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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. www.iso.org/directives

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 197.

Introduction

This publication represents an International Standard for the safe operation, substantial and durable construction and performance testing of thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers, for the on-board storage of compressed hydrogen for vehicle operation within limitations given below and in the scope of this International Standard.

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

1 Scope

1.1 General

This International Standard establishes minimum requirements for pressure relief devices intended for use on 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.

Pressure relief devices designed to comply with this International Standard are intended to be used with hydrogen fuel complying with SAE J2719 or ISO 14687.

Pressure relief devices may be of any design or manufacturing method that meets the requirements of this International Standard.

The construction of pressure relief devices, whether specifically covered in this International Standard or not, shall be in accordance with reasonable concepts of safety, performance and durability.

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

1.2 Relevant documents

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

Other regulations, standards, or codes may permit or require the use of pressure relief devices certified to comply with this International Standard. Additional service conditions or requirements beyond the scope of this document are the responsibility of those standards development organizations or the authority having jurisdiction.

1.3 Informative annexes

Annex A presents an informative record of recommended fuel container, fuel storage subsystem, and vehicle level requirements. As this International Standard contains component level requirements, these recommendations are outside the scope of this document.

Annex A statements are intended as recommendations for consideration of inclusion by the organizations and committees developing these sub system and vehicle level standards.

Annex B presents rationale for the design qualification tests in this International Standard.

1.4 Notes

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 will provide 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”.

1.5 Units of measurement

This International Standard contains SI (Metric) corresponding to the yard/pound quantities, the purpose being to allow the International Standard to be used in SI (Metric) units. (Standard for use of the International System of Units (SI): The Modern Metric System, IEEE/ASTM SI I0 or Metric Practice Guide, CAN/CSA Z234.1 are used as a guide in making metric conversion from yard/pound quantities.) If a value for a measurement and a corresponding value in other units are stated, the first stated value is to be regarded as the requirement. The given corresponding value may be approximate. If a value for a measurement and a corresponding value in other units are both specified as a quoted marking requirement, the first stated unit, or both shall be provided.

2 Normative references

The following referenced documents are indispensable for the application 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 (International Organization for Standardization)
1431-1:2004
Rubber, vulcanized or thermoplastic – Resistance to ozone cracking – Part 1: Static and dynamic strain testing

6270-2:2005
Paints and varnishes – Determination of resistance to humidity – Part 2: Procedure for exposing test specimens in condensation-water atmospheres

9001:2008
Quality Management Systems – Requirements

14687-2:2012
Hydrogen Fuel — Product Specification—Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles

ISO/TR 15916:2004
Basic considerations for the safety of hydrogen systems

80000-1:2009
Quantities and units – Part 1: General

AIAA (American Institute of Aeronautics and Astronautics)
ANSI/AIAA G-095-2004e
Guide to Safety of Hydrogen and Hydrogen Systems

ASME (American Society of Mechanical Engineers)
B31.12-2008
Hydrogen Piping and Pipelines

ASTM International
D572-04(R2010)
Standard Test Method for Rubber-Deterioration by Heat and Oxygen

D648-07
Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position

D1149-99
Standard Test Method for Rubber Deterioration-Surface Ozone Cracking in a Chamber

D1193-06(R2011)
Standard Specification for Reagent Water

D4814-11b
Standard Specification for Automotive Spark-Ignition Engine Fuel

G154-06
Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials

CGA (Compressed Gas Association)
CGA S1.1-2011
Pressure Relief Device Standards Part 1 – Cylinders for compressed gasses

CSA Group
ANSI HGV 4.1-2012
Hydrogen dispensing systems

ANSI HGV 2-2014
Compressed hydrogen gas vehicle fuel containers

CSA B51-09
Boiler, Pressure Vessel, and Pressure Piping Code

IEC (International Electrochemical Commission)
62282-4-101
Fuel cell power systems for propulsion other than road vehicles and auxiliary power units – Fuel cell power systems for industrial electrically driven forklift trucks - Safety

