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DRAFT PROPOSAL FOR COMPRESSED HYDROGEN STORAGE SYSTEM REQUIREMENTS

FUEL CELL VEHICLE GLOBAL TECHNICAL REGULATION

5.2 Storage system provisions

5.2.1 General

This section specifies the requirements for the Compressed Hydrogen Storage System of hydrogen powered motor vehicles.
A Compressed Hydrogen Storage System consists of the pressurized containment vessel(s), thermally-activated Pressure Relief Devices (TPRDs), shut off devices(s), and all components, fittings and fuel lines between the containment vessel(s) and these shut off device(s) that isolate high pressure hydrogen from the remainder of the fuel system and the environment.

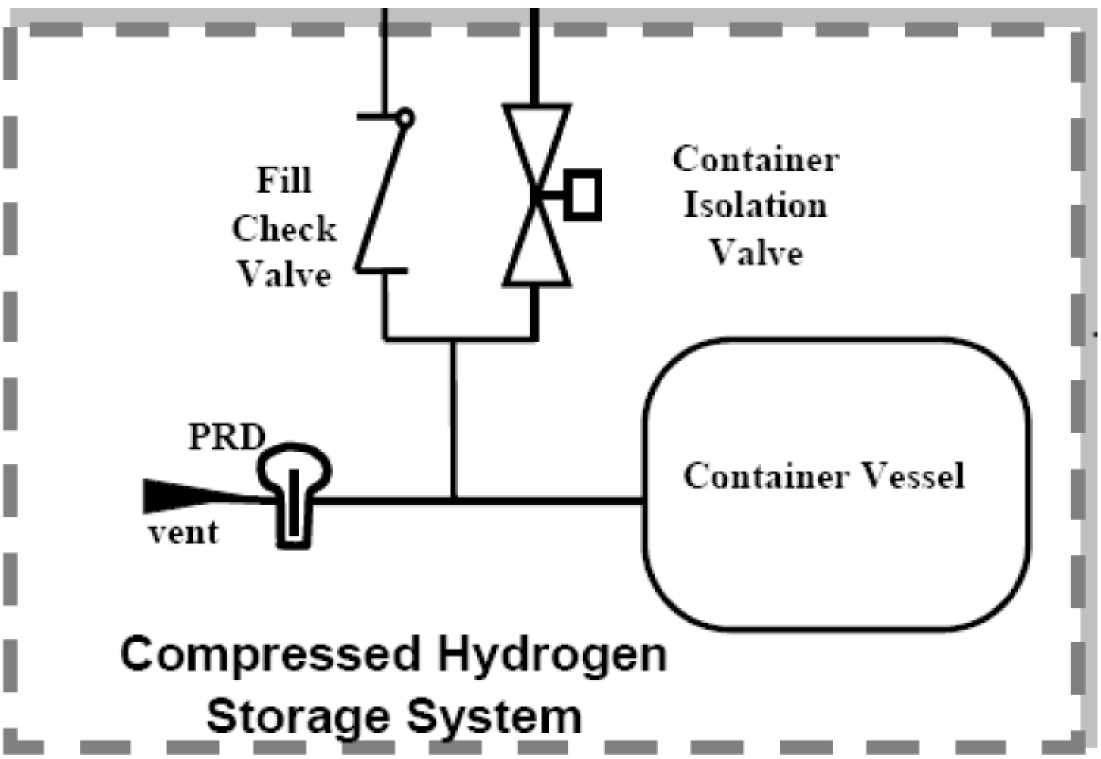

FIGURE 0 - HYPOTHETICAL COMPRESSED HYDROGEN STORAGE SYSTEM

A storage system design and construction does not have to be re-qualified if subsystem components used in an earlier performance verification (according to 5.2.2) are exchanged for components with comparable function, fittings and dimensions. All piping and primary closure components that define the containment boundaries of the storage system (e.g., shut-off valve, TPRD and check-valve as illustrated) must satisfy the same component performance standard as the component used in the original performance verification (design qualification) of the hydrogen storage system for the same hydrogen storage application. A change in the TPRD hardware, its position of installation and/or venting lines requires requalification, in addition, with a bonfire test (5.2.2.3.1).

This criteria applies to qualification of designs for future production. It does not apply to re-qualification of any single produced system for use beyond its expected useful service or re-qualification after a potentially significant damaging event.

