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ISO/TC **197** Secretariat: **SCC**

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INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Liquid hydrogen — Land vehicle fuel tanks —

Part 1:
Design, fabrication, inspection and testing

Hydrogène liquide — Réservoirs de carburant pour véhicules terrestres —

Partie 1: Conception, fabrication, inspection et essais

ICS 43.060.40

Member bodies are reminded to consult relevant national interests in each of the technical fields concerned [*Hydrogen technologies* **(ISO/TC 197) and** *Road vehicles* **(ISO/TC 22)] before returning their ballot to the Central Secretariat.**

To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.

Contents

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 13985 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 13985-1 was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*.

ISO 13985 consists of the following parts, under the general title *Liquid hydrogen — Land vehicle fuel tanks*:

— *Part 1: Design, fabrication, inspection and testing*

— *Part 2: Installation and maintenance*

Please note that ISO 13985 was separated in two parts based on the comments received during the circulation of the first enquiry draft. This second DIS vote therefore follows the first DIS vote on the original one part document identified as ISO/DIS 13985.

Introduction

The fuel tanks described in this International Standard is intended to be used in conjunction with the fuelling system interface described in ISO 13984: 1999.

Liquid hydrogen — Land vehicle fuel tanks — Part 1: Design, fabrication, inspection and testing

1 Scope

This part of ISO 13985~~International Standard~~ specifies the requirements for refillable tanks for liquid hydrogen that is used as a fuel in land vehicles as well as the testing methods required to ensure that a reasonable level of protection from loss of life and property resulting from fire and explosion is provided.

This part of ISO 13985~~International Standard~~ is applicable to fuel tanks permanently attached to land vehicles.

2 Normative reference(s)

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 13984: 1999, *Liquid hydrogen — Land vehicle fuelling system interface.*

3 Terms and definitions

For the purposes of this part of ISO 13985~~International Standard~~, the terms following apply.

3.1
burst pressure
pressure that causes the bursting of a ~~liquid~~inner vessel subjected to a constant increase of pressure during a destructive test

3.2
fill density
ratio, expressed as percentage, of the mass of liquid hydrogen in the ~~liquid~~inner vessel to the mass of water that the ~~liquid~~inner vessel would hold, on the basis of water density of 1000 kg/m^3

3.3
fire resistance
ability of a material or combination of materials used in fabrication of the fuel tank to prevent excessive pressure rise and assure resistance to rupture ~~buckling~~ when the fuel tank is tested as specified in 5.5.

3.4
fuel tank accessory ~~appurtenances~~
device~~s~~ connected to fuel tank openings for safety, control, or operating purposes

3.5
holding time
time, as determined by testing, that will elapse from filling ~~loading~~ until the pressure of the contents, under equilibrium conditions at ambient temperature, reaches the level of the lowest ~~pressure control valve or~~ pressure-relief valve setting of the fuel tank

3.6
~~liquid~~inner vessel
inner container of the fuel tank which actually contacts and holds the liquid hydrogen being transported

3.7
inspector
qualified person employed by a recognized independent national or international agency

3.8
liquid hydrogen
LH_2
hydrogen that has been liquefied, i.e. brought to a liquid state~~, either by chilling and compression or other means such as the magneto-caloric effect~~

3.9
lot
a group of ~~liquid~~inner vessels, outer shells or fuel tanks successively produced, having the same size, configuration, specified material of construction, process of manufacture, equipment of manufacture and heat treatment or curing, and conditions of time, temperature and atmosphere during heat treatment or curing

3.10
maximum permissible operating pressure
MPOP
maximum effective gauge pressure permitted to be developed at the top of a loaded ~~liquid~~inner vessel in its operating position. For vacuum-insulated fuel tanks, the maximum permissible operating pressure shall be established by subtracting the sum of 101,3 kilopascals and the hydrostatic head of lading from the maximum pressure difference between the inside and outside of the wall of the ~~liquid~~inner vessel for which the wall is designed

3.11
outer shell
outer housing around the insulation which protects it against humidity and contamination and maintains a certain vacuum

3.12
same design
refers to a fuel tank made by the same manufacturer, to the same engineering drawings and calculations, to the same dimensions of length, diameter, and volume, of the same materials of construction, and with the same insulation system and to the same tolerances and quality control and quality assurance procedures

3.13
service pressure
the pressure at the top of the ~~liquid~~inner vessel which is the pressure at which the fuel tank normally operates. This pressure shall not exceed the maximum permissible operating pressure

3.14
service temperature range
the temperature ranging from that of liquid hydrogen, i.e. - 253 °C to an assumed maximum ambient temperature of 85 °C ~~54 °C~~

3.15
vapour space
the space occupied by the saturated vapours of liquid hydrogen which are in equilibrium with the liquid hydrogen in the ~~liquid~~inner vessel

4 Design and construction of fuel tanks

4.1 General requirements

Liquid hydrogen fuel tanks for land vehicles shall be designed to be compatible with liquid and gaseous hydrogen and shall comply with the requirements of this part of ISO 13985~~International Standard~~.

Liquid hydrogen fuel tanks shall consist of an inner ~~liquid~~ vessel enclosed within an outer shell with appropriate insulation between the ~~liquid~~inner vessel and outer shell and having piping, valve supports and other ~~appurtenances~~accessories as specified in this International Standard.

~~The fuel tank holding time shall be established by the fuel tank manufacturer using the method described in 5.1.7. If more than one fuel tank is made to the same design, only one fuel tank shall be subjected to the full holding time test at the time of manufacture. However, each subsequent fuel tank made to the same design shall be performance tested during its first use. The holding time determined in this test may not be less than 90 % of the marked rated holding time.~~

The fuel tank shall be designed so that it can be filled with liquid hydrogen to a maximum permitted fill density which will yield a vapour space below the inlet to the pressure relief valve equivalent to at least 2 % of the volume of the fuel tank at the lowest set pressure of the transit pressure relief valve on stream.

