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Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers

Hydrogène gazeux — Dispositifs limiteurs de pression thermiquement activés pour les conteneurs de carburant de véhicules à hydrogène comprimé

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to promote the implementation of hydrogen powered land vehicles through the creation of performance based testing requirements for thermally activated pressure relief devices for compressed hydrogen fuel containers. The successful commercialization of hydrogen land vehicle technologies requires standards pertaining to fueling stations, vehicle fuel system components and the global homologation of standards requirements for technologies with the same end use. This will allow manufacturers to achieve economies of scale in production through the ability to manufacture one product for global use.

This document is based on the CSA Standard ANSI/CSA HPRD 1-2013.

Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers

1 Scope

This document establishes minimum requirements for pressure relief devices intended for use on hydrogen fuelled vehicle fuel containers that comply with ISO 19881, IEC 62282-4-101, ANSI HGV 2, CSA B51 Part 2, EC79/EU406, SAE J2579, or the UN GTR No. 13 for fuel cell vehicles.

The scope of this document is limited to thermally activated pressure relief devices installed on fuel containers used with fuel cell grade hydrogen according to SAE J2719 or ISO 14687 for fuel cell land vehicles, and Grade A or better hydrogen according to ISO 14687 for internal combustion engine land vehicles. This document also contains requirements for thermally activated pressure relief devices acceptable for use on-board light duty vehicles, heavy duty vehicles and industrial powered trucks such as forklifts and other material handling vehicles.

Pressure relief devices designed to comply with this document are intended to be used with high quality hydrogen fuel such as fuel complying with SAE J2719 or ISO 14687 Type 1 Grade D.

Pressure relief devices can be of any design or manufacturing method that meets the requirements of this document.

This document does not apply to reseating, resealing, or pressure activated devices.

Documents which apply to hydrogen fuel vehicles and hydrogen fuel subsystems include IEC 62282- 4- 101, SAE J2578 and SAE J2579.

Annex A presents an informative record of recommended fuel container, fuel storage subsystem and vehicle level requirements. The statements in Annex A are intended as recommendations for consideration of inclusion by the organizations and committees developing standards on these sub system and vehicle level standards.

Annex B presents a rationale for the design qualification tests in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1431-1, *Rubber, vulcanized or thermoplastic — Resistance to ozone cracking — Part 1: Static and dynamic strain testing*

ISO 6270-2, *Paints and varnishes — Determination of resistance to humidity — Part 2: Condensation (in-cabinet exposure with heated water reservoir)*

ISO 14687[1)], *Hydrogen fuel quality — Product specification*

ISO 19881[2)], *Gaseous Hydrogen — Land Vehicle Fuel Tanks*

ASTM D1149, *Standard Test Method for Rubber Deterioration-Surface Ozone Cracking in a Chamber*

ASTM D1193-06(R2011), *Standard Specification for Reagent Water*

1) Under preparation.

2) Under preparation.

CSA ANSI HGV 2, *Compressed hydrogen gas vehicle fuel containers*

CSA B51-14, *Boiler, Pressure Vessel, and Pressure Piping Code*

EC79 (EU406), *Type-approval of hydrogen-powered motor vehicles*

SAE J2579:2013, *Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles*

SAE J2719, *Hydrogen Fuel Quality for Fuel Cell Vehicles*

UN GTR No. 13, *UN Global Technical Regulation on Hydrogen and Fuel Cell Vehicles*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
flow capacity
<pressure relief device> capacity in volume per unit time at specified conditions

3.2
fusible material
metal, alloy, or other material capable of being melted by heat where the melting is integral to the function of the *pressure relief device* (3.6)

3.3
manufacturer's specified activation temperature
temperature, as specified by the pressure relief device manufacturer, at which the *pressure relief device* (3.6) is designed to release pressure

3.4
manufacturer's specified nominal working pressure
highest settled pressure at a uniform gas temperature of 15 °C of the container or container assembly with which the *pressure relief device* (3.6) may be used, as specified by the pressure relief device manufacturer

3.5
normal cubic centimeters
Ncc
dry gas that occupies a volume of 1 cm^3 at a temperature of 273,15 K (0 °C) and an absolute pressure of 101,325 kPa

3.6
pressure relief device
device that, when activated under specified performance conditions, is used to vent the container contents

Note 1 to entry: Reseating and resealing devices are not addressed by this document.

3.7
thermally activated pressure relief device
TPRD
pressure relief device (3.6) activated by temperature

4 Service conditions

4.1 General

Fuel containers may accidentally be exposed to fire or elevated temperature. These conditions may act to increase the contained pressure or to degrade the structural materials, depending on the container type and materials of construction. A pressure relief device provides a means to vent the fuel container under these conditions.

A specific pressure relief device may not be suitable for all container types, sizes or installations. Fuel container or installation standards may require that a pressure relief device be tested in conjunction with other components.

CGA S1.1 states: "relief devices may not prevent burst of a cylinder under all conditions of fire exposure. When the heat transferred to the cylinder is localized, intensive, and remote to the relief device, or when the fire builds rapidly, such as in an explosion, and is of very high intensity, the cylinder can weaken sufficiently to rupture before the relief device operates, or while it is operating".

The following service conditions are representative of what can be seen in an automotive service. These service conditions are provided as a basis for the design, manufacture, inspection and testing of pressure relief devices which are used in compressed hydrogen vehicle fuel containers.

4.2 Design service life

The design service life of the pressure relief device shall be specified by the pressure relief device manufacturer.

4.3 Nominal working pressure

This document applies to pressure relief devices that have a nominal working pressure, as specified by the manufacturer, of 25 MPa, 35 MPa, 50 MPa or 70 MPa at 15 °C, hereinafter referred to in this document as the following:

a) "H25" — 25 MPa;

b) "H35" — 35 MPa;

c) "H50" — 50 MPa;

d) "H70" — 70 MPa.

Other nominal working pressures for hydrogen gas besides those defined are allowed if the required qualification test requirements of this document are met.

4.4 Durability test cycles

The design pressure cycles for pressure relief devices shall be between not more than 10 % of the manufacturer's specified nominal working pressure and not less than 150 % of the manufacturer's specified nominal working pressure for ten cycles and between not more than 10 % of the manufacturer's specified nominal working pressure and not less than 125 % of the manufacturer's specified nominal working pressure for 14 990 cycles.

NOTE The maximum pressure under the condition of fueling station dispenser fault management is 150 % of the vehicle nominal working pressure, as defined in: SAE J2760, SAE J2579:2013, Appendix A and CSA HGV 4.1.

4.5 Temperature range

The pressure relief device shall be designed to maintain pressure integrity from −40 °C to 85 °C.

5 Quality assurance

Quality system programs shall be established and operated to demonstrate that pressure relief devices are produced in accordance with the qualified design.

