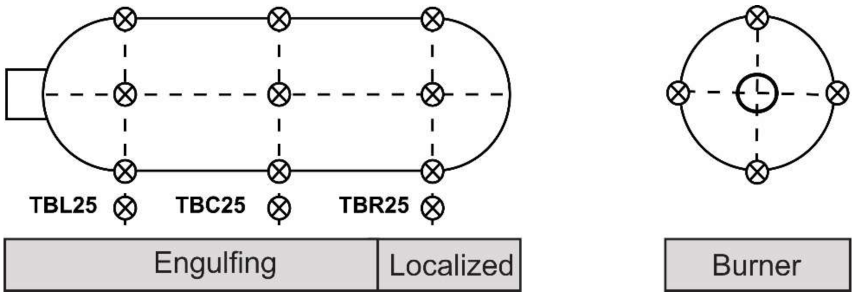

Figure-8: Thermocouple Locations for the Pre-Test Checkout

---

[84] Testing conducted to support enhancement of the fire test specifications in GTR No. 13 Phase 2 indicated that the container surface temperature specifications in the pre-test container fire test along with the burner temperatures provided the needed repeatability and reproducibility of the test.

The positioning of the pre-test container relative to the localized and engulfing zones of the burner in the pre-test checkout must be consistent with the positioning of the CHSS over the burner that is to be tested.

The three thermocouples along the bottom (labeled TBL25, TBC25, TBR25 in Figure-8) are considered burner monitor thermocouples. These thermocouples are positioned 25 mm below the pre-test container. Since these thermocouples are intended to monitor the burner, an alternative would be to position these thermocouples relative to the burner itself. NHTSA seeks comment on whether it is preferable to position the burner monitor thermocouples relative to the pre-test container or relative to the burner.

The pre-test checkout is performed at least once before the commissioning of a new test site. Additionally, if the burner and test setup is modified to accommodate a test of different CHSS configurations than originally defined or serviced, then repeat of the pre-test checkout is needed prior to performing CHSS fire tests. NHTSA seeks comment on the frequency of conducting this pre-test checkout for ensuring repeatability of the fire test on CHSS.

After the pre-test checkout is satisfactorily completed, the steel pre-test container is removed and the CHSS to be fire tested is mounted for testing. The CHSS fire test is then conducted with fuel flow settings identical to the pre-test checkout. The profile of the CHSS fire test is shown in Figure-9. During the CHSS fire test, the only thermocouples used are the burner monitor thermocouples, which are positioned 25 mm below the bottom of the CHSS. Temperatures on the surface of the CHSS will vary naturally based on interactions with the flames, and these temperatures are not controlled during the CHSS fire test. The burner monitor thermocouples are used only to ensure the burner is producing a fire closely matching the pre-test checkout.

The localized fire continues for a total of 10 minutes and then the test transitions to the engulfing stage which continues until the test is complete (test completion is discussed below). The minimum value for the burner monitor temperature during the localized fire stage ($\mathrm{Tmin}_{\mathrm{LOC}}$)

is calculated by subtracting 50 °C from the minimum of the 60-second rolling average of the burner monitor temperature in the localized fire zone of the pre-test checkout. The minimum value for the burner monitor temperature during the engulfing fire stage ($Tmin_{ENG}$) is calculated by subtracting 50 °C from the minimum of the 60-second rolling average of the average burner monitor temperature in the engulfing fire zone of the pre-test checkout.

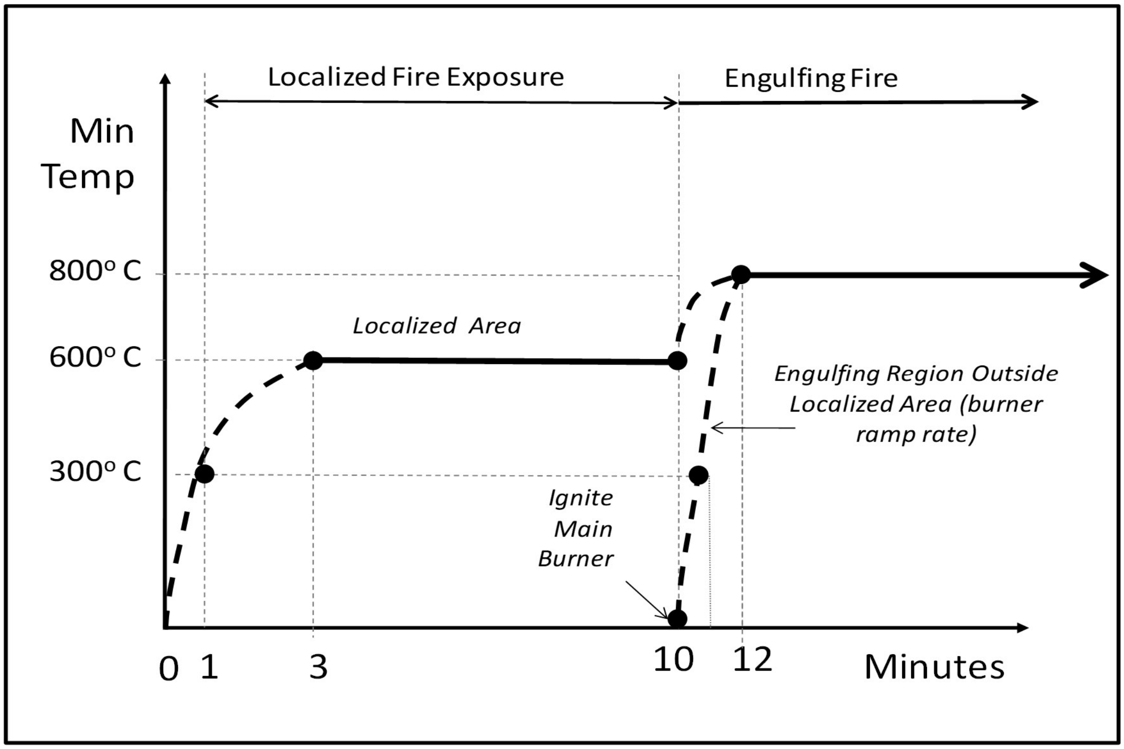

Figure-9 Temperature profile of the fire test.

NHTSA has conducted CHSS fire testing to verify the feasibility of the test for service termination performance in fire as currently proposed. Overall, the testing was completed successfully, demonstrating the feasibility of the proposed test for service terminating performance in fire. The results of this testing are summarized in the test report *GTR No. 13 Fire and Closures Tests*.[85]

---

[85] See the report titled "GTR No. 13 Fire and Closures Tests" submitted to the docket of this NPRM. This report will also be submitted to the National Transportation Library. https://rosap.ntl.bts.gov/

In some cases during testing, however, temperatures measured at the burner monitor thermocouples did not satisfy the required Tmin$_{\text{ENG}}$. NHTSA's testing indicated that the airflow during the pre-test may be different from that of the CHSS if the pre-test container length is substantially different from that of the CHSS to be tested. The difference in air flow between the two tests could cause differences in fire input to the CHSS compared to the pre-test container. Therefore, NHTSA recommends that for CHSS of length between 600 mm and 1650 mm, the difference in the length of the pre-test container and the CHSS be no more than 200 mm. NHTSA seeks comment on whether this recommendation should be a specification for the pre-test container.

In addition, NHTSA seeks comment on the requirement for Tmin$_{\text{ENG}}$. In particular, NHTSA seeks comment on allowing for a wider variation than 50 °C below the pre-test temperatures. A variation of 50 °C is small in the context of fire temperatures, and such a small variation limit may make the test more difficult for test labs to conduct. Furthermore, as currently specified, Tmin$_{\text{LOC}}$ and Tmin$_{\text{ENG}}$ would be time-dependent variables because they are based on a time-dependent rolling average. Having Tmin$_{\text{LOC}}$ and Tmin$_{\text{ENG}}$ being time-dependent is complex and would make the testing difficult to monitor. NHTSA seeks comment on a simpler calculation for T_{minLOC} and T_{minENG} that will result in constant values for Tmin$_{\text{LOC}}$ and Tmin$_{\text{ENG}}$. NHTSA proposes that Tmin$_{\text{LOC}}$ be calculated by subtracting 50 °C from the minimum value of the 60-second rolling average of the burner monitor temperature in the localized fire zone of the pre-test checkout. Similarly, NHTSA proposes that Tmin$_{\text{ENG}}$ be calculated by subtracting 50 °C from minimum value of the 60-second rolling average of the average of the three burner monitor temperatures during the engulfing fire stage of the pre-test checkout. NHTSA seeks comment on whether these revised calculations for T_{minLOC} and T_{minENG} should be required.

GTR No. 13 specifies additional pre-test checkout procedures intended for irregularly shaped CHSS which are expected to impede air flow through the burner. These procedures involve constructing a pre-test plate having similar dimensions to the CHSS to be tested. A second pre-test check out is conducted using the pre-test plate and using the burner monitor thermocouples. If the burner monitor thermocouple temperatures do not satisfy both $\mathrm{Tmin}_{\mathrm{LOC}}$ and $\mathrm{Tmin}_{\mathrm{ENG}}$, then the pre-test plate is raised by 50 mm, and a third pre-test checkout is conducted. GTR No. 13 specifies that this process is repeated until burner monitor thermocouple temperatures satisfy $\mathrm{Tmin}_{\mathrm{LOC}}$ and $\mathrm{Tmin}_{\mathrm{ENG}}$. NHTSA has considered this additional pre-test process and determined that it is unnecessary. The goal of the pre-test checkout is a repeatable and reproducible fire exposure among different testing facilities. NHTSA has determined there is no need for design-specific modification to the fire test procedure. Furthermore, the additional pre-test procedures add considerable complexity to the test procedure, and as a result could undermine the repeatability and reproducibility of the fire test. Therefore, NHTSA is not proposing these additional pre-test procedures. NHTSA seeks comment on this decision. If commenters believe that the additional pre-test procedures are necessary, NHTSA requests that they explain (1) how they would improve the safety outcome of the standard, and (2) how they would improve the repeatability and reproducibility of the fire test.

Liquefied petroleum gas, also known as liquified propane gas or simply LPG, is the selected fuel for the test burner because it is globally available and easily controllable to maintain the required thermal conditions. The use of LPG was deemed adequate by the IWG to reproduce the thermal conditions on the steel container that occurred during the JARI vehicle fire tests without concerns of carbon formation that can occur with other liquid fuels. The relatively low hydrogen to carbon (H/C) ratio of LPG at approximately 2.67 allows the flame to display flame radiation characteristics (from carbon combustion products) more similar to petroleum fires (with a H/C of roughly 2.1) than natural gas, for example, which has an H/C ratio of approximately 4.0. Also, The LPG flame is more uniform and is easier to control than natural gas and gasoline flames. For this reason, LPG fuel is the choice for most testing purposes to improve the repeatability and reproducibility of the test.

To further improve test reproducibility, a burner configuration is defined in S6.2.5.1 with localized and engulfing fire zones. The burner configuration specifications are listed in Table-8 below.

Table-8: Burner Specifications

Item	*Description*
Nozzle Type	Liquefied petroleum gas fuel nozzle with air pre-mix
• LPG Orifice in Nozzle	1 mm ± 0.1 mm inner diameter
• Air Ports in Nozzle	Four holes, 6.4 mm ± 0.6 mm inner diameter
• Fuel/Air Mixing Tube in Nozzle	10 mm ± 1 mm inner diameter
Number of Rails	Six
Center-to-center Spacing of Rails	105 mm ± 5 mm
Center-to-center Nozzle Spacing Along the Rails	50 mm ± 5 mm

These specifications allow the fire test to be performed without a burner development program. NHTSA believes that use of a standardized burner configuration is a practical way of conducting fire testing and should reduce variability in test results through commonality in hardware. Flexibility is provided to adjust the length of the engulfing fire zone to match the CHSS length, up to a maximum of 1.65 m. This allows test laboratories to reduce burner fuel consumption when testing small containers. The width of the burner, however, is fixed at 500 mm for all fire tests, regardless of the width or diameter of the CHSS container to be tested, so that each CHSS is evaluated with the same fire condition regardless of size. The length of the localized fire zone is also fixed to 250 mm for all fire tests. An example of a typical burner is shown in Figure-10 and Figure-11 below. NHTSA seeks comment on a specification for the burner rail tubing shape and size, which can affect the spacing between the nozzle tips.

GTR No. 13 specifies that the CHSS is rotated relative to the localized burner to minimize the ability for TPRDs to sense the fire and respond. GTR No. 13 specifies establishing a worst-case based on the specific CHSS design. However, NHTSA is concerned that establishing a worst-case based on a specific design may be subjective. NHTSA instead proposes that the CHSS is positioned for the localized fire by orienting the CHSS relative to the localized burner such that the distance from the center of the localized fire exposure to the TPRD(s) and TPRD sense point(s) is at or near maximum. This provides a challenging condition where the TPRD(s) may not sense the localized fire. The engulfing fire zone includes the localized fire zone and extends along the complete length of the container, in one direction, towards the nearest TPRD or TPRD sense point, up to a maximum burner length of 1.65 m. Some examples of possible burner orientations are shown in Figure-12 and Figure-13. NHTSA seeks comment on the proposed orientation of the CHSS relative to the localized burner.

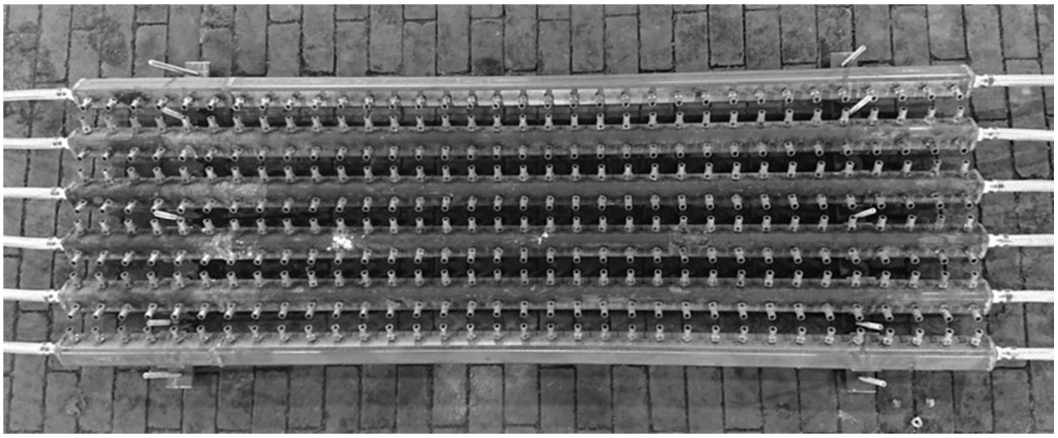

Figure-10: Example burner top view.

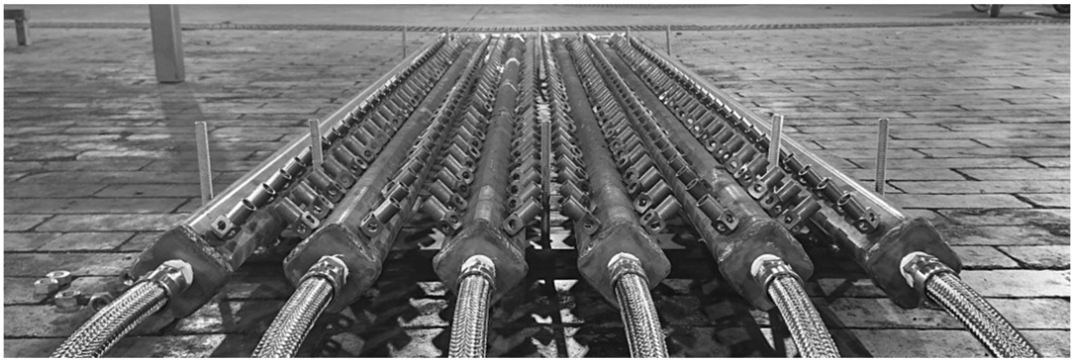

Figure-11: Example burner side view.

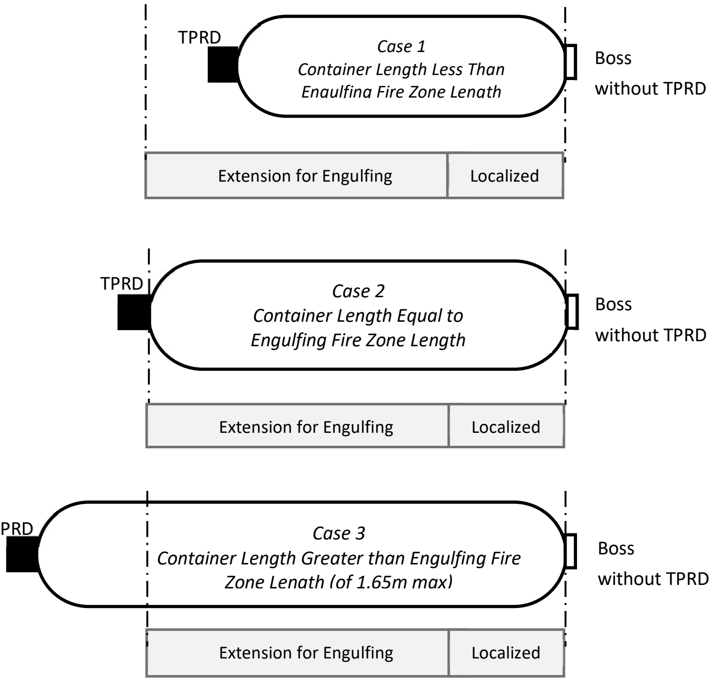

Figure-12: Example burner orientations with single TPRD.

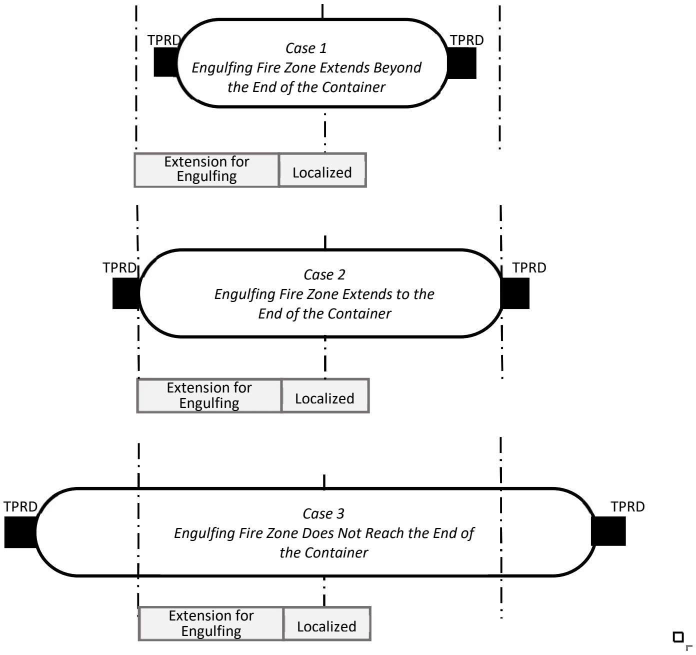

Figure-13 Example burner orientations with two TPRDs.

When testing is conducted outdoors, wind shielding is required to prevent wind from interfering with the flame temperatures. In order to ensure that wind shields do not obstruct the drafting of air to burner, which could cause variations in test results, the wind shields need to be at least 0.5 m away from the CHSS being tested. Finally, for consistency, the wind shielding used for the pre-test checkout must be the same as that for the CHSS fire test. NHTSA seeks comment on whether specifications for wind shielding should be provided in the regulatory text of the standard, and if so, what the specifications should be. As an additional approach to addressing wind interference with flame temperatures, NHTSA is considering for the final rule to limit average wind velocity during testing to 2.24 meters/second, as in FMVSS No. 304.[86] NHTSA seeks comment on limiting wind speed during testing.

In order to minimize hazard, jet flames occurring anywhere other than a TPRD outlet, such as the container walls or joints, cannot exceed 0.5 meters in length. NHTSA seeks comment on how to accurately measure jet flames.

---

[86] FMVSS No. 304, "Compressed natural gas fuel container integrity," https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-571/subpart-B/section-571.304

Consistent with GTR No. 13, if venting occurs though the TPRD(s), the venting is required to be continuous so the vent lines do not experience periodic flow blockages which could interfere with proper venting. The fire test is completed successfully after the CHSS vents its contents and the CHSS pressure falls to less than 1 MPa. If the CHSS has not vented below 1 MPa within 60 minutes for vehicles with a GVWR of 4,536 kg (10,000 pounds) or less, or 120 minutes for vehicles with a GVWR over 4,536 kg (10,000 pounds), the CHSS is considered to have failed the test.

The value of 1 MPa is selected such that the risk of stress rupture after venting is minimal. The time limits are selected to represent long-lasting fires such as battery fires or vehicle fires occurring inside of building structures. The time limit for heavy vehicles is longer because heavy vehicles are larger in size and often carry cargo or refuse. Both of these factors tend to prolong fire duration.

8. Tests for performance durability of closure devices

Like the CHSS, closure devices (like the TPRD, check valve and shut-off valve) must be durable and maintain their expected operational capabilities during their lifetime of service. Closure devices must demonstrate their operability and durability in service by completing a series of performance tests as discussed below. Closure device operability and durability is essential for the integrity of the CHSS because these devices isolate the high-pressure hydrogen from the remainder of the fuel system and the environment. While the closure devices are challenged in the CHSS performance tests above, additional specific tests may further enhance safety. In addition, specific component testing enables equivalent components to be safely exchanged in a CHSS.

The tests for performance durability of closure devices in GTR No. 13 are closely consistent with the industry standards CSA/ANSI HPRD 1-2021, *Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers*, and CSA/ANSI HGV 3.1-2022, *Fuel System Components for Compressed Hydrogen Gas Powered Vehicles*.[87,88] The tests for performance durability of closure devices carry a significant test burden. To evaluate a single TPRD design, 13 TPRD units are required for a total of 29 individual tests (some units undergo multiple tests in a sequence). Similarly, to evaluate a single shut-off valve or check valve, 8 units are required for a total of 17 individual tests. While NHTSA is proposing these requirements to be consistent with GTR No. 13, NHTSA seeks comment on whether testing of this extent is necessary to meet the need for safety, or whether it is still possible to meet the need for safety with a less-burdensome test approach or with a subset of the test for performance durability of closure devices. If commenters believe another approach or subset of tests is appropriate and meets the need for safety, NHTSA requests that commenters provide specific detail on (1) the alternate approach or subset of tests and (2) how it meets the need for safety adequately."

Furthermore, FMVSS represent minimum performance requirements for safety. FMVSS does not address issues such as component reliability or best practices. These considerations are left to industry standards. NHTSA seeks comment on whether a reduced subset of the tests for performance durability of closure devices could ensure safety with a lower overall test burden. In such a subset, only those tests directly linked to critical safety risks would be included.

The tests for performance durability of closure devices are conducted on finished components representative of normal production. To enable outdoor testing without special temperature controls that would increase testing costs, NHTSA proposes that testing be conducted at an ambient temperature of 5 °C to 35 °C, unless otherwise specified. In addition, GTR No. 13 specifies that all tests be performed using either:

- Hydrogen gas compliant with SAE J2719_202003, *Hydrogen Fuel Quality for Fuel Cell Vehicles*, or

---

[87] *See.* https://webstore.ansi.org/standards/csa/csaansihprd2021
[88] *See.* https://webstore.ansi.org/standards/csa/csaansihgv2015r2019

- Hydrogen gas with a hydrogen purity of at least 99.97 percent, less than or equal to 5 parts per million of water, and less or equal to 1 part per million particulate, or
- A non-reactive gas instead of hydrogen.

The standard J2719_202003 specifies maximum concentrations of individual contaminants such as methane and oxygen. Limiting these individual contaminants are critical for fuel cell operation, however, they are unlikely to affect the results of the tests for performance durability of closure devices.

As a result, FMVSS No. 308 will only require hydrogen with a purity of at least 99.97 percent, less than or equal to 5 parts per million of water, and less or equal to 1 part per million particulate. NHTSA seeks comment on any other impurities that could affect the results of the tests for performance durability of closure devices.

Using a non-reactive gas for testing would have the benefit of reducing the test lab safety risk related to handling pressurized hydrogen. However, it is not clear if replacing hydrogen with a non-reactive gas reduces stringency and therefore may not adequately address the safety need. As a result, this option has not been proposed in FMVSS No. 308. NHTSA seeks comment on whether testing with a non-reactive gas instead of hydrogen reduces test stringency. If commenters believe (and can explain) that it does not reduce test stringency, NHTSA requests that they identify a suitable non-reactive gas to replace hydrogen, such as helium or nitrogen, and explain why it is suitable.

a. TPRD

Failure of a TPRD to properly vent in the event of a fire could lead to burst. Accordingly, TPRDs must demonstrate operability and durability in service by successfully completing the applicable tests for performance durability of closure devices. This is a series of TPRD performance tests with requirements discussed below.