A fuel tank filled with liquid hydrogen shall be capable of withstanding the fire resistance test described in 5.5.

4.2 Materials

All the materials or combination of materials used in the construction of the fuel tank components that are in direct contact with liquid hydrogen shall not be subject to low temperature embrittlement for the service temperature range and shall resist degradation due to hydrogen.

The manufacturer shall demonstrate and document that the materials used, including austenitic stainless steels or other materials that are proven to be equivalent, are suitable for this application over the service temperature range.

4.3 Inner ~~Liquid~~ vessel

4.3.1 Maximum permissible operating pressure

The maximum permissible operating pressure of the ~~liquid~~inner vessel of the fuel tank shall be established by the fuel tank manufacturer.

4.3.2 Wall thickness

The minimum thickness of the ~~liquid~~inner vessel shall not be less than 1,5 millimetres and shall be such that at no point will the combined static and dynamic stresses on a plane containing or normal to the longitudinal axis exceed 25 % of the minimum specified tensile strength of the material of construction. The static forces, loads, and stresses considered in this requirement shall take into account the weight of the fuel tank itself, its internal pressure at the maximum permissible operating pressure plus 101,3 kilopascals if the fuel tank is vacuum insulated, its maximum weight of contents, ~~and~~ the articles supported by the fuel tank, the stresses transferred from vehicle structure, not including the weight of structures supporting the fuel tank.

The dynamic stresses shall be considered including direct tensile stress due to a rearward acceleration force, tensile stress due to the bending moment of a rearward acceleration applied at the road surface, and tensile flexure stress using applicable static loadings, and, stresses due to external vacuum and internal pressure and other causes and the shear stresses in the plane in question, including direct vertical shear due to the static vertical loading, direct lateral shear due to a lateral accelerative force, ~~and~~ torsional shear due to a lateral accelerative force, applied at the road surface using applicable static loadings and the stresses transferred from vehicle structure.

4.4 Outer shell

4.4.1 Construction

An outer shell, of approximately the same shape as the ~~liquid~~inner vessel shall be used over the insulation. This outer shell shall be so constructed and sealed to maintain the integrity of the environment between the ~~liquid~~inner vessel and the outer shell.

4.4.2 Material of construction

All materials or combination of materials used for the construction of the outer shell of fuel tanks shall be compatible with the other environments and fluids found in a land vehicle environment such that the performance of the fuel tank is not degraded.

~~The material or combination of materials shall be rated fire resistant.~~

4.4.3 Minimum collapsing pressure

The outer shell shall be designed for a minimum collapsing pressure of 200 kilopascals differential.

4.5 Insulation

The interstitial space between the ~~liquid~~inner vessel and the outer shell may be evacuated after its filling with an adequate insulating material. The insulating material shall not be subject to corrosive attack by hydrogen, either in its gaseous or liquid state.

The insulation shall maintain any properties required by design during an emergency when exposed to fire, heat, cold, or water as applicable. The insulation shall be such that a fire external to the outer shell will not cause significant deterioration to the insulation's thermal conductivity by melting or settling as specified in 5.5.

The insulation material and outside covering shall be of adequate design to prevent insulation attrition under normal operating conditions.

The insulation system shall prevent the fuel tank pressure from exceeding the pressure relief valve set pressure within the marked rated holding time when the fuel tank is loaded with liquid hydrogen and exposed to an average ambient temperature of 65°C~~54 °C~~.

4.6 Fuel tank ~~appurtenances~~accessories

4.6.1 Pressure relief systems

4.6.1.1 Pressure relief system of the ~~liquid~~inner vessel

4.6.1.1.1 General requirements for pressure relief devices

The design, material, and location of pressure relief devices shall be suitable for the intended service.

The fuel tank shall be provided with a primary system of one or more pressure relief valves and a secondary pressure relief system of one or more rupture disks or pressure relief valves. ~~The fuel delivery line to the propulsion system of the land vehicle shall be independent of the fuel tank pressure relief line.~~

The primary system of pressure relief valves shall be set to operate at a pressure not higher than 110 % of the maximum permissible operating pressure of the fuel tank. The secondary pressure relief system shall be set to operate as follows:

a) ~~The~~ ~~R~~rupture disks shall be set to operate not below 120 % and not more than 150 % of the maximum permissible operating pressure.

b) Pressure relief valves ~~used in the secondary pressure relief system~~ shall be set to operate at a pressure not higher than 136 % of the maximum permissible operating pressure.

Each pressure relief device shall be designed and located to minimize the possibility of tampering. If the pressure setting or adjustment is external to the pressure relief valve, this adjustment shall be sealed.

Each pressure relief device shall have direct communication with the vapour space of the fuel tank at the mid length of the top centreline and shall be mounted so as to remain at ambient temperature prior to operation.

The pressure relief system shall be arranged to prevent the accumulation of foreign material between the pressure relief devices and the atmospheric discharge opening. The arrangement shall not impede flow through the system.

The pressure relief valves shall, after discharge, close at a pressure higher ~~not lower~~ than 10 % below the pressure at which discharge starts or the maximum permissible operating pressure of the fuel tank, whichever is higher. ~~and~~ They shall remain closed at all lower pressures.