6 General requirements

6.1 Material requirements

Materials normally in contact with hydrogen shall be determined to be acceptable in hydrogen service, with the consideration of hydrogen embrittlement and hydrogen accelerated fatigue. The performance tests cannot guarantee that all cases and conditions of the hydrogen service are validated, so it is still incumbent on the designer/builder to carefully screen materials of construction for their intended use. The materials and design shall be such that there is no significant change in the functioning of the device, deformation or mechanical change in the device, and no harmful corrosion, deformation or deterioration of the materials when subject to the service conditions given in Clause 4.

NOTE 1 Material performance data and/or acceptance criteria in hydrogen environments can be found in the ISO 11114 series, the Sandia National Laboratory Technical Reference for Hydrogen Compatibility of Materials, ANSI/AIAA G-095, ANSI/CSA CHMC 1, ASME B31.12, SAE J2579:2013, Appendix B or in equivalent national requirements.

NOTE 2 Some fusible alloys can contain heavy metals that can be considered environmentally unacceptable by some customers and which can be prohibited by some jurisdictions.

Non-metallic materials normally in contact with hydrogen shall be verified to be acceptable in the hydrogen service. Consideration shall be given to the fact that hydrogen diffuses through these materials more easily than through metals; therefore the suitability of materials shall be verified. Non-metallic materials shall retain their mechanical stability with respect to strength (fatigue properties, endurance limit, creep strength) when exposed to the full range of service conditions and lifetime as specified by the container manufacturer. Materials shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation. The chemical and physical properties necessary for operational safety shall not be significantly affected within the scheduled lifetime of the equipment unless a replacement is foreseen; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, aging resistance, the effects of temperature variations, the effects arising when materials are put together (for example, galvanic corrosion), the effects of ultraviolet radiation, and to the degradation effects of hydrogen on the mechanical performance of a material.

6.2 Design requirements

The design shall be such that, once activated, the device fully vents the contents of the fuel container. The design should minimize the possibility of external hazards (e.g. projectiles) resulting from the activation of the device. Any material released shall not interfere with the proper venting of the pressure relief device.

The pressure relief device shall be designed to address degradation from creep or plastic deformation. The design or manufacturing process should account for the effects of material defects, particularly casting and shrinkage voids, which adversely impact the robustness of the design.

6.3 Flow capacity

The flow capacity shall be indicated in the manufacturer’s published literature and verified by the flow capacity test under 7.13.

The adequacy of the flow capacity of pressure relief devices for a given application shall be demonstrated by bonfire testing in accordance with ISO 19881, ANSI HGV 2, CSA B51 Part 2, EC79/EU406, SAE J2579, or the UN GTR No. 13 for fuel cell vehicles and by the minimization of the hazardous effects of the pressure peaking phenomenon which can take place during high flow rate releases from small diameter vents in enclosed spaces.

6.4 Rework and repair

New pressure relief devices that do not meet the requirements of this document may be reworked or repaired as long as they satisfy the requirements of this document.

6.5 Failure modes and effects analysis (FMEA)

Design FMEA and Process FMEA shall be performed for pressure relief devices. The documents shall be made available for review by fuel container or vehicle manufacturers upon request. A verification of the existence of these documents satisfies the intent of this provision.

NOTE FMEA is a methodology used in the automotive industry to identify potentially hazardous failure modes of safety devices and recommend changes in design, manufacturing, inspection or testing which eliminate such failure modes or minimize their effects. FMEA is applied to both device design and to the manufacturing and assembly process to identify corrective actions that improve device reliability and safety. Available references include SAE J1739.

7 Design qualification testing

7.1 General

Design qualification testing shall be conducted on finished pressure relief devices that are representative of the normal production. Test reports shall be kept on file by the pressure relief device manufacturer and made available for review by fuel container manufacturers and end users upon request.

The design qualification testing required by this document shall, as appropriate and necessary, be supplemented by additional tests defined in “design controls” or “recommended action” in the Design FMEA.

Pressure relief devices representative of each design and design change shall be subjected to tests as prescribed in Table 1. Designs which are sufficiently similar to an existing fully qualified design shall be permitted to be qualified through a reduced test program as defined in Table 1. Design changes not falling within the guidelines in Table 1 shall be qualified as original designs.

Any additional tests or requirements shall be performed in accordance with appropriate published standards or procedures, as available.

Unless stated otherwise, the tests specified herein shall be conducted at an ambient temperature of 20 °C ± 5 °C.

Unless stated otherwise, the tests specified herein shall be conducted with the following tolerances on specified pressures and temperatures:

Pressures 2 MPa or less: +0/−1 MPa

Pressures 125 % NWP or greater: +2 MPa/−0 MPa

Temperatures ±5 °C

Hydrogen used for testing shall be high quality hydrogen fuel, such as fuel meeting the requirements of SAE J2719 or ISO 14687 Type 1 Grade D.

Table 1 — Test requirements for design and design changes

ISO 19882 Tests	Original design	Manufacturer's specified nominal working pressure	Manufacturer's specified activation temperature	Elastomeric seals	Orifice size	Body material	Surface coating	Inlet connection	Outlet connection
7.2 Pressure cycling	X	X	X	X		X		X	
7.3 Accelerated life	X	X	X	X		X			
7.4 Thermal cycling	X		X	X		X	X		
7.5 Accelerated cyclic corrosion	X			X		X	X		
7.6 Automotive fluid exposure	X	X				X	X		
7.7 Atmospheric exposure	X			External only					
7.8 Stress corrosion cracking resistance	X	X				X	X	X	
7.9 Impact due to drop & vibration	X	X	X			X		X	
7.10 Leakage	X	X	X	X		X	X	X	X
7.11 Bench top activation	X	X	X	X	X	X	X		
7.12 Flow capacity	X	X			X			X	X
7.13 High pressure activation and flow	X	X			X			X	X

NOTE "X" requires physical testing.

7.2 Pressure cycling

7.2.1 Sampling

Five finished pressure relief devices shall be subjected to the pressure cycling test.

7.2.2 Procedure

Pressure cycling shall be performed in accordance with the following procedure:

At a sample temperature not less than 85 °C, the first 10 pressure cycles shall be from not greater than 2 MPa to not less than 150 percent of the manufacturer's specified nominal working pressure rating, followed by 2 240 pressure cycles from not greater than 2 MPa to not less than 125 percent of the manufacturer's specified nominal working pressure, followed by 10 000 pressure cycles at a sample temperature not less than 20 °C from not greater than 2 MPa to not less than 125 percent of the manufacturer's specified nominal working pressure, followed by a final 2 750 pressure cycles at a sample temperature not more than −40 °C from not greater than 2 MPa to not less than 80 percent of the manufacturer's specified nominal working pressure. The pressure cycling shall be performed with hydrogen gas at a rate not exceeding 10 cycles per minute.

Table 2 — Pressure cycling conditions

Pressure cycles to %	No. of cycles	Sample temperature for cycles
2 MPa to 150 %	First 10	85 °C
2 MPa to 125 %	Next 2 240	85 °C
2 MPa to 125 %	Next 10 000	20 °C
2 MPa to 80 %	Final 2 750	−40 °C
NOTE All cycles are conducted at a rate not greater than 10 cycles per minute.		