GTR No. 13 does not consider the possibility of the TPRD activating during the pressure cycling test, temperature cycling test, salt corrosion test, vehicle environment test, stress corrosion cracking test, drop and vibration test, or leak test. The temperatures applied during these tests are not characteristic of fire and therefore should not cause the TPRD to activate. TPRD activation in the absence of temperatures characteristic of a fire indicates that the TPRD is not functioning as intended and presents a safety risk due to the hazards associated with TPRD discharge. As a result, NHTSA is proposing that if the TPRD activates at any point during the pressure cycling test, temperature cycling test, salt corrosion test, vehicle environment test, stress corrosion cracking test, drop and vibration test, or leak test, that TPRD will be considered to have failed the test. NHTSA seeks comment on this proposed requirement.

(1) **Pressure cycling test**

Similar to the CHSS test for expected on-road performance, the pressure cycling test would evaluate a TPRD's ability to withstand repeated pressurization and depressurization. One TPRD unit undergoes 15,000 internal pressure cycles with hydrogen gas. While the proposed 15,000 pressure cycles for the TPRD is consistent with GTR No. 13, NHTSA notes that this number of cycles is higher than the maximum 11,000 pressure cycles applied to containers. NHTSA seeks comment on the need for 15,000 pressure cycles for TPRDs. The testing is performed under the conditions shown in Table-9 with a maximum cycling rate of 10 cycles per minute.

Table-9: Test conditions

Pressure	**Number of cycles**	**Temperature**
2 MPa to 150% NWP	First 10	85 °C
2 MPa to 125% NWP	Next 2,240	85 °C
2 MPa to 125% NWP	Next 10,000	20 °C
2 MPa to 80% NWP	Final 2,750	−40 °C

The pressure cycling test is designed to replicate fueling events during service. This is important because over time, repeated fueling events can produce fatigue failures. NHTSA seeks comment on the number of TPRD pressure cycles. The first 10 cycles use 150 percent NWP to replicate over-pressurization events at fueling stations. The remaining cycles are conducted to 125 percent NWP for the reasons discussed above for the baseline pressure cycle test.

The test temperature of 85 °C for the first 2,250 cycles and the test temperature of -40 °C for the final 2,750 cycles are selected to replicate the extreme hot and cold environments described above for the test for performance durability. After the completion of pressure cycling, the TPRD units are subjected to the Leak Test, Benchtop Activation Test, and Flow Rate Test. These three tests, discussed below, verify the essential functions of the TPRD.

(2) **Accelerated life test**

A TPRD needs to activate at its intended activation temperature, but also must not activate prematurely due to a long-duration exposure to elevated temperature that is below its activation temperature. Holding the TPRD at an elevated temperature T_L could lead to creep failure of the materials within the TPRD and result in a false activation. The purpose of the accelerated life test is to evaluate the TPRD's ability to activate at intended activation temperature, while demonstrating resistance to creep failure at elevated temperatures that are below its activation temperature.

During the test, the TPRD units are pressurized with hydrogen at 125 percent NWP and placed in a temperature-controlled environment. One unit is tested at the manufacturer's specified activation temperature, T_f, and one unit is tested at the accelerated life temperature, T_L, given by the expression:[89]

$$T_L = \left(\frac{0.502}{\beta + T_f} + \frac{0.498}{\beta + T_{85}}\right)^{-1} - \beta$$

---

[89] Details are provided in the technical document "New equation for calculating accelerated life test temperature.pdf" submitted to the docket of this NPRM.

where $\beta = 273.15$ if T is in Celsius and $\beta = 459.67$ if T is in Fahrenheit, $T_{85} = 85$ °C (185 °F), and T_f is the manufacturer's specified activation temperature. The unit tested at T_f must activate in less than 10 hours and the unit tested at T_L must not activate in less than 500 hours. The required 500 hours without activation demonstrates the unit's resistance to creep.

(3) Temperature cycling test

Similar to the container and CHSS, the TPRD must be able to withstand extreme temperatures while in service. A study found that pressure release devices at extreme cold temperature as low as -40 °C could cause a TPRD gas release failure.[90] The temperature cycling test evaluates a TPRD's ability to withstand extreme temperature conditions that may lead to gas release failures when combined with pressure cycling. The TPRD is first exposed to 15 thermal cycles by alternating between hot (85 °C) and cold (-40 °C) temperature baths. This is to simulate rapid swings in environmental temperature, which can stress the TPRD through thermal expansion and contraction. The TPRD is then pressure cycled in the cold bath for 100 cycles at 80 percent NWP to simulate fueling and defueling in an extreme cold environment. After these stresses have been applied, the TPRD is subjected to the low-temperature condition Leak Test, Benchtop Activation Test, and Flow Rate Test. These three tests, discussed below, verify the essential functions of the TPRD. Only the low-temperature condition leak test is conducted after the temperature cycling test because leaks are most likely to occur at low temperatures.

(4) Salt corrosion resistance test

The purpose of the salt corrosion resistance test is to verify that the TPRD can withstand an extreme external salt corrosion environment. The test occurs in a chamber designed to coat the TPRD with atomized droplets of salt solution. This creates a highly corrosive environment. The chamber cycles through wet and dry stages to maximise corrosion affects. The parameters for this test, such as the chamber design, the salts and water used, the salt concentrations, temperatures, humidity levels and cycle times are all based on HGV 3.1-2022 and HPRD 1-

---

[90] Livio Gambone et al., Performance testing of pressure relief devices for NGV cylinders, June 1997.

2021.[91,92,93] After the salt corrosion exposure, the TPRD units are subjected to the Leak Test, Benchtop Activation Test, and Flow Rate Test. These tests, discussed below, verify the essential functions of the TPRD. NHTSA seeks comment on the clarity and objectivity of the salt corrosion resistance test procedure. If commenters have suggestions on how to change the salt corrosion resistance test procedure, NHTSA asks that they please explain how their suggested changes improve the clarity and objectivity, and how they continue to meet the need for safety represented by this test.

(5) Vehicle environment test

The purpose of the vehicle environment test is to demonstrate that the TPRD can withstand exposure to chemicals that might be encountered during on-road service. Prior to testing, the inlet and outlet ports are capped because the test is not intended to expose the interior of the TPRD. The TPRD is then exposed to the following fluids for 24 hours each at 20 °C:

- Sulfuric acid at 19 percent in water to simulate battery acid.
- Ethanol at 10 percent in gasoline to simulate fueling station fluids.
- Methanol at 50 percent in water to simulate windshield-washer fluid.

The TPRD is exposed to all of fluids separately in a sequence. The fluids are replenished as needed for complete exposure throughout the duration of the test. After exposure to each chemical fluid, the unit is wiped off and rinsed with water to end any reactions that may be occurring.

---

[91] CSA/ANSI HGV 3.1-2022 Fuel System Components For Compressed Hydrogen Gas Powered Vehicles.

[92] CSA/ANSI HPRD 1-2021 Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers.

[93] HGV 3.1, HPRD 1, GTR No. 13, and the proposed FMVSS No. 308 reference the standards ASTM D1193-06(2018), Standard Specification for Reagent Water and ISO 6270-2:2017 Determination of resistance to humidity. ASTM D1193-06(2018) provides specification for the water to be used during salt corrosion resistance testing.
https://www.astm.org/d1193-06r18.html
ISO 6270-2:2017 provides specifications for the cyclic corrosion chamber to be used.
https://www.iso.org/standard/64858.html
These two standards would be incorporated by reference into the proposed FMVSS No. 308. A summary of these two standards is provided in Section V. Regulatory Analyses and Notices of this notice.

GTR No. 13 does not specify the method of exposure to these chemical solutions. The method described in HPRD 1-2021 is to immerse the test unit in each fluid.[94] The duration of 24 hours is based on industry practices. NHTSA seeks comment on the exposure method.

After the conclusion of the exposures, the TPRD unit is subjected to the Leak Test, Benchtop Activation Test, and Flow Rate Test. These tests, discussed below, verify the essential functions of the TPRD. In addition to these subsequent tests, the TPRD must not show signs of cracking, softening, or swelling. GTR No. 13 further specifies that "cosmetic changes such as pitting or staining are not considered failures." NHTSA seeks comment on including this specification, and notes that pitting can be an aggressive form of corrosion which can ultimately lead to component failure due to cracking at the pitting site.

(6) Stress corrosion cracking test

The purpose of the stress corrosion cracking test is to ensure that the TPRD can resist stress corrosion cracking. Stress corrosion cracking is the growth of crack formation in a corrosive environment. It can lead to unexpected and sudden failure of normally ductile metal alloys subjected to a tensile stress, especially at elevated temperature. In particular, TPRDs containing copper-based alloys can be susceptible to stress corrosion cracking in the presence of aqueous ammonia. This is a significant risk because ammonia can be found in the natural and vehicle environment.

The TPRD test unit is degreased to remove any protective grease that may be present. The unit is then exposed for ten days to a moist ammonia-air mixture maintained in a glass chamber. Under GTR No. 13, the moist ammonia-air mixture is achieved using an ammonia-water mixture with specific gravity of 0.94. Specific gravity is affected by temperature and, therefore, is an inconvenient metric for concentration specification because concentrations will need to be adjusted for different temperatures. NHTSA seeks comment on a more direct metric

---

[94] CSA/ANSI HPRD 1-2021, Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers.

for ammonia concentration specification, such as 20 weight percent ammonium hydroxide in water.

The chamber is maintained at atmospheric pressure and 35 °C. This simulates a slightly elevated temperature. In GTR No. 13, the only requirement to pass the stress corrosion cracking test is that the components must not exhibit cracking or delaminating due to this test. NHTSA seeks comment on this performance requirement and whether there are alternative requirements for this test beyond basic visual inspection, such as subjecting the TPRD to the leak test.

(7) **Drop and vibration test**

The purpose of the drop and vibration test is to evaluate the TPRD's ability to withstand drop and vibration. Dropping a TPRD could occur during installation, and vibration is likely to occur during on-road service. A TPRD may be dropped in any one of six different orientations covering the opposing directions of three orthogonal axes: vertical, lateral and longitudinal. After the drop, the TPRD unit is examined for damage that would prevent its installation in a test fixture for vibration according to the manufacturer's instructions. If damage is present that would prevent installation, the TPRD is discarded, and it is not considered a test failure. Damage that would prevent its installation is acceptable because the TPRD could never enter service with this type of damage.

A TPRD that is not discarded after the drop test proceeds to the vibration test. In addition, one new undamaged TPRD that was not dropped is also subjected to the vibration test. The units are vibrated for 30 minutes along each of the three orthogonal axes (vertical, lateral, and longitudinal). The units are vibrated at a resonant frequency which is determined by using an acceleration of 1.5 g and sweeping through a sinusoidal frequency range of 10 to 500 Hz with a sweep time of 10 minutes. According to GTR No. 13, the resonance frequency is identified by a "pronounced" increase in vibration amplitude. However, if the resonance frequency is not found, the test is conducted at 40 Hz. Specifying a pronounced increase in vibration amplitude could be partially subjective. NHTSA seeks comment on a more objective criteria for establishing resonance, such as a frequency where the amplitude of the response of the test article is at least twice the input energy as measured by response accelerometers. Furthermore, the acceleration level was not defined in GTR No. 13 for the resonant dwells. NHTSA seeks comment on an appropriate acceleration level for the resonant dwells.

After vibration, the TPRD units are subjected to the Leak Test, Benchtop Activation Test, and Flow Rate Test. These tests, discussed below, verify the essential functions of the TPRD.

(8) **Leak test**

The leak test evaluates the TPRD's basic ability to contain hydrogen at ambient and extreme temperature conditions. In particular, the leak test is used after other tests to verify the TPRD's integrity after undergoing the stresses from previous tests. Each TPRD under test is conditioned for one hour by immersion in a temperature-controlled liquid at ambient temperature, high temperature, and low temperature. These test temperatures and corresponding test pressures are as follows:

- Ambient temperature: 5 °C to 35 °C, test at 2 MPa and 125 percent NWP
- High temperature: 85 °C, test at 2 MPa and 125 percent NWP
- Low temperature: -40 °C, test at 2 MPa and 100 percent NWP

The above temperatures are selected for the same reasons discussed above for the test for performance durability. At the ambient and high temperature tests, the TPRD is evaluated for leaks at 2 MPa and 125 percent NWP. The test pressure of 125 percent NWP represents the peak pressure that typically occurs during fueling. For the low temperature test, however, the maximum pressure is reduced to 100 percent NWP because maximum fueling pressure is lower in extremely cold environments. NHTSA seeks comment on the need to perform the leak test at 2 MPa in addition to the higher pressures.

After the required pre-conditioning period, the evaluation for leak involves observing the pressurized valve for hydrogen bubbles while immersed in the temperature-controlled fluid. If hydrogen bubbles are observed, the leak rate is measured by any method available to the test lab.

The total leak rate must be less than 10 NmL/h, which represents an extremely low leak rate. NHTSA seeks comment on the leak rate requirement of 10 NmL/hour. This leak rate of 10 NmL/hour is much lower than the minimum hydrogen flow rate of 3.6 NmL/min necessary for initiating a flame.[95] NHTSA seeks comment on objective methods for measuring the leak rate.

(9) Benchtop activation test

The purpose of the benchtop activation test is to demonstrate that the TPRD will activate as intended when exposed to high temperature. As with the leak test, the benchtop activation test is applied after other tests to ensure the TPRD retains its basic functions after other stresses have been applied.

The test setup consists of either an oven or a chimney which is capable of controlling air temperature and flow to achieve 600 °C in the air surrounding the test sample. This provides a sufficiently high air temperature to activate TPRDs. TPRD units are pressurized to 25 percent NWP or 2 MPa, whichever is less. This provides sufficient pressure for activation.

Three new TRPD units are tested to establish a baseline activation time, which is the average of the activation time of the three new TPRDs. TPRD units used in the pressure cycling test, accelerated life test, temperature cycling test, salt corrosion resistance test, vehicle environment test, and drop and vibration test are also tested in the benchtop activation test and these TPRDs must activate within 2 minutes of the average activation time established from the tests with the new units.

GTR No. 13 does not provide any information on how to proceed in the event that a TPRD does not activate at all during the benchtop activation test. A TPRD that does not activate when inserted into the oven or chimney is not functioning as intended and therefore presents a safety risk. As a result, NHTSA is proposing that if a TPRD does not activate within 120 minutes from the time of insertion into the oven or chimney, the TPRD is considered to have

---

[95] SAE Technical report 2008-01-0726. Flame Quenching Limits of Hydrogen Leaks. The paper finds that the lowest possible flammable flow is about 0.005 mg/s (3.6 NmL/min).

failed the test. The time limit of 120 minutes is selected based on the maximum possible duration of the CHSS fire test. NHTSA seeks comment on this requirement.

(10) Flow rate test

After benchtop activation, the flow rate test evaluates the TPRD for flow capacity to ensure that the flow rate of a TPRD exposed to the various environmental conditions during prior testing is similar to that of a new TPRD. This test can be performed with hydrogen, air, or any other inert gas because the test simply evaluates flow rate through the TPRD. Flow rate through the TPRD is measured with the inlet pressurized to 2 MPa and the outlet unpressurized. This pressure difference generates flow through the TPRD. The lowest measured flow rate must be no less than 90 percent of a baseline flow rate established as the measured flow rate of a new TPRD. This ensures low variation in flow rates and that all TPRDs tested are free from blockages.

The number of significant figures used in the measurement of flow rate can impact the test result. For example, a test flow rate of 1.7 flow units compared against a baseline flow rate of 2.0 flow units does not meet the requirement. However, in this case, if flow rate were measured using only one significant figure, the two flow rates would be identical (2 flow units). As a result, NHTSA proposes requiring that the flow rate be measured in units of kilograms per minute with a precision of at least 2 significant digits. NHTSA seeks comment on this proposed requirement.

(11) Atmospheric exposure test

GTR No. 13 includes an atmospheric exposure test to ensure that non-metallic components which are exposed to the atmosphere and provide a fuel-containing seal have sufficient resistance to oxygen. This is because oxygen can degrade non-metallic components.

The oxygen exposure of 96 hours at 70°C at 2 MPa, is based on industry standards.[96,97] The requirement to pass this test is that the component not crack nor show visible evidence of deterioration.

However, NHTSA is concerned that this test is not objectively enforceable because the requirement involves a subjective determination of evidence of deterioration. Furthermore, the test would require NHTSA to determine which components are non-metallic, exposed to the atmosphere, and provide a fuel-containing seal. As a result, this test has not been included in FMVSS No. 308. NHTSA seeks comment on not including the atmospheric exposure test.

b. Check valves and shut-off valves

Failure of a check valve or shut-off valve to properly contain pressure within the CHSS can lead to a severe hydrogen leak. Accordingly, check valves and shut-off valves must demonstrate their operability and durability in service by completing the applicable tests for performance durability of closure devices. This is a series of performance tests applicable to check valves and shut-off valves with requirements described below.

(1) Hydrostatic strength test

Since the check valve and the shut-off valve ensure containment of high pressure hydrogen, the hydrostatic strength test is conducted to ensure the valves are able to withstand extreme pressure of up to 250 percent NWP. Additionally, the test also ensures that the burst pressure of the valves exposed to various environmental conditions during prior testing is not degraded beyond 80 percent of a new unexposed valve's burst pressure.

One new unit is tested to establish a baseline failure pressure, which must be at least 250 percent NWP, and other units are tested as specified in other sections, after being subjected to other tests. All outlet openings are plugged, and valve seats or internal blocks are placed in the

---

[96] ASTM D572-04(2019) Standard Test Method for Rubber—Deterioration by Heat and Oxygen. https://www.astm.org/d0572-04r19.html

[97] ISO 188:2011 Rubber, vulcanized or thermoplastic—Accelerated ageing and heat resistance tests. https://www.iso.org/standard/57738.html

open position. This allows the test pressure to be distributed throughout the valve. The strength test is performed at 20 °C with a hydrostatic pressure of 250 percent NWP applied at the inlet. This high pressure simulates an extreme over-pressurization and is held for three minutes.

From 250 percent NWP, the hydrostatic pressure is increased at a rate of less than or equal to 1.4 MPa/second to avoid failure due to rapid pressurization. The pressure continues to increase until the component fails. The failure pressure of previously tested units should be no less than 80 percent of the failure pressure of the baseline unit unless the hydrostatic pressure exceeds 400 percent NWP.

In the event of a leak, it may become impossible for the test laboratory to increase pressure on the valve. This occurs when any increase in applied pressure is offset by leakage flow, thereby negating the pressure increase. If this occurs, it is not possible to complete testing. To address this issue, NHTSA is proposing that valves shall not leak during the hydrostatic strength test, and that a leak would constitute a test failure. NHTSA seeks comment on the requirement that valves not leak during the hydrostatic strength test.

(2) **Leak test**

The leak test evaluates the valve's basic ability to contain hydrogen at ambient and extreme temperature conditions. In particular, the leak test is used after other tests to verify the valve's integrity after undergoing the stresses from previous tests. Each valve under test is conditioned for one hour by immersion in a temperature-controlled liquid at ambient temperature, high temperature, and low temperature. These test temperatures and corresponding test pressures are as follows:

- Ambient temperature: 5 °C to 35 °C, test at 2 MPa and 125 percent NWP
- High temperature: 85 °C, test at 2 MPa and 125 percent NWP
- Low temperature: -40 °C, test at 2 MPa and 100 percent NWP

These temperatures and pressures are selected for the same reasons described above for the TPRD leak test. After the required pre-conditioning period, the evaluation for leak involves observing the pressurized valve for hydrogen bubbles while immersed in the temperature-controlled fluid. If hydrogen bubbles are observed, the leak rate is measured by any method available to the test lab. Similar to the TPRD leak test, the total leak rate must be less than 10 NmL/h. For the same reasons discussed above for the TPRD leak test, NHTSA seeks comment on the leak rate requirement of 10 NmL/h and seeks comment on objective methods for measuring the leak rate.

(3) Extreme temperature pressure cycling test

Similar to the extreme temperatures applied to containers and CHSS, the shut-off valve and the check valve must be able to withstand extreme temperatures while in service. The extreme temperature pressure cycling test simulates extreme temperature conditions that may lead to gas release failures when combined with pressure cycling.

Check valves and shut-off valves may also be subject to “chatter” which is an excess of vibration that causes the valves to open and close quickly and repeatedly. This causes a clicking and rattling noise that is referred to as chatter. Valves can develop chatter when they are not able to handle the pressure applied or are improperly sized. Chatter of a valve can cause excessive wear of the valve mechanism that can cause failure of the valve over time. Therefore, this test evaluates the check valve and shut-off valve for chatter after the extreme temperature pressure cycling.

The total number of operational cycles is 15,000 for the check valve, consistent with the 15,000 cycles used for the TPRD above. The total number of operational cycles is 50,000 for the shut-off valve. The higher 50,000 cycles for the shut-off valve reflects the multiple pressure pulses the shut-off valve experiences as it opens and closes repeatedly during service. In contrast, the check valve only experiences a pressure pulse during fueling. NHTSA seeks comment on the number of pressure cycles for check valves and shut-off valves.

Pressure cycling is conducted at different environmental temperatures and pressures:

- Ambient: Between 5.0 °C and 35.0 °C, 100 percent NWP

- High: 85 °C, 125 percent NWP
- Low: -40°C, 80 percent NWP

For a check valve, the pressure is applied in six incremental pulses to the valve inlet with the outlet closed. The pressure is then vented from the inlet, with outlet side pressure reduced to below 60 percent NWP prior to the next cycle. This simulates the fueling process. The valve is held at the corresponding temperature for the duration of the cycling at each condition.

For a shut-off valve, the pressure is applied through the inlet port. The shut-off valve is then energized to open the valve and the pressure is reduced to any pressure less than 50 percent of the specified pressure range. The shut-off valve is then de-energized to close the valve prior to the next cycle. This simulates operation of the shut-off valve during service. The valve is held at the corresponding temperature for the duration of the cycling at each condition.

After cycling, each valve is subjected to 24 hours of “chatter flow” to simulate the chatter condition described above. Chatter flow means the application of a flow rate of gas through the valve that results in chatter as described above. NHTSA is concerned, however, that the application of chatter flow could be partially subjective. NHTSA seeks comment on the following aspects of the chatter flow test:

- Appropriate methodology or a procedure for inducing chatter flow.
- Appropriate instrumentation and criteria to measure and quantify chatter flow such as a decibel meter and minimum sound pressure level.
- How to proceed in cases where no chatter occurs.
- The specific safety risks that are addressed by the chatter flow test.
- The possibility of not including the chatter flow test.

In the case of shut-off valves, GTR No. 13 specifies the chatter flow test is required only in the case of a shut-off valve which functions as a check valve during fueling and that the flow rate used to induce chatter should be within the normal operating conditions of the valve. However, NHTSA has no way of determining whether a shut-off valve is functioning as a check valve during fueling or the normal operating conditions of the valve. As a result, NHTSA is proposing that the chatter flow test will apply to all shut-off valves and will not specify flow rate limitations for the chatter flow test. NHTSA seeks comment on this decision.

After the completion of the chatter flow test, the valve must comply with the leak test and the hydrostatic strength test to verify it retains its basic ability to contain hydrogen and resist burst due to over-pressurization.

(4) **Salt corrosion resistance test**

The salt corrosion resistance test is conducted in the same manner and for the same reasons discussed above for TPRDs. At the completion of the salt corrosion resistance test, the tested valve must comply with the ambient temperature leak test and the hydrostatic strength test to verify it retains its basic ability to contain hydrogen and resist burst due to over-pressurization.

(5) **Vehicle environment test**

The vehicle environment test is conducted in the same manner and for the same reasons discussed above for TPRDs. At the completion of the vehicle environment test, the tested valve shall comply with the leak test and the hydrostatic strength test to verify it retains its basic ability to contain hydrogen and resist burst due to over-pressurization. In addition to these subsequent tests, the valve shall not show signs of cracking, softening, or swelling.

(6) **Atmospheric exposure test**

GTR No. 13 includes an atmospheric exposure test for check valves and shut-off valves identical to the atmospheric exposure test for TPRDs. However, this test has not been included for check valves and shut-off valves for the same reasons it was not included for TPRDs. NHTSA seeks comment on not including the atmospheric exposure test for check valves and shut-off valves.

(7) **Electrical tests**

The electrical tests apply to the shut-off valve only. The electrical tests evaluate the shut-off valve for:

- Leakage, unintentional valve opening, fire, and/or melting after exposure to an abnormal voltage.
- Failure of the electrical insulation between the power conductor and casing when the valve is exposed to a high voltage.

The exposure to abnormal voltage is conducted by applying twice the valve's rated voltage or 60 V, whichever is less to the valve for at least one minute. After the test, the valve is subject to the leak test and leak requirements. The test for electrical insulation is conducted by applying 1000 V between the power conductor and the component casing for at least two seconds, consistent with the industry standards NGV 3.1-2012 and HGV 3.1-2022.[98,99] The isolation resistance between the valve and the casing must be 240 kΩ or more. This represents a high level of resistance to prevent the valve casing from being energized in the event the power conductor short circuits within the valve.[100]

Some valves may have requirements specified by their manufacturers for peak and hold pulse width modulation duty cycle. NHTSA seeks comment on whether and how to adjust the proposed test procedure to account for a manufacturer's specified peak and hold pulse width modulation duty cycle requirements.