~~When operation of pressure build-up coils, or other conditions imposed by the service can produce pressures in excess of the maximum permissible operating pressure of the fuel tank, pressure relief valves shall be provided that are capable of preventing the development of fuel tank pressure in excess of 120 % of the maximum permissible operating pressure.~~

4.6.1.1.2 Flow capacities of pressure-relief devices

The minimum required flow capacity of the pressure relief devices shall be calculated using formula 1 if the fuel tank insulation is ~~will be~~ destroyed below 922 K:

$$Q_a = \frac{4{,}665 \times 10^4 \; A^{0{,}82}}{L} \sqrt{ZT} \qquad (1)$$

or the formula 2 if the fuel tank insulation ~~will~~ remains in place at 922 K:

$$Q_a = \frac{0{,}476\,8\,(922 - T)\; UA^{0{,}82}}{L} \sqrt{ZT} \qquad (2)$$

where

Q_a is the flow capacity of the pressure relief device(s) required at the applicable flow rating pressure and 15 °C, expressed in cubic metres per hour (m^3/h);

A is the arithmetic mean of the inner and outer surface areas of the fuel tank insulation, expressed in square metres (m^2). For fuel tanks with insulation which will not remain in place at 922 K, surface area of the ~~liquid~~inner vessel shall be used;

Z is the compressibility factor at the temperature corresponding to the flow rating pressure. When *Z* is not known, the conservative value 1,0 should be used;

T is the temperature of hydrogen at flowing conditions, which shall be established based on the pressure set point of the pressure relief device plus the allowable accumulation pressure, expressed in degrees Kelvin (K);

L is the latent heat of hydrogen at the flow rating pressure, expressed in kilojoules per kilogram (kJ/kg);

U is the overall heat transfer coefficient of the fuel tank insulating material when saturated with gaseous lading or air at atmospheric pressure, whichever is greater, expressed in kJ/(h·m^2· °C). The value of *U* may be determined at the mean temperature of the insulation. *U* may be calculated as the thermal conductivity of the insulation, if the insulation is fully effective for conduction, convection, and radiation heat transfer for an external temperature of 922 K and an internal temperature corresponding to the flow rating pressure. Vacuum space, gas space, or space occupied by the deteriorated insulation shall not be included in the thickness of the insulation. The effectiveness of these spaces or deteriorated insulation in reducing conduction, convection, or radiation heat transfer may be evaluated separately and included in the overall heat transfer coefficient, *U*, using methods found in published heat transfer literature. Deterioration of the insulation can be caused by the following:

a) moisture condensation;

b) air condensation;

c) increase in density of the insulation due to sudden loss of vacuum;

d) degradation due to heat.

The minimum required total flow capacity of the primary system of pressure relief valves shall be calculated using the applicable formula above for a flow rating pressure not to exceed 120 % of the maximum permissible operating pressure of the fuel tank.

The minimum required total flow capacity of the secondary system of pressure relief devices shall be calculated using the formula above for a flow rating pressure not to exceed 150 % of the maximum permissible operating pressure of the fuel tank

~~**4.6.1.1.3Thermal expansion relief valves**~~

~~A thermal expansion relief valve shall be installed as required to prevent overpressure in any section of a liquid or cold vapour pipeline that can be isolated by valves~~

~~Thermal expansion relief valves shall be set to discharge at or below 110 % of the maximum permissible operating pressure of the section of the line it protects.~~

~~Discharge from such valves shall be directed so as to minimize hazard to personnel and equipment.~~

4.6.1.2 Pressure relief system of the outer shell

The outer shell of fuel tank shall be protected by a suitable pressure relief device to release internal pressure. This pressure relief device shall function at a pressure not exceeding 172 kilopascals or the internal design pressure of the outer shell or the maximum external collapse pressure of ~~on~~ the ~~liquid~~inner vessel calculated with a safety factor of 2, whichever is less.

The total discharge area of outer shell pressure relief devices on a fuel tank shall be at least 0,341 4 mm^2/kg of water capacity of the fuel tank.

4.6.1.3 Location ~~Piping~~ of pressure relief systems

Pressure relief devices shall be mounted as close as possible to the fuel tank, preferably rigidly attached, to minimize unsecured sections of pipe in the event of accidents.

Should ~~When~~ fittings and piping be ~~are~~ used on the upstream and/or downstream sides of pressure relief systems, the passages shall be so designed that the flow capacity of the pressure relief systems will not be reduced below the capacity required for the fuel tank on which the pressure relief systems are installed. The flow area of all piping and fittings shall be at least equal to the flow area of the inlet of the pressure relief device to which it is connected. The flow area of the discharge piping shall be as least as large as that of the pressure relief device outlet. Oversized pressure relief devices may be used without requiring all piping and fittings in their line to have the same flow area, provided the required flow capacity is assured through the system.

~~Pressure relief systems on fuel tanks for liquid hydrogen shall be arranged to discharge upward to the open air.~~

4.6.1.4 Pressure tests of pressure relief valves

Each pressure relief valve installed on the ~~liquid~~inner vessel or on the outer shell shall be subjected to an air or gas pressure test to determine that the start-to-discharge pressure is within tolerances of the set pressure marked on the valve as required by the applicable standard.

CAUTION: In setting the valve, care must be taken that evidence of start-to-discharge is due to opening of the valve and not due to a defect.

After the start-to-discharge pressure test, the resealing pressure shall ~~not~~ be higher ~~less~~ than 90 % of the start-to-discharge pressure or the maximum permissible operating pressure of the fuel tank, whichever is higher .

~~Pressure relief valves shall be examined and tested at least every five years.~~

4.6.2 Pressure gauges

A pressure gauge, if provided, shall be capable of reading at least 1,5 times the system maximum permissible operating pressure.