5.2.2 Performance Verification Tests for Design Qualification

The hydrogen storage systems used in fuel cell vehicles shall meet the performance requirements specified in paragraphs 5.2.2.1 through 5.2.2.3.

Tests
5.2.2.1 Expected Service (Pneumatic) Performance Test
5.2.2.1.1 Fueling Performance Verification Test: Gas Pressure Cycling at Environmental Temperature Limits 5.2.2.1.1.a and 5.2.2.1.1.b
5.2.2.1.2 Parking Performance Verification Test: Static Gas Pressure Exposure at Extreme Temperature 5.2.2.1.2.a and 5.2.2.1.2.b
5.2.2.1.3 Leak/Permeation Test
5.2.2.1.4 Proof Pressure Test (Hydraulic and / or Pneumatic) *to be done in 5.2.2.1 and 5.2.2.2 and 5.2.2.4*
5.2.2.1.5 Residual Strength Burst Test (Hydraulic) *to be done in 5.2.2.1 and 5.2.2.2 and 5.2.2.4*
5.2.2.2 Durability (Hydraulic) Performance Test
5.2.2.2.1 Drop (Impact) Test
5.2.2.2.2 Surface damage and Chemical Exposure Test
5.2.2.2.3 Extreme Fueling Usage; Extended Pressure Cycling Test **
5.2.2.3.1 Engulfing Fire (Bonfire) Test
5.2.2.3.2 Penetration Test
5.2.2.3.3 Ultimate Burst Pressure
5.2.2.3.4 Ambient Cycling Test in Design Qualification Test (Leak Before Break Test)
5.2.2.3.5 Maximum Defect Size Inspection Test in Design Qualification Test
5.2.3.1 Routine Production Quality Tests * *still missing in the text – to be done in 5.2.2.1 and 5.2.2.2 and 5.2.2.4

[grey box] Pneumatic (gas type to be clarified) [white box] Hydraulic

Table 1 - Overview on Compressed Hydrogen Storage Systems Performance Test

Prior to performing the pressure cycling sequences specified in paragraphs 5.2.2.1 and 5.2.2.2, the number of test cycles for each sequence must be established. Using the designation by the vehicle manufacturer for vehicle lifetime mileage (L) and vehicle range on a fully filled storage system (R), the number of test cycles is specified as follows:

- The number of cycles for paragraph 5.2.2.1 = L/R, but not less than 500.
- The number of cycles for paragraph 5.2.2.2 and 5.2.2.4 = 3 X L/R, but not less than 5500.

Applicable test procedures for the hydrogen storage system are provided in Annex **TBD**.

5.2.2.1 Expected Service (Pneumatic) Performance Test

(Comment: This pneumatic test is under investigation. The test condition of temperature and cycle times should be review.)

Expected Service (Pneumatic) Performance Test applies to the nonmetal liner containers. If alternative test is effective technically for the failure, manufactures can select the alternative test instead of the gas test.

At least one hydrogen storage system shall demonstrate the capability to function through the expected cumulative exposures associated with worst-case conditions of fueling and de-fueling (pressure cycling at environmental temperature limits) and parking (prolonged static pressure). The storage system will demonstrate required performance through the following specified sequence, as illustrated in Figure 1:

- → Routine Production Quality Pressure Proof Test at 150% NWP (5.2.3.1) (hydraulic – vessel only)
  - → Extreme-Temperature Gas Cycling (5.2.2.1.1.a): Fueling Performance (pneumatic)
    - → Extended Static High Pressure Gas Test (5.2.2.1.2 a): Parking Performance (pneumatic)
      - → Extreme-Temperature Gas Cycling (5.2.2.1.1.b): Fueling Performance (pneumatic)
        - → Extended Static High Pressure Gas Test (5.2.2.1.2 b): Parking Performance (pneumatic)
          - → Gas Leak/Permeation Test (5.2.2.1.3) (pneumatic)
            - → Pressure Proof Test at 180% NWP (5.2.2.1.4) (hydraulic – vessel only)
              - → Residual Strength Burst Test (5.2.2.1.5) (hydraulic – vessel only)