(8) Vibration test

The vibration test evaluates a valve's resistance to vibration. The valve is pressurized to 100 percent NWP and exposed to vibration for 30 minutes along each of the three orthogonal axes (vertical, lateral, and longitudinal). After the test, the valve is inspected for visual exterior damage and required to comply with the ambient temperature leak test. Vibration is conducted along the three orthogonal axes to cover different possible mounting positions within a vehicle.[101]

---

[98] NGV 3.1-2012. Fuel system components for compressed natural gas powered vehicles. https://webstore.ansi.org/standards/csa/ansingv2012csa12

[99] HGV 3.1-2022. Fuel system components for compressed hydrogen gas powered vehicles.

[100] *Id.*

[101] *Id.*

The vibration frequencies used for the test are determined by frequency sweeps along each axis in the range of 10 Hz to 500 Hz. The most severe resonant frequency in each axis is selected for the test. Resonant frequencies are determined as those frequencies of the vibration table that result in considerably different acceleration measurements from an accelerometer mounted to the acceleration table and that mounted on the component under test. If a most severe resonant frequency is determined, the component undergoes vibration at that frequency for 30-minutes. If no resonant frequency is found, then 40 Hz is selected for that axis. The vibration acceleration is 1.5 g, which represents vibration acceleration within a typical vehicle.

This test is conducted with the valve pressurized to 100 percent NWP to simulate vibrations occurring while the valve is in service. After vibration, the valve shall comply with the leak test and the hydrostatic strength test to verify it retains its basic ability to contain hydrogen and resist burst due to over-pressurization.

GTR No. 13 also contains a requirement that "each sample shall not show visible exterior damage that indicates that the performance of the part is compromised." Showing signs of damage is a subjective measure and lacks the objectivity needed per the Motor Vehicle Safety Act. Therefore, this language has been removed.

(9) Stress corrosion cracking test

The stress corrosion cracking test is conducted in the same manner and for the same reasons discussed above for TPRDs.

9. Labeling requirements

Labels on a container are important for informing the consumer that the container is intended for hydrogen fuel, information on the nominal working pressure of the container, and information on when the container should be removed from service. The information on the container labels would also facilitate the agency's enforcement efforts by providing a ready means of identifying the container and its manufacturer, and by providing the information needed for conducting compliance tests. NHTSA tentatively concludes that the container label(s) include the following information:

- Manufacturer, serial number, date of manufacture
- The statement “Compressed Hydrogen Only.”
- The container’s NWP in MPa and pounds per square inch (psi).
- Date when the system should be removed from service
- BP_O in MPa and psi.

B. FMVSS No. 307, “Fuel system integrity of hydrogen vehicles”

FMVSS No. 307 would set requirements for the vehicle fuel system to mitigate hazards associated with hydrogen leakage and discharge from the fuel system, as well as requirements to ensure hydrogen leakage, hydrogen concentration in enclosed spaces of the vehicle, and hydrogen container displacement are within safe limits post-crash. A hydrogen fuel system includes the fueling receptacle, CHSS, fuel cell system or internal combustion engine, exhaust systems, and the fuel lines that connect these systems. Table-10 lists the requirements for the hydrogen fuel system to be incorporated in FMVSS No. 307, which includes separate sections for normal vehicle operations and post-crash requirements. The fuel system integrity requirements for normal vehicle operations would apply to all hydrogen-fueled vehicles, while the post-crash fuel system integrity requirements only apply to light vehicles. NHTSA seeks comment on the application of FMVSS No. 307 to all vehicles, including heavy vehicles (vehicles with a GVWR greater than 4,536 kg (10,000 pounds).[102]

Table-10: Performance test requirements for hydrogen vehicle fuel system integrity

Performance test requirements for hydrogen vehicle fuel system

---

[102] The proposed FMVSS No. 307 would apply, in general, to all hydrogen vehicles regardless of GVWR. However, not all vehicles would be subject to crash testing under FMVSS No. 307. As described below, passenger cars, multipurpose passenger vehicles, trucks and buses with a GVWR of less than or equal to 4,536 kg would be subject to barrier crash testing. School buses with a GVWR greater than 4,536 kg would also be subject a barrier crash test. Heavy vehicles other than school buses with a GVWR greater than 4,536 kg would not be subject to crash testing under the proposed standard.

Fuel system integrity requirements for light and heavy vehicles during normal vehicle operations
Fueling receptacle requirements
Over-pressure protection for the low-pressure system
Hydrogen discharge systems
Protection against flammable conditions
Fuel system leakage requirements
Tell-tale warning to driver
Post-crash fuel system integrity requirements for light vehicles
Fuel leakage limit
Concentration limit in enclosed spaces
Container displacement

1. Fuel system integrity during normal vehicle operations

The first half of the proposed FMVSS No. 307 would adopt GTR No. 13's protections during the normal operation of the vehicle. The proposed requirements in this section apply to all hydrogen fuel vehicles regardless of GVWR.

a. Fueling receptacles

This proposal includes five performance requirements for the hydrogen fueling receptacle. These requirements ensure safe use and proper function of the receptacle. If hydrogen is not properly contained by the fueling receptacle, hydrogen may escape into the surrounding environment where it may accumulate and become ignited, leading to an explosion or fire.

The first requirement for the fueling receptacle is to prevent reverse flow to the atmosphere. This requirement is intended to prevent hydrogen leakage out of the fueling receptacle.

The second requirement is for a label with the statement, "Compressed Hydrogen Only" as well as the statement "Service pressure ____________ MPa (________ psig)." Including this information on a label near the fueling receptacle is intended to prevent incorrect fueling.

Incorrect fueling with a fuel other than hydrogen or with a hydrogen pressure greater than the vehicle NWP could damage the fuel system. The label must also contain the statement, "See instructions on fuel container(s) for inspection and service life."

The third requirement is for positive locking that prevents the disconnection of the fueling hose during fueling. This requirement is intended to prevent the fueling nozzle from being prematurely removed during fueling, which could result in hydrogen leakage.

The fourth requirement is for protection against ingress of dirt and water to protect the fueling receptacle from contamination that could lead to degradation of the fuel system over time. A degraded fuel system is a safety risk because it could lead to a failure to contain hydrogen.

The fifth requirement is to prevent the receptacle from being mounted in a location that would be highly susceptible to crash deformations in order to prevent degradation in the event of a crash. The receptacle is also prevented from being mounted in the enclosed or semi-enclosed spaces of the vehicle because these areas can accumulate hydrogen.[103]

The assessment for all five receptacle requirements is by visual inspection. NHTSA seeks comment on these proposed requirements for the fueling receptacle and on the objectivity of assessment by visual inspection.

b. Over-pressure protection for low-pressure systems

Hydrogen is stored on hydrogen vehicles at high pressures. However, fuel cells and hydrogen combustion engines require lower pressures to operate, and higher pressures have the potential to damage their internal mechanisms. As a result, downstream fuel lines are designed for much lower pressures than the CHSS. Pressure regulators are used between the CHSS and the downstream lines to lower the pressure delivered downstream.

---

[103] Enclosed or semi-enclosed spaces means the volumes within the vehicle, external to the hydrogen fuel system (fueling receptacle, CHSS, fuel cell system or internal combustion engine, fuel lines, and exhaust systems) such as the passenger compartment, luggage compartment, and space under the hood.

NHTSA is proposing to adopt GTR No. 13's requirement of over-pressure protection for low-pressure systems. Accordingly, the agency proposes requiring countermeasures to prevent failure of downstream components in the event a pressure regulator fails to properly reduce the fuel pressure from the much higher pressure in the CHSS. The activation pressure of the overpressure protection device would be lower than or equal to the maximum allowable working pressure for the appropriate section of the hydrogen system as determined by the manufacturer. NHTSA seeks comment on the requirement for an overpressure protection device in the fuel system and how to test the performance of such a device.

c. Hydrogen discharge systems

TPRDs are designed to discharge the hydrogen stored in the CHSS to mitigate the risk of a rupture when the temperature surrounding the CHSS reaches a dangerous temperature. However, venting a flammable fuel source during an emergency can create its own potential hazard if handled improperly. For those reasons, we believe there is a safety need to propose standards for the hydrogen discharge system.

The first proposed requirement is that the TPRD vent line be protected from ingress of dirt or water to prevent contamination that could degrade or compromise the TPRD or the TPRD discharge stream. This requirement protects the TPRD from degradation due to the ingress of dirt and water. A degraded TPRD that fails to activate during a fire could lead to a container burst. Alternatively, if the vent line itself became clogged by dirt and water, it could fail to properly vent the hydrogen in the event of a TPRD activation.

Next, we are proposing several requirements from GTR No. 13 related to the TPRD vent discharge direction. The primary purpose of these requirements is to prevent additional safety hazards due to hydrogen discharge from the TPRD that could compromise other vehicle components and/or inhibit the ability of passengers to safely exit the vehicle. Accordingly, we propose that the TPRD discharge must not be directed towards nor impinge upon:

1. Any enclosed or semi-enclosed spaces where hydrogen could unintentionally accumulate, such as the trunk, passenger compartment, or engine compartment.
2. The vehicle wheel housing.
3. Hydrogen gas containers—if the hydrogen being released from the TPRD becomes ignited, this would pose a burst risk.
4. Rechargeable electrical energy storage system (REESS) because if the TPRD discharge became ignited, this could engulf the REESS and start a battery fire.
5. Any emergency exit(s) or service door(s), because this would create a hazard to persons exiting the vehicle.

In addition to these requirements from GTR No. 13, we believe an additional requirement is necessary to protect potential occupants attempting to exit the vehicle or first responders approaching the vehicle. We are proposing that hydrogen vented through the TPRD(s) be directed upwards within 20° of vertical relative to the level surface or downwards within 45° of vertical relative to the level surface. This requirement would prevent the TPRD discharge from being directed horizontally, which would create a hazard to persons exiting the vehicle and/or to first responders approaching the vehicle. NHTSA seeks comment on this additional requirement for TPRD discharge direction, and on the proposed discharge angles.

NHTSA is proposing that the discharge direction from TPRDs and other pressure relief devices is evaluated through visual inspection. We seek comment on whether there is a more appropriate test.

d. Vehicle exhaust system

NHTSA is proposing to adopt GTR No. 13's vehicle exhaust system requirements. Similar to the previous requirements, elevated concentrations of hydrogen in the exhaust increases the risk of a fire. The GTR requires that the hydrogen concentration never exceed eight percent, and not exceed four percent for any three second moving average value of the hydrogen concentration.

At an ambient temperature of 20 °C, 4 percent by volume of hydrogen in air can ignite and propagate in the direction opposite gravity. However, the propagation is extremely weak and not sustained. At approximately eight percent hydrogen, ignition of hydrogen/air mixture can propagate in any direction regardless of ignition source location. Furthermore, tests demonstrated that as the hydrogen concentration approaches eight percent, exhaust becomes intermittently flammable, igniting in the presence of an ignition source, but extinguishing when the ignition source is removed.[104] As a result, fire occurring at eight percent hydrogen concentration is small and fairly easy to extinguish. Therefore, limiting the hydrogen content of any instantaneous peak to eight percent limits the hazard to near the exhaust discharge point even if an ignition source is present.

NHTSA is proposing adopting the test requirement outlined in GTR No. 13. The test procedure would be conducted after the vehicle has been set to the "on" or "run" position for at least five minutes prior to testing. A hydrogen measuring device is placed in the center line of the exhaust within 100 mm from the external discharge point. The fuel system would undergo a shutdown, start-up, and idle operation to stimulate normal operating conditions. The measurement device used should have a response time of less than 0.3 seconds to ensure an accurate three second moving average calculation. Response times higher than 0.3 seconds could result in inaccurate data collection because the sensor may not have time to register the true concentration levels before recording each data point.

The time period of three seconds for the rolling average ensures that the space around the vehicle remains non-hazardous in the case of an idling vehicle in a closed garage. This is conservatively determined by assuming that a standard size vehicle purges the equivalent of a 250 kW (340 HP) fuel cell system. The power system output of a Toyota Mirai is 182 HP. The time is then calculated for a nominal space occupied by a standard passenger vehicle (4.6 meters

---

[104] SAE Technical Report 2007-01-437. Development of Safety Criteria for Potentially Flammable Discharges from Hydrogen Fuel Cell Vehicles, Local Discharge Flammability - Flowing Exhaust. https://www.sae.org/publications/technical-papers/content/2007-01-0437/

× 2.6 meters × 2.6 meters) to build up to 25 percent of the LFL, or one percent by volume in air. The time limit for this rolling-average situation is determined to be three seconds.[105]

e. Fuel system leakage

GTR No. 13 includes fuel system leakage requirements specifying no leakage from the fuel lines. A flammable or explosive condition can arise if hydrogen leaks from the fuel lines. However, the safety risk of a leak applies to the entire fuel system, not only to the fuel lines. As a result, NHTSA is proposing that the fuel system leakage requirement for no leakage apply to the entire hydrogen fuel system downstream of the shut-off valve, which includes the fuel lines and the fuel cell system. NHTSA is further proposing to define fuel lines to include all piping, tubing, joints, and any components such as flow controllers, valves, heat exchangers, and pressure regulators. From a safety standpoint, there is no difference between a leak coming from fuel line piping, and a leak coming from a valve, pressure regulator, or the fuel cell system itself. While NHTSA is proposing a strict no leakage standard, we are seeking comment on whether there is a safe level of hydrogen that may leak, and if so, what would be an objective leakage limit and how to accurately quantify hydrogen leakage from the fuel system.

NHTSA is proposing to test this requirement using either a gas leak detector or leak detecting liquid (bubble test).[106] NHTSA seeks comment if one of these tests is preferrable. NHTSA is also proposing that the test would be conducted with the fuel system at NWP after having been in the "on" or "run" position for at least five minutes. We believe these conditions produce an elevated likelihood of leakage. We seek comment on whether alternative conditions would better simulate realistic scenarios when downstream lines are more likely to leak.

f. Protection against flammable conditions

---

[105] SAE 2578_201408. Recommended Practice for General Fuel Cell Vehicle Safety. Appendix C3. https://www.sae.org/standards/content/j2578_201408/

[106] As discussed above, a bubble leak test is not an objective method for quantifying a leakage rate during the extreme temperature static gas pressure leak/permeation test. However, NHTSA is proposing a strict no leakage requirement for the test for fuel line leakage. This requirement does not require that the leak be quantified, and therefore, a bubble test may be used to evaluate this requirement. Any observed bubble would indicate leakage and constitute a failure of the test for fuel line leakage.

The final component of GTR No. 13's safety measures for the fuel system during normal use is ensuring that the enclosed and semi-enclosed spaces of the vehicle do not accumulate potentially dangerous concentrations of hydrogen.

The agency proposes requiring a visual warning within 10 seconds in the event that the hydrogen concentration in an enclosed or semi-enclosed space exceeds 3.0 percent (75 percent of the LFL). This concentration limit for the warning is selected because while 3.0 percent hydrogen is below the LFL, and is therefore inflammable, accumulation of hydrogen to 3.0 percent indicates the presence of a leak and the potential for continued hydrogen accumulation beyond the LFL. Additionally, in accordance with GTR No. 13, we propose requiring the shut-off valve to close within 10 seconds if at any point the concentration in an enclosed or semi-enclosed space exceeds 4.0 percent (the LFL). Closure of the shut-off valve isolates the CHSS and ensures hydrogen cannot accumulate beyond the LFL. The details of the warning itself are discussed below in the following section.

GTR No. 13 provides two options for evaluating this requirement. The first option is to use a remote-controlled release of hydrogen to simulate a leak, along with laboratory-installed hydrogen concentration detectors in the enclosed or semi-enclosed spaces. The laboratory-installed hydrogen concentration detectors are used to verify that the required warning and shut-off valve closure occur at the appropriate hydrogen concentrations in the enclosed or semi-enclosed spaces. GTR No. 13 allows for the remote-controlled release of hydrogen to be drawn from the vehicle's own CHSS. Therefore, by using this option, it is possible for a vehicle to meet the requirements without a built-in hydrogen concentration detector. This is accomplished by the vehicle monitoring hydrogen outflow from its CHSS. The vehicle can then trigger the required warning and shut-off valve closure if significant hydrogen outflow from the CHSS is detected that is not accounted for by fuel cell hydrogen consumption.

The second option for evaluating the requirement is to use an induction hose and a cover to apply hydrogen test gas directly to the vehicle's built-in hydrogen concentration detector(s) within the enclosed or semi-enclosed spaces. Test gas with a hydrogen concentration of 3.0 to 4.0 percent is used to verify the warning, and test gas with a hydrogen concentration of 4.0 to 6.0 percent is used to verify the closure of the shut-off valve. The warning and shut-off valve closure must occur within 10 seconds of applying the respective test gas to the detector. The warning is verified by visual inspection, and the shut-off valve closure can be verified by monitoring the electric power to the shut-off valve or by the sound of the shut-off valve activation.

This second option indirectly requires the presence of at least one hydrogen concentration detector in the enclosed or semi-enclosed spaces that can detect the hydrogen test gas and trigger the warning and shut-off valve closure at appropriate hydrogen concentration levels. NHTSA is proposing this second option as the only test method in FMVSS No. 307, which would thereby require each vehicle to have at least one built-in hydrogen concentration detector. NHTSA seeks comment on requiring built-in hydrogen concentration detectors and seeks comment on the reliability of the required warning and shut-off valve closure for vehicles that do not have built-in hydrogen concentration detectors.

In addition to the above requirement regarding a warning and shut-off valve closure, GTR No. 13 includes a requirement that any failure downstream of the main hydrogen shut off valve shall not result in any level of hydrogen concentration in the passenger compartment. This requirement is evaluated by applying a remote-controlled release of hydrogen simulating a leak in the fuel system, along with laboratory-installed hydrogen concertation detectors in the passenger compartment. After remote release of hydrogen, GTR No. 13 requires that the hydrogen concentration in the passenger compartment not exceed 1.0 percent. The number, location, and flow capacity of the release points for the remote-controlled release of hydrogen are defined by the vehicle manufacturer.

A concentration of 1.0 percent hydrogen is inflammable at only 25 percent of the LFL for hydrogen. NHTSA has determined there is no need to apply such a stringent concentration limit in the passenger compartment. NHTSA is instead proposing that the remote-controlled release of hydrogen shall not result in a hydrogen concentration exceeding 3.0 percent in the enclosed or semi-enclosed spaces of the vehicle (including the passenger compartment). NHTSA believes that this is a more balanced requirement that ensures there is no accumulation of hydrogen too near the LFL in any enclosed or semi-enclosed spaces of the vehicle. NHTSA seeks comment on this requirement and on specific test procedures for initiating a remote-controlled release of hydrogen in a vehicle.

To evaluate this requirement, NHTSA proposes that a hydrogen concentration detector be installed in any enclosed or semi-enclosed space where hydrogen may accumulate from the simulated hydrogen release. After the remote-controlled release of hydrogen, the hydrogen concentration would be measured continuously using the laboratory-installed hydrogen concertation detector. The test would be completed five minutes after initiating the simulated leak or when the hydrogen concentration does not change for three minutes, whichever is longer. Five minutes is selected as the minimum time for monitoring the hydrogen concentration because five minutes is generally considered a sufficient time frame for vehicle occupants to evacuate in the event of an emergency.

The test procedures in this section are intended to work together to ensure safety. Primary protection is provided by ensuring that hydrogen cannot accumulate as a result of a leak beyond a 3.0 percent concentration in the enclosed or semi-enclosed spaces. This ensures that there is no potential for ignition to occur due to hydrogen leakage. The requirement for the visual warning and shut-off valve closure serves as a secondary measure in preventing a flammable condition from occurring in the event of a failure resulting in an accumulation of hydrogen.

The proposed test procedures in this section would be conducted without the influence of any wind. NHTSA seeks comment on providing more specific wind protection requirements and seeks comment on limiting the maximum wind velocity during testing to 2.24 meters/second as in FMVSS No. 304.[107]

g. Warning for Elevated Hydrogen Concentration

While the aim of the GTR and this proposal is to set safety requirements that prevent hydrogen from leaking and causing hazardous conditions, if hydrogen manages to accumulate to the LFL of 4.0 percent, there is a risk of a fire or explosion occurring. As discussed above, NHTSA is proposing requiring a telltale[108] warning when hydrogen concentration exceeds 3.0 percent in the enclosed or semi-enclosed spaces of the vehicle. Given the serious threat posed by elevated hydrogen levels in the passenger compartment, NHTSA is proposing the visual warning be red in color and remain illuminated while the vehicle is in operation with hydrogen concentration levels exceeding 3.0 percent in enclosed or semi-enclosed spaces of the vehicle. The visual warning must be in clear view of the driver. For a vehicle with automated driving systems and without manually-operated driving controls, the visual warning must be in clear view of all the front seat occupants. NHTSA seeks comment on whether the warning should be in clear view of all occupants, including occupants in rear seating positions, in vehicles with automated driving systems. NHTSA also seeks comment on whether an auditory warning be required when hydrogen concentration exceeds 3.0 percent in the enclosed or semi-enclosed spaces of the vehicle.

NHTSA is also proposing that a telltale be activated if the hydrogen warning system malfunctions, such as in the case of a circuit disconnection, short circuit, sensor fault, or other system failure. NHTSA proposes that when the telltale activates for these circumstances that it illuminates as yellow to distinguish a malfunction of the warning system from that of excess hydrogen concentration.

---

[107] FMVSS No. 304, “Compressed natural gas fuel container integrity.” https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-571/subpart-B/section-571.304

[108] A telltale is an optical signal that, when illuminated, indicates the actuation of a device, a correct or improper functioning or condition, or a failure to function.

2. Post-crash fuel system integrity

The second half of proposed FMVSS No. 307 are post-crash requirements for the fuel system. After a vehicle crash, there is a high risk of hydrogen escaping from the CHSS and other parts of the vehicle fuel system due to structural damage. The primary safety strategy applied in GTR No. 13 is to ensure the proper containment of hydrogen in the container and the fuel system after a crash has occurred.

In accordance with GTR No. 13, NHTSA is proposing that the post-crash requirements only apply to passenger cars, multipurpose passenger vehicles, trucks and buses with a GVWR less than or equal to 4,536 kg (10,000 pounds) and to all school buses, that use hydrogen fuel for propulsion power. NHTSA is not proposing that these post-crash requirements apply to all heavy vehicles with a GVWR greater than 4,536 kg (10,000 pounds). We are tentatively making this decision because there is not a comparable crash test for heavy vehicles to conduct the tests necessary for compliance assessment. NHTSA seeks comment on whether heavy vehicles should be subject to these proposed post-crash requirements and if so, what crash tests should NHTSA conduct on heavier vehicles.

During Phase I of GTR No. 13, the IWG decided not to attempt creating a uniform crash test and instead provided the option to Contracting Parties to determine the appropriate test based on their existing standards. NHTSA is proposing to use the crash tests equivalent to those applied to conventionally fueled vehicles in accordance with FMVSS No. 301. For light vehicles with a GVWR under 4,536 kg, these crash tests include an 80 kilometers per hour (km/h) (~50 miles per hour (mph)) impact of a rigid barrier into the rear of the vehicle, a 48 km/h (~30 mph) frontal crash test into a rigid barrier, and a 53 km/h (~33 mph) impact of a moving deformable barrier into the side of the vehicle. For school buses with a GVWR greater than or equal to 4,536 kg, the crash test is a moving contoured barrier impact at 48 km/h. NHTSA has determined that it is appropriate to apply equivalent crash tests to hydrogen vehicles as those for conventionally fueled vehicles. NHTSA seeks comment on whether there are alternative crash tests that should be used for the forthcoming proposed regulations.

NHTSA is proposing that there be no fire during the test, and that vehicles meet three additional post-crash requirements described by GTR No. 13. These three requirements echo the same safety goals of the first half of FMVSS No. 307. They are designed to prevent CHSS bursts, the creation of additional hazards caused by hydrogen leakage, and to protect occupants.

The first proposed requirement is based on FMVSS No. 301. The volumetric flow of hydrogen gas leakage from the CHSS must not exceed an average of 118 normal liters per minute (NL/min) from the time of vehicle impact through a time interval Δt of at least 60-minutes after impact. This leakage limit of 118 NL/min is equivalent to a total allowable mass leakage of 606 grams of hydrogen gas in 60 minutes.[109]

The volumetric leak rate of hydrogen post-crash is determined as a function of the pressure in the container before and after the crash test. The interval Δt is at least 60 minutes after impact to provide time for any leaks to reduce the CHSS pressure by an accurately measurable amount. For a pressure drop to be measured accurately by a sensor, the drop should be at least 5 percent of the pressure sensor's full range. However, for a CHSS larger than about 400 liters, 60 minutes may be insufficient for a leak exceeding the leakage limit to result in 5 percent of full range pressure drop. This is due to the non-linear relationship between the density and pressure of hydrogen and helium gas. Therefore, the variables of CHSS volume, sensor range, and CHSS NWP need to be considered when determining the time interval Δt. GTR No.