SAE International
J1739:2009
Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA)

J2578:2009
Recommended Practice for General Fuel Cell Vehicle Safety

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

J2719:2011
Hydrogen Fuel Quality for Fuel Cell Vehicles

J2760:2011
Pressure Terminology Used in Fuel Cells and Other Hydrogen Vehicle Applications

Sandia National Laboratory
Technical Reference for Hydrogen Compatibility of Materials (2008)

United Nations
UN GTR No. 13
UN Global Technical Regulation on Hydrogen and Fuel Cell Vehicles

3 Terms and definitions

3.1
Flow Capacity — For a pressure relief device, this is the capacity in volume per unit time at specified conditions.

3.2
Fusible Material — A metal, alloy, or other material capable of being melted by heat where the melting is integral to the function of the pressure relief device.

3.3
Manufacturer's Specified Activation Temperature — The temperature as specified by the pressure relief device manufacturer at which the pressure relief device is designed to release pressure.

3.4
Manufacturer's Specified Nominal Working Pressure — The highest settled pressure at a uniform gas temperature of 15 °C of the container or container assembly with which the pressure relief device may be used, as specified by the pressure relief device manufacturer.

3.5
Ncc (normal cubic centimeters) — The 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 — A device that, when activated under specified performance conditions, is used to vent the container contents. Reseating and resealing devices are not addressed by this International Standard.

3.7
Thermally Activated Pressure Relief Device (TPRD) — A pressure relief device activated by temperature.

4 Service conditions

4.1 General

The following service conditions are representative of what can be seen in 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 International Standard applies to pressure relief devices that have a nominal working pressure, as specified by the manufacturer, of 25MPa, 35MPa, 50MPa, or 70MPa at 15 °C, hereinafter referred to in this International Standard as the following:

a) "H25" — 25 MPa;
b) "H35" — 35 MPa;
c) "H50" — 50 MPa; or
d) "H70" — 70 MPa.

Note: *Other nominal working pressures for hydrogen gas besides those defined are allowed if the required qualification test requirements of this International Standard are met.*

4.4 Durability test cycles

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

Note: *The maximum developed pressure under the condition of fueling station dispenser fault management is 150 percent of the vehicle nominal working pressure. (As defined in: SAE J2760, SAE J2579 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

5.1 General

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

Quality systems shall be in accordance with Clause 5.2 or 5.3.

5.2 Quality system

Quality management systems shall be registered for compliance with ISO 9001 by an accredited registrar. Other systems which incorporate ISO 9001, such as ISO/TS 16949 are acceptable.

5.3 Independent inspection

The manufacturer shall employ an independent inspector with responsibilities for inspection and review of the manufacturer's quality system.

5.3.1 General

The manufacturer shall arrange for independent verification of the quality system and of pressure relief device production by an independent inspection agency which is acceptable to the authority having jurisdiction.

5.3.2 System audit

The independent inspector shall monitor the quality system of the manufacturer, notify the manufacturer of deficiencies in the quality system, and shall maintain a written record of deficiencies and corrective action.

The independent inspector shall perform the following duties at least once every year:

a) Verify that the manufacturer has a quality manual which addresses design, purchasing, process control, inspection, test, and configuration management, and that the quality manual and practices of the manufacturer are consistent with one another. The system shall be described in a comprehensive and orderly manner in the form of written policies, procedures and instructions that will permit a clear and consistent understanding of the manufacturer's intent with respect to quality assurance.

b) Verify that product drawings adequately define the configuration to be manufactured and that pressure relief devices meet the drawing requirements.
c) Verify that design documents contain appropriate acceptance criteria.
d) Verify that purchased parts are inspected for conformance to specified requirements.
e) Verify that adequate written instructions are provided for manufacture of pressure relief devices which are in conformance with specified requirements.
f) Verify that incoming product and material have been inspected or otherwise verified as conforming to specified requirements.
g) Verify that no product is in service usage until all specified inspections and tests are completed and the pressure relief devices are found to be compliant with specifications.
h) Verify that inspection and test equipment are properly calibrated.
i) Verify that records are kept which give evidence that the product has passed inspection and test requirements with defined acceptance criteria.
j) Verify that procedures are followed which control documents and data related to the manufacturer of pressure relief devices. These procedures apply to both initial document release and to revisions.