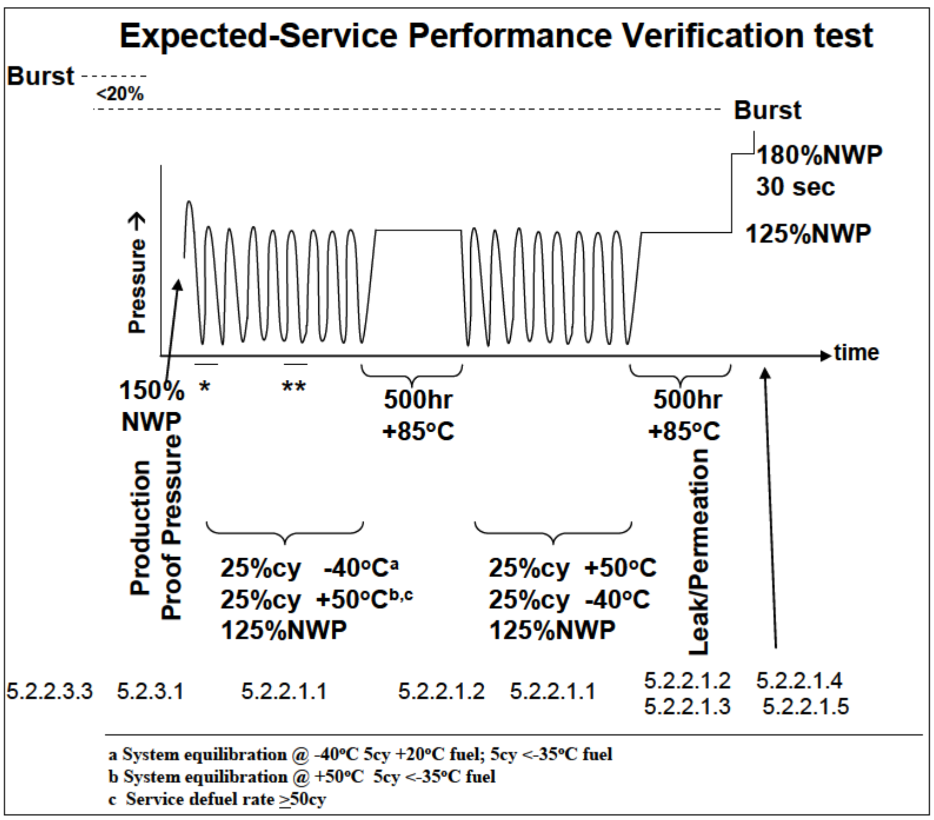

FIGURE 1 – COMPRESSED HYDROGEN STORAGE EXPECTED-SERVICE PERFORMANCE VERIFICATION TEST

5.2.2.1.1 Fueling Performance Verification Test: Gas Pressure Cycling at Environmental Temperature Limits

The hydrogen storage system shall maintain full function after exposure to hydrogen gas fueling/de-fueling pressure cycles of <2 MPa to 125% NWP. The required number of test cycles is defined in 5.2.2.

All of the fuelings should be conducted under normal fast-fill conditions. All defuelings should be conducted at a rate no less than the defueling rate for maximum-load vehicle operation as defined by the vehicle manufacturer and implemented in the vehicle.

If devices and/or controls are used in the system to prevent an extremely low temperature (e.g., lower than -40°C), the test may be conducted with these devices and/or controls (or equivalent measures for the purpose of test).

The pneumatic pressure cycles shall be executed as follows:

a. Half (50%) of the Expected-Service Test Cycles shall be conducted before exposure to static pressure as illustrated in Figure 1.

- Half of these cycles (one-fourth of the total Expected-Service Test Cycles) are conducted with hydrogen gas at –35 °C in an external environment stabilized at –40 °C. If the manufacturer restricts vehicle use to a different lower ambient temperature (as identified in the Owner's Manual), that specified lower temperature shall be used in this test sequence.

- The system shall be equilibrated at nominal full fill density at –40 °C (80% of the NWP rating) at the onset and between each of the first ten cycles. Fuel at +20 °C will be used for fueling in the first 5 equilibrated cycles. Fuel at <–35 °C will be used for fueling in the next 5 equilibrated cycles (and for fueling in the remaining cycles, which are not equilibrated).

- Half of these cycles (the following one-fourth of the Expected-Service Test Cycles) are conducted with hydrogen gas cooled to –35 °C in an external environment stabilized at +50 °C (122 °F) and 95% relative humidity. Fifty of the defuelings shall occur at the rate prescribed in the vehicle manufacturer's procedures for vehicle maintenance/repair service. The system shall be equilibrated unfilled at +50 °C (122 °F) and 95% relative humidity at the onset and between each of the first five cycles conducted at +50 °C.