---

[109] Based on requirements in FMVSS No. 301 S5.5 and S5.6, a total amount of allowable energy loss for gasoline fuel from impact through the 60-minute interval after motion has ceased is 72,590 kiloJoules (KJ). This total amount of allowable energy loss is applied to hydrogen, and based on hydrogen energy density, equates to 606 grams of hydrogen loss. From the total allowable hydrogen mass leakage of 606 g, total allowable volumetric leakage, with a reference temperature of 15 °C, during 60-minute interval after impact can be calculated as follows:

$$\frac{606\text{ g}}{2.0159\text{ gram/mole}}\text{ x }\frac{22.41\text{ liter}}{\text{mole}}\text{ x }\frac{288}{273} = 7107\text{ NL}$$

where 2.0159 gram/mole is the molar weight of a hydrogen molecule and 22.41 liter/mole is the molar volume of hydrogen at standard conditions, and the factor 288/273 adjusts the calculation for a temperature of 15 °C. Therefore, the allowable volumetric flow rate of hydrogen after impact through the 60-minute interval after impact has ceased is: 7107 NL/60 minutes = 118 NL/minute. For additional information, see the associated technical document "Post-crash hydrogen leakage limit for FMVSS No. 307.pdf" in the docket of this NPRM. Reference: SAE 2578_201408. Recommended Practice for General Fuel Cell Vehicle Safety. Appendix A.1.1.

13 provides an equation to increase Δt as necessary to ensure an accurate pressure drop measurement.[110]

Helium may be used in place of hydrogen during crash-testing, as a safer alternative to hydrogen, with the corresponding calculation modifications discussed below. Due to the differing physical properties of hydrogen and helium gas, the allowable leakage limit for helium is 75 percent of the 118 NL/min allowed for hydrogen. This corresponds to a helium leakage limit of 88.5 NL/min.

The second requirement ensures hydrogen does not accumulate in the enclosed or semi-enclosed spaces which could present a post-crash hazard. This hydrogen concentration limit is set to four percent by volume (for helium, this corresponds to a concentration of three percent by volume). This requirement is satisfied if the CHSS shut-off valve(s) are confirmed to be closed within five seconds of the crash and there is no hydrogen leakage from the CHSS. If the shut-off valve has closed and the leakage from the CHSS is no more than 118 NL/min, it is not likely for hydrogen to accumulate in enclosed or semi-enclosed spaces.

For the purpose of measuring the hydrogen concentration, GTR No. 13 specifies that data from the sensors shall be collected at least every five seconds and continue for a period of 60 minutes. GTR No. 13 also discusses filtering of the data to provide smoothing of the data, but is unclear about the exact data filtration method to be used. NHTSA proposes using a three data point rolling average for filtering the data steam. Since a data point will collected at least every five seconds, this rolling average will be, at most, a 15-second rolling average. NHTSA seeks comment on this proposed data filtration method.

The third requirement in GTR No. 13 that NHTSA is proposing is requiring that the container(s) remains attached to the vehicle by at least one component anchorage, bracket, or any structure that transfers loads from the device to the vehicle structure. This ensures that a

---

[110] The time interval after impact, Δt, shall be the greater of: (1) 60 minutes; or (2) $\Delta t = V_{CHSS} \times NWP / 1000 \times ((-0.027 \times NWP + 4) \times R_s - 0.21) - 1.7 \times R_s$, where $R_s = P_s / NWP$, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), and V_{CHSS} is the volume of the CHSS (L).

container is not separated from the vehicle during a crash. Most containers rely at least partially on the vehicle for protection and shielding. As a result, the container cannot be allowed to separate from the vehicle during a crash. This requirement is evaluated by visual inspection of the container attachment points.

NHTSA will evaluate the presence of vehicle fire by visual inspection for the duration of the test, which includes the time needed to determine fuel leakage from the CHSS.

GTR No. 13 specifies that each contracting party maintain its existing national crash tests (frontal, side, rear and rollover) for post-crash evaluation. However, the crash tests specified in FMVSS No. 301 and post-crash requirements are only intended for light vehicles. In GTR No. 13 Phase 1, the scope of the regulation was confined to light vehicles under 4,536 kg (10,000 pounds). Since the scope of GTR No. 13 was expanded under Phase 2 to cover heavy vehicles, the IWG considered different alternative options to replace full vehicle crash tests for heavy vehicles. However, none of these alternative options for heavy vehicles were implemented into GTR No. 13 Phase 2.

Under Phase 2, the European Union proposed sled tests to replace full-scale crash testing for light and heavy vehicles. The sled test proposal involved applying several acceleration pulses to CHSS mounted on a sled with attachment structures similar to those on a corresponding hydrogen vehicle. The acceleration pulses of three separate sled tests simulate a peak of 10 g acceleration in the forward and rearward direction of travel, and 8 g in the direction perpendicular to the direction of travel.

NHTSA questioned the safety need for this sled test during the IWG discussions on the European Union proposal. The proposed sled test's only performance requirement is for the CHSS to remain attached to the vehicle by at least one anchorage point. In the U.S., there is no corresponding sled test for CNG heavy vehicles, and NHTSA is not aware of any safety issues related to anchorage failures in CNG heavy vehicles. Therefore, NHTSA questions the safety relevance of a sled test for hydrogen-fueled heavy vehicles. NHTSA seeks comment on the safety need for a heavy vehicle sled test.

GTR No. 13 Phase 2 also considered the possibility of an impact test for heavy vehicles in place of a full-scale vehicle crash test. The potential impact test would be conducted on the CHSS along with relevant vehicle-specific shielding, panels and/or structural supports on the vehicle. It would thereby simulate a vehicle-level crash test without destroying an entire vehicle. Since the manufacturer is most familiar with the protective design features of their vehicle, the manufacturer would specify which shields, panels, and protective structures to include in the impact test. After the impact, the CHSS would be required to meet the same leakage limit described above for light vehicles. The concentration limit in enclosed spaces and the container displacement requirement would not apply because the impact test would not involve a full vehicle. NHTSA seeks input and comment with supporting data on implementing a possible alternative heavy vehicle impact test for the CHSS.

NHTSA seeks comment on the possibility of including a moving contoured barrier impact test on heavy vehicles (other than school buses) in accordance with S6.5 of FMVSS No. 301. This test would allow for a moving contoured barrier to impact the CHSS along with shields, panels, and protective structures specified by the manufacturer at any angle. Such an impact test would evaluate the ability of side-saddle mounted CHSS to withstand light vehicle impacts and meet the allowable leakage limits.

C. Lead-time

NHTSA is proposing that the rule take effect the September 1st the year after the final rule is published. As discussed above, NHTSA believes that the requirements in the proposal are closely aligned to current industry practice and manufacturers will not require an extended lead-time. NHTSA seeks comment on whether any of the requirements necessitate additional lead-time.

V. Rulmaking Analyses and Notices

Executive Order 12866, Executive Order 13563, and DOT Regulatory Policies and Procedures

We have considered the potential impact of this proposed rule under Executive Order 12866, Executive Order 13563, and DOT Order 2100.6A. This NPRM is nonsignificant under E.O. 12866 and was not reviewed by the Office of Management and Budget. It is also not considered "of special note to the Department" under DOT Order 2100.6A, Rulemaking and Guidance Procedures.

Today, there are only two publicly available vehicle models that may be affected by the proposed rule, which collectively equal less than 5,000 vehicles sold per model year. Most manufacturers and vehicle lines currently in production would be unaffected by this proposal. Of those vehicles that would be covered by today's proposed standards, we expect the compliance cost to be minimal. As discussed earlier, the few manufacturers that already offer hydrogen vehicles in the marketplace already take safety precautions to attempt to emulate the safety of conventional and battery electric vehicles, and adhere to the industry guidelines that informed the creation of GTR No. 13. As today's proposed rule is intended to coalesce industry practice and future designs through harmonized regulations, we also do not expect that the proposal would pose a significant cost to those manufacturers, nor for those manufacturers that may be planning to enter the market.

Given NHTSA is proposing these standards during the early development of hydrogen vehicles, there is no baseline to compare today's proposal against. While we anticipate the regulations, if adopted, would promote safer hydrogen vehicles, we cannot quantify this benefit with any degree of certainty, especially given we cannot forecast what the industry would look like in the absence of our proposed standard. Furthermore, most of the safety benefits that would accrue to this rule, would only be realized when hydrogen vehicles become more prevalent and the net present value of these costs and benefits would be minimal.

We seek comment on all of these assumptions and ask commenters, if they do disagree with this assessment, to identify which portions of the proposal may accrue costs and identify a methodology for quantifying the potential costs and benefits of this proposal.

Regulatory Flexibility Act

Pursuant to the Regulatory Flexibility Act (5 U.S.C. 601 et seq., as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996), whenever an agency is required to publish a notice of proposed rulemaking or final rule, it must prepare and make available for public comment a regulatory flexibility analysis that describes the effect of the rule on small entities (i.e., small businesses, small organizations, and small governmental jurisdictions). The Small Business Administration's regulations at 13 CFR part 121 define a small business, in part, as a business entity “which operates primarily within the United States.” (13 CFR 121.105(a)(1)). No regulatory flexibility analysis is required if the head of an agency certifies the proposed or final rule will not have a significant economic impact on a substantial number of small entities. SBREFA amended the Regulatory Flexibility Act to require Federal agencies to provide a statement of the factual basis for certifying that a proposed or final rule will not have a significant economic impact on a substantial number of small entities.

I certify that the proposed standards would not have a significant impact on a substantial number of small entities. This proposed action would create FMVSS Nos. 307 and 308 to establish minimum safety requirements for the CHSS and fuel system integrity of hydrogen vehicles. FMVSS Nos. 307 and 308 are vehicle standards. We anticipate any burdens of the standard will fall onto manufacturers of hydrogen vehicles. NHTSA is unaware of any small entities that are planning to manufacture hydrogen vehicles. Furthermore, NHTSA is proposing to adopt standards similar to those already in place across industry. Thus, we anticipate the impacts of this NPRM on all manufacturers to be minimal regardless of manufacturer size.

Executive Order 13132

NHTSA has examined this proposed rule pursuant to Executive Order 13132 (64 FR 43255, August 10, 1999) and concluded that no additional consultation with States, local governments or their representatives is mandated beyond the rulemaking process. The Agency has concluded that this action would not have “federalism implications” because it would not have “substantial direct effects on States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government,” as specified in section 1 of the Executive order. This proposed rule would apply to motor vehicle manufacturers. Further, no state has adopted requirements regulating the CHSS or fuel integrity of hydrogen powered vehicles. Thus, Executive Order 13132 is not implicated and consultation with State and local officials is not required.

NHTSA rules can preempt in two ways. First, the National Traffic and Motor Vehicle Safety Act contains an express preemption provision: When a motor vehicle safety standard is in effect under this chapter, a State or a political subdivision of a State may prescribe or continue in effect a standard applicable to the same aspect of performance of a motor vehicle or motor vehicle equipment only if the standard is identical to the standard prescribed under this chapter. 49 U.S.C. 30103(b)(1). It is this statutory command by Congress that preempts any non-identical State legislative and administrative law addressing the same aspect of performance.

The express preemption provision described above is subject to a savings clause under which compliance with a motor vehicle safety standard prescribed under this chapter does not exempt a person from liability at common law. 49 U.S.C. 30103(e). Pursuant to this provision, State common law tort causes of action against motor vehicle manufacturers that might otherwise be preempted by the express preemption provision are generally preserved.

However, the Supreme Court has recognized the possibility, in some instances, of implied preemption of such State common law tort causes of action by virtue of NHTSA's rules, even if not expressly preempted. This second way that NHTSA rules can preempt is dependent upon there being an actual conflict between an FMVSS and the higher standard that would effectively be imposed on motor vehicle manufacturers if someone obtained a State common law tort judgment against the manufacturer, notwithstanding the manufacturer's compliance with the NHTSA standard. Because most NHTSA standards established by an FMVSS are minimum standards, a State common law tort cause of action that seeks to impose a higher standard on motor vehicle manufacturers will generally not be preempted. However, if and when such a conflict does exist—for example, when the standard at issue is both a minimum and a maximum standard—the State common law tort cause of action is impliedly preempted. See *Geier* v. *American Honda Motor Co.,* 529 U.S. 861 (2000).

Pursuant to Executive Order 13132 and 12988, NHTSA has considered whether this proposed rule could or should preempt State common law causes of action. The agency's ability to announce its conclusion regarding the preemptive effect of one of its rules reduces the likelihood that preemption will be an issue in any subsequent tort litigation. To this end, the agency has examined the nature (*i.e.,* the language and structure of the regulatory text) and objectives of this proposed rule and finds that this rule, like many NHTSA rules, would prescribe only a minimum safety standard. As such, NHTSA does not intend this NPRM to preempt state tort law that would effectively impose a higher standard on motor vehicle manufacturers rule. Establishment of a higher standard by means of State tort law will not conflict with the minimum standard adopted here. Without any conflict, there could not be any implied preemption of a State common law tort cause of action.

Executive Order 12988 (Civil Justice Reform)

When promulgating a regulation, Executive Order 12988 specifically requires that the agency must make every reasonable effort to ensure that the regulation, as appropriate: (1) Specifies in clear language the preemptive effect; (2) specifies in clear language the effect on existing Federal law or regulation, including all provisions repealed, circumscribed, displaced, impaired, or modified; (3) provides a clear legal standard for affected conduct rather than a general standard, while promoting simplification and burden reduction; (4) specifies in clear language the retroactive effect; (5) specifies whether administrative proceedings are to be required before parties may file suit in court; (6) explicitly or implicitly defines key terms; and (7) addresses other important issues affecting clarity and general draftsmanship of regulations.

Pursuant to this Order, NHTSA notes as follows. The preemptive effect of this proposed rule is discussed above in connection with E.O. 13132. NHTSA notes further that there is no requirement that individuals submit a petition for reconsideration or pursue other administrative proceeding before they may file suit in court.

Executive Order 13609 (Promoting International Regulatory Cooperation)

Executive Order 13609, "Promoting International Regulatory Cooperation," promotes international regulatory cooperation to meet shared challenges involving health, safety, labor, security, environmental, and other issues and to reduce, eliminate, or prevent unnecessary differences in regulatory requirements.

Today's proposed rule adopts the technical requirements of GTR No.13, a technical standard for hydrogen vehicles adopted by the United Nations Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29). As a Contracting Party who voted in favor of GTR No. 13, NHTSA is obligated to initiate rulemaking to incorporate safety requirements and options specified in GTR. While today's proposal does contain some differences from GTR No. 13 to reflect U.S. law, they are consistent with the regulatory process envisioned and encourage from the outset of GTR No. 13. NHTSA will continue to participate with the international community on GTR No. 13, and evaluate further amendments on their merits as they are adopted by WP.29.

NHTSA has analyzed this proposed rule under the policies and agency responsibilities of Executive Order 13609, and has determined this proposal would have no effect on international regulatory cooperation.

National Environmental Policy Act

NHTSA has analyzed this NPRM for the purposes of the National Environmental Policy Act. The agency has determined that implementation of this action would not have an adverse impact on the quality of the human environment. As described earlier, the proposal would coalesce industry practice into uniformed regulations and harmonize with international standards. NHTSA expects the changes to existing vehicles would be minimal, and mitigating the hazards associated with hydrogen leakage and discharge from the fuel system, as well as instituting post-crash restrictions on hydrogen leakage, concentration in enclosed spaces, container displacement, and fire, would result in a public health and safety benefit.

For these reasons, the agency has determined that implementation of this action would not have any adverse impact on the quality of the human environment.

Paperwork Reduction Act

Under the procedures established by the Paperwork Reduction Act of 1995 (PRA) (44 U.S.C. 3501, et. seq.), Federal agencies must obtain approval from the OMB for each collection of information they conduct, sponsor, or require through regulations. A person is not required to respond to a collection of information by a Federal agency unless the collection displays a valid OMB control number. The Information Collection Request (ICR) for a revision of a previously approved collection described below will be forwarded to OMB for review and comment. In compliance with these requirements, NHTSA asks for public comments on the following proposed collection of information for which the agency is seeking approval from OMB. In this NPRM, we are proposing a revision to an existing OMB approved collection, OMB Clearance No. 2127–0512, Consolidated Labeling Requirements for Motor Vehicles (except the VIN). We are soliciting public comment for the proposed addition of labeling requirements for FMVSS Nos. 307 and 308.

Title: Consolidated Labeling Requirements for Motor Vehicles (except the VIN)

OMB Control Number: OMB Control No. 2127–0512

Type of Request: Revision of a previously approved collection.

Type of Review Requested: Regular

Requested Expiration Date of Approval: 3 years from the date of approval.

Summary of the Collection of Information:

> FMVSS No. 307 specifies requirements for the integrity of motor vehicle fuel systems using compressed hydrogen as a fuel source. Each hydrogen vehicle must have a permanent label which lists the fuel type, service pressure, and a statement directing vehicle users/operators to instructions for inspection and service life of the fuel container. FMVSS No. 308 specifies requirements for the integrity of compressed hydrogen storage systems (CHSS). Each hydrogen container must have a permanent label containing manufacturer contact information, the container serial number, manufacturing date, date of removal from service, and applicable BP_O burst pressure. If the proposed requirements are made final, we will submit a request for OMB clearance of the proposed collection of information and seek clearance prior to the effective date of the final rule.

Description of the likely respondents: Vehicle manufacturers.

Estimated Number of Respondents: 20

Estimated Total Annual Burden Hours: $8,468

It is estimated that vehicle manufacturers will provide labels on 10 different hydrogen vehicle models. Since manufacturers have provided CNG vehicles with similar required labels for many years, it is estimated that manufacturers will have a generalized label template which only requires minor adjustments for hydrogen and then population with the required information. There is an annual 1.0 hour burden for manufacturers to have a Mechanical Drafter put the correct information into a label template to create a model specific label. The annual burden for this label creation is 10 hours (10 CNG vehicle model labels * 1 hour per model label) and $404 (10 CNG vehicle model labels * 1 hour per model label * $28.37 labor rate per hour ÷ 70.3% of labor rate as total wage compensation). Manufacturers will also bear a cost burden of $1,884 (2,850 hydrogen vehicles * $0.73 per label) for the required labels to be attached to the CNG vehicles. The combined total annual burden to vehicle manufacturers from the requirements to have the specified label text on hydrogen vehicles is 10 hours and $2,288. These hour and cost burdens represent a new addition to this information collection request.

It is estimated that vehicle manufacturers will provide labels on 10 different hydrogen container models. Since manufacturers have provided CNG containers with similar labels for many years, it is estimated that manufacturers will have a generalized label template which only requires only minor adjustments for hydrogen and then population with their current contact information, the container serial number, manufacturing date, date of removal from service, and applicable BP_O burst pressure. There is an annual 1.0 hour burden for manufacturers to have a Mechanical Drafter put the correct information into a label template to create a model specific label. The annual burden for this label creation is 10 hours (10 hydrogen container model labels * 1.0 hours per model label) and $404 (10 hydrogen container models labels * 1.0 hours per model label * $28.37 labor rate per hour ÷ 70.3% of labor rate as total wage compensation). Manufacturers will also bear a cost burden of $5,776 (7,910 hydrogen containers * $0.730 per label) for the required labels to be attached to the hydrogen containers. The combined total annual burden to vehicle manufacturers from the requirements to have the specified label text on hydrogen containers is 10 hours and $6,180. These hour and cost burdens represent a new addition to this information collection request.

Public Comments Invited: You are asked to comment on any aspects of this information collection, including (a) whether the proposed collection of information is necessary for the proper performance of the functions of the Department, including whether the information will have practical utility; (b) the accuracy of the Department's estimate of the burden of the proposed information collection; (c) ways to enhance the quality, utility and clarity of the information to be collected; and (d) ways to minimize the burden of the collection of information on respondents, including the use of automated collection techniques or other forms of information technology.

Please submit any comments, identified by the docket number in the heading of this document, by the methods described in the ADDRESSES section of this document to NHTSA and OMB. Although comments may be submitted during the entire comment period, comments received within 30 days of publication are most useful.

National Technology Transfer and Advancement Act

Under the National Technology Transfer and Advancement Act of 1995 (NTTAA) (Pub. L. 104- Section 12(d) of the National Technology Transfer and Advancement Act (NTTAA) requires NHTSA to evaluate and use existing voluntary consensus standards in its regulatory activities unless doing so would be inconsistent with applicable law (e.g., the statutory provisions regarding NHTSA's vehicle safety authority) or otherwise impractical. Voluntary consensus standards are technical standards developed or adopted by voluntary consensus standards bodies. Technical standards are defined by the NTTAA as "performance-based or design-specific technical specification and related management systems practices." They pertain to "products and processes, such as size, strength, or technical performance of a product, process or material."

Examples of organizations generally regarded as voluntary consensus standards bodies include ASTM International, the Society of Automotive Engineers (SAE), and the American National Standards Institute (ANSI). If NHTSA does not use available and potentially applicable voluntary consensus standards, we are required by the Act to provide Congress, through OMB, an explanation of the reasons for not using such standards.

Today's proposed standards are consistent with voluntary standards cited above such as SAEJ2578_201408, SAEJ2579_201806, HPRD-1 2021, and HGV 3.1 2022.

We are proposing to incorporate by reference ISO 6270-2:2017, Determination of resistance to humidity, Second Edition, November 2017 into § 571.308. ISO 6270-2:2017 specifies methods for assessing the resistance of materials to humidity by focusing on how materials behave when exposed to high humidity. The standard provides detailed procedures for conducting tests in controlled environments where humidity is the primary variable. These environments simulate conditions that materials might encounter during their lifecycle, thereby offering insights into potential degradation processes such as corrosion, mold growth, or other forms of moisture-induced damage. The standard sets out guidelines for preparing test specimens, the conditions under which the tests should be conducted, and the criteria for evaluating the results, including specifying the temperature, humidity levels, and duration of exposure necessary to evaluate a material's resistance to humidity. ISO 6270-2:2017 is available on the ISO webpage for purchase and a copy is available for review at NHTSA's headquarters in Washington, DC through the means identified in ADDRESSES.[111]

We are proposing to incorporate by reference ASTM D1193-06, Standard Specification for Reagent Water, approved March 22, 2018 into § 571.308. ASTM D1193-06 is a standard that outlines specifications for reagent water quality across various scientific and analytical applications. This standard defines the requirements for the purity of water used in laboratories, ensuring that experiments and tests are not compromised by water impurities that could affect the results. It categorizes water into different types (I, II, III, and IV), each with specific purity levels suitable for particular applications, ranging from high-precision analytical work to general laboratory procedures. The standard details methods for testing and validating the quality of water, including the acceptable limits for contaminants like organic and inorganic compounds, as well as microbial content. It also provides guidelines for the storage and handling of reagent water to maintain its purity. ASTM D1193-06 is available on the ASTM's online reading room and a copy is available for review at NHTSA's headquarters in Washington, DC through the means identified in ADDRESSES.[112]

---

[111] *See*, https://www.iso.org/standard/64858.html.

[112] *See*, https://www.astm.org/d1193-06r18.html.

This proposal to adopt GTR No. 13 is consistent with the goals of the NTTAA. This NPRM proposes to adopt a global consensus standard. The GTR was developed by a global regulatory body and is designed to increase global harmonization of differing vehicle standards. The GTR leverages the expertise of governments in developing safety requirements for hydrogen fueled vehicles. NHTSA's consideration of GTR No. 13 accords with the principles of NTTAA as NHTSA's consideration of an established, proven regulation has reduced the need for NHTSA to expend significant agency resources on the same safety need addressed by GTR No. 13.

Unfunded Mandates Reform Act

Section 202 of the Unfunded Mandates Reform Act of 1995 (UMRA) requires Federal agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditure by State, local, or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for the year 2020 results in $158 million (113.625/71.868 = 1.581). Before promulgating a rule for which a written statement is needed, section 205 of the UMRA generally requires the agency to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows the agency to adopt an alternative other than the least costly, most cost-effective, or least burdensome alternative if the agency publishes with the final rule an explanation of why that alternative was not adopted.

This NPRM would not result in expenditures by State, local, or tribal governments, in the aggregate, or by the private sector in excess of $158 million (in 2020 dollars) annually. As a result, the requirements of Section 202 of the Act do not apply.

Executive Order 13045 (Protection of Children from Environmental Health and Safety Risks)

Executive Order 13045, "Protection of Children from Environmental Health and Safety Risks," (62 FR 19885, April 23, 1997) applies to any proposed or final rule that: (1) Is determined to be "economically significant," as defined in E.O. 12866, and (2) concerns an environmental health or safety risk that NHTSA has reason to believe may have a disproportionate effect on children. If a rule meets both criteria, the agency must evaluate the environmental health or safety effects of the rule on children and explain why the rule is preferable to other potentially effective and reasonably feasible alternatives considered by the agency.

This rulemaking is not subject to the Executive order because it is not economically significant as defined in E.O. 12866.

Executive Order 13211

Executive Order 13211 (66 FR 28355, May 18, 2001) applies to any rulemaking that: (1) is determined to be economically significant as defined under E.O. 12866, and is likely to have a significantly adverse effect on the supply of, distribution of, or use of energy; or (2) that is designated by the Administrator of the Office of Information and Regulatory Affairs as a significant energy action. This rulemaking is not subject to E.O. 13211 as this rule is not economically significant and should not have an adverse effect on the supply of, distribution of, or use of energy as explained in our discussion of Executive Orders 12866 and 13563.