7.2.3 Acceptable results

Following the pressure cycling test, the pressure relief devices shall meet the requirements of 7.10, 7.11, and 7.12.

7.3 Accelerated life

7.3.1 Sampling

a) Five finished pressure relief devices shall be subjected to the accelerated life test.

b) Three additional pressure relief devices shall be subjected to the manufacturer's specified activation temperature until activation.

Pressure relief devices employing a glass bulb (thermobulb) or shape memory alloys (or other materials that do not exhibit creep rupture phenomena) for activation are exempted from this Clause.

7.3.2 Procedure

Accelerated life testing shall be performed in accordance with the following procedure:

Pressure relief devices shall be placed in an oven or liquid bath with the temperature of the specimens held constant within ±1 °C throughout the test. Pressure on the inlet of the devices shall be elevated to 125 % of the manufacturer's specified nominal working pressure and held constant within ±0,7 MPa. The pressure supply may be located outside the controlled temperature oven or bath. The volume of liquid or gas should be limited to prevent damage to the test apparatus upon activation and venting. Each device may be pressurized individually or through a manifold system.

The accelerated life test temperature is T_L, given in °C by the expression:

$$T_L = 9{,}1 T_f^{0{,}503} \quad (1)$$

where T_f is the manufacturer's specified activation temperature in °C.

7.3.3 Acceptable results

a) The five pressure relief devices tested at their accelerated life test temperature shall not activate in less than 500 h and shall meet the requirements of 7.10.

b) The three pressure relief devices tested at the manufacturer's specified activation temperature shall activate in less than 10 h.

NOTE The 10 h time is to confirm conformance for the basis for Formula (1).

7.4 Thermal cycling

7.4.1 Sampling

One finished pressure relief device shall be subjected to the thermal cycling test.

7.4.2 Procedure

Thermal cycling shall be performed in accordance with the following procedure:

The pressure relief device shall be thermally cycled between 85 °C or higher and −40 °C or lower as follows:

a) Place an unpressurized pressure relief device in a liquid bath maintained at −40 °C or lower for a period of 2 h or more. Transfer to a liquid bath maintained at 85 °C or higher within 5 min.

b) Maintain the unpressurized pressure relief device in a liquid bath maintained at 85 °C or higher for a period of 2 h or more. Transfer to a liquid bath maintained at −40 °C or lower within 5 min.

c) Repeat steps a) and b) until a total of 15 thermal cycles have been achieved.

d) With the pressure relief device conditioned for a minimum of 2 h in the −40 °C or lower liquid bath, cycle the pressure relief device between not more than 10 % of the manufacturer's specified nominal working pressure and not less than 80 % of the manufacturer's specified nominal working pressure for a total of 100 cycles. The liquid bath shall be maintained at −40 °C or lower during this test.

When testing long trigger devices, the longest length permitted by the design shall be used for this test.

7.4.3 Acceptable results

Following the thermal and pressure cycling, the pressure relief device shall meet the requirements of 7.10 (except that the test shall be conducted at −40 °C or lower), 7.11, and 7.12.

7.5 Accelerated cyclic corrosion

7.5.1 Sampling

Three finished pressure relief devices shall be subjected to the accelerated cyclic corrosion test.

7.5.2 Procedure

Accelerated cyclic corrosion shall be performed in accordance with the following procedure:

The pressure relief devices shall be exposed to an accelerated laboratory corrosion test, under a combination of cyclic conditions (salt solution, various temperatures, humidity, and ambient environment). The test method is comprised of 1 % (approximate) complex salt mist applications coupled with high temperature, high humidity and high temperature dry off. One (1) test cycle is equal to 24 h, as illustrated in Figure 1.

The apparatus used for this test shall consist of a fog/environmental chamber, suitable water supply conforming to ASTM D1193 Type IV, provisions for heating the chamber and the necessary means of controlling the temperature between 22 °C and 62 °C. The apparatus shall include provisions for a supply of suitably conditioned 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 test samples.

The apparatus shall consist of the chamber design as defined in ISO 6270-2. During "wet-bottom" generated humidity cycles, the testing agency shall confirm that visible water droplets are found on the samples to verify proper wetness.

Steam generated humidity may be used provided the source of water used in generating the steam is free of corrosion inhibitors. During steam generated humidity cycles, the testing agency shall confirm that visible water droplets are found on the samples to verify proper wetness.

The apparatus for the dry off stage shall have the ability to obtain and maintain the following environmental conditions: temperature: 60 °C ± 2 °C and humidity: ≤30 % RH. The apparatus shall also have sufficient air circulation to prevent temperature stratification and also allow thorough drying of the test samples.

The force/impingement from this salt application should not remove corrosion or damage the coatings/paints system of test samples.

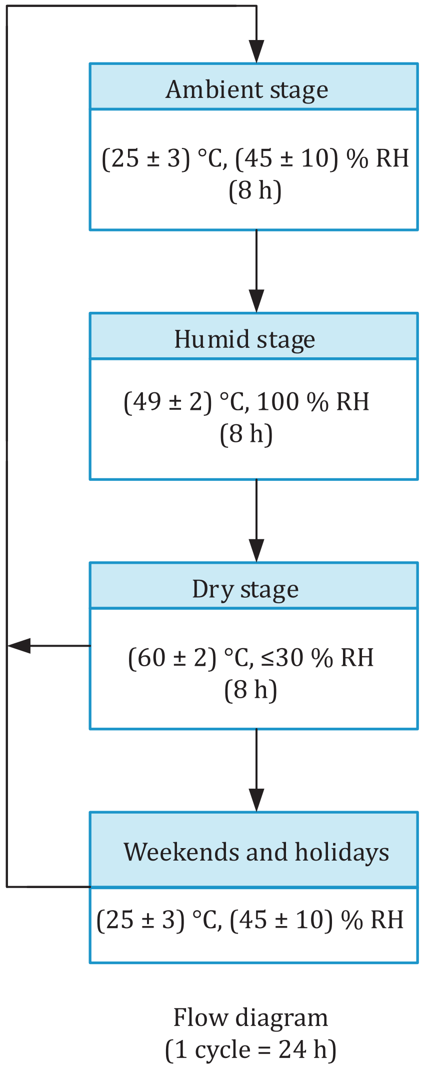

Figure 1 — Accelerated cyclic corrosion flow diagram

The complex salt solution in percent by mass shall be as specified below:

a) Sodium Chloride (NaCl): 0,9 %;

b) Calcium Chloride ($CaCl_2$): 0,1 %;

c) Sodium Bicarbonate ($NaHCO_3$): 0,075 %.

Sodium Chloride shall be reagent grade or food grade. Calcium Chloride shall be reagent grade. Sodium Bicarbonate shall be reagent grade (e.g., Baking Soda or comparable product is acceptable). Water shall meet ASTM D1193 Type IV requirements.