5.3.3 Inspector's duties

The independent inspector shall conduct or audit any necessary inspections and sign all test reports before shipment of product.

6 General requirements

6.1 Material requirements

Materials normally in contact with hydrogen shall be determined to be acceptable in hydrogen service, with consideration of hydrogen embrittlement and hydrogen accelerated fatigue. The performance tests may not guarantee that all cases and conditions of hydrogen service will be validated, so it is still incumbent on the designer/builder to carefully screen materials of construction for their intended use. Materials and design shall be such that there will be 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 condition given in Clause 4.

Notes:

a) Material performance data in hydrogen environments may be found in the Sandia National Laboratory Technical Reference for Hydrogen Compatibility of Materials or ANSI/AIAA G-095 or ASME B31.12.

b) Some fusible alloys may contain heavy metals which may be considered environmentally unacceptable by some customers and which may be prohibited by some jurisdictions.

Non-metallic materials normally in contact with hydrogen shall be determined to be acceptable in hydrogen service. Consideration shall be given to the fact that hydrogen diffuses through these materials much easier 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 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 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 will fully vent the contents of the fuel container. The design should minimize the possibility of external hazards (e.g. projectiles) resulting from activation of the device. Any material released shall not interfere with the proper venting of the pressure relief device.

Note: *The pressure relief device should be designed to prevent degradation of function from creep or plastic deformation. The design or manufacturing process should account for the effects that material defects, particularly casting and shrinkage voids, may have in decreasing the resistance to the failure modes.*

6.3 Flow capacity

The flow capacity shall be determined by the flow capacity test under Clause 7.13 and published by the manufacturer.

Note: *The adequacy of flow capacity of pressure relief devices for a given application is to 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 could take place during high flow rate releases from small diameter vents in enclosed spaces.*

6.4 Rework and repair

New pressure relief devices that are found to be non-compliant with this International standard may be reworked or repaired as long as they comply with all requirements and are retested as required to confirm that they satisfy the requirements of this International Standard.

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 on request. 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 which are representative of normal production. An independent inspection or testing agency which is acceptable to the authority having jurisdiction shall certify the conformance of all design qualification tests within the requirements of this International Standard. 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 on request.

The design qualification testing required by this International Standard 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 ambient temperature 20 °C ± 5 °C.

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

Pressures 2 MPa or less: +0 / -1 MPa

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

Hydrogen used for testing shall comply with SAE J2719 or ISO 14687-2.

Table 1
Test requirements for design and design changes
(See Clause 7.1).

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 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 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 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
(See Clause 7.2)

Pressure Cycles to % NWP	**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 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 Clauses 7.10, 7.11, and 7.12.

7.3 Accelerated life

7.3.1 Sampling

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

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

7.3.2 Procedure

Pressure cycling 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 percent 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 pressured individually or through a manifold system. If a manifold system is utilized, each pressure connection should include a check valve to prevent pressure depletion of the system when one specimen fails.

The Accelerated Life test temperature is TL, given in °C by the expression:

$$T_L = 9.1\ T_f^{\ 0.503}$$

where *Tf* is the manufacturer's specified activation temperature, °C

7.3.3 Acceptable results

Three pressure relief devices tested at the manufacturer's specified activation temperature shall activate in less than ten hours.

Five pressure relief devices tested at their accelerated life test temperature shall not activate in less than 500 hours.