Plain Language

Executive Order 12866 requires each agency to write all rules in plain language. Application of the principles of plain language includes consideration of the following questions:

- Have we organized the material to suit the public's needs?
- Are the requirements in the rule clearly stated?
- Does the rule contain technical language or jargon that isn't clear?
- Would a different format (grouping and order of sections, use of headings, paragraphing) make the rule easier to understand?

- Would more (but shorter) sections be better?
- Could we improve clarity by adding tables, lists, or diagrams?
- What else could we do to make the rule easier to understand?

If you have any responses to these questions, please include them in your comments on this proposal.

Regulation Identifier Number (RIN)

The Department of Transportation assigns a regulation identifier number (RIN) to each regulatory action listed in the Unified Agenda of Federal Regulations. The Regulatory Information Service Center publishes the Unified Agenda in April and October of each year. You may use the RIN contained in the heading at the beginning of this document to find this action in the Unified Agenda.

VI. Public Participation

How do I prepare and submit comments?

To ensure that your comments are correctly filed in the Docket, please include the Docket Number in your comments.

Your comments must be written and in English. Your comments must not be more than 15 pages long. NHTSA established this limit to encourage you to write your primary comments in a concise fashion. However, you may attach necessary additional documents to your comments, and there is no limit on the length of the attachments.

If you are submitting comments electronically as a PDF (Adobe) file, NHTSA asks that the documents be submitted using the Optical Character Recognition (OCR) process, thus allowing NHTSA to search and copy certain portions of your submissions.

Please note that pursuant to the Data Quality Act, in order for substantive data to be relied on and used by NHTSA, it must meet the information quality standards set forth in the OMB and DOT Data Quality Act guidelines. Accordingly, NHTSA encourages you to consult the guidelines in preparing your comments. DOT's guidelines may be accessed at https://www.transportation.gov/regulations/dot-information-dissemination-quality-guidelines.

Tips for Preparing Your Comments

When submitting comments, please remember to:

Identify the rulemaking by docket number and other identifying information (subject heading, Federal Register date and page number).

Explain why you agree or disagree, suggest alternatives, and substitute language for your requested changes.

Describe any assumptions you make and provide any technical information and/or data that you used.

If you estimate potential costs or burdens, explain how you arrived at your estimate in sufficient detail to allow for it to be reproduced.

Provide specific examples to illustrate your concerns and suggest alternatives.

Explain your views as clearly as possible, avoiding the use of profanity or personal threats.

To ensure that your comments are considered by the agency, make sure to submit them by the comment period deadline identified in the DATES section above.

For additional guidance on submitting effective comments, see https://www.regulations.gov/docs/Tips_For_Submitting_Effective_Comments.pdf.

How can I be sure my comments were received?

If you wish Docket Management to notify you upon its receipt of your comments, enclose a self-addressed, stamped postcard in the envelope containing your comments. Upon receiving your comments, Docket Management will return the postcard by mail.

How do I submit confidential business information?

If you wish to submit any information under a claim of confidentiality, you should submit three copies of your complete submission, including the information you claim to be confidential business information, to the Chief Counsel, NHTSA, at the address given above under FOR FURTHER INFORMATION CONTACT. In addition, you should submit a copy from which you have deleted the claimed confidential business information to the docket. When you send a comment containing information claimed to be confidential business information, you should include a cover letter setting forth the information specified in our confidential business information regulation. (49 CFR part 512.)

Will the Agency consider late comments?

NHTSA will consider all comments that the docket receives before the close of business on the comment closing date indicated above under DATES. To the extent possible, NHTSA will also consider comments that the docket receives after that date. If the docket receives a comment too late for the agency to consider it in developing a final rule, NHTSA will consider that comment as an informal suggestion for future rulemaking action.

How can I read the comments submitted by other people?

You may read the comments received by the docket at the address given above under ADDRESSES. You may also see the comments on the internet (http://regulations.gov).

Please note that even after the comment closing date, NHTSA will continue to file relevant information in the docket as it becomes available. Further, some people may submit late comments. Accordingly, the agency recommends that you periodically check the docket for new material.

Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the Federal Register published on April 11, 2000 (Volume 65, Number 70; Pages 19477-78).

49 CFR Part 571

Imports, Incorporation by reference, Motor vehicle safety, Reporting and recordkeeping requirements, Tires.

In consideration of the foregoing, NHTSA proposes to amend 49 CFR Part 571 as set forth below.

PART 571 – FEDERAL MOTOR VEHICLE SAFETY STANDARDS

1. The authority citation for part 571 continues to read as follows:

Authority: 49 U.S.C. 322, 30111, 30115, 30117 and 30166; delegation of authority at 49 CFR 1.95

2. Section 571.5(d) is amended by redesignating paragraphs (19) through (39) as paragraphs (20) through (40) and adding paragraph (19);

3. Section 571.5(i) is amended by redesignating paragraphs (1) through (4) as paragraphs (2) through (5) and adding paragraph (1) to read as follows:

§571.5 Matter incorporated by reference.

* * * * *

(d) * * *

(19) ASTM D1193-06 (Reapproved 2018), Standard Specification for Reagent Water, approved March 22, 2018; into § 571.308.

* * * * *

(i) * * *

(1) ISO 6270-2:2017, Determination of resistance to humidity, Second Edition, November 2017; into § 571.308.

* * * * *

4. Section 571.307 is added to read as follows:

§571.307 Standard No. 307; Fuel system integrity of hydrogen vehicles.

S1. *Scope.* This standard specifies requirements for the integrity of motor vehicle hydrogen fuel systems.

S2. *Purpose.* The purpose of this standard is to reduce deaths and injuries occurring from fires that result from hydrogen fuel leakage during vehicle operation and after motor vehicle crashes.

S3. *Application.* This standard applies to each motor vehicle that uses compressed hydrogen gas as a fuel source to propel the vehicle.

S4. *Definitions.*

Check valve means a valve that prevents reverse flow.

Closure devices mean the check valve(s), shut-off valve(s) and thermally activated pressure relief device(s) that control the flow of hydrogen into and/or out of a CHSS.

Container means a pressure-bearing component of a compressed hydrogen storage system that stores a continuous volume of hydrogen fuel in a single chamber or in multiple permanently interconnected chambers.

Container attachments means non-pressure bearing parts attached to the container that provide additional support or protection to the container and that may be removed only with the use of tools for the specific purpose of maintenance or inspection.

Compressed hydrogen storage system (CHSS) means a system that stores compressed hydrogen fuel for a hydrogen-fueled vehicle, composed of a container, container attachments (if any), and all closure devices required to isolate the stored hydrogen from the remainder of the fuel system and the environment.

Enclosed or semi-enclosed spaces means the volumes external to the hydrogen fuel system such as the passenger compartment, luggage compartment, and space under the hood.

Fuel cell system means a system containing the fuel cell stack(s), air processing system, fuel flow control system, exhaust system, thermal management system and water management system.

Fueling receptacle means the equipment to which a fueling station nozzle attaches to the vehicle and through which fuel is transferred to the vehicle.

Fuel lines means all piping, tubing, joints, and any components such as flow controllers, valves, heat exchangers, and pressure regulators.

Hydrogen concentration means the percentage of the hydrogen molecules within the mixture of hydrogen and air (equivalent to the partial volume of hydrogen gas).

Hydrogen fuel system mean the fueling receptacle, CHSS, fuel cell system or internal combustion engine, fuel lines, and exhaust systems.

Luggage compartment means the space in the vehicle for luggage, cargo, and/or goods accommodation, bounded by a roof, hood, floor, side walls being separated from the passenger compartment by the front bulkhead or the rear bulkhead.

Maximum allowable working pressure (MAWP) means the highest gauge pressure to which a component or system is permitted to operate under normal operating conditions.

Nominal working pressure (NWP) means the settled pressure of compressed gas in a container or CHSS fully fueled to 100 percent state of charge and at a uniform temperature of 15 °C.

Normal milliliter means a quantity of gas that occupies one milliliter of volume when its temperature is 0 °C and its pressure is 1 atmosphere.

Passenger compartment means the space for occupant accommodation that is bounded by the roof, floor, side walls, doors, outside glazing, front bulkhead, and rear bulkhead or rear gate.

Pressure relief device (PRD) means a device that, when activated under specified performance conditions, is used to release hydrogen from a pressurized system and thereby prevent failure of the system.

Rechargeable electrical energy storage system (REESS) means the rechargeable energy storage system that provides electric energy for electrical propulsion.

Service door means a door that allows for the entry and exit of vehicle occupants under normal operating conditions.

Shut-off valve means an automatically activated valve between the container and the remainder of the hydrogen fuel system that must default to the "closed" position when not connected to a power source.

State of charge (SOC) means the density ratio of hydrogen in the CHSS between the actual CHSS condition and that at NWP with the CHSS equilibrated to 15 °C, as expressed as a percentage using the formula:

$$SOC(\%) = \frac{\rho(P,T)}{\rho(NWP, 15°C)} x100$$

where ρ is the density of hydrogen (g/L) at pressure (P) in MegaPascals (MPa) and temperature (T) in Celsius (°C) as listed in the table below or linearly interpolated therein.

TEMPERATURE	**PRESSURE (MPa)**												
(°C)	**1**	**10**	**20**	**30**	**35**	**40**	**50**	**60**	**65**	**70**	**75**	**80**	**87.5**
-40	1.0	9.7	18.1	25.4	28.6	31.7	37.2	42.1	44.3	46.4	48.4	50.3	53.0
-30	1.0	9.4	17.5	24.5	27.7	30.6	36.0	40.8	43.0	45.1	47.1	49.0	51.7
-20	1.0	9.0	16.8	23.7	26.8	29.7	35.0	39.7	41.9	43.9	45.9	47.8	50.4
-10	0.9	8.7	16.2	22.9	25.9	28.7	33.9	38.6	40.7	42.8	44.7	46.6	49.2
0	0.9	8.4	15.7	22.2	25.1	27.9	33.0	37.6	39.7	41.7	43.6	45.5	48.1
10	0.9	8.1	15.2	21.5	24.4	27.1	32.1	36.6	38.7	40.7	42.6	44.4	47.0
15	0.8	7.9	14.9	21.2	24.0	26.7	31.7	36.1	38.2	40.2	42.1	43.9	46.5
20	0.8	7.8	14.7	20.8	23.7	26.3	31.2	35.7	37.7	39.7	41.6	43.4	46.0

30	0.8	7.6	14.3	20.3	23.0	25.6	30.4	34.8	36.8	38.8	40.6	42.4	45.0
40	0.8	7.3	13.9	19.7	22.4	24.9	29.7	34.0	36.0	37.9	39.7	41.5	44.0
50	0.7	7.1	13.5	19.2	21.8	24.3	28.9	33.2	35.2	37.1	38.9	40.6	43.1
60	0.7	6.9	13.1	18.7	21.2	23.7	28.3	32.4	34.4	36.3	38.1	39.8	42.3
70	0.7	6.7	12.7	18.2	20.7	23.1	27.6	31.7	33.6	35.5	37.3	39.0	41.4
80	0.7	6.5	12.4	17.7	20.2	22.6	27.0	31.0	32.9	34.7	36.5	38.2	40.6
85	0.7	6.4	12.2	17.5	20.0	22.3	26.7	30.7	32.6	34.4	36.1	37.8	40.2

Thermally-activated pressure relief device (TPRD) means a non-reclosing PRD that is activated by temperature to open and release hydrogen gas.

S5. *Hydrogen fuel system.*

S5.1. *Fuel system integrity during normal vehicle operations.*

S5.1.1. *Fueling receptacle requirements.*

(a) A compressed hydrogen fueling receptacle shall prevent reverse flow to the atmosphere.

(b) A label shall be affixed close to the fueling receptacle showing the following information:

(1) The statement, “Compressed hydrogen gas only.”

(2) The statement, “Service pressure ____________ MPa (________ psig).”

(3) The statement, “See instructions on fuel container(s) for inspection and service life.”

(c) The fueling receptacle shall ensure positive locking of the fueling nozzle.

(d) The fueling receptacle shall be protected from the ingress of dirt and water.

(e) The fueling receptacle shall not be mounted to or within the impact energy-absorbing elements of the vehicle and shall not be installed in enclosed or semi-enclosed spaces.

S5.1.2. *Over-pressure protection for the low-pressure system.* An overpressure protection device is required downstream of a pressure regulator to protect the low-pressure portions of the hydrogen fuel system from overpressure. The activation pressure of the overpressure protection device shall be less than or equal to the MAWP for the respective downstream section of the hydrogen fuel system.

S5.1.3. *Hydrogen discharge systems.*

S5.1.3.1. *Pressure relief systems.*

(a) If present, the outlet of the vent line for hydrogen gas discharge from the TPRD(s) of the CHSS shall be protected from ingress of dirt and water.

(b) With the vehicle on a level surface, the hydrogen gas discharge from the TPRD(s) of the CHSS shall be directed upwards within 20° of vertical relative to the level surface or downwards within 45° of vertical relative to the level surface.

(c) The hydrogen gas discharge from TPRD(s) of the CHSS shall not impinge upon:

(1) Enclosed or semi-enclosed spaces;

(2) Any vehicle wheel housing;

(3) Container(s);

(4) REESS(s);

(5) Any emergency exit(s) as identified in FMVSS No. 217; nor

(6) Any service door(s).

S5.1.3.2. *Vehicle exhaust system.* When tested in accordance with S6.5, the hydrogen concentration at the vehicle exhaust system's point of discharge shall not:

(a) Exceed an average of 4.0 percent by volume during any moving three-second time interval, and

(b) Exceed 8.0 percent by volume at any time.

S5.1.4 *Protection against flammable conditions.*

(a) When tested in accordance with S6.4.1, a warning in accordance with S5.1.6 shall be provided within 10 seconds of the application of the first test gas. When tested in accordance with S6.4.1, the main shut-off valve shall close within 10 seconds of the application of the second test gas.

(b) When tested in accordance with S6.4.2, the hydrogen concentration in the enclosed or semi-enclosed spaces shall be less than 3.0 percent.

S5.1.5 *Fuel system leakage.* When tested in accordance with S6.6, the hydrogen fuel system downstream of the shut-off valve(s) shall not leak.

S5.1.6 *Tell-tale warning.* The warning shall be given to the driver, or to all front seat occupants for vehicles without a driver’s designated seating position, by a visual signal or display text with the following properties:

(a) Visible to the driver while seated in the driver's designated seating position or visible to all front seat occupants of vehicles without a driver’s designated seating position;

(b) Yellow in color if the warning system malfunctions;

(c) Red in color if hydrogen concentration in enclosed or semi-enclosed spaces exceeds 3.0 percent by volume;

(d) When illuminated, shall be visible to the driver (or to all front seat occupants in vehicles without a driver’s designated seating position) under both daylight and night-time driving conditions; and

(e) Remains illuminated when hydrogen concentration in any of the vehicle’s enclosed or semi-enclosed spaces exceeds 3.0 percent by volume or when the warning system malfunctions, and the ignition locking system is in the "On" ("Run") position or the propulsion system is activated.

S5.2. *Post-crash fuel system integrity.* Each vehicle with a gross vehicle weight rating (GVWR) of 4,536 kg or less to which this standard applies must meet the requirements in S5.2.1 through S5.2.4 when tested according to S6 under the conditions of S7. Each school bus with a GVWR greater than 4,536 kg to which this standard applies must meet the requirements in S5.2.1 through S5.2.4 when tested according to S6 under the conditions of S7.

S5.2.1. *Fuel leakage limit.* If hydrogen gas is used for testing, the volumetric flow of hydrogen gas leakage shall not exceed an average of 118 normal liters per minute for the time interval, Δt, as determined in accordance with S6.2.1. If helium is used for testing, the volumetric flow of helium leakage shall not exceed an average of 88.5 normal litres per minute for the time interval, Δt, as determined in accordance with S6.2.2.

S5.2.2. *Concentration limit in enclosed spaces.* One of the requirements in (a), (b) or (c).

(a) Hydrogen gas leakage shall not result in a hydrogen concentration in the air greater than 4.0 percent by volume in enclosed or semi-enclosed spaces for 60 minutes after impact when tested in accordance with S6.3.

(b) Helium gas leakage shall not result in a helium concentration in the air greater than 3.0 percent by volume in enclosed or semi-enclosed spaces for 60 minutes after impact when tested in accordance with S6.3.

(c) The shut-off valve of the CHSS shall close within 5 seconds of the crash.

S5.2.3. *Container displacement.* The container(s) shall remain attached to the vehicle by at least one component anchorage, bracket, or any structure that transfers loads from the container to the vehicle structure.

S5.2.4. *Fire.* There shall be no fire in or around the vehicle for the duration of the test.

S6. *Test Requirements.*

S6.1. *Vehicle Crash Tests.* A test vehicle with a GVWR less than or equal to 4,536 kg, under the conditions of S7, is subject to any one single barrier crash test of S6.1.1, S6.1.2, and S6.1.3. A school bus with a GVWR greater than 4,536 kg, under the conditions of S7, is subject to the contoured barrier crash test of S6.1.4. A vehicle subject to S6 need not undergo further testing.

S6.1.1. *Frontal barrier crash.* The test vehicle, with test dummies in accordance with S6.1 of 571.301 of this chapter, traveling longitudinally forward at any speed up to and including 48.0 km/h, impacts a fixed collision barrier that is perpendicular to the line of travel of the vehicle, or at an angle up to 30 degrees in either direction from the perpendicular to the line of travel of the vehicle.

S6.1.2. *Rear moving barrier impact.* The test vehicle, with test dummies in accordance with S6.1 of 571.301 of this chapter, is impacted from the rear by a barrier that conforms to S7.3(b) of 571.301 of this chapter and that is moving at any speed up to and including 80.0 km/h.

S6.1.3. *Side moving deformable barrier impact.* The test vehicle, with the appropriate 49 C.F.R. Part 572 test dummies specified in 571.214 at positions required for testing by S7.1.1, S7.2.1, or S7.2.2 of Standard 214, is impacted laterally on either side by a moving deformable barrier moving at any speed between 52.0 km/h and 54.0 km/h

S6.1.4. *Moving contoured barrier crash.* The test vehicle is impacted at any point and at any angle by the moving contoured barrier assembly, specified in S7.5 and S7.6 in 571.301 of this chapter, traveling longitudinally forward at any speed up to and including 48.0 km/h.

S6.2. *Post-crash CHSS leak test.*

S6.2.1. *Post-crash leak test for CHSS filled with compressed hydrogen.*

(a) The hydrogen gas pressure, P_0 (MPa), and temperature, T_0 (°C), shall be measured immediately before the impact. The hydrogen gas pressure P_f (MPa) and temperature, T_f (°C) shall also be measured immediately after a time interval Δt (in minutes) after impact. The time interval, Δt, starting from the time of impact, shall be the greater of:

(1) 60 minutes; or

(2) $\Delta t = V_{CHSS} \times NWP / 1000 \times ((-0.027 \times NWP + 4) \times R_s - 0.21) - 1.7 \times R_s$

where $R_s = P_s / NWP$, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), and V_{CHSS} is the volume of the CHSS (L).

(b) The initial mass of hydrogen M_0 (g) in the CHSS shall be calculated from the following equations:

$P_0' = P_0 \times 288 / (273 + T_0)$

$\rho_0' = -0.0027 \times (P_0')^2 + 0.75 \times P_0' + 1.07$

$M_0 = \rho_0' \times V_{CHSS}$

(c)The final mass of hydrogen in the CHSS, M_f (in grams), at the end of the time interval, Δt, shall be calculated from the following equations:

$P_f' = P_f \times 288 / (273 + T_f)$

$\rho_f' = -0.0027 \times (P_f')^2 + 0.75 \times P_f' + 1.07$

$M_f = \rho_f' \times V_{CHSS}$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f (°C) is the measured final temperature.

(d) The average hydrogen flow rate over the time interval shall be calculated from the following equation:

$V_{H2} = (M_f - M_0) / \Delta t \times 22.41 / 2.016 \times (P_{target} / P_0)$

where V_{H2} is the average volumetric flow rate (normal millilitres per min) over the time interval.

S6.2.2 *Post-crash leak test for CHSS filled with compressed helium.*

(a) The helium pressure, P_0 (MPa), and temperature, T_0 (°C), shall be measured immediately before the impact and again immediately after a time interval starting from the time of impact. The time interval, Δt (min), shall be the greater of:

(1) 60 minutes; or

(2) $\Delta t = V_{CHSS} \times NWP / 1000 \times ((-0.028 \times NWP + 5.5) \times R_s - 0.3) - 2.6 \times R_s$

where $R_s = P_s / NWP$, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), and V_{CHSS} is the volume of the CHSS (L).

(b) The initial mass of helium M_0 (g) in the CHSS shall be calculated from the following equations:

$P_0' = P_0 \times 288 / (273 + T_0)$

$\rho_0' = -0.0043 \times (P_0')^2 + 1.53 \times P_0' + 1.49$

$M_0 = \rho_0' \times V_{CHSS}$

(c) The final mass of helium M_f (g) in the CHSS at the end of the time interval, Δt (min), shall be calculated from the following equations:

$$P_f' = P_f \times 288 / (273 + T_f)$$

$$\rho_f' = -0.0043 \times (P_f')^2 + 1.53 \times P_f' + 1.49$$

$$M_f = \rho_f' \times V_{CHSS}$$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f (°C) is the measured final temperature.

(d) The average helium flow rate over the time interval shall be calculated from the following equation:

$$V_{He} = (M_f - M_0) / \Delta t \times 22.41 / 4.003 \times (P_{target} / P_0)$$

where V_{He} is the average volumetric flow rate (normal millilitres per min) of helium over the time interval.

S6.3. *Post-crash concentration test for enclosed spaces*.

(a) Sensors shall measure either the accumulation of hydrogen or helium gas, as appropriate, or the reduction in oxygen.

(b) Sensors shall have an accuracy of at least 5 percent at 4.0 percent hydrogen or 3.0 percent helium by volume in air, and a full-scale measurement capability of at least 25 percent above these criteria. The sensor shall be capable of a 90 percent response to a full-scale change in concentration within 10 seconds.

(c) Prior to the crash impact, the sensors shall be located in the passenger and luggage compartments of the vehicle as follows:

(1) At any interior point at any distance between 240 mm and 260 mm of the headliner above the driver's seat or near the top center of the passenger compartment.

(2) At any interior point at any distance between 240 mm and 260 mm of the floor in front of the rear (or rear most) seat in the passenger compartment.

(3) At any interior point at any distance between 90 mm and 110 mm below the top of luggage compartment(s).

(d) The sensors shall be securely mounted on the vehicle structure or seats and protected from debris, air bag exhaust gas and projectiles.

(e) The vehicle shall be located either indoors or in an area outdoors protected from direct and indirect wind.

(f) Post-crash data collection in enclosed spaces shall commence from the time of impact. Data from the sensors shall be collected at least every 5 seconds and continue for a period of 60 minutes after the impact.

(h) The data shall be compiled into a three-data-point rolling average prior to evaluating the applicable concentration limit in accordance with S5.2.2(a) or S5.2.2(b).

S6.4. Test procedure for protection against flammable conditions.

S6.4.1. *Test for hydrogen gas leakage detectors*

(a) The vehicle shall be set to the “on” or “run” position for at least 5 minutes prior to testing, and left operating for the test duration. If the vehicle is not a fuel cell vehicle, it shall be warmed up and kept idling. If the test vehicle has a system to stop idling automatically, measures shall be taken to prevent the engine from stopping.

(b) Two mixtures of air and hydrogen gas shall be used in the test: The first test gas has any hydrogen concentration between 3.0 and 4.0 percent by volume in air to verify function of the warning, and the second test gas has any hydrogen concentration between 4.0 and 6.0 percent by volume in air to verify function of the shut-down.

(c) The test shall be conducted without any influence of wind.

(d) A vehicle hydrogen leakage detector located in the enclosed or semi-enclosed spaces is enclosed with a cover and a test gas induction hose is attached to the hydrogen gas leakage detector.

(e) The hydrogen gas leakage detector is exposed to continuous flow of the first test gas specified in (b) until the warning turns on.

(f) Then the hydrogen gas leakage detector is then exposed to continuous flow of the second test gas specified in (b) until the main shut-off valve closes to isolate the CHSS. The test is completed when the shut-off valve closes.

S6.4.2. *Test for integrity of enclosed spaces and detection systems.*

(a) The test shall be conducted without influence of wind.

(b) Prior to the test, the vehicle is prepared to simulate remotely controllable hydrogen releases from the fuel system or from an external fuel supply. The number, location, and flow capacity of the release points downstream of the shut-off valve are defined by the vehicle manufacturer.

(c) A hydrogen concentration detector shall be installed in any enclosed or semi-enclosed volume where hydrogen may accumulate from the simulated hydrogen release.

(d) Vehicle doors, windows and other covers are closed.

(e) The vehicle shall be set to the “on” or “run” position for at least 5 minutes prior to testing, and left operating for the test duration. If the vehicle is not a fuel cell vehicle, it shall be warmed up and kept idling. If the test vehicle has a system to stop idling automatically, measures shall be taken to prevent the engine from stopping.

(f) A leak shall be simulated using the remote controllable function.

(g) The hydrogen concentration is measured continuously until the end of the test.