Either $CaCl_2$ or $NaHCO_3$ material shall be dissolved separately in water and added to the solution of the other materials. If all solid materials are added dry, an insoluble precipitate may result.

The pressure relief devices shall be installed in accordance with the manufacturer's recommended procedure and exposed to the cyclic corrosion test method illustrated in the Flow Diagram (Figure 1). Repeat the cycle daily until 100 cycles of exposure have been completed. 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/dripping. Suitable application techniques include using a plastic bottle, or a siphon spray powered by oil-free 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. The first salt mist application occurs at the beginning of the ambient stage. Each subsequent salt mist application should be applied approximately 90 min after the previous application in order to allow adequate time for the test sample to dry.

Humidity ramp times between the ambient and wet condition, and between the wet and dry conditions, can have a significant effect on test acceleration (this is because corrosion rates are highest during these transition periods). The time from ambient to wet conditions shall be (60 + 5) min and the transition time between wet and dry conditions shall be (180 + 10) min.

7.5.3 Acceptable results

Immediately following the cyclic corrosion test, the pressure relief devices shall be rinsed with fresh tap water and allowed to dry. The tested samples shall then be subjected to 7.10, 7.11 and 7.12.

7.6 Automotive fluids exposure

7.6.1 Sampling

One finished pressure relief device shall be subjected to the automotive fluids exposure test.

7.6.2 Procedure

Automotive fluids exposure shall be performed in accordance with the following procedure:

External portions of components shall be able to withstand exposure to the following fluids without mechanical degradation. Resistance may be determined by the following test, by comparable published data, or by known properties (e.g., 300 series stainless steel). The decision about the applicability of test data and known properties is at the discretion of the testing authority.

The external surfaces of the pressure relief device shall be exposed to the following test. The inlet and outlet connections of one device shall be connected or capped in accordance with the pressure relief device manufacturer's installation instructions. The pressure relief device shall be exposed at an ambient temperature by spraying the exterior of the component once per hour, 24 times, over a period of up to three days (3 8 h shifts over 3 days or 24 h straight, for example). Alternatively, the pressure relief device may be immersed in the solution for a period of 24 h. In the immersion method, the fluid shall be replenished as needed to assure complete exposure for the duration of the test. A distinct test shall be performed with each of the following three fluids. One pressure relief device may be used for all three exposures sequentially.

a) Sulfuric acid – 19 % solution by volume in water;

b) Methanol/gasoline – 5 %/95 % concentration of M5 fuel meeting the requirements of Standard Specification for Automotive Spark-Ignition Engine Fuel, ASTM D4814;

c) Windshield washer fluid (50 % by volume solution of methyl alcohol and water).

7.6.3 Acceptable results

After exposure to each chemical solution, the device shall be wiped off and rinsed with water and examined. The device shall not show signs of mechanical degradation that can impair the function of the device such as cracking, softening or swelling. Cosmetic changes such as pitting or staining are not considered failures. At the conclusion of all exposures, the device(s) shall meet the requirements of 7.10 and 7.11.

7.7 Atmospheric exposure test

7.7.1 General

The atmospheric exposure test applies to the qualification of pressure relief devices that have non-metallic materials exposed to the atmosphere during normal operating conditions.

7.7.2 Oxygen aging

7.7.2.1 Sampling

Three samples of each non-metallic material that provides a fuel containing seal shall be subjected to the oxygen aging test.

7.7.2.2 Procedure

The oxygen aging test shall be performed in accordance with the following procedure:

The samples shall be exposed to oxygen for 96 h at 70 °C at 2 MPa in accordance with ASTM D572.

7.7.2.3 Acceptable results

The samples shall not crack or show visible evidence of deterioration after exposure to oxygen aging.

7.7.3 Ozone

7.7.3.1 Sampling

Three samples of each non-metallic material shall be subjected to the ozone test.

7.7.3.2 Procedure

The ozone test shall be performed in accordance with one of the following procedures:

a) specification of elastomer compounds with established resistance to ozone;

b) pressure relief device testing in accordance with ISO 1431-1, ASTM D1149, or equivalent test methods;

c) the test piece which shall be stressed to 20 % elongation shall be exposed to air at 40 °C with an ozone concentration of 50 parts per hundred million during 120 h.

7.7.3.3 Acceptable results

The samples shall not crack or show visible evidence of deterioration after exposure to ozone.

7.8 Stress corrosion cracking resistance

7.8.1 Sampling

One finished pressure relief device shall be subjected to the stress corrosion cracking resistance test.

7.8.2 Procedure

The stress corrosion cracking resistance test shall be performed in accordance with the following procedure:

For pressure relief devices containing components made of a copper based alloy, one unit shall be tested as an assembly, such that the copper alloy components are subjected to the stresses normally imposed on them as a result of assembly.

All copper alloy components shall be degreased and then continuously exposed for ten days to a moist ammonia-air mixture maintained in a glass chamber having a glass cover. Aqueous ammonia having a specific gravity of 0,94 shall be maintained at the bottom of the glass chamber below the samples at a concentration of 20 ml per liter of chamber volume. The samples shall be positioned 38 mm above the aqueous ammonia solution and supported in an inert tray. The moist ammonia-air mixture shall be maintained at the atmospheric pressure with the temperature constant at 34 °C ± 2 °C.

7.8.3 Acceptable results

Copper alloy components shall not exhibit cracking or delamination due to this test.

7.9 Impact due to drop and vibration

7.9.1 Impact due to drop

7.9.1.1 Sampling

Six finished pressure relief devices shall be subjected to the impact due to drop test.

When subjected to a vertical drop of 1,83 m onto a smooth concrete floor or pad, pressure relief devices shall meet all operational performance requirements without loss of function or degradation of service life, or shall exhibit obvious visible exterior (physical) damage which indicates the part is unsuitable for use.

7.9.1.2 Procedure

The impact due to drop test shall be performed in accordance with the following procedure:

The pressure relief device samples shall be subjected to impact by being dropped from a height of 1,83 m, from the lowest point on the device, at the room ambient temperature, onto a smooth concrete pad or floor. For devices having extended flexible elements such as hoses, these shall be dropped with the flexible element in the pre-installation condition, with no packaging material. Each sample shall be allowed to bounce on the concrete pad or floor after the initial impact. One sample shall be dropped in each of the six major axes of orientation (opposing directions of 3 orthogonal axes, vertical, lateral and longitudinal).

7.9.1.3 Acceptable results

After each drop, the sample shall be examined for visible damages.

If each of the six dropped samples does not show a visible exterior damage that indicates the part is unsuitable for use, then it shall meet the requirements of 7.9.2.

If one or more of the dropped samples exhibits a visible exterior damage that indicates the part is unsuitable for use, the damage signature(s) shall be graphically documented and provided to the pressure relief device manufacturer as the relative measure for the rejection of visibly damaged parts. In this case, the samples have failed the test.

7.9.2 Vibration

7.9.2.1 Sampling

Each of the six samples identified in 7.9.1 and one finished pressure relief device not subjected to a drop shall be shall be subjected to the vibration test.