4.6.3 Liquid level gauging devices

The~~A~~ fuel tank shall be equipped with one or more liquid level gauging devices, which accurately indicate the maximum permitted liquid level at the loading pressure, in order to provide a minimum of 2% ullage ~~outage~~ below the inlet of the pressure control valve or pressure-relief valve at the condition of incipient opening of that valve. A fixed trycock line, or a liquid level gauge shall be used as the primary control for filling. Other gauging devices, except gauge glasses, may be used, but not as the primary control for filling.

~~The fuel tank shall be provided with a high-liquid level alarm. The alarm shall be set so that the operator will have sufficient time to stop the flow without exceeding the maximum permissible filling height and shall be located so that it is audible to personnel controlling the filling. A high-liquid level flow cut-off device, if used, shall not be considered as a substitute for the alarm.~~

The pressure range of each liquid level gauging device shall be at least that of the fuel tank.

If a fixed trycock line gauging device is used, it shall consist of a pipe or tube of small diameter equipped with a valve at or near the jacket and extending into the fuel tank to a specified filling height. The fixed height at which the tube ends in the fuel tank shall be such that the device will function when the liquid reaches the maximum level permitted in loading.

The liquid level gauging device used as a primary control for filling shall be designed and installed to accurately indicate the maximum filling level at the midway point of the fuel tank both longitudinally and laterally.

4.6.4 Valves

Valves, valve packing, and gaskets shall be suitable for hydrogen over the full range of pressures and temperatures to which they may be subjected under normal operating conditions.

The design of the valve shall be such that the removal of the valve stem without removing the complete valve bonnet or disassembling the valve body is not possible.

Every fuel tank shall be equipped with a manual or normally closed remotely actuated shutoff valve connected directly to the fuel tank. The s~~S~~hutoff valve~~s~~ shall have a rated service pressure not less than the maximum permissible operating pressure of the entire system and shall be capable of withstanding a hydrostatic test of at least 1,5 times the maximum permissible operating pressure without distortion. The valve seat shall be proven free of leaks greater than 10^{-4} Pa·m^3·s^{-1} when examined at a pressure of 1,25 times the maximum permissible operating pressure with a gas mixture containing at least 10 % ~~gaseous~~ helium using a method that guarantees the detection of leaks having a leak rate greater than 10^{-4}Pa·m^3·s^{-1}.

~~**4.6.5Hoses and hose connections**~~

~~Metallic hoses shall be vacuum jacketed or insulated to reduce heat input and to prevent the condensation of atmospheric air. The jacket design shall consider the inner line's thermal flexibility and allow the jacket to follow its natural thermal displacement.~~

~~Flexible metallic hoses, flexible tubing, and their connections shall have a design burst pressure of at least 4 times the maximum permissible operating pressure.~~

~~**4.6.6Piping**~~

~~Pipes, rigid tubing, fittings, gaskets, and packing material shall be compatible with liquid hydrogen under the service conditions.~~

~~Liquid hydrogen piping shall be fabricated and tested in accordance with the requirements specified below:~~

~~The bursting strength of all pipes, valves, fittings, and hoses shall be at least 4 times the maximum permissible operating pressure of the liquid vessel and not less than 4 times the pressure to which they shall be subjected in normal service by the action of a pump or other device, the action of which could subject portions of piping to pressures greater than the liquid vessel's maximum permissible operating pressure.~~

~~Each valve shall be designed and constructed for a rated pressure and the service temperature range not less than the liquid vessel maximum permissible operating pressure or the maximum permissible operating pressure of the section of piping where the valve is used, whichever is higher. Each valve shall be compatible with liquid hydrogen or cold hydrogen gas service.~~

~~Means shall be provided to minimize exposure of personnel to piping and to prevent air condensate from contacting piping, structural members and surfaces not suitable for cryogenic temperatures. Insulation shall maintain any properties that are required by design, during an emergency when exposed to fire, heat, cold, or water as applicable. It shall be designed to have a vapour-tight seal in the outer covering to prevent the condensation of air and subsequent oxygen enrichment within the insulation. The insulation material and outer covering shall also be of adequate design to prevent attrition of the insulation due to normal operating conditions.~~

~~Pipes, tubing, fittings, and other piping components shall be capable of withstanding a hydrostatic test of at least 1,5 times the maximum permissible operating pressure without structural failure.~~

4.6.5 Filters

Filter materials shall be compatible with liquid hydrogen under the service conditions. The filters shall be replaceable and easily accessible for maintenance.

4.6.6 Grounding

The fuel tank shall be provided with means to ensure its grounding during filling.

~~5 Installation of fuel tanks~~

~~Liquid hydrogen fuel tanks shall be installed so that any release of gaseous hydrogen is directed away from the driver or passenger compartment of the land vehicle preferably above or adjacent to these compartments. All connections to the fuel tank shall be external to, or sealed and vented from, these compartments.~~

~~Each fuel tank shall be mounted in a location to minimize damage from collision to the fuel tank itself and its appurtenances. No part of a fuel tank or its appurtenances shall protrude beyond the sides of the land vehicle at the point where it is installed.~~

~~The land vehicle fuel system shall be installed with as much road clearance as practical but not less than the minimum road clearance of the vehicle when loaded to its gross vehicle weight rating. This minimum clearance shall be measured from the lowest part of the fuel system.~~

~~No portion of the fuel tank or fuel tank appurtenances shall be located ahead of the front axle or behind the rear bumper mounting face of a land vehicle. Fuel tank valves shall be protected from physical damage using the land vehicle structure, valve protectors, or a suitable metal shield.~~

~~The fuel tank weight shall not be supported by outlet valves, manifolds, or other fuel connections.~~