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 for a period of two hours or more. Transfer to a liquid bath maintained at 85 °C within five minutes.
b) Maintain the unpressurized pressure relief device in a liquid bath maintained at 85 °C for a period of two hours or more. Transfer to a liquid bath maintained at -40 °C within five minutes.
c) Repeat steps (a) and (b) until a total of 15 thermal cycles have been achieved.
d) d) With the pressure relief device conditioned for a minimum of two hours in the -40 °C liquid bath, cycle the pressure relief device between not more than 10 percent of the manufacturer's specified nominal working pressure and not less than 80 percent of the manufacturer's specified nominal working pressure for a total of 100 cycles. The liquid bath shall be maintained at -40 °C 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 Clause 7.10 except that the test shall be conducted at -40 °C, Clauses 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 percent (approximate) complex salt mist applications coupled with high temperature, high humidity and high temperature dry off. One (1) test cycle is equal to 24 hours, 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 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.

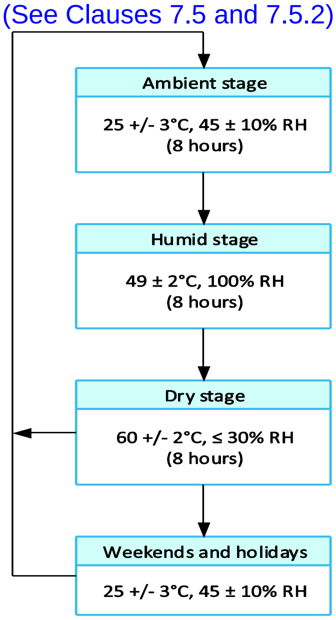
The apparatus shall consist of the chamber design as defined in ISO 6270-2. During “wet-bottom” generated humidity cycles the testing agency must confirm that visible water droplets are found on the samples to verify proper wetness.

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 must 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 ± 2 °C and humidity: ≤ 30 percent RH. The apparatus shall also have sufficient air circulation to prevent temperature stratification, and also allow thorough drying of the test samples.

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

Figure 1
Accelerated cyclic corrosion flow diagram
(See Clauses 7.5 and 7.5.2).



Flow Diagram
(1 cycle = 24 hours)

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

Note: *Either $CaCl_2$ or $NaHCO_3$ material must 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 ninety minutes after the previous application in order to allow adequate time for 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 the wet condition shall be 60 + 5 minutes and the transition time between wet and dry conditions shall be 180 + 10 minutes.

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 before evaluating the tested samples shall then subject to Clauses 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 will be 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 ambient temperature by spraying the exterior of the component once per hour, 24 times, over a period of up to three days (3 eight hour shifts over 3 days or 24 hours straight, for example). Alternatively, the pressure relief device may be immersed in the solution for a period of 24 hours. 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 percent solution by volume in water;
b) Methanol/gasoline - 5/95 percent concentration of M5 fuel meeting the requirements of Standard Specification for Automotive Spark-Ignition Engine Fuel, ASTM D4814; and
c) Windshield washer fluid (50 percent by volume solution of methyl alcohol and water).

7.6.3 Acceptable results

After exposure to each chemical, the device shall be wiped off and rinsed with water and examined. The device shall not show signs of mechanical degradation that could impair the function of the device such as cracking, softening, or swelling. Cosmetic changes such as pitting or staining are not considered failures. In lieu of a visual inspection this test is considered satisfied when exposed parts meet the requirements of Clause 7.2 and the requirements of this clause. At the conclusion of all exposures, the device(s) shall meet the requirements of Clauses 7.10 and 7.11.

7.7 Atmospheric exposure test

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

7.7.1 Oxygen aging

7.7.1.1 Sampling

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

7.7.1.2 Procedure

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

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

7.7.1.3 Acceptable results

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

7.7.2 Ozone

7.7.2.1 Sampling

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

7.7.2.2 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 has to be stressed to 20 per cent elongation shall be exposed to air at 40 °C with an ozone concentration of 50 parts per hundred million during 120 hours.

7.7.2.3 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 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 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 damage.