The resulting sequence is:

→ 5 cycles equilibrated full fill @ –40 °C → defuel → fill with <–35 °C dispensed gas

→ 5 cycles equilibrated full fill @ –40 °C → defuel → fill with +20 °C dispensed gas

→ 115 fuel/defuel cycles @ –40 °C external environment and <–35 °C dispensed gas

→ 5 cycles equilibrated empty @ +50 °C → fill with <–35 °C dispensed gas → defuel

→ 70 fuel/defuel cycles @ +50 °C external environment and <–35 °C dispensed gas

→ 50 fuel/defuel cycles @ +50 °C external environment and <–35 °C dispensed gas and maintenance defuel rate

b. Half of the Expected-Service Test Cycles shall be conducted after exposure to static pressure as illustrated in Figure 1.

- Half of these cycles (one-fourth of the Expected-Service Test Cycles) are conducted with hydrogen gas cooled to –35 °C (or as specified in SAE J2601) in an external environment stabilized at +50 °C and 95% relative humidity.
- The remainder of these cycles (the following one-fourth of the Expected-Service Test Cycles) are conducted with hydrogen gas at –35 °C in an external environment stabilized at –40 °C (unless a different ambient air temperature limit for vehicle use is specified by the vehicle manufacturer).

The resulting sequence is:

→ 125 fuel/defuel cycles @ +50 °C external environment and <–35 °C dispensed gas

→ 125 fuel/defuel cycles @ –40 °C external environment and <–35 °C dispensed gas cycles

5.2.2.1.2 Parking Performance Verification Test: Static Gas Pressure Exposure at Extreme Temperature

The hydrogen storage systems are pressurized with hydrogen gas to 125% NWP and held for 1000 hrs at +85 °C.

a. Half of the Static Pressure Exposure (500 hrs) are conducted after the initial Expected-Service Test Cycles (5.2.1.1)

b. Half of the Static Pressure Exposure (500 hrs) should be conducted after the final Expected-Service Test Cycles (5.2.1.1)

5.2.2.1.3 Leak/Permeation Test

The fully filled storage system shall be held at a temperature of 55$_o$C to stabilize and measure the total discharge rate due to leakage and permeation. At the manufacturer's option, this test may be conducted coincidentally with the last half of testing in 5.2.2.1.2 (at 85$_o$C) or after testing in 5.2.2.1.2 is completed with the system temperature held at 55$_o$C for the measurement. The maximum allowable discharge from the compressed hydrogen storage system is 150 Ncc/min for standard passenger vehicles.

At the conclusion, a localized leak test shall be conducted to confirm that localized leakage, if any, is not capable of sustaining a flame.

5.2.2.1.4 Proof Pressure Test (Hydraulic or Pneumatic)

The hydrogen storage system should be pressurized with hydrogen gas to 180% NWP and held 30 seconds without burst. This test may be performed hydraulically with the container vessel.

5.2.2.1.5 Residual Strength Burst Test (Hydraulic)

The container vessel shall undergo a (hydraulic) burst pressure test to verify that the burst pressure is within 20% of the new vessel burst pressure as determined in 5.2.2.3.3.

5.2.2.2 Durability (Hydraulic) Performance Test

The hydrogen storage vessel shall not burst or exhibit unacceptable leak when subjected to the following sequence of exposures, as illustrated in Figure 2:

- → Routine Production Quality Tests (5.2.3.1)
  - → Drop Test (5.2.2.2.1)
    - → Surface Damage and Chemical Exposure (5.2.2.2.2)
      - → Static High Pressure Test (5.2.2.2.3.a)
        - → Pressure Cycling Tests (5.2.2.2.3.b)
          - → Proof Pressure Test at 180% NWP (5.2.2.2.3.c)
            - → Residual Strength Burst Test (5.2.2.1.5)