~~Fuel tanks shall not be installed so as to adversely affect the driving characteristics of the land vehicle.~~

~~Each fuel tank shall be secured to the land vehicle body, bed, or frame to prevent damage from road hazards, slippage, loosening, or rotation using a method capable of withstanding a static force in the six principal directions (right‹›left, backward‹›forward, up‹›down) of 8 times the weight of the full liquid hydrogen fuel tank with a maximum displacement of 13 millimetres.~~

~~Each fuel tank in a rack shall be secured to its cradle in such a manner that it is capable of withstanding a static force applied in the six principal directions (right‹›left, backward‹›forward, up‹›down) of 8 times the weight of the liquid hydrogen full fuel tank with a maximum displacement of 13 mm.~~

~~Fuel tank shall be located more than 200 mm from any unshielded source of direct heat.~~

~~Any land vehicle compartment housing the liquid hydrogen fuel tank shall be equipped with a hydrogen detection system that sounds an audible alarm if the level of gaseous hydrogen exceeds 20 % of the lower flammability limit.~~

~~6 Installation of venting systems~~

~~All pressure relief devices and connections between pressure carrying components installed within a closed compartment shall be vented to the outside of the land vehicle in a suitable location.~~

~~The vent outlets of the venting system shall not terminate in the land vehicle engine compartment nor into a wheel well.~~

~~The venting system for the discharge of pressure relief devices (pressure relief device channels) shall be constructed of metallic tubing with welded fittings and shall be secured at the outer end.~~

~~A vent shall not restrict the operation of a pressure relief device or pressure relief channel. The vent line shall rise continuously and shall not contain any traps where water or other impediments to the flow of the venting gas can collect.~~

~~Vent outlets shall be protected by caps, covers, or other means to keep water, dirt, and insects from collecting in the lines. Protective devices shall not restrict the flow of gas.~~

~~A fuel tank, when located in a land vehicle compartment capable of accumulating hydrogen, shall be installed such that:~~

~~a)The pressure relief device for the protection of the fuel tank is installed in the same land vehicle compartment as the fuel tank;~~

~~b)The discharge from a pressure relief device referred to in (a) above is:~~

~~1)vented to the outside through a smooth walled metallic tube no smaller than the outlet diameter of the pressure relief device, and~~

~~2)located so that the vent opening will not be blocked by debris thrown up from the road, such as snow, ice, mud, or otherwise affected by the elements.~~

~~7 Installation of piping~~

~~Piping shall be joined by methods that permanently seal the joints to prevent hydrogen permeation to the outside and that will not degrade over time due to vibration and impact caused by land vehicle motion.~~

~~Where necessary to prevent abrasion, fuel lines passing through a panel shall be protected by grommets or similar devices.~~

~~Reasonable clearance shall be provided for the fuel lines passing close to hot components.~~

~~Fuel lines shall be mounted, braced, and supported to minimize vibration and protected against damage, corrosion, or breakage due to strain or wear. A fuel line shall be supported at least every 600 mm.~~

~~A bend in piping or tubing shall be prohibited where such a bend weakens the pipes or tubing.~~

~~A joint or connection shall be located in a readily accessible location.~~

~~8 Installation of valves~~

~~8.1Shutoff valve~~

~~Every fuel tank shall be equipped with a manual or normally closed remotely actuated shutoff valve connected directly to the fuel tank and installed in a readily accessible location that will permit isolation of the fuel tank from the remainder of the land vehicle fuel system.~~

~~No shutoff valve shall be installed between the pressure relief devices and the fuel tank. However, in cases where two or more pressure relief valves are installed on the same fuel tank, a shutoff valve may be used where the arrangement of the shutoff valve or valves is such as always to ensure full required flow capacity through the pressure relief devices opened to the liquid vessel.~~

~~8.2Automatic shutoff valves~~

~~An automatic shutoff valve shall be provided in the system in order to prevent the flow of gaseous fuel to the land vehicle engine when the engine is not running even if the ignition is switched on.~~

~~Where multiple fuel systems are installed on the land vehicle, automatic shutoff valves shall be provided, as necessary, to shut off the fuel not being used.~~

~~NOTE – Electronic fuel injectors are considered to be automatic shutoff valves.~~

~~8.3Backflow check valve~~

~~Fuelling systems that fill the fuel tank from the bottom shall be equipped with a backflow check valve that will prevent the return flow of gas or liquid from the fuel tank to the filling connection. A cold hydrogen return pipe shall be provided.~~

~~9 Installation of pressure gauges~~

~~A pressure gauge located within a driver or passenger compartment of a land vehicle shall be installed in such a manner that no gas will flow through the gauge in the event of a failure.~~

~~A pressure gauge installed outside a driver or passenger compartment of a land vehicle shall be equipped with a limiting orifice, a shatterproof dial lens, and a body relief.~~

~~Pressure gauges shall be securely mounted, shielded, and installed in a protected location to prevent damage from vibration and unsecured objects.~~

5 Qualification tests

5.1 Approval of a new design

Unless otherwise specified, ~~the qualification of a~~ new designs shall be approved only when the qualification tests of ~~in accordance with the requirements of~~ 5.3, 5.4, 5.5 and 5.6 have satisfactorily been ~~it shall be~~ carried out by or under the supervision of an Inspector. Prior to the shipment of ~~a lot of~~ fuel tanks of a new ~~approved~~ design, representative fuel tanks shall have passed the ~~new design~~ qualification tests.

5.2 Fuel tanks submitted for approval of design

Fuel tanks submitted for approval of design shall not have been in service and shall be selected prior to any pressure testing.