(h) The test is completed 5 minutes after initiating the simulated leak or when the hydrogen concentration does not change for 3 minutes, whichever is longer.

S6.5. *Test for the vehicle exhaust system*.

(a) The vehicle shall be set to the “on” or “run” position for at least 5 minutes prior to testing.

(b) The measuring section of the measuring device shall be placed along the centerline of the exhaust gas flow within 100 mm of where the exhaust is released to the atmosphere.

(c) The exhaust hydrogen concentration shall be continuously measured during the following steps:

(1) The fuel cell system shall be shut down.

(2) The fuel cell system shall be immediately restarted.

(3) After one minute, the vehicle shall be set to the “off” position and measurement continues until the until the vehicle shut-down is complete shut-down procedure is completed.

(d) The measurement device shall have a resolution time of less than 300 milliseconds;

(e) Have a measurement response time ($t_0 - t_{90}$) of less than 2 seconds, where t_0 is the moment of hydrogen concentration switching, and t_{90} is the time when 90 percent of the final indication is reached and have a resolution time of less than 300 milliseconds (sampling rate of greater than 3.33 Hz).

S6.6. *Test for fuel system leakage*. The vehicle CHSS shall be filled with hydrogen to any pressure between 90 percent NWP and 100 percent NWP for the duration of the test for fuel system leakage.

(a) The vehicle shall be set to the “on” or “run” position for at least 5 minutes prior to testing, and left operating for the test duration. If the vehicle is not a fuel cell vehicle, it shall be warmed up and kept idling. If the test vehicle has a system to stop idling automatically, measures shall be taken to prevent the engine from stopping.

(b) Hydrogen leakage shall be evaluated at accessible sections of the hydrogen fuel system downstream of the shut-off valve(s), using a gas leak detector or a leak detecting liquid as follows:

(1) When a gas leak detector is used, detection shall be performed by operating the leak detector for at least 10 seconds at locations as close to fuel lines as possible.

(2) When a leak detecting liquid is used, hydrogen gas leak detection shall be performed immediately after applying the liquid.

S7 Test Conditions. The requirements of S5.2 shall be met under the following conditions. Where a range of conditions is specified, the vehicle must be capable of meeting the requirements at all points within the range.

(a) Prior to conducting the crash test, instrumentation is installed in the CHSS to perform the required pressure and temperature measurements if the vehicle does not already have instrumentation with the required accuracy.

(b) The CHSS is then purged, if necessary, following manufacturer directions before filling the CHSS with compressed hydrogen or helium gas.

(c) The target fill pressure P_{target} shall be calculated from the following equation:

$$P_{target} = NWP \times (273 + T_o) / 288$$

where NWP is in MPa, T_o is the ambient temperature in °C to which the CHSS is expected to settle, and P_{target} is the target fill pressure in MPa after the temperature settles.

(d) The container(s) shall be filled to any pressure between 95.0 percent and 100.0 percent of the calculated target fill pressure.

(e) After fueling, the vehicle shall be maintained at rest for any duration between 2.0 and 3.0 hours before conducting a crash test in accordance with S6.1.

(f) The CHSS shut-off valve(s) and any other shut-off valves located in the fuel system downstream hydrogen gas piping shall be in normal driving condition immediately prior to the impact.

(g) The parking brake is disengaged and the transmission is in neutral prior to the crash test.

(h) Tires are inflated to manufacturer's specifications.

(i) The vehicle, including test devices and instrumentation, is loaded as follows:

(1) A passenger car, with its fuel system filled as specified in S7(d), is loaded to its unloaded vehicle weight plus its rated cargo and luggage capacity weight, secured in the luggage area, plus the necessary test dummies as specified in S6, restrained only by means that are installed in the vehicle for protection at its seating position.

(2) A multipurpose passenger vehicle, truck, or bus with a GVWR of 10,000 pounds or less, whose fuel system is filled as specified in S7(d), is loaded to its unloaded vehicle weight, plus the necessary test dummies as specified in S6, plus 136.1 kg, or its rated cargo and luggage capacity weight, whichever is less, secured to the vehicle and distributed so that the weight on each axle as measured at the tire-ground interface is in proportion to its gross axle weight rating (GAWR). Each dummy shall be restrained only by means that are installed in the vehicle for protection at its seating position.

(3) A school bus with a GVWR greater than 10,000 pounds, whose fuel system is filled as specified in S7(d), is loaded to its unloaded vehicle weight, plus 54.4 kg of unsecured weight at each designated seating position.

5. Section 571.308 is added to read as follows:

§571.308 Standard No. 308; Compressed hydrogen storage system integrity.

S1. *Scope.* This standard specifies requirements for compressed hydrogen storage systems used in motor vehicles.

S2. *Purpose.* The purpose of this standard is to reduce deaths and injuries occurring from fires that result from hydrogen leakage during vehicle operation and to reduce deaths and injuries occurring from explosions resulting from the burst of pressurized hydrogen containers.

S3. *Application.* This standard applies to each motor vehicle that uses compressed hydrogen gas as a fuel source.

S4. *Definitions.*

BP_O means the manufacturer-supplied median burst pressure for a batch of new containers.

Burst means to break apart or to break open.

Burst pressure means the highest pressure achieved for a container tested in accordance with S6.2.2.1.

Check valve means a valve that prevents reverse flow.

Closure devices mean the check valve(s), shut-off valve(s) and thermally activated pressure relief device(s) that control the flow of hydrogen into and/or out of a CHSS.

Container means a pressure-bearing component of a compressed hydrogen storage system that stores a continuous volume of hydrogen fuel in a single chamber or in multiple permanently interconnected chambers.

Container attachments means non-pressure bearing parts attached to the container that provide additional support and/or protection to the container and that may be removed only with the use of tools for the specific purpose of maintenance and/or inspection.

Compressed hydrogen storage system (CHSS) means a system that stores compressed hydrogen fuel for a hydrogen-fueled vehicle, composed of a container, container attachments (if any), and all closure devices required to isolate the stored hydrogen from the remainder of the fuel system and the environment.

Nominal working pressure (NWP) means the settled pressure of compressed gas in a container or CHSS fully fueled to 100 percent state of charge and at a uniform temperature of 15 °C.

Normal milliliter means a quantity of gas that occupies one milliliter of volume when its temperature is 0 °C and its pressure is 1 atmosphere.

Pressure relief device (PRD) means a device that, when activated under specified performance conditions, is used to release hydrogen from a pressurized system and thereby prevent failure of the system.

Service life (of a container) means the time frame during which service (usage) is authorized by the manufacturer.

Shut-off valve means an electrically activated valve between the container and the remainder of the vehicle fuel system that must default to the "closed" position when unpowered.

State of charge (SOC) means the density ratio of hydrogen in the CHSS between the actual CHSS condition and that at NWP with the CHSS equilibrated to 15 °C, as expressed as a percentage using the formula:

$$SOC(\%) = \frac{\rho(P,T)}{\rho(NWP, 15°C)} x100$$

where ρ is the density of hydrogen (g/L) at pressure (P) in MegaPascals (MPa) and temperature (T) in Celsius (°C) as listed in the table below or linearly interpolated therein.

TEMPERATURE (°C)	**PRESSURE (MPa)**												
	1	**10**	**20**	**30**	**35**	**40**	**50**	**60**	**65**	**70**	**75**	**80**	**87.5**
-40	1.0	9.7	18.1	25.4	28.6	31.7	37.2	42.1	44.3	46.4	48.4	50.3	53.0
-30	1.0	9.4	17.5	24.5	27.7	30.6	36.0	40.8	43.0	45.1	47.1	49.0	51.7
-20	1.0	9.0	16.8	23.7	26.8	29.7	35.0	39.7	41.9	43.9	45.9	47.8	50.4
-10	0.9	8.7	16.2	22.9	25.9	28.7	33.9	38.6	40.7	42.8	44.7	46.6	49.2
0	0.9	8.4	15.7	22.2	25.1	27.9	33.0	37.6	39.7	41.7	43.6	45.5	48.1
10	0.9	8.1	15.2	21.5	24.4	27.1	32.1	36.6	38.7	40.7	42.6	44.4	47.0
15	0.8	7.9	14.9	21.2	24.0	26.7	31.7	36.1	38.2	40.2	42.1	43.9	46.5
20	0.8	7.8	14.7	20.8	23.7	26.3	31.2	35.7	37.7	39.7	41.6	43.4	46.0
30	0.8	7.6	14.3	20.3	23.0	25.6	30.4	34.8	36.8	38.8	40.6	42.4	45.0
40	0.8	7.3	13.9	19.7	22.4	24.9	29.7	34.0	36.0	37.9	39.7	41.5	44.0
50	0.7	7.1	13.5	19.2	21.8	24.3	28.9	33.2	35.2	37.1	38.9	40.6	43.1
60	0.7	6.9	13.1	18.7	21.2	23.7	28.3	32.4	34.4	36.3	38.1	39.8	42.3
70	0.7	6.7	12.7	18.2	20.7	23.1	27.6	31.7	33.6	35.5	37.3	39.0	41.4
80	0.7	6.5	12.4	17.7	20.2	22.6	27.0	31.0	32.9	34.7	36.5	38.2	40.6

85	0.7	6.4	12.2	17.5	20.0	22.3	26.7	30.7	32.6	34.4	36.1	37.8	40.2

Thermally-activated pressure relief device (TPRD) means a non-reclosing PRD that is activated by temperature to open and release hydrogen gas.

TPRD sense point means instrumentation that detects elevated temperature for the purpose of activating a TPRD.

S5. *Requirements.*

S5.1. *Requirements for the CHSS.* Each vehicle CHSS shall include the following functions: shut-off valve, check valve, and TPRD. Each vehicle CHSS shall have a NWP of 70 MPa or less. Each vehicle container, closure device, and CHSS, shall meet the applicable performance test requirements listed in the table below.

Table to S5.1

Requirement section	Test article
S5.1.1. *Tests for baseline metrics*	Container
S5.1.2. *Test for performance durability*	Container
S5.1.3. *Test for expected on-road performance*	CHSS
S5.1.4. *Test for service terminating performance in fire*	CHSS
S5.1.5. *Tests for performance durability of closure devices*	Closure devices

S5.1.1. *Tests for baseline metrics.*

S5.1.1.1 *Baseline initial burst pressure.* The manufacturer shall immediately specify upon request, in writing, and within five business days: the primary constituent of the container. When a new container with its container attachments (if any) is tested in accordance with S6.2.2.1, all of the following requirements shall be met:

(a) The burst pressure of the container shall not be less than 2 times NWP.

(b) The burst pressure of the container having glass-fiber composite as a primary constituent shall not be less than 3.5 times NWP.

(c) The bust pressure of the container for which the manufacturer fails to specify upon request, in writing, and within five business days, the primary constituent of the container, shall not be less than 3.5 times NWP.

(d) The burst pressure of the container shall be within 10 percent of the BP_O listed on the container label.

S5.1.1.2. *Baseline initial pressure cycle test.* When a new container with its container attachments (if any) is hydraulically pressure cycled in accordance with S6.2.2.2 to any pressure between 125.0 percent NWP and 130.0 percent NWP,

(a) containers for vehicles with a GVWR of 10,000 pounds or less

(1) shall not leak nor burst for at least 7,500 cycles, and

(2) thereafter shall not burst for an additional 14,500 cycles. If the required pressure cannot be achieved due to leakage or if a visible leak occurs for more than 3 minutes while conducting the test as specified in S5.1.1.2(a)(2), the test is stopped and not considered a failure.

(b) containers for vehicles with a GVWR of over 10,000 pounds

(1) shall not leak nor burst for at least 11,000 cycles, and

(2) thereafter shall not burst for an additional 11,000 cycles. If the required pressure cannot be achieved due to leakage or if a visible leak occurs for more than 3 minutes while conducting the test as specified in S5.1.1.2(b)(2), the test is stopped and not considered a failure.

S5.1.2. *Test for performance durability.* A new container shall not leak nor burst when subjected to the sequence of tests in S5.1.2.1 to S5.1.2.7. Immediately following S5.1.2.7, and without depressurizing the container, the container is subjected to a burst test in accordance with S6.2.2.1(c) and S6.2.2.1(d). The burst pressure of the container at the end of the sequence of tests in this section shall not be less than 0.8 times the BP_O listed on the container label. The sequence of tests and the burst pressure test are illustrated in Figure 1.

S5.1.2.1. *Proof pressure test.* The container with its container attachments (if any) is hydraulically pressurized in accordance with S6.2.3.1 to any pressure between 1.500 times NWP and 1.550 times NWP and held for any duration between 30.0 to 35.0 seconds.

S5.1.2.2. *Drop test.* The container with its container attachments (if any) is dropped once in accordance with S6.2.3.2 in any one of the four orientations specified in that section. Any container with damage from the drop test that prevents further testing of the container in accordance with S6.2.3.4 shall be considered to have failed to meet the test for performance durability requirements.

S5.1.2.3. *Surface damage test.* The container, except if an all-metal container, is subjected to the surface damage test in accordance with the S6.2.3.3. Container attachments designed to be removed shall be removed and container attachments that are not designed to be removed shall remain in place. Container attachments that are removed, shall not be reinstalled for the remainder of S5.1.2; container attachments that are not removed, shall remain in place for the remainder of S5.1.2.

S5.1.2.4. *Chemical exposure and ambient-temperature pressure cycling test.* The container is exposed to chemicals in accordance with S6.2.3.4 and then hydraulically pressure cycled in accordance with S6.2.3.4 for 60 percent of the number of cycles as specified in S5.1.1.2(a)(1) or S5.1.1.2(b)(1) as applicable. For all but the last 10 of these cycles, the cycling pressure shall be any pressure between 125.0 percent NWP and 130.0 percent NWP. For the last 10 cycles, the pressure shall be any pressure between 150.0 percent NWP and 155.0 percent NWP.

S5.1.2.5. *High temperature static pressure test.* The container is pressurized to any pressure between (or equal to) 125 percent NWP and 130 percent NWP and held at that pressure no less than 1,000 and no more than 1,050 hours in accordance with S6.2.3.5 and with the temperature surrounding the container at any temperature between 85.0 °C and 90.0 °C.

S5.1.2.6. *Extreme temperature pressure cycling test.* The container is pressure cycled in accordance with S6.2.3.6 for 40 percent of the number of cycles specified in S5.1.1.2(a)(1) or

S5.1.1.2(b)(1) as applicable. The pressure for the first half of these cycles equals any pressure between 80.0 percent NWP and 85.0 percent NWP with the temperature surrounding the container equal to any temperature between -45.0 °C and -40.0 °C. The pressure for the next half of these cycles equals any pressure between 125.0 percent NWP and 130.0 percent NWP and the temperature surrounding the container equal to any temperature between 85.0 °C and 90.0 °C and the relative humidity surrounding the container not less than 80 percent.

S5.1.2.7. *Residual pressure test.* The container is hydraulically pressurized in accordance with S6.2.3.1 to a pressure between 180.0 percent NWP and 185.0 percent NWP and held for any duration between 240 to 245 seconds.

S5.1.3. *Test for expected on-road performance*. When subjected to the sequence of tests in S5.1.3.1 to S5.1.3.2, the CHSS shall meet the permeation and leak requirements specified in S5.1.3.3 and shall not burst. Thereafter, the container of the CHSS shall not burst when subjected to a residual pressure test in accordance with S5.1.3.4. Immediately following S5.1.3.4, and without depressurizing the container, the container of the CHSS is subjected to a burst test in accordance with S6.2.2.1(c) and S6.2.2.1(d). The burst pressure of the container at the end of the sequence of tests in this section shall not be less than 0.8 times the BP_O listed on the container label.

S5.1.3.1. *Proof pressure test.* The container of the CHSS is pressurized with hydrogen gas to any pressure between 1.500 times NWP and 1.550 times NWP and held for any duration between 30 to 35 seconds in accordance with the S6.2.3.1 test procedure. The ambient temperature surrounding the container shall be at any temperature between 5.0 °C to 35.0 °C. The fuel delivery temperature used for pressurizing the container with hydrogen shall be at any temperature between -40.0 °C to -33.0 °C.

S5.1.3.2. *Ambient and extreme temperature gas pressure cycling test.* The CHSS is pressure cycled using hydrogen gas for 500 cycles under any temperature and pressure condition for the number of cycles as specified in the Table to S5.1.3.2, and in accordance with the S6.2.4.1 test procedure. A static gas pressure leak/permeation test performed in accordance with S5.1.3.3 is conducted after the first 250 pressure cycles and after the remaining 250 pressure cycles.

Table to S5.1.3.2

No. of cycles	*Ambient Conditions*	*Initial System Equilibration*	*Fuel Delivery Temperature*	*Cycle Initial and Final Pressure*	*Cycle Peak Pressure*
5	-30.0 °C to -25.0 °C	-30.0 °C to -25.0 °C	15.0 °C to 25.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
5	-30.0 °C to -25.0 °C	-30.0 °C to -25.0 °C	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
15	-30.0 °C to -25.0 °C	not appliable	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
5	50.0 °C to 55.0 °C 80% to 100% relative humidity	50 °C to 55 °C 80% to 100% relative humidity	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
20	50.0 °C to 55.0 °C, 80% to 100% relative humidity	not appliable	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
200	5.0 °C to 35.0 °C	not appliable	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC

Extreme temperature static gas pressure leak/permeation test S5.1.3.3	55.0 °C to 60.0 °C	55.0 °C to 60.0 °C	not appliable	not appliable	100.0% SOC to 105.0% SOC
25	50.0 °C to 55.0 °C, 80% to 100% relative humidity	not appliable	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
25	-30.0 °C to -25.0 °C	not appliable	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
200	5.0 °C to 35.0 °C	not appliable	-40.0 °C to -33.0 °C	1.0 MPa to 2.0 MPa	100.0% SOC to 105.0% SOC
Extreme temperature static gas pressure leak/permeation test S5.1.3.3	55.0 °C to 60.0 °C	55.0 °C to 60.0 °C	not appliable	not appliable	100.0% SOC to 105.0% SOC

S5.1.3.3. *Extreme temperature static gas pressure leak/permeation test.* When tested in accordance with S6.2.4.2 after each group of 250 pneumatic pressure cycles in S5.1.3.2, the CHSS shall not discharge hydrogen more than 46 millilitres per hour (mL/h) for each litre of CHSS water capacity.

S5.1.3.4. *Residual pressure test.* The container of the CHSS is hydraulically pressurized in accordance with S6.2.3.1 to any pressure between 1.800 times NWP and 1.850 times NWP and held at that pressure for any duration between 240 to 245 seconds.

S5.1.4. *Test for service terminating performance in fire.* When the CHSS is exposed to the two-stage localized or engulfing fire test in accordance with S6.2.5, the container shall not burst. The pressure inside the CHSS shall fall to 1 MPa or less within the test time limit specified in S6.2.5.3(o). Any leakage or venting, other than that through TPRD outlet(s), shall not result in jet flames greater than 0.5 m in length. If venting occurs though the TPRD, the venting shall be continuous.

S5.1.5. *Tests for performance durability of closure devices.* All tests are performed at ambient temperature of 5 °C to 35 °C unless otherwise specified.

S5.1.5.1. *TPRD requirements.* The TPRD shall not activate at any point during the test procedures specified in S6.2.6.1.1, S6.2.6.1.3, S6.2.6.1.4, S6.2.6.1.5, S6.2.6.1.6, S6.2.6.1.7, and S6.2.6.1.8.

(a) A TPRD subjected to pressure cycling in accordance with S6.2.6.1.1, shall be sequentially tested in accordance with S6.2.6.1.8, S6.2.6.1.9, and S6.2.6.1.10;

(1) When tested in accordance with S6.2.6.1.8, the TPRD shall not exhibit leakage greater than 10 normal milliliters per minute (NmL/hour).

(2) When tested in accordance with S6.2.6.1.9, the TPRD shall activate within no more than 2 minutes of the average activation time of three new TPRDs tested in accordance with S6.2.6.1.9;

(3) When tested in accordance with S6.2.6.1.10, the TPRD shall have a flow rate of at least 90 percent of the highest baseline flow rate established in accordance with S6.2.6.1.10;

(b)(1) A TPRD shall activate in less than ten hours when tested at the manufacturer's specified activation temperature in accordance with S6.2.6.1.2.

(2) When tested at the accelerated life temperature in accordance with S6.2.6.1.2, a TPRD shall not activate in less than 500 hours and shall not exhibit leakage greater than 10 NmL/hour when tested in accordance with S6.2.6.1.8;

(c) A TPRD subjected to temperature cycling testing in accordance with S6.2.6.1.3 shall be sequentially tested in accordance with S6.2.6.1.8(a)(3), S6.2.6.1.9, and S6.2.6.1.10;

(1) When tested in accordance with S6.2.6.1.8(a)(3), the TPRD shall not exhibit leakage greater than 10 NmL/hour;

(2) When tested in accordance with S6.2.6.1.9, the TPRD shall activate within no more than 2 minutes of the average activation time of three new TPRDs tested in accordance with S6.2.6.1.9;

(3) When tested in accordance with S6.2.6.1.10, the TPRD shall have a flow rate of at least 90 percent of the highest baseline flow rate established in accordance with S6.2.6.1.10;

(d) A TPRDs subjected to salt corrosion resistance testing in accordance with S6.2.6.1.4 shall be sequentially tested in accordance with S6.2.6.1.8, S6.2.6.1.9, and S6.2.6.1.10;

(1) When tested in accordance with S6.2.6.1.8, the TPRD shall not exhibit leakage greater than 10 NmL/hour;

(2) When tested in accordance with S6.2.6.1.9, the TPRD shall activate within no more than 2 minutes of the average activation time of three new TPRDs tested in accordance with S6.2.6.1.9;

(3) When tested in accordance with S6.2.6.1.10, the TPRD shall have a flow rate of at least 90 percent of the highest baseline flow rate established in accordance with S6.2.6.1.10;

(e) A TPRD subjected to vehicle environment testing in accordance with S6.2.6.1.5 shall not show signs of cracking, softening, or swelling, and thereafter shall be sequentially tested in accordance with S6.2.6.1.8, S6.2.6.1.9, and S6.2.6.1.10.

(1) When tested in accordance with S6.2.6.1.8, the TPRD shall not exhibit leakage greater than 10 NmL/hour.

(2) When tested in accordance with S6.2.6.1.9, the TPRD shall activate within no more than 2 minutes of the average activation time of three new TPRDs tested in accordance with S6.2.6.1.9,

(3) When tested in accordance with S6.2.6.1.10, the TPRD shall have a flow rate of at least 90 percent of the highest baseline flow rate established in accordance with S6.2.6.1.10;

(f) A TPRD subjected to stress corrosion cracking testing in accordance with S6.2.6.1.6 shall not exhibit visible cracking or delaminating;

(g) A TPRD shall be subjected to drop and vibration testing in accordance with S6.2.6.1.7. If the TPRD progresses beyond S6.2.6.1.7(c) to complete testing under S6.2.6.1.7(d), it shall then be sequentially tested in accordance with S6.2.6.1.8, S6.2.6.1.9, and S6.2.6.1.10.

(1) When tested in accordance with S6.2.6.1.8, the TPRD shall not exhibit leakage greater than 10 NmL/hour.

(2) When tested in accordance with S6.2.6.1.9, the TPRD shall activate within no more than 2 minutes of the average activation time of three new TPRDs tested in accordance with S6.2.6.1.9,

(3) When tested in accordance with S6.2.6.1.10, the TPRD shall have a flow rate of at least 90 percent of the highest baseline flow rate established in accordance with S6.2.6.1.10;

(h) One new TPRD subjected to leak testing in accordance with S6.2.6.1.8 shall not exhibit leakage greater than 10 NmL/hour;

(i) Three new TPRDs are subjected to a bench top activation test in accordance with S6.2.6.1.9. The maximum difference in the activation time between any two of the three TPRDs shall be 2 minutes or less.

S5.1.5.2. *Check valve and shut-off valve requirements.* This section applies to both check valves and shut-off valves.

(a) A valve subjected to hydrostatic strength testing in accordance with S6.2.6.2.1 shall not leak nor burst at less than 250 percent NWP;

(b) A valve subjected to leak testing in accordance with S6.2.6.2.2 shall not exhibit leakage greater than 10 NmL/hour;

(c)(1) A check valve shall meet the requirements when tested sequentially as follows:

(i) The check valve shall reseat and prevent reverse flow after each cycle when subjected to 13,500 pressure cycles in accordance with S6.2.6.2.3 to any pressure between 100.0 and 105.0 percent NWP and at any temperature between 5.0 °C and 35.0 °C;

(ii) The same check valve shall reseat and prevent reverse flow after each cycle when subjected to 750 pressure cycles in accordance with S6.2.6.2.3 to any pressure between 125.0 and 130.0 percent NWP and at any temperature between 85.0 °C and 90.0 °C;

(iii) The same check valve shall reseat and prevent reverse flow after each cycle when subjected to 750 pressure cycles in accordance with S6.2.6.2.3 to any pressure between 80.0 and 85.0 percent NWP and at any temperature between -45.0 °C and -40.0 °C;

(iv) The same check valve shall be subjected to chatter flow testing in accordance with S6.2.6.2.4;

(v) When tested in accordance with S6.2.6.2.2, the same check valve shall not exhibit leakage greater than 10 NmL/hour;

(vi) When tested in accordance S6.2.6.2.1, the same check valve shall not leak nor burst at less than 250 percent NWP nor burst at less than 80 percent of the burst pressure of the new unit tested in accordance with S5.1.5.2(a) unless the burst pressure of the valve exceeds 400 percent NWP.