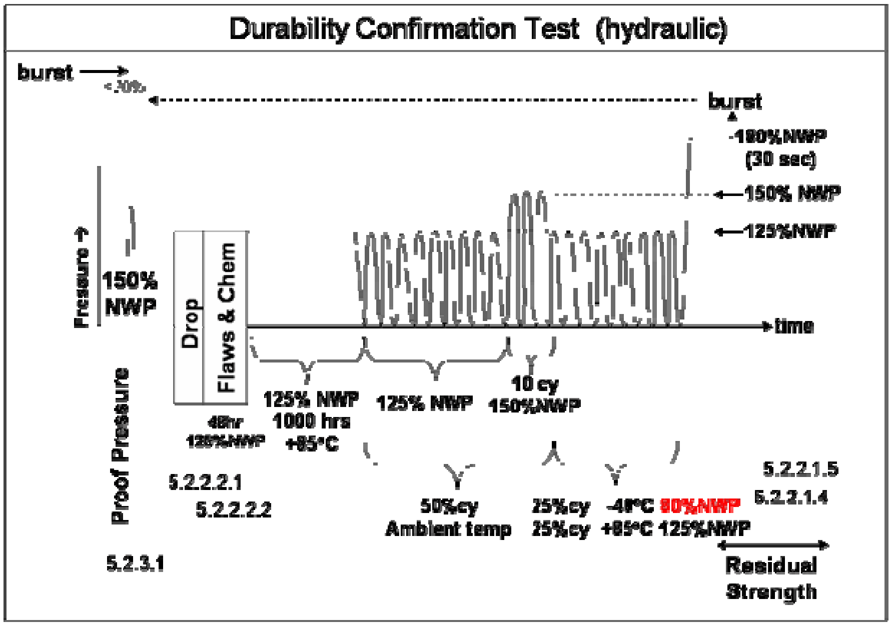

FIGURE 2 – COMPRESSED HYDROGEN STORAGE DURABILITY TEST

5.2.2.2.1 Drop (Impact) Test

The test is designed to demonstrate that containment vessels have the capability to survive representative pre-installation drop impacts if the system does not have unalterable markers that record exposure to comparable impacts to designate that installation is not authorized.

5.2.2.2.2 Surface damage and Chemical Exposure Test

Prior to exposure to chemicals the high pressure container vessel wall is subjected to surface damage by cutting, abrasion and puncture. The surface damage shall include surface-layer punctures of larger dimension than occur within manufacturing tolerances and consistent with impact of road gravel. The damaged areas of the high pressure container vessel wall are then subjected to the application of reactive chemicals found in the environment and onboard the vehicle. After 48 hrs of exposure to the chemicals, the container shall be inspected to verify that the vessel wall shows no damage beyond the initial impacts.

5.2.2.2.3 Extreme Fueling Usage; Extended Pressure Cycling Test

Tests shall be conducted as follows:

a. Static High Pressure Test. The vessel should be pressurized with a fluid to 125% NWP and held for 1000 hrs at +85 °C. Storage systems that are being qualified for commercial heavy-duty use shall be pressurized to 135% NWP.

b. The container should demonstrate durability (resistance to leak and burst) throughout exposure to pressure cycles of < 2 MPa to 125% NWP. The minimum required number of test cycles is defined in 5.2.2. The first 50% of pressure cycles should be conducted at 15 – 25 °C ambient temperature. [See Appendices C.5 and C.6 for guidance.] The last 10 cycles within the first half of cycles should be pressure cycles of ≤2MPa to 150% NWP. Half of the remaining 50% of pressure cycles should be cycles of ≤2MPa to 80% NWP with the first 25% conducted at -40oC and the final remaining 25% cycles should be cycles of ≤2MPa to 125% NWP conducted at +85oC. During pressure cycling, the systems should show no evidence of rupture, unintended release or physical deterioration such as fiber unraveling.

c. The hydrogen storage system shall then be pressurized to 180% NWP and held for 30 sec without rupture or evidence of leak.

5.2.2.3 Performance Under Service-Terminating Conditions

Storage systems shall not rupture when subjected to the service-terminating events specified in 5.2.2.3.1 through 5.2.2.3.3.

5.2.2.3.1 Engulfing Fire (Bonfire) Test

A hydrogen storage system shall be pressurized to NWP and exposed to an engulfing fire as specified in Annex **TBD**. The storage system shall not burst, and the temperature-activated pressure relief device, if activated, shall release the contained gases in a controlled manner.