5.3 Pressure cycling test

Three representative samples of ~~liquid~~inner vessels shall be pressure cycling tested. Pressurization shall be performed hydrostatically between no more than 10 % of the maximum permissible operating pressure and 125 % of the maximum permissible operating pressure for 12 000 cycles at a rate not to exceed 10 cycles per minute. Appropriate recording instruments shall be used when the cycling pressurization equipment is left operating unattended for periods of time.

The lower cycling pressure shall not exceed 10 % of the upper cycling pressure. During each cycle, the time spent when the pressure is over 90 % of the upper cycling pressure shall be at least equal to 20 % of the cycle period.

Each test ~~liquid~~inner vessel shall withstand the cycle test without distortion, structural damage or leakage.

~~When one sample of the liquid vessels fails to withstand the cycle test, the lot represented shall be rejected. The test may be repeated if an improper test was made due to the presence of a defect in the specimen or if the equipment or procedure was faulty. The reason for failure shall be determined. If the cause for rejection was the presence of a defect in the specimen, the lot shall be 100 % non-destructively inspected to remove similarly defective liquid vessels. A second test shall then be performed with three other representative samples of liquid vessels. The lot shall be considered acceptable if each of the three samples withstands the test.~~

All ~~liquid~~inner vessels used in the cycling test shall be destroyed after completion of the test.

5.4 Burst test

Three ~~liquid~~inner vessels shall be tested hydrostatically to destruction. The rate of pressurization shall not exceed 1,4 MPa/min.

The burst pressure shall be at least 3 times the maximum permissible operating pressure for welded metallic ~~liquid~~inner vessels or at least 2,25 times the maximum permissible operating pressure for seamless steel ~~liquid~~inner vessels. The burst tear shall initiate in the longitudinal direction in the cylindrical portion when the ratio of tangential length to diameter is greater than 2.

For composite ~~liquid~~inner vessels, the burst pressure shall exceed the specified minimum burst pressure specified in Table 1, and in no case be less than the value necessary to meet the stress ratio requirements of Table 1. Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at the maximum permissible operating pressure.

~~When analyzing liquid vessels with hybrid reinforcement (two or more different fibres), consideration shall be given to the load share between the different fibres based on the different elastic moduli of the fibres. The stress ratio requirements for each individual fibre type shall be in accordance with the values given in Table 2.~~

Table 1 —Minimum actual values for burst pressures and stress ratios for composite ~~liquid~~inner vessels

Fibre Type	Stress Ratio	Minimum Burst Pressure
Glass	3,65	3,65 times the maximum permissible operating pressure
Aramid	3,10	3,10 times maximum permissible operating pressure
Carbon	2,35	2,35 times maximum permissible operating pressure
Hybrid	[a]	

[a] When analyzing inner vessels with hybrid reinforcement (two or more different fibres), consideration shall be given to the load share between the different fibres based on the different elastic moduli of the fibres. The stress ratio requirements for each individual fibre type shall be in accordance with the values given in this Table. ~~Stress ratios and burst pressures shall be calculated.~~

The actual pressure at burst shall be recorded. The ~~liquid~~inner vessel shall not fragment. The reason for failure to meet the requirements of the burst test shall be determined.

~~When one sample of the liquid vessels fails to withstand pressure up to the minimum prescribed burst pressure, the lot represented shall be rejected. The test may be repeated if an improper test was made due to the presence of a defect in the specimen or if the equipment or procedure was faulty. If the cause for rejection was the presence of a defect in the specimen, the lot shall be 100 % non-destructively inspected to remove similarly defective liquid vessels. A second test shall then be performed with three other representative samples of liquid vessels. The lot shall be considered acceptable if each of the three samples withstands the test.~~

~~When the liquid vessel subjected to the burst test is the same liquid vessel which has been subjected to the cycling test, and the burst test criteria is not met due to a flaw resulting from the cycling test, then the test may be repeated on a second liquid vessel to qualify the lot.~~

5.5 Fire resistance test

A fuel tank filled with liquid hydrogen shall be submitted to a temperature of 900 °C for a period of thirty minutes during which period the pressure inside the ~~liquid~~inner vessel shall not rise to ~~above~~ more than 20 % of the maximum permissible operating pressure of the fuel tank. During the test period of thirty minutes, the ~~liquid~~inner vessel shall not rupture and vent hydrogen except through installed pressure relief devices. ~~as long as it is not completely empty and holds a positive hydrogen overpressure.~~

5.6 Holding time

The test to determine the holding time shall be performed by charging the fuel tank with liquid hydrogen or liquid helium to its maximum permitted filling density and stabilizing to the lowest practical pressure, which shall be equal to or less than the pressure to be used for loading. The fuel tank together with its contents shall then be exposed to ambient temperature.

The fuel tank pressure and ambient temperature shall be recorded at 3-hour intervals until the pressure level of the contents reaches the set-to-discharge pressure of the pressure control valve or pressure-relief valve with the lowest setting. This total time lapse in hours represents the measured holding time at the actual average ambient temperature. This measured holding time shall be adjusted to an equivalent holding time for liquid hydrogen at an average ambient temperature of 65 °C~~54 °C~~, which is the rated holding time.

6 Non-destructive examination of finished or partly finished fuel tanks

6.1 Batch tests

6.1.1 Radiographic inspection of metallic inner vessels

One finished longitudinal seam and one finished transverse seam shall be taken at random from each lot of 100 ~~liquid~~inner vessels or less and radiographed throughout their ~~its~~ entire length. These ~~is longitudinal~~ seams shall pass the radiographic inspection criteria for lot acceptance. Should these~~is~~ samples fail to meet the requirements, two additional seams shall be radiographed, and pass the radiographic inspection for lot acceptance. If either of these fails to meet the requirements, then, each ~~liquid~~inner vessel of the lot shall be radiographed as outlined above, and pass the radiographic inspection criteria. Only those passing the radiographic inspection shall be accepted.