(2) A shut-off valve shall meet the requirements when tested sequentially as follows:

(i) The shut-off valve shall be subjected to 45,000 pressure cycles in accordance with S6.2.6.2.3 to any pressure between 100.0 and 105.0 percent NWP and at any temperature between 5.0 °C and 35.0 °C;

(ii) The same shut-off valve shall be subjected to 2,500 pressure cycles in accordance with S6.2.6.2.3 to any pressure between 125.0 and 130.0 percent NWP and at any temperature between 85.0 °C and 90.0 °C;

(iii) The same shut-off valve subjected to 2,500 pressure cycles in accordance with S6.2.6.2.3 to any pressure between 80.0 and 85.0 percent NWP and at any temperature between -45.0 °C and -40.0 °C;

(iv) The same shut-off valve shall be subjected to chatter flow testing in accordance with S6.2.6.2.4;

(v) When tested in accordance with S6.2.6.2.2, the same shut-off valve shall not exhibit leakage greater than 10 NmL/hour;

(vi) When tested in accordance S6.2.6.2.1, the same shut-off valve shall not leak nor burst at less than 250 percent NWP nor burst at less than 80 percent of the burst pressure of the new unit tested in accordance with S5.1.5.2(a) unless the burst pressure of the valve exceeds 400 percent NWP.

(d) A valve subjected to salt corrosion resistance testing in accordance with S6.2.6.1.4 shall be tested sequentially in accordance with S6.2.6.2.2 followed by S6.2.6.2.1.

(1) When tested in accordance with S6.2.6.2.2, the valve shall not exhibit leakage greater than 10 NmL/hour;

(2) When tested in accordance S6.2.6.2.1, the valve shall not leak nor burst at less than 250 percent NWP nor burst at less than 80 percent of the burst pressure of the new unit tested in accordance with S5.1.5.2(a) unless the burst pressure of the valve exceeds 400 percent NWP;

(e) A valve subjected to vehicle environment testing in accordance with S6.2.6.1.5 shall not show signs of cracking, softening, or swelling and shall be tested sequentially in accordance with S6.2.6.2.2 followed by S6.2.6.2.1. Cosmetic changes such as pitting or staining are not considered failures.

(1) When tested in accordance with S6.2.6.2.2, the valve shall not exhibit leakage greater than 10 NmL/hour;

(2) When tested in accordance S6.2.6.2.1, the valve shall not leak nor burst at less than 250 percent NWP nor burst at less than 80 percent of the burst pressure of the new unit tested in accordance with S5.1.5.2(a) unless the burst pressure of the valve exceeds 400 percent NWP;

(f) A shut-off valve shall have a minimum resistance of 240 kΩ between the power conductor and the valve casing, and shall not exhibit open valve, smoke, fire, melting, or leakage greater than 10 NmL/hour when subjected to electrical testing in accordance with S6.2.6.2.5 followed by leak testing in accordance with 6.2.6.2.2;

(g) A valve subjected to vibration testing in accordance with S6.2.6.2.6 shall be tested sequentially in accordance with S6.2.6.2.2 followed by S6.2.6.2.1.

(1) When tested in accordance with S6.2.6.2.2, the valve shall not exhibit leakage greater than 10 NmL/hour;

(2) When tested in accordance S6.2.6.2.1, the valve shall not leak nor burst at less than 250 percent NWP nor burst at less than 80 percent of the burst pressure of the new unit tested in accordance with S5.1.5.2(a) unless the burst pressure of the valve exceeds 400 percent NWP;

(h) A valve shall not exhibit visible cracking or delaminating when subjected to stress corrosion cracking testing in accordance with S6.2.6.1.6;

S5.1.6. *Labeling.* Each vehicle container shall be permanently labeled with the information specified in paragraphs (a) through (f) of this section. Any label affixed to the container in compliance with this section shall remain in place and be legible for the manufacturer's recommended service life of the container. The information shall be in English and in letters and numbers that are at least 6.35 millimeters (1⁄4 inch) high.

(a) The statement: “If there is a question about the proper use, installation, or maintenance of this compressed hydrogen storage system, contact__________,” inserting the vehicle manufacturer's name, address, and telephone number. The name provided shall be consistent with the manufacturer’s filing in accordance with 49 CFR Part 566.

(b) The container serial number.

(c) The statement: “Manufactured in ______,” inserting the month and year of manufacture of the container.

(d) The statement “Nominal Working Pressure _____MPa (____psig)” Inserting the nominal working pressure which shall be no greater than 70 MPa.

(e) The statement “Compressed Hydrogen Gas Only.”

(f) The statement: “Do Not Use After ______” inserting the month and year that mark the end of the manufacturer's recommended service life for the container.

(g) The statement: “This container should be visually inspected for damage and deterioration after a motor vehicle accident or fire, and either (i) at least every 12 months when installed on a vehicle with a GVWR greater than 4,536 kg, or (ii) at least every 36 months or 36,000 miles, whichever comes first, when installed on a vehicle with a GVWR less than or equal to 4,536 kg.”

(h) The statement: “The burst pressure BP_O applicable to this container is _____” inserting the manufacturer’s specified value of BP_O in MPa.

S6. *Test procedures*

S6.1. [Reserved]

S6.2. *Test procedures for compressed hydrogen storage.*

S6.2.1. Unless otherwise specified, data sampling for pressure cycling under S6.2 shall be at least 1 Hz.

S6.2.2. *Test procedures for baseline performance metrics.*

S6.2.2.1. *Burst test.*

(a) The container is filled with a hydraulic fluid.

(b) The container, the surrounding environment, and the hydraulic fluid are at any temperature between 5.0 °C and 35.0 °C.

(c) The rate of pressurization shall be less than or equal to 1.4 MPa per second for pressures higher than 1.50 times NWP. If the rate exceeds 0.35 MPa per second at pressures higher than

1.50 times NWP, then the container is placed in series between the pressure source and the pressure measurement device.

(d) The container is hydraulically pressurized until burst and the burst pressure of the container is recorded.

S6.2.2.2. *Pressure cycling test.*

(a) The container is filled with a hydraulic fluid.

(b) The container surface, or the surface of the container attachments if present, the environment surrounding the container, and the hydraulic fluid are at any temperature between 5.0 °C and 35.0 °C at the start of testing and maintained at the specified temperature for the duration of the testing.

(c) The container is pressure cycled at any pressure between 1.0 MPa and 2.0 MPa up to the pressure specified in the respective section of S5. The cycling rate shall be any rate between or equal to 5 and 10 cycles per minute.

(d) The temperature of the hydraulic fluid entering the container is maintained and monitored at any temperature between 5.0 °C and 35.0 °C.

(e) The container manufacturer may specify a hydraulic pressure cycle profile within the specifications of S6.2.2.2(c). Manufacturers shall submit this profile to NHTSA upon request, in writing, and within five business days, otherwise NHTSA shall determine the profile. At NHTSA's option, NHTSA shall cycle the container within 10 percent of the manufacturer's specified cycling profile.

S6.2.3. *Performance durability test*.

S6.2.3.1. *Proof pressure test*. The container is pressurized smoothly and continually with hydraulic fluid or hydrogen gas as specified until the pressure level is reached and held for the specified time.

S6.2.3.2. *Drop impact test.* The container is drop tested without internal pressurization or attached valves. The surface onto which the container is dropped shall be a smooth, horizontal, uniform, dry, concrete pad or other flooring type with equivalent hardness. No attempt shall be made to prevent the container from bouncing or falling over during a drop test, except for the vertical drop test, during which the test article shall be prevented from falling over. The container shall be dropped in any one of the following four orientations described below and illustrated in Figure 2.

(a) From a position within 5° of horizontal with the lowest point of the container at any height between 1.800 meters and 1.820 meters above the surface onto which it is dropped. In the case of a non-axisymmetric container, the largest projection area of the container shall be oriented downward and aligned horizontally;

(b) From a position within 5° of vertical with the center of any shut-off valve interface location upward and with any potential energy of between 488 Joules and 538 Joules. If a drop energy of between 488 Joules and 538 Joules would result in the height of the lower end being more than 1.820 meters above the surface onto which it is dropped, the container shall be dropped from any height with the lower end between 1.800 meters and 1.820 meters above the surface onto which it is dropped. If a drop energy of between 488 Joules and 538 Joules would result in the height of the lower end being less than 0.100 meters above the surface onto which it is dropped, the container shall be dropped from any height with the lower end between 0.100 meters and 0.120 meters above the surface onto which it is dropped. In the case of a non-axisymmetric container, the center of any shut-off valve interface location and the container's center of gravity shall be aligned vertically, with the center of that shut-off valve interface location upward;

(c) From a position within 5° of vertical with the center of any shut-off valve interface location downward with any potential energy of between 488 Joules and 538 Joules. If a potential energy of between 488 Joules and 538 Joules would result in the height of the lower end being more than 1.820 meters above the surface onto which it is dropped, the container shall be dropped from any height with the lower end between 1.800 meters and 1.820 meters above the surface onto which it is dropped. If a drop energy of between 488 Joules and 538 Joules would result in the height of the lower end being less than 0.100 meters above the surface onto which it is dropped, the container shall be dropped from any height with the lower end between 0.100 meters and 0.120 meters above the surface onto which it is dropped. In the case of a non-axisymmetric container, the center of any shut-off valve interface location and the container's center of gravity shall be aligned vertically, with the center of that shut-off valve interface location downward;

(d) From any angle between 40° and 50° from the vertical orientation with the center of any shut-off valve interface location downward, and with the container center of gravity between 1.800 meters and 1.820 meters above the surface onto which it is dropped. However, if the lowest point of the container is closer to the ground than 0.60 meters, the drop angle shall be changed so that the lowest point of the container is between 0.60 meters and 0.62 meters above the ground and the center of gravity is between 1.800 meters and 1.820 meters above the surface onto which it is dropped. In the case of a non-axisymmetric container, the line passing through the center of any shut-off valve interface location and the container's center of gravity shall be at any angle between 40° and 50° from the vertical orientation. If this results in more than one possible container orientation, the drop shall be conducted from the orientation that results in the lowest positioning of the center of the shut-off valve interface location.

S6.2.3.3. *Surface damage test.* The surface damage test consists of surface cut generation and pendulum impacts as described below.

(a) Surface cut generation: Two longitudinal saw cuts are made at any location on the same side of the outer surface of the unpressurized container, as shown in Figure 3, or on the container attachments if present. The first cut is 0.75 millimeters to 1.25 millimeters deep and 200 millimeters to 205 millimeters long; The second cut, which is only required for containers affixed to the vehicle by compressing its composite surface, is 1.25 millimeters to 1.75 millimeters deep and 25 millimeters to 28 millimeters long.

(b) Pendulum impacts: Mark the outer surface of the container, or the container attachments if present, on the side opposite from the saw cuts, with five separate, non-overlapping circles each having any linear diameter between 100.0 millimeters and 105.0 millimeters, as shown in Figure 3. Within 30 minutes following preconditioning for any duration from 12 hours to 24 hours in an environmental chamber at any temperature between -45.0 °C and -40.0 °C, impact the center of each of the five areas with a pendulum having a pyramid with equilateral faces and square base, and the tip and edges being rounded to a radius of between 2.0 millimeters and 4.0 millimeters. The center of impact of the pendulum shall coincide with the center of gravity of the pyramid. The energy of the pendulum at the moment of impact with each of the five marked areas on the container is any energy between 30.0 Joules and 35.0 Joules. The container is secured in place during pendulum impacts and is not pressurized above 1 MPa.

S6.2.3.4. *Chemical exposure and ambient temperature pressure cycling test.*

(a) Each of the 5 areas preconditioned by pendulum impact in S6.2.3.3(b) is exposed to any one of five solutions:

(1) 19 to 21 percent by volume sulfuric acid in water;

(2) 25 to 27 percent by weight sodium hydroxide in water;

(3) 5 to 7 percent by volume methanol in gasoline;

(4) 28 to 30 percent by weight ammonium nitrate in water; and

(5) 50 to 52 percent by volume methyl alcohol in water.

(b) The container is oriented with the fluid exposure areas on top. A pad of glass wool approximately 0.5 centimeters thick and 100 millimeters in diameter is placed on each of the five preconditioned areas. A sufficient amount of the test fluid is applied to the glass wool to ensure that the pad is wetted across its surface and through its thickness for the duration of the test. A plastic covering shall be applied over the glass wool to prevent evaporation.

(c) The exposure of the container with the glass wool is maintained for at least 48 hours and no more than 60 hours with the container hydraulically pressurized to any pressure between

125.0 percent NWP and 130.0 percent NWP. During exposure, the temperature surrounding the container is maintained at any temperature between 5.0 °C and 35.0 °C.

(d) Hydraulic pressure cycling is performed in accordance with S6.2.2.2 at any pressure within the specified ranges according to S5.1.2.4 for the specified number of cycles. The glass wool pads are removed and the container surface is rinsed with water after the cycles are complete.

S6.2.3.5. *Static pressure test* The container is hydraulically pressurized to the specified pressure in a temperature-controlled chamber. The temperature of the chamber and the container surface, or the surface of the container attachments if present, are held at the specified temperature for the specified duration.

S6.2.3.6. *Extreme temperature pressure cycling test.*

(a) The container is filled with hydraulic fluid for each test;

(b) At the start of each test, the container surface, or the surface of the container attachments if present, the hydraulic fluid, and the environment surrounding the container are at any temperature and relative humidity (if applicable) within the ranges specified in S5.1.2.6 and maintained for the duration of the testing.

(c) The container is pressure cycled from any pressure between 1.0 MPa and 2.0 MPa up to the specified pressure at a rate not exceeding 10 cycles per minute for the specified number of cycles;

(d) The temperature of the hydraulic fluid entering the container shall be measured as close as possible to the container inlet.

S6.2.4. *Test procedures for expected on-road performance*

S6.2.4.1. Ambient and extreme temperature *gas pressure cycling test.*

(a) In accordance with the Table to S5.1.3.2, the specified ambient conditions of temperature and relative humidity, if applicable, are maintained within the test environment throughout each pressure cycle. When required in accordance with the Table to S5.1.3.2, the

CHSS temperature shall be in the specified initial system equilibration temperature range between pressure cycles.

(b) The CHSS is pressure cycled from any pressure between 1.0 MPa and 2.0 MPa up to any pressure within the specified peak pressure range in accordance with the Table to S5.1.3.2. The temperature of the hydrogen fuel dispensed to the container is controlled to within the specified temperature range within 30 seconds of fueling initiation. The specified number of pressure cycles are conducted.

(c) The ramp rate for pressurization shall be greater than or equal to the ramp rate given in the Table to S6.2.4.1(c) according to the CHSS volume, the ambient conditions, and the fuel delivery temperature. If the required ambient temperature is not available in the table, the closest ramp rate value or a linearly interpolated value shall be used. The pressure ramp rate shall be decreased if the gas temperature in the container exceeds 85 °C.

Table to S6.2.4.1(c)

CHSS VOLUME (L)	*CHSS Pressurization Rate (MPa/min)*			
	50.0 °C to 55.0 °C Ambient Conditions -33.0 °C to -40.0 °C Fuel Delivery Temperature	*5.0 °C to 35.0 °C Ambient Conditions -33.0 °C to -40.0 °C Fuel Delivery Temperature*	-30.0 °C to -25.0 °C *Ambient Conditions -33.0 °C to -40.0 °C Fuel Delivery Temperature*	-30.0 °C to -25.0 °C *Ambient Conditions* 15.0 °C to 25.0 °C *Fuel Delivery Temperature*
50	7.6	19.9	28.5	13.1
100	7.6	19.9	28.5	7.7
174	7.6	19.9	19.9	5.2
250	7.6	19.9	19.9	4.1
300	7.6	16.5	16.5	3.6
400	7.6	12.4	12.4	2.9

500	7.6	9.9	9.9	2.3
600	7.6	8.3	8.3	2.1
700	7.1	7.1	7.1	1.9
1000	5.0	5.0	5.0	1.4
1500	3.3	3.3	3.3	1.0
2000	2.5	2.5	2.5	0.7
2500	2.0	2.0	2.0	0.5

(d) The de-fueling rate shall be any rate greater than or equal to the intended vehicle's maximum fuel-demand rate. Out of the 500 pressure cycles, any 50 pressure cycles are performed using a de-fueling rate greater than or equal to the maintenance de-fueling rate.

S6.2.4.2. *Gas permeation test.*

(a) A CHSS is filled with hydrogen gas to any SOC between 100.0 percent and 105.0 percent and placed in a sealed container. The CHSS is held for any duration between 12 hours and 24 hours at any temperature between 55.0 °C and 60.0 °C prior to the start of the test.

(b) The permeation from the CHSS shall be determined hourly throughout the test.

(c) The test shall continue for 500 hours or until the permeation rate reaches a steady state. Steady state is achieved when at least 3 consecutive leak rates separated by any duration between 12 hours and 48 hours are within 10 percent of the previous rate.

S6.2.5. *Test procedures for service terminating performance in fire.* The fire test consists of two stages: a localized fire stage followed by an engulfing fire stage. The burner configuration for the fire test is specified in S6.2.5.1. The overall test configuration of the fire test is verified using a pre-test checkout in accordance with S6.2.5.2 prior to the fire test of the CHSS. The fire test of the CHSS is conducted in accordance with S6.2.5.3.

S6.2.5.1. *Burner Configuration.*

(a) The fuel for the burner shall be liquefied petroleum gas (LPG).

(b) The width of the burner shall be between 450 millimeters and 550 millimeters.

(c) The length of the burner used for the localized fire stage shall be between 200 millimeters and 300 millimeters.

(d) The length of the burner used for the engulfing fire stage shall be in accordance with S6.2.5.3(m).

(e) The burner nozzle configuration and installation shall be in accordance with the Table below. The nozzles shall be installed uniformly on six rails.

Table to S6.2.5.1

Item	*Description*
Nozzle type	Liquefied petroleum gas fuel nozzle with air pre-mix
LPG orifice in nozzle	0.9 to 1.1 millimeter inner diameter
Air ports in nozzle	Four (4) holes, 5.8 to 7.0 millimeter inner diameter
Fuel/Air mixing tube in nozzle	9 to 11 millimeter inner diameter
Number of rails	6
Center-to-center spacing of rails	100 to 110 millimeter
Center-to-center nozzle spacing along the rails	45 to 55 millimeter

S6.2.5.2. *Pre-test Checkout.*

(a) The pre-test checkout procedure in this section shall be performed to verify the fire test configuration for the CHSS tested in accordance with S6.2.5.3.

(b) A pre-test container is a 12-inch Schedule 40 Nominal Pipe Size steel pipe with end caps. The cylindrical length of the pre-test container shall be equal to or longer than overall length of the CHSS to be tested in S6.2.5.3, but no shorter than 0.80 m and no longer than 1.65 m.

(c) The pre-test container shall be mounted over the burner:

(1) At any height between 95 millimeters and 105 millimeters above the burner;

(2) Such that the nozzles from the two center rails are pointing toward the bottom center of the pre-test container; and

(3) Such that its position relative to the localized and engulfing zones of the burner are consistent with the positioning of the CHSS over the burner in S6.2.5.3.

(d) For outdoor test sites, wind shielding shall be used. The separation between the pre-test container and the walls of the wind shields shall be at least 0.5 meters.

(e) Temperatures during the pre-test check-out shall be measured at least once per second using 3.2 millimeter diameter or less K-type sheath thermocouples.

(f) The thermocouples shall be located in sets to measure temperatures along the cylindrical section of the pre-test container. These thermocouples are secured by straps or other mechanical attachments within 5 millimeters from the pre-test container surface. One set of thermocouples consists of:

(1) One thermocouple located at the bottom surface exposed to the burner flame,

(2) One thermocouple located mid-height along the left side of the cylindrical surface,

(3) One thermocouple located mid-height along the right side of the cylindrical surface, and

(4) One thermocouple located at the top surface opposite to the burner flame.

(g) One set of thermocouples shall be centrally located at the localized fire zone of the CHSS to be tested as determined in S6.2.5.3. Two additional sets of thermocouples shall be spread out over the remaining length of the engulfing fire zone of the CHSS to be tested that is not part of the localized fire zone of the CHSS to be tested.

(h) Burner monitor thermocouples shall be located between 20 millimeters and 30 millimeters below the bottom surface of the pre-test container in the same three horizontal locations described in S6.2.5.2(g). These thermocouples shall be mechanically supported to prevent movement.

(i) With the localized burner ignited, the LPG flow rate to the burner shall be set such that the 60-second rolling averages of individual temperature readings in the localized fire zone shall be in accordance with the localized stage row in the table below.

(j) With the entire burner ignited, the LPG flow rate to the burner shall be set such that the 60-second rolling averages of individual temperature readings shall be in accordance with the engulfing stage row in the table below.

Table to S6.2.5.2

Fire Stage	*Temperature Range on Bottom of Pre-test Container*	*Temperature Range on Sides of Pre-test Container*	*Temperature Range on Top of Pre-test Container*
Localized	450 °C to 700 °C	less than 750 °C	less than 300 °C
Engulfing	Average temperatures of the pre-test container surface measured at the three bottom locations shall be greater than 600 °C	Not applicable	Average temperatures of the pre-test container surface measured at the three top locations shall be at least 100 °C, and when greater than 750 °C, shall also be less than the average temperatures of the pre-test container surface measured at the three bottom locations

S6.2.5.3. *CHSS Fire Test.*

(a) The CHSS to be fire tested shall include TPRD vent lines.

(b) The CHSS to be fire tested shall be mounted at any height between 95 millimeters and 105 millimeters above the burner.

(c) CHSS shall be positioned for the localized fire test by orienting the CHSS such that the distance from the center of the localized fire exposure to the TPRD(s) and TPRD sense point(s) is at or near maximum.

(d) When the container is longer than the localized burner, the localized burner shall not extend beyond either end of the container in the CHSS.

(e) The CHSS shall be filled with compressed hydrogen gas to any SOC between 100.0 percent and 105.0 percent.

(f) For outdoor test sites, the same wind shielding shall be used as was used for S6.2.5.2. The separation between the CHSS and the walls of the wind shields shall be at least 0.5 meters.

(g) Burner monitor temperatures shall be measured below the bottom surface of the CHSS in the same positions as specified in S6.2.5.2(h).

(h) The allowable limits for the burner monitor temperatures during the CHSS fire test shall be established based on the results of the pre-test checkout as follows:

(1) The minimum value for the burner monitor temperature during the localized fire stage ($\mathrm{Tmin}_{\mathrm{LOC}}$) shall be calculated by subtracting 50 °C from the 60-second rolling average of the burner monitor temperature in the localized fire zone of the pre-test checkout. If the resultant $\mathrm{Tmin}_{\mathrm{LOC}}$ exceeds 600 °C, $\mathrm{Tmin}_{\mathrm{LOC}}$ shall be 600 °C.

(2) The minimum value for the burner monitor temperature during the engulfing fire stage ($\mathrm{Tmin}_{\mathrm{ENG}}$) shall be calculated by subtracting 50 °C from the 60-second rolling average of the average of the three burner monitor temperatures during the engulfing fire stage of the pre-test checkout. If the resultant $\mathrm{Tmin}_{\mathrm{ENG}}$ exceeds 800 °C, $\mathrm{Tmin}_{\mathrm{ENG}}$ shall be 800 °C.

(i) The localized fire stage is initiated by starting the fuel flow to the localized burner and igniting the burner.

(j) The 10-second rolling average of the burner monitor temperature in the localized fire zone shall be at least 300 °C within 1 minute of ignition and for the next 2 minutes.

(k) Within 3 minutes of the igniting the burner, using the same LPG flow rate as S6.2.5.2(i), the 60-second rolling average of the localized zone burner monitor temperature shall be greater than $\mathrm{Tmin}_{\mathrm{LOC}}$ as determined in S6.2.5.3(h)(1).

(l) After 10 minutes from igniting the burner, the engulfing fire stage is initiated.

(m) The engulfing fire zone includes the localized fire zone and extends in one direction towards the nearest TPRD or TPRD sense point along the complete length of the container up to a maximum burner length of 1.65 m.

(n) Within 2 minutes of the initiation of the engulfing fire stage, using the same LPG flow rate as S6.2.5.2(j), the 60-second rolling average of the engulfing burner monitor temperature shall be equal or greater than $\mathrm{Tmin}_{\mathrm{ENG}}$ as determined in S6.2.5.3(h)(2).

(o) The fire testing continues until the pressure inside the CHSS is less than or equal to 1.0 MPa or until:

(1) A total test time of 60 minutes for CHSS on vehicles with a GVWR of 10,000 pounds or less or;

(2) A total test time of 120 minutes for CHSS on vehicles with a GVWR over 10,000 pounds.