7.9.2.2 Procedure

The vibration test shall be performed in accordance with the following procedure:

The samples shall be mounted in accordance with the pressure relief device manufacturer's installation instructions and vibrated for 30 min along each of the three orthogonal axes (vertical, lateral and longitudinal) at the most severe resonant frequencies. Devices with long triggering elements shall be mounted and tested with a length that tests all relevant mounting conditions covered by the manufacturer's installation instructions. More than one unit may be used if needed. This shall include at least one end and intermediate mounting, if mounts at intervals are used. The frequencies shall be determined by the following: acceleration of 1,5 g with a sweep time of 10 min, within a sinusoidal frequency range of 10 Hz to 500 Hz. If the resonance frequency is not found in this range, the test shall be conducted at 40 Hz.

7.9.2.3 Acceptable results

Following this test, each sample shall not show any indication of fatigue or component damage, and shall meet the requirements of 7.10, 7.11 and 7.12.

7.10 Leakage

7.10.1 Sampling

Previously tested pressure relief devices shall be subjected to the leakage test.

7.10.2 Procedure

The leakage test shall be performed in accordance with the following procedure:

Prior to conditioning, purge the component with nitrogen or any inert gas. The outlet opening is plugged with the appropriate mating connection and 2,5 % of the nominal working pressure, using hydrogen, is applied to the inlet. All tests shall be conducted while the component is continuously exposed to the specified test temperatures.

At all test temperatures, immerse the components in a suitable test medium for 1 min, or use a global accumulation method (or equivalent).

The component shall be conditioned at −40 °C or lower, or until thermal stability is attained, and pressurized at both 100 % and then at 5 % of the nominal working pressure.

The component shall be conditioned at room temperature 20 °C ± 5 °C, or until thermal stability is attained, and pressurized at 150 % and then at 5 % of the nominal working pressure.

The component shall be conditioned at 85 °C or higher, or until thermal stability is attained, and pressurized at 150 % and then at 5 % of the nominal working pressure.

7.10.3 Acceptable results

If no bubbles are observed for 1 min, the sample passes the test. If bubbles are detected, the leak rate shall be measured by an appropriate method (e.g. gas chromatography, etc.).

The leak rate shall not exceed 10 Ncc/h of hydrogen gas.

7.11 Bench top activation

7.11.1 Sampling

Two finished pressure relief devices and pressure relief devices subjected to the tests of 7.2, 7.4, 7.5, 7.6 and 7.9 shall be subjected to the bench top activation test.

NOTE The bench top activation test does not predict the performance of any pressure relief device in the system level bonfire test, as the performance of a given device in the bonfire test is dependent upon the system integration of the pressure relief device, container valve and fuel storage container.

7.11.2 Procedure

The bench top activation test shall be performed in accordance with the following procedure:

The test setup shall consist of a chimney, capable of controlling the air temperature and flow, to achieve a consistent temperature of 600 °C ± 10 °C in the air surrounding the pressure relief device. The pressure relief device shall not be exposed directly to flame. The pressure relief device shall be mounted in a fixture according to the manufacturer's installation instructions that shall be documented in accordance with Clause 11. The testing conditions for the new and aged pressure relief device comparison samples should be the same.

Pressurize one pressure relief device that has not been subject to previous testing, to no more than 25 % of the manufacturer's specified nominal working pressure. Place a thermocouple in the chimney to monitor the temperature. The temperature shall remain within the acceptable range for 2 min prior to running the test. Insert the pressure relief device and/or a portion of the triggering element into the chimney and record the time for the device to activate to establish the baseline time for comparison.

If the entire pressure relief device is not being placed in the chimney, the size of the chimney or heat exposure shall be determined by the manufacturer and be documented.

Pressurize the pressure relief devices that were subject to the tests of 7.2, 7.4, 7.5, 7.6 and 7.9 to no more than 25 % of the manufacturer's specified nominal working pressure, and test under the same conditions.

Pressurize one pressure relief device that has not been subject to previous testing to 100 % of the manufacturer's specified nominal working pressure, and test under the same conditions.

7.11.3 Acceptable results

The difference in the activation time of the pressure relief devices that have not previously undergone testing shall be no more than 2 min.

The pressure relief devices subjected to the tests of 7.2, 7.4, 7.5, 7.6 and 7.9 shall activate no more than 2 min longer than the baseline activation time of the pressure relief device which had not been subjected to previous design qualification tests and subjected to no more than 25 % of the manufacturer's specified nominal working pressure.

7.12 Flow capacity

7.12.1 Sampling

Eight pressure relief devices shall be tested for flow capacity. The sample population shall consist of one device from those previously tested in each of 7.2, 7.4, 7.5, 7.6 and 7.9, and three new devices.

7.12.2 Procedure

The flow capacity test shall be performed in accordance with the following procedure:

Each device tested shall be activated using the test procedure in 7.11.

After activation and without cleaning, removing parts or reconditioning, each pressure relief device shall be subjected to the flow test using hydrogen, air or an inert gas wherein the rate of gas released by the device is measured.

Flow testing shall be conducted with a gas inlet pressure of (2,0 ± 0,5) MPa. The outlet shall be under ambient pressure. The inlet temperature, pressure and flow rate shall be recorded.

The flow shall be measured with an accuracy within ±2 %.

7.12.3 Acceptable results

The lowest measured value of the nine pressure relief devices shall not be less than 90 % of the highest flow value.

Flow capacity shall be reported as the lowest measured value of the nine pressure relief devices. The flow rate may also be reported in grams per second.

7.13 High pressure activation and flow

7.13.1 Sampling

Six finished pressure relief devices shall be subjected to the high pressure activation and flow test.

Since minimum gas volume in the setup of the test depends in part on the final results, more devices may be required to determine the correct initial setup.

7.13.2 Procedure

The high pressure activation and flow test shall be performed in accordance with the following procedure:

The test setup shall consist of a chimney which is capable of controlling the air temperature and flow to achieve a consistent temperature of 600 °C ± 10 °C in the air surrounding the pressure relief device. The pressure relief device shall not be exposed directly to flame. The pressure relief device shall be mounted in a fixture that shall be documented. A volume of gas shall be installed ahead of the pressure relief device, in accordance with the manufacturer’s installation instructions. The volume of gas shall be sufficient that the pressure relief device vents down to 10 % of the start pressure in greater than 10 s, and shall be enough that the pressure relief device reaches a stable Cv before reaching 25 % of the starting pressure. The testing conditions for the new and aged pressure relief device comparison samples shall be the same.

Pressurize the pressure relief device to the manufacturer's specified nominal working pressure ±2 %. In the case of multiple rated nominal working pressures of a single design, the highest may be used as acceptable test conditions for all pressures. The gas temperature shall be below 40 °C. The pressure of the stored gas shall be measured in such a way that it is not affected by the flow past the pressure measurement device.

Place a thermocouple in the chimney to monitor the temperature. The temperature shall remain within the acceptable range for 2 min prior to running the test. Insert the pressure relief device into the chimney.