Reference radiographs of ASTM E390 are accepted as a guide to types and degrees of discontinuities detectable by radiographs of steel welds.

Welds whose radiographs show any of the following types of imperfections shall be unacceptable:

a) An elongated slag inclusion that has a length greater than 6,35 millimetres for *T* up to 19,0 millimetres, or 12,7 mm, for *T* from 19,0 to 57,2 millimetres, where *T* is thickness of the thinner plate of the joint.

b) A group of slag inclusions in line that have an aggregate length greater than *T* in a weld length of 12*T*, except when the distance between successive inclusions exceeds 6*L*, where *L* is the length of the longest inclusion in the group.

c) Any type of crack, or zone of incomplete fusion or incomplete penetration.

d) Porosity in excess of that specified as acceptable in Table 2.

e) Other round inclusions shall be judged on the same basis as porosity.

Table 2 — Maximum permissible porosity indications in radiographs per 15,2-mm length of weld

Unless otherwise stated, all dimensions are in millimetres

Weld thickness	Total area of permitted porosity (mm^2)	Large pore size		Medium pore size		Small pore size	
		Decimal value	No.	Decimal value	No.	Decimal value	No.
6,35	9,68	—	—	0,64	31	0,351	100
12,7	19,4	2,54	4	0,79	40	0,495	101
19,0	29,0	3,18	4	0,86	50	0,610	99
25,4	38,7	3,18	5	0,99	50	0,699	101
38,1	58,1	3,18	7	1,22	50	0,864	99
50,8	77,4	3,18	10	1,40	51	0,991	101

6.1.2 Inspection of composite inner vessels

One finished ~~liquid~~inner vessel of filament or fibre-reinforced polymer-matrix composite shall be taken at random from each lot of 100 ~~liquid~~inner vessels or less and be 100 % inspected using ultrasonic or acoustic emission methods. Where acoustic emission is used, sources of emission shall be located and each source area examined ultrasonically. The ~~liquid~~inner vessel shall pass the inspection criteria for lot acceptance. Should this sample fail to meet the requirements, two additional ~~liquid~~inner vessels shall be inspected ultrasonically or with acoustic emission and pass the inspection criteria for lot acceptance.

If either of these fail to meet the requirements, then each ~~liquid~~inner vessel of the lot shall be tested as outlined above and pass the inspection criteria. Only those passing the ultrasonic inspection shall be accepted.

All unbonds, voids, foreign material or delamination with a maximum dimension of 2,5 millimetres or greater shall be evaluated.

Flaws under 2,5 millimetres maximum dimension shall not be evaluated unless the *K* factors of the following paragraph apply. The *K* factor pertains to multiple flaws and is defined as the ratio of the maximum dimensions of the larger flaws to the distance between two flaws. Cases where *K* factors are equal to or exceed 4 shall be rejected.

Any foreign material greater than 4 millimetres detected during ultrasonic inspection that appears on the C-scan recording shall cause the rejection of the ~~liquid~~inner vessel.

Any single void having a minor dimension in excess of 1,5 millimetres and a major dimension of 13 millimetres shall not be accepted. Any two voids having minor dimension in excess of 1,5 millimetres and lying within 4 times the major dimensions of a larger void shall not be accepted (K = 4). Linear voids shall not be accepted when their size exceeds 3 millimetres.

6.1.3 Composite inner vessel with metallic liner

The fibre- or filament-reinforced polymer matrix composite part of the ~~liquid~~inner vessel shall be tested in accordance with 6.1.2 and the liner in accordance with 6.1.1.

6.2 Tests on every tanks

6.2.1 Hydrostatic proof pressure test

Before insulating and jacketing, each ~~liquid~~inner vessel shall be inspected under a pressure of 1,5 times the sum of its maximum permissible operating pressure, the hydrostatic head of lading and 101,3 kilopascals. The pressure shall be maintained for minimum time of 10 minutes.

The accuracy of the test equipment shall be maintained by periodic re-calibration. The pressure measuring device used shall permit reading the pressure to an accuracy of 1 % in the range of 80 % to 120 % of the test pressure.

All ~~liquid~~inner vessels failing to pass the hydrostatic test, by showing evidence of leakage, distortion or other defects, shall be rejected.

6.2.2 Pneumatic test

A pneumatic test made at 1,25 times the sum of the maximum permissible operating pressure, the hydrostatic head of lading and 101,3 kilopascals may be used in place of the hydrostatic test. Due regard for all personnel should be taken because of the potential hazard involved in a pneumatic test. The ~~liquid~~inner vessel shall be pressurized with air or an inert gas. The pneumatic test pressure in the ~~liquid~~inner vessel shall be reached by gradually increasing the pressure to one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately 10 % of the test pressure until the test pressure has been reached. The pressure shall be maintained for a minimum time of 10 minutes. Then the pressure shall be reduced to a value equal to 80 % of the test pressure and held for a sufficient time to conduct the examination for leakage.

All ~~liquid~~inner vessels failing to pass the pneumatic test, by showing evidence of leakage, distortion or other defects, shall be rejected.

6.2.3 Leakage test

Subsequent to the hydrostatic or pneumatic proof pressure test described in 6.2.1 and 6.2.2 respectively and before insulation and jacketing, each ~~liquid~~inner vessel shall be subjected to a leakage test using a gas mixture containing at least 10% ~~gaseous~~ helium. The ~~liquid~~inner vessel shall be suitably prepared for the leakage test including drying to remove any water.