S6.2.6. *Test procedures for performance durability of closure devices.*

S6.2.6.1. *TPRD performance tests.* Unless otherwise specified, testing is performed with hydrogen gas with a purity of at least 99.97 percent, less than or equal to 5 parts per million of water, and less or equal to 1 part per million particulate. All tests are performed at any temperature between 5.0 °C and 35.0 °C unless otherwise specified.

S6.2.6.1.1. *Pressure cycling test.* A TPRD undergoes 15,000 internal pressure cycles at a rate not exceeding 10 cycles per minute. The table below summarizes the pressure cycles. Any condition within the ranges specified in the table may be selected for testing.

(a) The first 10 pressure cycles shall be from any low pressure of between 1.0 MPa and 2.0 MPa to any high pressure between 150.0 percent NWP and 155.0 percent NWP. These cycles are conducted at any sample temperature between 85.0 °C to 90.0 °C.

(b) The next 2,240 pressure cycles shall be from any low pressure between 1.0 MPa and 2.0 MPa to any high pressure of between 125.0 percent NWP and 130.0 percent NWP. These cycles are conducted at any sample temperature between 85.0 °C to 90.0 °C.

(c) The next 10,000 pressure cycles shall be from any low pressure of between 1.0 MPa and 2.0 MPa to any high pressure between 125.0 percent NWP and 130.0 percent NWP. These cycles are conducted at a sample temperature between 5.0 °C to 35.0 °C.

(d) The final 2,750 pressure cycles shall be from any low pressure between 1.0 MPa and 2.0 MPa to any high pressure between 80.0 percent NWP and 85.0 percent NWP. These cycles are conducted at any sample temperature between -45.0 °C to -40.0 °C.

Table to S6.2.6.1.1

Number of cycles	Low Pressure	High Pressure	Sample temperature for cycles
First 10	1.0 MPa to 2.0 MPa	150.0% NWP to 155.0% NWP	85.0 °C to 90.0 °C
Next 2,240	1.0 MPa to 2.0 MPa	125.0% NWP to 130.0% NWP	85.0 °C to 90.0 °C
Next 10,000	1.0 MPa to 2.0 MPa	125.0% NWP to 130.0% NWP	5.0 °C to 35.0 °C
Final 2,750	1.0 MPa to 2.0 MPa	80.0% NWP to 85.0% NWP	-45.0 °C to -40.0 °C

S6.2.6.1.2. *Accelerated life test.*

(a) Two TPRDs undergo testing; one at the manufacturer's specified activation temperature, and one at an accelerated life temperature, T_L, given in °C by the expression:

$$T_L = \left(\frac{0.502}{\beta + T_f} + \frac{0.498}{\beta + T_{ME}}\right)^{-1} - \beta$$

Where β = 273.15 °C, T_{ME} is 85 °C, and T_f is the manufacturer's specified activation temperature in °C.

(b) The TPRDs are placed in an oven or liquid bath maintained within 5.0 °C of the specified temperature per S6.2.6.1.2(a). The TPRD inlets are pressurized with hydrogen to any pressure between 125.0 percent NWP and 130.0 percent NWP and time until activation is measured.

S6.2.6.1.3. *Temperature cycling test.*

(a) An unpressurized TPRD is placed in a cold liquid bath maintained at any temperature between -45.0 °C and -40.0 °C. The TPRD shall remain in the cold bath for any duration not less than 2 hours and not more than 24 hours. The TPRD is removed from the cold bath and transferred, within five minutes of removal, to a hot liquid bath maintained at any temperature between 85.0 °C and 90.0 °C. The TPRD shall remain in the hot bath for any duration not less than 2 hours and not more than 24 hours. The TPRD is removed from the hot bath and, within five minutes of removal, transferred back into the cold bath maintained at any temperature between -45.0 °C and -40.0 °C;

(b) Step (a) is repeated until 15 thermal cycles have been achieved.

(c) The TPRD remains in the cold liquid bath for any duration not less than 2 and not more than 24 additional hours, then the internal pressure of the TPRD is cycled with hydrogen gas from any pressure between 1.0 MPa and 2.0 MPa to any pressure between 80.0 percent NWP and 85.0 percent NWP for 100 cycles. During cycling, the TPRD remains in the cold bath and the cold bath is maintained at any temperature between -45.0 °C and -40.0 °C.

S6.2.6.1.4. *Salt corrosion resistance test.*

(a) Each closure device is exposed to a combination of cyclic conditions of salt solution, temperatures, and humidity. One test cycle is equal to any duration not less than 22 and not more than 26 hours, and is in accordance with the table below.

Table to S6.2.6.1.4

Accelerated Cyclic Corrosion Conditions (1 cycle = 22 hours to 26 hours)			
Cycle Condition	*Temperature*	*Relative Humidity*	*Cycle Duration*
Ambient stage	22.0 °C to 28.0 °C	35 percent to 55 percent	470 minutes to 490 minutes
Transition 55 min to 60 min			
Humid stage	47.0 °C to 51.0 °C	95 percent to 100 percent	410 minutes to 430 minutes
Transition 170 minutes to 190 minutes			
Dry stage	55.0 °C to 65.0 °C	less than 30 percent	290 minutes to 310 minutes

(b) The apparatus used for this test shall consist of a fog/environmental chamber as defined in ISO 6270-2:2017 (incorporated by reference, see §571.5), with a suitable water supply conforming to Type IV requirements in ASTM D1193-06(R2018) (incorporated by reference, see §571.5). The chamber shall include a supply of compressed air and one or more nozzles for fog generation. The nozzle or nozzles used for the generation of the fog shall be directed or baffled to minimize any direct impingement on the closure devices.

(c) During “wet-bottom” generated humidity cycles, water droplets shall be visible on the samples.

(d) Steam generated humidity may be used provided the source of water used in generating the steam is free of corrosion inhibitors and visible water droplets are formed on the samples to achieve proper wetness.

(e) The drying stage shall occur in the following environmental conditions: any temperature not less than 60 °C and not greater than 65 °C and relative humidity no more than 30 percent with air circulation.

(f) The impingement force from the salt solution application shall not remove corrosion and/or damage the coatings of the closure devices.

(g) The complex salt solution in percent by mass shall be as specified below:

(1) Sodium Chloride: not less than 0.08 and not more than 0.10 percent.

(2) Calcium Chloride: not less than 0.095 and not more than 0.105 percent

(3) Sodium Bicarbonate: not less than 0.07 and not more than 0.08 percent

(4) Sodium Chloride must be reagent grade or food grade. Calcium Chloride must be reagent grade. Sodium Bicarbonate must be reagent grade. For the purposes of S6.2.6.1.4, water must meet ASTM D1193-06(R2018) Type IV requirements (incorporated by reference, see §571.5).

(5) Either calcium chloride or sodium bicarbonate material must be dissolved separately in water and added to the solution of the other materials.

(h) The closure devices shall be installed in accordance with the manufacturer’s recommended procedure and exposed to the 100 daily corrosion cycles, with each corrosion cycle in accordance with the table above.

(i) For each salt mist application, the solution shall be sprayed as an atomized mist, using the spray apparatus to mist the components until all areas are thoroughly wet and dripping. Suitable application techniques include using a plastic bottle, or a siphon spray powered by oilfree regulated air to spray the test samples. The quantity of spray applied should be sufficient to visibly rinse away salt accumulation left from previous sprays. Four salt mist applications shall be applied during the ambient stage. The first salt mist application occurs at the beginning of the ambient stage. Each subsequent salt mist application should be applied not less than 90 and not more than 95 minutes after the previous application.

(j) The time from ambient to the wet condition shall be any duration not less than 60 and not more than 65 minutes and the transition time between wet and dry conditions shall be any duration not less than 180 and not more than 190 minutes.

S6.2.6.1.5. *Vehicle environment test*

(a) The inlet and outlet connections of the closure device are connected or capped in accordance with the manufacturer's installation instructions. All external surfaces of the closure device are exposed to each of the following fluids for any duration between 24 hours and 26 hours. The temperature during exposure shall be any temperature between 5.0 °C and 35.0 °C. A separate test is performed with each of the fluids sequentially on a single closure device.

(1) Sulfuric acid: not less than 19 and not more than 21 percent by volume in water;

(2) Ethanol/gasoline: not less than 10 and not more than 12 percent by volume ethanol and not less than 88 and not more than 90 percent by volume gasoline; and

(3) Windshield washer fluid: not less than 50 and not more than 52 percent by volume methanol in water.

(b) The fluids are replenished as needed to ensure complete exposure for the duration of the test.

(c) After exposure to each fluid, the closure device is wiped off and rinsed with water.

S6.2.6.1.6. *Stress corrosion cracking test*

(a) All components exposed to the atmosphere shall be degreased. For check valves and shut-off valves, the closure device shall be disassembled, all components degreased, and then reassembled.

(b) The closure device is continuously exposed to a moist ammonia air mixture maintained in a glass chamber having a glass cover. The exposure lasts any duration not less than 240 hours and not more than 242 hours. The aqueous ammonia shall have any specific gravity not less than 0.940 and not more than 0.941. Aqueous ammonia shall be located at the bottom of the glass chamber below the sample at any volume not less than 20 mL and not more than 22 mL of aqueous ammonia per liter of chamber volume. The bottom of the sample is positioned any distance not less than 30 and not more than 40 millimeters above the aqueous ammonia and supported in an inert tray.

(c) The moist ammonia-air mixture is maintained at atmospheric pressure and any temperature not less than 35 °C and not more than 40 °C.

S6.2.6.1.7. *Drop and vibration test.*

(a) The TPRD is aligned vertically to any one of the six orientations covering the opposing directions of three orthogonal axes: vertical, lateral and longitudinal.

(b) A TPRD is dropped in free fall from any height between 2.00 meters and 2.02 meters onto a smooth concrete surface. The TPRD is allowed to bounce on the concrete surface after the initial impact.

(c) Any sample with damage from the drop that results in the TPRD not being able to be tested in accordance with S6.2.6.1.7(d) shall not proceed to S6.2.6.1.7(d) and shall not be considered a failure of this test.

(d) Each TPRD dropped in S6.2.6.1.7(a) that did not have damage that results in the TPRD not being able to be tested is mounted in a test fixture in accordance with manufacturer's installation instructions and vibrated for any duration between 30.0 minutes and 35.0 minutes along each of the three orthogonal axes (vertical, lateral and longitudinal) at the most severe resonant frequency for each axis.

(1) The most severe resonant frequency for each axis is determined using any acceleration between 1.50 g and 1.60 g and sweeping through a sinusoidal frequency range from 10 Hz to 500

Hz with any sweep time between 10.0 minutes and 20.0 minutes. The most severe resonant frequency is identified by a pronounced increase in vibration amplitude.

(2) If the resonance frequency is not found, the test shall be conducted at any frequency between 35 Hz and 45 Hz.

S6.2.6.1.8. *Leak test.* Unless otherwise specified, the TPRD shall be thermally conditioned to the ambient temperature condition, then checked for leakage, then conditioned to the high temperature condition, then checked for leakage, then conditioned to low temperature, then checked for leakage.

(a) The TPRD shall be thermally conditioned at test temperatures in each of the test conditions and held for any duration between 1.0 hour and 24.0 hours. The TPRD is pressurized with hydrogen at the inlet. The required test conditions are:

(1) Ambient temperature: condition the TPRD at any temperature between 5.0 °C and 35.0 °C; test in accordance with S6.2.6.1.8(b) at any pressure between 1.5 MPa and 2.5 MPa and then at any pressure between 125.0 percent NWP and 130.0 percent NWP.

(2) High temperature: condition the TPRD at any temperature between 85.0 °C and 90.0 °C; test in accordance with S6.2.6.1.8(b) at any pressure between 1.5 MPa and 2.5 MPa and then at any pressure between 125.0 percent NWP and 130.0 percent NWP.

(3) Low temperature: condition the TPRD at any temperature between -45.0 °C and -40.0 °C; test in accordance with S6.2.6.1.8(b) at any pressure between 1.5 MPa and 2.5 MPa and then at any pressure between 100.0 percent NWP and 105.0 percent NWP.

(b) Following conditioning at each of the specified test temperature ranges, the TPRD is observed for leakage while immersed in a temperature-controlled liquid at the same specified temperature range for any duration between 1.0 minutes and 2.0 minutes at each of the pressures ranges listed above. If no bubbles are observed for the specified time period, it is not considered a failure. If bubbles are detected, the leak rate is measured.

S6.2.6.1.9. *Bench top activation test.*

(a) The test apparatus consists of either a forced air oven or chimney with air flow. The TPRD is not exposed directly to flame. The TPRD is mounted in the test apparatus according to the manufacturer's installation instructions.

(b) The temperature of the oven or chimney is at any temperature between 600.0 °C and 605.0 °C for any duration between 2 minutes and 62 minutes prior to inserting the TPRD.

(c) Prior to inserting the TPRD, pressurize the TPRD to any pressure between 1.5 MPa and 2.5 MPa.

(d) The pressurized TPRD is inserted into the oven or chimney, the temperature within the oven or chimney is maintained at any temperature between 600.0 °C and 605.0 °C, and the time for the TPRD to activate is recorded. If the TPRD does not activate within 120 minutes from the time of insertion into the oven or chimney, the TPRD shall be considered to have failed the test.

S6.2.6.1.10. *Flow rate test.*

(a) At least one new TPRD is tested to establish a baseline flow rate.

(b) After activation in accordance with S6.2.6.1.9, and without cleaning, removal of parts, or reconditioning, the TPRD is subjected to flow testing using hydrogen, air or an inert gas;

(c) Flow rate testing is conducted with any inlet pressure between 1.5 MPa and 2.5 MPa. The outlet is at atmospheric pressure.

(d) Flow rate is measured in units of kilograms per minute with a precision of at least 2 significant digits.

S6.2.6.2. *Check valve and shut-off valve performance tests.* Unless otherwise specified, testing shall be performed with hydrogen gas with a purity of at least 99.97 percent, less than or equal to 5 parts per million of water, and less or equal to 1 part per million particulate. All tests are performed at any temperature between 5.0 °C and 35.0 °C unless otherwise specified.

S6.2.6.2.1. *Hydrostatic strength test.*

(a) The outlet opening is plugged and valve seats or internal blocks are made to assume the open position.

(b) Any hydrostatic pressure between 250.0 percent NWP and 255.0 percent NWP is applied using water to the valve inlet for any duration between 180.0 seconds and 185.0 seconds. The unit is examined to ensure that burst has not occurred.

(c) The hydrostatic pressure is then increased at a rate of less than or equal to 1.4 MPa/sec until component failure. The hydrostatic pressure at failure is recorded.

S6.2.6.2.2. *Leak test.*

Each unit shall be thermally conditioned to the ambient temperature condition, then checked for leakage, then conditioned to the high temperature condition, then checked for leakage, then conditioned to low temperature, then checked for leakage.

(a) Each unit shall be pressurized to any pressure between 2.0 MPa and 3.0 MPa and held for any duration between 1.0 hours and 24.0 hours in the specified temperature range before testing. The outlet opening is plugged. The test conditions are:

(1) Ambient temperature: condition the unit at any temperature between 5.0 °C and 35.0 °C; test at any pressure between 1.5 MPa and 2.5 MPa and at any pressure between 125.0 percent NWP and 130.0 percent NWP.

(2) High temperature: condition the unit at any temperature between 85.0 °C and 90.0 °C; test at any pressure between 1.5 MPa and 2.5 MPa and any pressure between 125.0 percent NWP and 130.0 percent NWP.

(3) Low temperature: condition the unit at any temperature between -45.0 °C and -40.0 °C; test at any pressure between 1.5 MPa and 2.5 MPa and any pressure between 100.0 percent NWP and 105.0 percent NWP.

(b) While within the specified temperature and pressure range, the unit is observed for leakage while immersed in a temperature-controlled liquid held within the same specified temperature range as the test condition for any duration between 1.0 minutes and 2.0 minutes at each of the test pressures. If no bubbles are observed for the specified time period, the sample passes the leak test. If bubbles are detected, the leak rate is measured.

S6.2.6.2.3. *Extreme temperature pressure cycling test.*

(a) The valve unit is connected to a test fixture.

(b) For a check valve, the pressure is applied in six incremental pulses to the check valve inlet with the outlet closed. The pressure is then vented from the check valve inlet. The pressure is lowered on the check valve outlet side to any pressure between 55.0 percent NWP and 60.0 percent NWP prior to the next cycle;

(c) For a shut-off valve, the specified pressure is applied through the inlet port. The shut-off valve is then energized to open the valve and the pressure is reduced to any pressure less than 50 percent of the specified pressure range. The shut-off valve shall then be de-energized to close the valve prior to the next cycle.

S6.2.6.2.4. *Chatter flow test.* The valve is subjected to between 24.0 hours and 26.0 hours of chatter flow at a flow rate that causes the most valve flutter.

S6.2.6.2.5. *Electrical Tests.* This section applies to shut-off valves only.

(a) The solenoid valve is connected to a variable DC voltage source, and the solenoid valve is operated as follows:

(1) Held for any duration between 60.0 and 65.0 minutes at any voltage between 0.50 V and 1.5 times the rated voltage.

(2) The voltage is increased to any voltage between 0.5 V to two times the rated voltage, or between 60.0 V and 60.5 V, whichever is less, and held for any duration between 60.0 seconds and 70.0 seconds.

(b) Any voltage between 1,000.0 V DC and 1,010.0 V DC is applied between the power conductor and the component casing for any duration between 2.0 seconds to 4.0 seconds.

S6.2.6.2.6. *Vibration test.*

(a) The valve is pressurized with hydrogen to any pressure between 100.0 percent NWP and 105.0 percent NWP, sealed at both ends, and vibrated for any duration between 30.0 and 35.0

minutes along each of the three orthogonal axes (vertical, lateral and longitudinal) at the most severe resonant frequencies.

(b) The most severe resonant frequencies are determined using any acceleration between 1.50 g and 1.60 g and sweeping through a sinusoidal frequency range from 10 Hz to 500 Hz with any sweep time between 10.0 minutes and 20.0 minutes. The resonance frequency is identified by a pronounced increase in vibration amplitude.

(c) If the resonance frequency is not found, the test shall be conducted at any frequency between 35 Hz and 45 Hz.

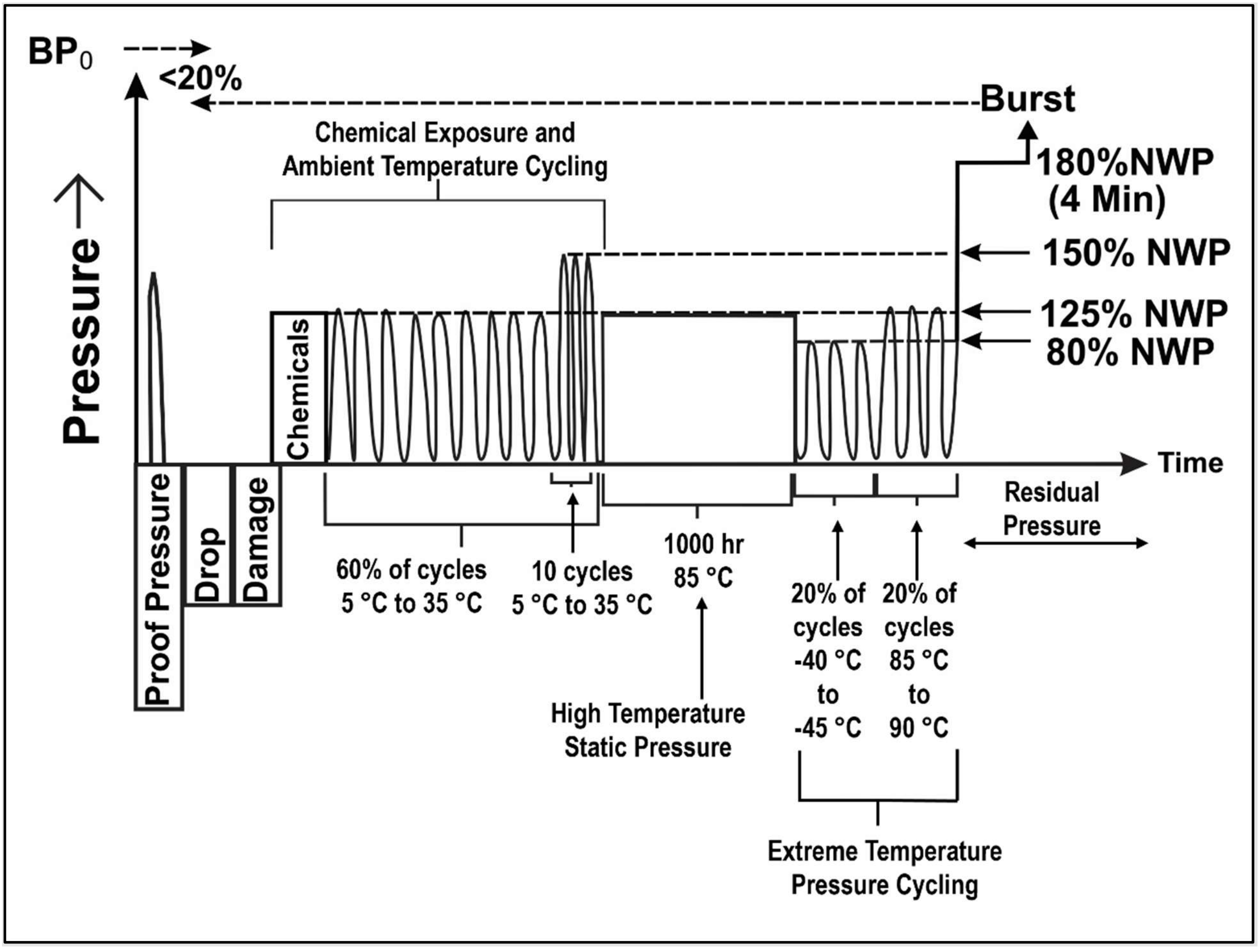

Figure 1. Performance durability test; (for illustration purposes only)

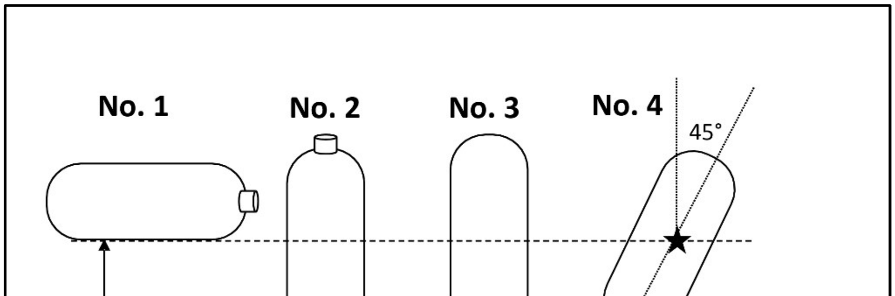

Figure 2. The four drop orientations; (for illustration purposes only)

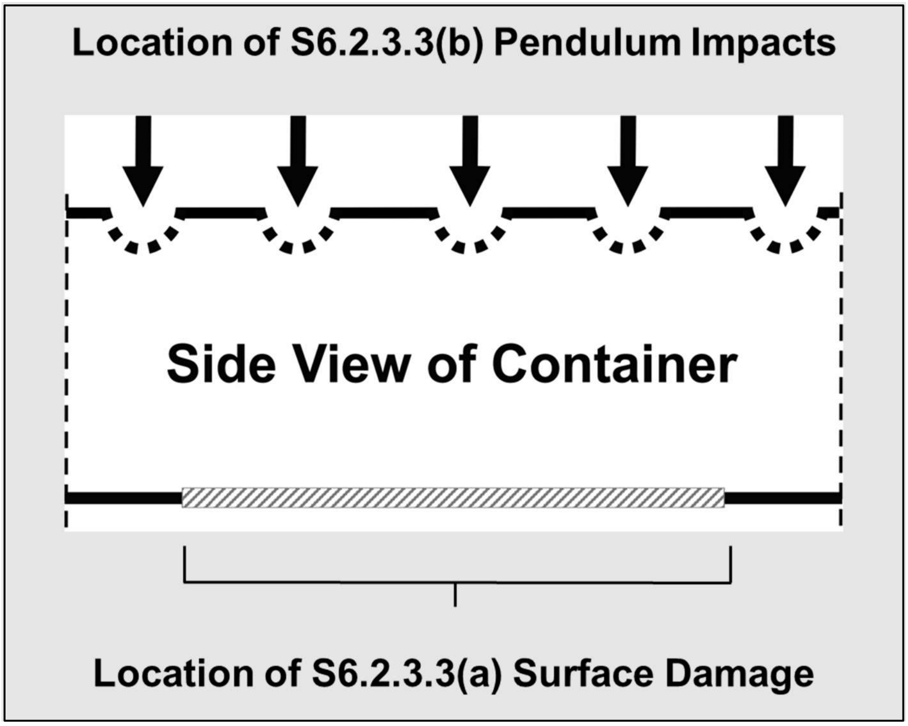

Figure 3. Locations of surface damage for S6.2.3.3(a) and pendulum impacts for S6.2.3.3(b);

(for illustration purposes only)

Authority: 49 U.S.C. 322, 30111, 30115, 30117, 30122 and 30166; delegation of authority at 49 CFR 1.95 and 501.5.

Sophie Shulman
Deputy Administrator