Record the pressure over time, from the point of insertion into the chimney, until venting is complete.

The graph of the pressure data for all devices shall be made available in the component literature.

7.13.3 Acceptable results

The flow of the devices shall not stop until the tank is below 1 MPa.

8 Inspection and acceptance testing

8.1 Inspection and acceptance testing plan

The pressure relief device manufacturer shall prepare a plan for inspection and acceptance testing. Inspections and tests may be conducted by suppliers, the pressure relief device manufacturer or by an independent agency.

8.2 Inspector's responsibilities

The inspector is responsible for verifying that all drawing, test and specification requirements have been met. The inspector shall select units to be tested and shall prepare or review all inspection and test reports.

8.3 Inspection of system critical components

System critical components identified in the FMEA shall be inspected using a suitable system before assembly or shipment.

Fusible components not within the manufacturer's tolerances for voids, inclusions or other harmful defects shall be destroyed.

8.4 Leak testing

All pressure relief devices shall be tested for leakage at both 5 % and a minimum of 125 % of the manufacturer's specified nominal working pressure. Devices which leak greater than 10 Ncc/h hydrogen or hydrogen equivalent shall be rejected. Helium or hydrogen, at any concentration, may be used to measure leakage in this test, provided the leak rate of the test gas is converted to an equivalent leak rate for hydrogen.

9 Production batch testing

9.1 General

For testing purposes, the ambient temperature shall be between 16 °C and 38 °C.

Batch testing shall be conducted on system critical components identified in the FMEA, and finished pressure relief devices. Batch tests of system critical components may be conducted by the supplier, an independent agency or the pressure relief device manufacturer. Batch tests for pressure relief devices may be conducted by the pressure relief device manufacturer or by an independent agency. Test reports shall be kept on file by the pressure relief device manufacturer for the design service life of the pressure relief device plus five years, and made available to fuel container manufacturers and end users upon request.

When the test results fail to meet the requirements, the pressure relief device or component batch shall be rejected. Retest of a rejected batch is authorized if the test equipment or procedure was faulty.

9.2 Production batch sizes

9.2.1 General

The size of batches for pressure relief device components, except as specified in 9.2.2 and 9.2.3, shall be determined by the manufacturer. Batch sizes shall be consistent with good manufacturing practice and appropriate levels of inspection utilizing the results of the FMEA performed in accordance with the requirements of 6.5.

9.2.2 Fusible materials

The batch size is limited to what can be produced by one common set of raw materials (e.g., a single oven melt).

9.2.3 Pressure relief devices

The batch size is limited to what can be produced from a single batch of system critical components. The batch size shall be determined and managed under the container manufacturer’s quality control system.

9.3 Pressure relief device components

The pressure relief device manufacturer shall either obtain certification from component suppliers that their components are in accordance with the appropriate specifications for materials, heat treat, physical properties and mechanical properties, or conduct tests or inspections to confirm that the appropriate specifications have been met.

9.4 Thermal activation verification

9.4.1 General

One unit of the pressure relief device shall be selected at random from its batch.

9.4.2 High temperature soak

The pressure relief device shall be immersed in a liquid bath that is maintained at a temperature from 0 °C to 5 °C lower than the manufacturer's specified activation temperature. The pressure relief device shall be pressurized to 1,38 MPa ± 0,2 MPa . The temperature and pressure shall be maintained for at least 24 h. The pressure relief device shall not activate within this time.

9.4.3 Activation

The pressure relief device shall be pressurized to 25 % of the manufacturer's specified nominal working pressure. The temperature of the fluid bath shall be increased to a level from 0 °C to 5 °C higher than the manufacturers specified activation temperature. The pressure relief device shall activate within 4 h of reaching the target temperature range.

9.5 Pressure cycle verification

9.5.1 General

One unit of the pressure relief device shall be selected at random from its batch.

9.5.2 Procedure

The pressure relief device shall be subjected to 15 000 hydraulic pressure cycles at 20 °C from 2 MPa to not less than 125 % of the manufacturer’s specified nominal working pressure.

9.5.3 Acceptable results

Following this test, the sample shall not show any indication of fatigue or component damage, and shall meet the requirements of 7.10.

10 Marking

10.1 Required information

Pressure relief devices shall be marked with the name and year of this document (ISO 19882), type of gas (H2), the manufacturer's specified nominal working pressure or pressure class (H25, H35, etc.), the manufacturer's identification, part number, and traceability code.

If it is possible to install the pressure relief device to allow the flow in the wrong direction, the pressure relief device shall be marked with an arrow to show the direction of the flow.

10.2 Marking methods

Markings shall be permanent. Permanent adhesive labels are permissible, or markings may be etched or stamped onto the pressure relief device housing.

11 Component literature

Manufacturers of pressure relief devices shall provide component literature for their devices. These instructions shall provide information to guide the installer in making a proper installation, and applicable concerns as identified in Annex A. The instructions shall also require that intermediate assemblers or container manufacturers who assemble a pressure relief device to a container must transmit the warning and instructions to the installer. The manufacturer shall provide duplicate instructions in response to requests, including service parts. The instructions shall be published in the predominant language(s) of the destination country. Critical parts of the component literature shall be worded in the imperative (shall or must, not should or may).

Component literature shall include at least

a) gasses the device is certified to,

b) maximum nominal working pressure,

c) activation temperature and/or pressure,

d) flow rate as determined by 7.12,

e) flow data as determined by 7.13,

f) design cycle life or service life, and

g) identification of parts which require regular periodic replacement.

Component literature should include the following items, if applicable:

h) installation torques or similar values;

i) mounting location limitations;

j) installation orientations, if any, particularly considering the accumulation of contaminants in the high pressure or vent outlet lines;

k) vent line requirements for the flow, protection of the pressure relief device from contamination and containment of projectiles;

l) inspection procedures, if any;

m) inlet connection requirements, including minimum flow characteristics;

n) requirements for warning labels that may be required as part of the installation.

All of these requirements need only to be addressed as it affects the function of the pressure relief device. Requirements that arise from other standards, such as vent line routing, do not need to be addressed in the instructions.

Annex A
(informative)

Subsystem and vehicle level considerations

A.1 Purpose

The purpose of this annex is to record the fuel container, fuel storage subsystem and vehicle level requirements. As this document is a component level standard, these recommendations are outside the scope of this document, and the pressure relief device manufacturers would not be able to demonstrate compliance if they were included in this document. In addition, the pressure relief device manufacturer does not control the usage and installation of their devices, and therefore cannot certify that they comply with the following statements.

These statements are intended as recommendations for consideration of inclusion to the organizations and committees developing these sub system and vehicle level standards, such as IEC 62282-4-101, SAE J2578 and SAE J2579.

A.2 Design service life

The design service life of the pressure relief device should meet or exceed the design service life of the fuel container with which it is used.

A.3 Design nominal working pressure

The design nominal working pressure of the pressure relief device should meet or exceed the design nominal working pressure of the fuel container for which it is used.