The inner vessel and a~~A~~ll welded seams or bonded joint of the ~~liquid~~inner vessel shall be proven free of leaks greater than 10^{-4} Pa·m^3·s^{-1} when examined at the maximum permissible operating pressure using a method that guarantees the detection of leaks having a leak rate greater than 10^{-4} Pa·m^3·s^{-1}.

~~All welded seams or bonded joints shall be examined for leakage.~~ Inner ~~Liquid~~ vessels that leak shall be rejected.

~~7Maintenance and inspection~~

~~7.1Repair of a fuel tank~~

~~Welding or bonding for the repair or alteration of a fuel tank shall comply with the documents under which the fuel tank was fabricated including inspection requirements. Other welding of metallic fuel tank shall be performed only on saddle plates, lugs, or brackets attached to the fuel tank by the fuel tank manufacturer.~~

~~Brazing shall not be performed.~~

~~7.2Replacement of a pressure relief valve~~

~~If at any time it is necessary to break the seal for adjustment of a pressure relief valve, the valve shall be removed from service until it has been reset and sealed. Any adjustment necessary shall be made by the manufacturer or other companies having competent personnel and adequate facilities for the repair, adjustment, and testing of such valves. The organization making such adjustment shall attach a permanent tag with the setting, capacity and date to the pressure relief valve.~~

~~7.3Periodic in-service inspections~~

~~Each fuel tank as well as the control and safety devices shall be inspected at least every 42 months for damage and deterioration. The inspection shall be performed by a qualified person in accordance with the manufacturer's established re-inspection criteria.~~

~~7.4Fuel tanks involved in accidents~~

~~Fuel tanks which have been subjected to the stress of vehicular accidents shall be returned to the manufacturer and re-qualified before the fuel tank can be placed back into service.~~

~~7.5Fuel tanks involved in fire~~

~~Fuel tanks which have been subject to the action of fire shall be condemned and removed from service.~~

7 Marking and labelling

7.1 Marking of fuel tanks

Each fuel tank shall be marked with the following:

a) The pressure vessel code according to which the fuel tank is designed and constructed;

b) The name of the manufacturer of the fuel tank;

c) The maximum permissible operating pressure in kilopascals with the coincident temperature in degrees Celsius[1)];

d) The minimum design material temperature in degrees Celsius with the coincident service pressure in kilopascals;

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1) When a fuel tank is expected to operate at more than one pressure and temperature condition, other values of maximum permissible operating pressure with the coincident permissible temperature may be added as required.

e) The fuel tank's serial number;

f) The year and month of manufacture and testing;

g) The words "PROHIBITION OF WELDING, MILLING OR STAMPING";

h) The date of evacuation of insulation (year in four digits and month in two digits);

i) The service temperature range (^{o}C);

j) Total fuel tank water volume in litres;

k) The rated holding time of the fuel tank in days as determined in 5.6 or a lesser value as may be deemed appropriate;

l) A reference to this part of ISO 13985.

The required marking shall be stamped directly on the fuel tank or shown on a permanently attached nameplate. When the required marking is applied directly on the fuel tank, it shall be low stress stamped with letters at least 7 mm ~~in~~ high. When a nameplate is used, the required marking shall be in characters not less than 3 mm in high. The required marking or nameplate shall be located in a visible place on the fuel tank when it is installed on the vehicle.~~conspicuous place on the fuel tank.~~

Each fuel tank shall also be marked with the words "LIQUID HYDROGEN (LH_2) ONLY" ~~"HYDROGEN, REFRIGERATED LIQUID ONLY"~~ in letters at least 25 mm high in contrasting colour and a cryogenic hazard symbol.~~and~~ in a location that will be visible after installation. Decals or stencils may be used. Marking shall be permanent and indelible.

Piping components such as valves, gauges and filters shall be permanently marked by the manufacturer to indicate the service ratings.

7.2 Marking of valves

The valve body shall be low stress stamped by the manufacturer to indicate the service ratings.

The presence of a manual shutoff valve described in 4.6.4 shall be marked with the words "MANUAL SHUTOFF VALVE". Decals or stencils may be used. Marking shall be permanent and indelible.

~~7.3Marking of hoses~~

~~Hoses and metallic hoses shall be distinctly marked by the manufacturer, either by a manufacturer's permanently attached tag or by distinct markings, indicating the manufacturer's name or trademark, applicable service identifier, and maximum permissible operating pressure.~~

~~7.4Labelling of the land vehicle~~

~~7.4.1Engine compartment~~

~~A label shall be located in the land vehicle engine compartment and be readily visible and shall include the following:~~

~~a)The wording: LH_2 FUELLED VEHICLE;~~

~~b)Maximum permissible operating pressure;~~

~~c)Installer's name or company;~~

~~d)Fuel tank retest date(s) or expiration date;~~

~~e)Total fuel tank water volume in litres;~~

~~f)Test pressure;~~

~~g)Fuel tank's serial number;~~

~~h)The rated holding time of the fuel tank as determined in 5.1.7 or a lesser value as may deemed appropriate.~~

~~7.4.2Fuelling connection receptacle~~

~~A label shall be located at the fuelling connection receptacle of the land vehicle and shall include the following:~~

~~a)The wording: LH_2-FUELLED VEHICLE;~~

~~b)The warning: REFILL WITH HYDROGEN, REFRIGERATED LIQUID ONLY;~~

~~c)A reference to this International Standard.~~

~~The refuelling receptacle shall incorporate a means to prevent the entry of dust, water, and other foreign material. If the means used is capable of sealing system pressure, it shall be capable of being depressurized before removal.~~