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

If one or more of the dropped samples exhibits visible exterior damage which indicates that the part is unsuitable for use, the damage signature(s) shall be graphically documented and provided to the container manufacturer as the relative measure for rejection of visibly damaged parts.

7.9.2 Vibration

7.9.2.1 Sampling

Each of the six samples identified in Clause 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 test:

The samples shall be mounted in accordance with the pressure relief device manufacturer's installation instructions and vibrated 30 minutes 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 minutes, within a sinusoidal frequency range of 10 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 Clauses 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 percent of 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 one minute or use a global accumulation method (or equivalent).

The component shall be conditioned at -40 °C or lower and pressurized at both 100 percent and 5 percent of nominal working pressure.

The component shall be conditioned at room temperature 20 °C ± 5 ºC and pressurized at both 5 percent and 150 percent of nominal working pressure.

The component shall be conditioned at 85 °C or higher and pressurized at both 5 percent and 150 percent of nominal working pressure.

7.10.3 Acceptable results

If no bubbles are observed for one minute, the sample passes the test. If bubbles are detected, the leak rate shall be measured by an appropriate method.

The leak rate shall not exceed 10 Ncc/hour 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 Clauses 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 which is capable of controlling 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 percent of 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 two minutes 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 will be documented.

Pressurize the pressure relief devices that were subject to the tests of Clauses 7.2, 7.4, 7.5, 7.6 and 7.9 to no more than 25 percent of manufacturer's specified nominal working pressure or 2.07 MPa, whichever is less and test under the same conditions.

Pressurize one pressure relief device that has not been subject to previous testing to 100 percent of 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 two minutes.

The pressure relief devices subjected to the tests of Clauses 7.2, 7.4, 7.5, 7.6 and 7.9 must activate no more than two minutes 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 percent of manufacturer's specified nominal working pressure or 2.07 MPa, whichever is less.

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 Clause 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 Clause 7.11.

After activation and without cleaning, removing parts, or reconditioning, each pressure relief device shall be subjected to 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 ambient pressure. The inlet temperature and pressure shall be recorded.

Flow shall be measured with an accuracy within ± 2 percent.

7.12.3 Acceptable results

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

Flow capacity shall be reported as the mean measured value of the nine pressure relief devices. The flowrate 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.

Note: *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 air temperature and flow to achieve a consistent temperature of 600 ℃ ± 10 ℃ 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 will vent down to 10 percent of the start pressure in greater than 10 seconds, and shall be enough that the pressure relief device reaches a stable Cv before reaching 25 percent of 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 percent. 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 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 two minutes 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 must 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 10 percent of initial pressure. 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 percent and a minimum of 125 percent of manufacturer's specified nominal working pressure. Devices which leak greater than 10 Ncc/hr hydrogen equivalent shall be rejected. Helium or hydrogen at any concentration may be used to measure leakage in this test, providing 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, ambient temperature must 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 or an independent agency, with appropriate certification, or by 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 on request.

When the test results fail to meet 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 Clauses 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 Clause 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 9.4.2 High temperature soak

The pressure relief device shall be immersed in a liquid bath that is maintained at a temperature 5.6 °C - 0 °C lower than the manufacturer's specified activation temperature. The pressure relief device shall be pressurized to 1.38 MPa. The temperature and pressure shall be maintained for at least 24 hours. The pressure relief device shall not activate within this time.

9.4.3 Activation

The pressure relief device shall be pressurized to 25 percent of manufacturer's specified nominal working pressure. The temperature of the fluid bath shall be increased to a level 5.6 °C + 0 °C higher than the manufacturers specified activation temperature. The pressure relief device must activate within four hours 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 percent of the manufacturer’s specified nominal working pressure.