5.2.2.3.2 Penetration Test

The hydrogen storage container is pressurized to NWP with a gas and then penetrated by an armor piercing bullet or impactor with a diameter of at least 7.6 mm. The bullet or impactor shall impact a side wall and completely penetrate at least one side wall. Expected performance is absence of burst.

5.2.2.3.3 Ultimate Burst Pressure *(Comment: This § is still under investigation)*

The manufacturer will establish the nominal burst pressure of new container vessels, BPDQ, and will document the measurements and statistical analyses used to establish that the burst pressure of production units is controlled to BPDQ $\pm \eta$ where $\eta \leq 10\%$ and $(1-\eta/100)$ BPDQ > 180% of NWP. BPDQ will be verified in design qualification by hydraulically pressurizing 3 new vessels until burst. All 3 must have burst pressures within 10% of BPDQ; if not, BPDQ is reset to the highest burst pressure measured in 5.2.2.3.3 when greater than the original BPDQ. The resultant BPDQ is used to satisfy requirements of 5.2.2.1.5.

5.2.2.3.4 Ambient Cycling Test in Design Qualification Test *(Comment: This § is still under investigation)*

1. Two containers taken from the same design shall meet the ambient cycling test in accordance with the terms of the next paragraph and Paragraph c.
2. The ambient cycling test of the previous paragraph shall be performed in accordance with the terms of each of the following items.
   (1) Pressure equal to or greater than 125% of the maximum filling pressure shall be cycled at a rate not exceed 10 times per minute until leakage occurs or more than 22,000 cycles. (45,000 cycles for commercial vehicles)
   (2) The test shall be undertaken by drainage tank format. The tested container shall be completely filled with fluid, cycle the pressure in the container between not more than 2 MPa and not less than 125% of the maximum filling pressure.
3. The ambient cycling test of Paragraph 1 shall meet the both of the following requirements.
   (1) The container does not fracture, and there are no damages to fiber.
   (2) There is no leakage from the container less than 5,500 cycles. (11,250 cycles for commercial vehicles) When the cycle of the vessel in personal vehicles is less than 11,250 cycles, the manufacturer should explain the adequacy of test result by 5.2.2.3.5 Maximum Defect Size Inspection Test in Design Qualification Test.

5.2.2.3.5 Maximum Defect Size Inspection Test in Design Qualification Test

The containers (except plastic liner containers) shall be performed the maximum defect size inspection test in accordance with the terms of the paragraph a. to f. and then shall meet the test. The maximum depth and length of defect which does not cause damage due to fatigue or rupture of the container within a period of 15 years shall be calculated in according to the following paragraph.

a. The level-surface defect model shall be used for analysis. Calculation method shall be the fatigue assessment in Chapter 3 on Guidance covering the test method for assessing tolerable defects in welds structural material, BS7910 (2005).

b. The stress condition at the fatigue-susceptible part is determined by a stress analysis in the case of the pressure at 2 MPa or less and 125% of pressure of the maximum filling pressure or more. Bending stress and membrane stress can be calculated independently.

c. The number of pressurizing shall be 5,500 cycles (11,250 cycles for commercial vehicles) or more.

d. The fatigue crack propagation rate shall be determined by the average of three results in accordance with the Standards for measurement and inspection of the fatigue crack propagation rate, ASTME647. In this case the fatigue crack propagation rate shall be measured in hydrogen of 99.99% or greater and the pressure shall be 125% of the maximum filling pressure or higher. In accordance with the standard test method for planestrain fracture toughness of metallic materials, ASTM E399, the crack surface direction shall be parallel to the longitudinal direction of the container and perpendicular to the circumferential direction of the container. The test shall be performed at ambient temperature. The frequency of the test shall be 1 Hz or less. When fatigue crack propagation rate data of the same material and conditions, the data can be used for the analysis.

e. The crack propagation per cycle in the longitudinal direction and in the direction of thickness shall be determined from the fatigue crack propagation rate as measured in item 4 above and the stress intensity factor, in accordance with Section 14.2 of fracture dynamics analysis of plane surface flaws in Chapter 3 on fatigue assessment in Guidance Covering the Test Method for Assessing Tolerable Flaws, BS7910 (2005)

f. In accordance with paragraph e. above, the maximum defect size shall be calculated which does not lead to any damage from fatigue or burst during the use of the container for a period of 15 years.

The maximum defect size designated by the container manufacturer should be within the range of the maximum depth and length of defect which is calculated above.