A.4 External environment

A.4.1 Location of pressure relief devices

The thermally reactive portion of the thermally activated pressure relief devices should be located in the same area or compartment, and should be exposed to the same environment, as the fuel container or systems that are being protected.

A.4.2 Pressure relief device cautionary labelling

Pressure relief devices that are mounted externally to the container valve assembly should have a yellow caution label affixed to them, stating that the component contains high pressure even when the service valve is closed.

A.4.3 Pressure relief device discharge vent and leakage capture systems

A.4.3.1 General

The primary function of the pressure relief device discharge vent system, if used, is to direct the discharge from a pressure relief device. The primary function of a leakage capture system, if used, is to capture potential leakage from the various connections to pressure relief devices, valves and bosses of containers and direct the gas out of the compartment to prevent a combustible mixture in a confined space.

A.4.3.2 Pressure relief device discharge vent system vent line materials of construction

Pressure relief device discharge vent systems, which may consist of interconnecting lines, ducting, vent tubes, outlets and restraining systems, should be protected, by design, routing and materials of construction, from mechanical or thermal failure or degradation, and maintain system integrity until venting is completed. Accumulation of electrostatic charge during discharge should be mitigated (e.g. by avoiding the use of nonconductive vent lines). Additionally, the materials of construction should mitigate the risk of corrosion, and should not cause galvanic corrosion at the interface connection to the pressure relief device.

A.4.3.3 Pressure relief device discharge vent system routing

Pressure relief devices and discharge vent systems should transfer the pressure relief device discharge outside of the passenger, luggage or cargo compartments. The discharge vent system should also be able to release the build-up of permeation from the pressure relief device while still remaining functional. Consideration should be given to the minimization of risk to occupants or persons outside the vehicle, as well as the reduction of risk of progression of hazards within the vehicle or its surroundings, when directing the flow of the pressure relief device discharge. The pressure relief device discharge should not direct the exhaust into or toward the passenger, luggage or cargo compartment, into or toward wheel housings, toward hydrogen storage systems, or toward the front of the vehicle. The design and installation should minimize the possibility of external hazards (e.g., projectiles) resulting from the activation of the device.

Routing of the interconnecting lines, ducting, vent tubes and outlets of pressure relief devices should avoid constrictions or pinching, as well as be protected in case of vehicle collisions, such that functionality is not compromised due to flow restrictions. The vent line should not reduce the intended flow capacity of the pressure relief device by introducing choke points or other restrictions.

Vent lines should be adequately secured to prevent damage during the vehicle's lifetime usage or uncontrolled movement during venting.

Examples of design requirements may include specifications for the size, restriction and routing of the vent piping to prevent restriction by lodging of the material released. Orientation of the discharge in a direction away from locations likely to be occupied by people may be used to minimize hazards from projectiles. Directing the discharge against some fixed surface so as to intercept projectiles may reduce safety by promoting turbulent mixing of compressed hydrogen gas and air. If the activation occurs during a fire, small projectiles may not pose a significant hazard to the emergency personnel in the protective gear. The important goal is to minimize hazards in an already inherently hazardous situation.

A.4.3.4 Pressure relief device discharge vent system intrusion

Pressure relief device discharge vent systems should be designed to prevent the ingress of foreign material or accumulation of moisture in the system. Moisture may collect in the vent side of the pressure relief device or in the discharge vent system due to the condensation and/or ingress of water. Water or ice in discharge vent systems may inhibit the function of the pressure relief device, cause unexpected venting or damage discharge vent system components. Discharge vent systems, including vent line closures if used, should prevent water invasion due to rain or car wash, and should maintain functional integrity when exposed to vehicle washing or environmental exposure. The discharge vent system shall be able to preclude or relieve the pressure build-up occurring due to allowable leakage of the pressure relief device without losing function or integrity.

Pressure relief device discharge vent systems and vent line closures shall not restrict the flow from the pressure relief device in such a way as to affect function.

A.4.3.5 Leakage capture systems (boxes/housings)

Leakage capture system design and materials of construction, if used, should not retard the thermal input to thermally activated pressure relief devices.

Vent box or gas-tight housing are a form of flow barrier that is sometimes used by the industry to capture potential leakage from the bosses of containers and direct the gas into vent lines. Care should be taken with these configurations so that these devices do not interfere with the ability of pressure relief devices to protect the containers.

The primary function of a leakage capture system, if used, is to capture potential leakage from the various connections to pressure relief devices, valves and bosses of containers, and direct the gas out of the compartment to prevent a combustible mixture in a confined space. The thermal effect of the leakage capture system design and material of construction to the safety performance of thermally activated pressure relief devices should be taken into consideration.

Leakage capture systems or gas-tight housings are forms of flow barriers that are sometimes used by the industry to capture potential leakage from the bosses of containers and direct the gas into vent lines. Care should be taken with these configurations so that these devices do not interfere with the ability of pressure relief devices to protect the containers.

Pressure relief device leakage capture systems should be protected from thermal degradation if they are functional components of the pressure relief device discharge vent system.

A.4.3.6 Fuel storage system barriers/shields

Shields may be used to protect the fuel storage system from physical, chemical and thermal effects. Solar shields should be considered to protect against thermal and UV effects due to direct exposure to sunlight. Thermal shields should be also used (when necessary) on hydrogen storage systems to minimize local thermal exposures due to fire in adjacent compartments/areas of the vehicle (such as the passenger compartment or wheel wells) until pressure relief devices can activate to mitigate potentially hazardous events. Consideration as to the location and design of seams, maintenance access holes and hatchways in the vehicle, shields or flow barriers, should be such that the effectiveness of the pressure relief device is not compromised.

The design and location of both shields and flow barriers should not interfere with the ability of the pressure relief device to protect the fuel storage system.

A.4.3.7 Pressure relief device pressure connections

Pressure relief devices and connections can also be damaged by water accumulating and freezing in the high pressure passages. This may occur due to filling equipment faults or excessively wet gas, but is not a normal occurrence. Consideration should be given to avoiding having the pressure relief device or associated connections and tubes becoming a trap for liquid.

A.5 Flow capacity

The adequacy of flow capacity of the pressure relief device for a given application should be demonstrated by bonfire testing and by the minimization of the hazardous effects of the pressure peaking phenomenon which can take place during high flow rate releases from small diameter vents in enclosed spaces. The supply and discharge lines, if used, should not reduce the intended flow capacity of the pressure relief device by introducing unintended choke points or other restrictions, thereby compromising its performance. If the system configuration allows more than one fuel container to flow through a single pressure relief device, then the flow capacity should be capable of handling the flow from all the containers.

A.6 In-service conditions

A.6.1 Inspection

The pressure relief device should be inspected at the same time as the container for which it is installed in accordance with the pressure relief device, container or vehicle manufacturer's instructions for damage or deterioration. The exterior of the pressure relief device may be cleaned with non-corrosive cleaners during inspection or at other times. The pressure relief device vent lines and vent caps, if used, should be inspected at the same time, in accordance with the vehicle manufacturer's instructions.