9.5.3 Acceptable results

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

10 Marking

10.1 Required information

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

If it is possible to install the pressure relief device to allow flow in the wrong direction, the pressure relief device shall be marked with an arrow to show the direction of 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 the informative annex. 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 Clause 7.12
e) Flow data as determined by Clause 7.13
f) Design cycle life or service life
g) Identification of parts which require regular periodic replacement

Component literature should include the following items, if applicable:

a) Installation torques or similar values
b) Mounting location limitations
c) Installation orientations, if any, particularly considering accumulation of contaminants in the high pressure or vent outlet lines.
d) Vent line requirements for flow, protection of the pressure relief device from contamination, and containment of projectiles.
e) Inspection procedures, if any
f) Inlet connection requirements, including minimum flow characteristics
g) Requirements for warning labels that may be required as part of the installation

All of these requirements need only be addressed as concerns 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

Note: *This annex is informative and is not part of this International Standard.*

A.1 Scope/purpose

The purpose of this informative annex is to record the fuel container, fuel storage subsystem, and vehicle level requirements. As this International Standard 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 International Standard. 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 with 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 labeling

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

The primary function of the pressure relief device (PRD) discharge vent system, if used, is to direct the discharge from a pressure relief device (PRD). 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.4.3.1 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. 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.4.3.2 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 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 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 vehicle lifetime usage or uncontrolled movement during venting.

Note: *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 emergency personnel in protective gear. The important goal is to minimize hazards in an already inherently hazardous situation.*

A.4.3.3 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 condensation and /or ingress of water. Water or ice in discharge vent systems may inhibit the function of the pressure relief device (PRD), may cause unexpected venting, or may 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 must be able to preclude or relieve pressure build-up occurring due to allowable leakage of the pressure relief device (PRD) without losing function or integrity.

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

A.4.3.4 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.

Note: *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 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. Leakage capture system design and materials of construction should take into consideration to the impact to the thermal input to thermally activated pressure relief devices.

Notes:

a) *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 that these devices do not interfere with the ability of pressure relief devices to protect the containers.*

b) *Pressure relief device (PRD) leakage capture systems should be protected from thermal degradation if they are functional component of the pressure relief device discharge vent system.*

A.4.3.5 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 (PRDs) 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 (PRD) to protect the fuel storage system.

A.4.3.6 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 could 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 shall be considered destroyed when it has been rendered impossible to hold pressure by mechanical means. Examples; crushing sufficiently to prevent reattachment or drilling a minimum 5mm hole through the body of the device.

Annex B (informative)
Design qualification test rationale

Note: *This Annex is informative and is not a mandatory part of this International Standard.*

B.1 Design qualification tests

B.1.1 Pressure cycling test

The life of fuel containers is defined to range between 11 000 and 15 000 cycles to 125 percent of 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 were 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.1.2 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 percent of 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.1.3 Thermal cycling test

Pressure relief devices will 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 will be limited, and that relief devices with either be sensitive to them in a few cycles or not sensitive to them at all. The pressure cycles conducted at 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.1.4 Accelerated cyclic corrosion test

The accelerated cyclic corrosion test is replacing 500 hours of salt fog testing as 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 could 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.1.5 Automotive fluid exposure test

The components, while in service will most likely be 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 could 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 would normally be exposed in automotive service.

B.1.6 Atmospheric exposure test

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

B.1.7 Stress corrosion cracking resistance test

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

B.1.8 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 will document 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 to 500 Hz. The original frequency of 17 Hz was established through 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 will change based upon the pressure relief device design and mounting provisions, therefore the change in procedure will more accurately demonstrate the performance of the assembly.

B.1.9 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.1.10 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.1.11 Flow capacity test

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

B.1.12 High pressure activation and flow test

Some pressure relief devices will, 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 will flow 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 cumulative flow exists and isn't tested for. This is counter to the assumption that a single bonfire test is representative, and the requirement of +/-5 percent flow variation in the existing test. The current test is not representative of actual use, in that a tiny volume of gas at 25 percent nominal working pressure is used in the test, avoiding any effect of continuous flow, such as cooling, or other effects of 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.