A.6.2 Rework and repair

No pressure relief device that has been in service should be repaired or reworked without the written authorization of the pressure relief device manufacturer, fuel container manufacturer, systems manufacturer or vehicle manufacturer.

A.6.3 Replacement

A pressure relief device that requires replacement during its service life should only be replaced with an identical unit or a suitable substitute authorized by the fuel container manufacturer, systems manufacturer or vehicle manufacturer.

A.6.4 Reuse and reinstallation

No pressure relief device that has been in service should be moved or reused on another fuel container.

Pressure relief devices should only be reinstalled on the same container if it is done in accordance with the systems or vehicle manufacturer's recommended service procedures.

A.6.5 Destroyed

A pressure relief device should be considered destroyed when it has been rendered impossible to hold pressure by mechanical means.

EXAMPLE Crushing sufficiently to prevent reattachment or drilling a minimum 5 mm hole through the body of the device.

Annex B
(informative)

Design qualification test rationale

B.1 Pressure cycling test

The life of fuel containers is defined to range between 11 000 and 15 000 cycles to 125 % of the nominal working pressure. The pressure relief device should not leak and should not have a significant change in actuation time after passing the pressure cycling test.

The specification of the first ten cycles to 150 % of the manufacturer's specified nominal working pressure is added to test the devices at the maximum station default fill pressure. This also harmonizes with the ten cycles to the same pressure that is specified for the hydrogen storage system, including the pressure relief device, in SAE J2579 and the UN GTR No. 13 for fuel cell vehicles.

B.2 Accelerated life test

The assessment of long-term, reliable performance is perhaps the most significant and difficult task for qualification testing of pressure relief devices. Elevated temperatures are used to accelerate testing in order to project successful performance for a cumulative exposure of 3 years at 85 °C over a 20 year lifetime, and for a 20 year lifetime at 57 °C. The requirement for 3 years at 85 °C addresses the cumulative time expected from heating due to fast fill conditions, and for elevated ambient temperatures if mounted in the trunk in a warm, sunny environment or if mounted beneath the vehicle and subject to heating from the engine or exhaust system.

Testing is conducted at 125 % of the nominal working pressure since the highest temperature conditions are likely to be combined with fast fill pressure limits. Requiring multiple data points at multiple temperatures provides statistical significance to the data. The Arrhenius rate equation is expected to give the best correlation for results.

B.3 Thermal cycling test

Pressure relief devices see thermal shock during operation, due in part to moving between cold ambient environments and a garage and in part by fast fill and blowdown cycles. The requirement for only 15 cycles reflects a belief that the number of severe thermal shock cycles is limited, and that relief devices are either sensitive to them in a few cycles or not sensitive to them at all. The pressure cycles conducted at a cold temperature are to demonstrate that the relief device components are not brittle at low temperatures and do not develop leaks due to differences in thermal coefficients of expansion.

B.4 Accelerated cyclic corrosion test

The accelerated cyclic corrosion test is replacing 500 h of salt fog testing since it has been demonstrated that the accelerated cyclic corrosion test is more representative of the in-use exposures for these components. In addition, this procedure is effective for evaluating a variety of corrosion mechanisms, such as general, galvanic, crevice, etc. This test was loosely based upon the General Motors cyclic corrosion test (GMW14872). One hundred cycles was selected as the test duration to evaluate part failures which can lead to safety concerns in service, as pressure relief devices are a primary container pressure retention component. The parts are evaluated for post corrosion exposure functional performance by means of the leakage and bench top activation tests.

B.5 Automotive fluid exposure test

The components, while in service, are most likely exposed to either a splash or spray condition, so the methodology proposed is to spray the exterior surface. As the highest risk factors are for fluids that can be expected to be present normally in an automotive environment, sodium hydroxide and ammonium nitrate exposures have been eliminated, as they are not chemicals to which these components are normally exposed in automotive service.

B.6 Atmospheric exposure test

The atmospheric exposure test applies to the qualification of pressure relief devices that have non-metallic materials exposed to the atmosphere during normal operating conditions.

B.7 Stress corrosion cracking resistance test

This test demonstrates that copper alloy components are not subject to stress corrosion cracking.

B.8 Impact due to drop and vibration test

The impact due to drop requirement addresses damage that may be incurred during handling, shipping and installation of the pressure relief device. This requirement documents visible damage that renders the part unsuitable for use, or ensure that parts with no visible signs of damage after drop meet all functional requirements (no hidden damage).

The vibration requirement has been changed from a single frequency for testing purposes to a sweep of a sinusoidal frequency range from 10 Hz to 500 Hz. The original frequency of 17 Hz was established through the demonstration of one vehicle traveling over a variety of road surfaces. The change to determine the most severe resonant frequency for a given pressure relief device more accurately measures the performance of a given design. The resonant frequency changes based upon the pressure relief device design and mounting provisions, therefore the change in procedure demonstrates more accurately the performance of the assembly.

B.9 Leakage test

The pressure relief device assembly should not exhibit leakage after being subjected to the various non-destructive design qualification tests. The test conditions are harmonized with the UN GTR No. 13 for fuel cell vehicles.

B.10 Benchtop activation test

This test is intended to be a quick and inexpensive way to assess whether the response characteristics of the relief device are affected by the various non-destructive qualification tests. This test is not intended to replace the bonfire test as a means of determining the acceptability of a given pressure relief device with a given fuel container. Some vehicle fuel container bonfire tests specify a minimum flame temperature of 593 °C, which is the basis for the flue gas temperature in this test. Since it is a comparative test between relief devices which have been subjected to various non-destructive qualification tests and devices which have not been so tested, there is no requirement to maintain the temperature within the target range once the relief device is put into the flue. The comparative time to activate is intended to show that the qualification tests do not prevent the device from activating or cause it to activate prematurely.

B.11 Flow capacity test

This measurement is taken for the information of the purchaser of the pressure relief device.

B.12 High pressure activation and flow test

Some pressure relief devices, in some tests, open and then reclose. This has been seen in bonfire tests with different devices and by various labs, and has resulted in container rupture during the test. Some devices do not open fully when first activated. They may open progressively. This is not, in itself, a problem if it is consistent. The opening characteristics, including the above noted conditions, are not consistent between different models of pressure relief devices. This may not itself be a problem, but the existing flow rating, namely a single flow value, implies that a given PRD flows a given amount, throughout its activation. This may lead to improper PRD selection. The two opening characteristics listed above are not consistent from test to test or unit to unit, so significant variation in the cumulative flow exists and is not tested for. This is counter to the assumption that a single bonfire test is representative, and the requirement of ±5 % flow variation in the existing test. The current test is not representative of actual use, in that a tiny volume of gas at 25 % nominal working pressure is used in the test, avoiding any effect of the continuous flow, such as cooling, or other effects of the continuous flow and high pressure. This may overlook certain failure modes or create others. Both false high and false low values have been observed in testing.

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