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Gaseous hydrogen — Fuelling stations —

Part 1: General requirements

Carburant d'hydrogène gazeux — Stations-service —

Partie 1: Exigences générales

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Foreword

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

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

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

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

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

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

This first edition cancels and replaces ISO/TS 19880-1:2016, which has been technically revised.

The main changes compared to the ISO/TS 19880-1:2016 are as follows:

— where appropriate, guidance information from the TS was converted to requirements;

— the difference between the risk assessment and the design requirement clauses were clarified and references were added to ensure that the appropriate clauses were linked;

— Annex A from the TS on safety distances was removed;

— Annex C from the TS on hydrogen quality control was removed to ISO 19880-8;

— the presentation of the information was improved and much of the guidance information was moved to informative annexes.

A list of all parts in the ISO 19880 series can be found on the ISO website.

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

Gaseous hydrogen — Fuelling stations —

Part 1: General requirements

1 Scope

This document defines the minimum design, installation, commissioning, operation, inspection and maintenance requirements, for the safety, and, where appropriate, for the performance of public and non-public fuelling stations that dispense gaseous hydrogen to light duty road vehicles (e.g. fuel cell electric vehicles).

This document is not applicable to the dispensing of cryogenic hydrogen, or hydrogen to metal hydride applications.

Since this document is intended to provide minimum requirements for fuelling stations, manufacturers can take additional safety precautions as determined by a risk management methodology to address potential safety risks of specific designs and applications.

While this document is targeted for the fuelling of light duty hydrogen road vehicles, requirements and guidance for fuelling medium and heavy duty road vehicles (e.g. buses, trucks) are also covered.

Many of the generic requirements within this document are applicable to fuelling stations for other hydrogen applications, including but not limited to the following:

— fuelling stations for motorcycles, fork-lift trucks, trams, trains, fluvial and marine applications;

— fuelling stations with indoor dispensing;

— residential applications to fuel land vehicles;

— mobile fuelling stations; and

— non-public demonstration fuelling stations.

However, further specific requirements that can be necessary for the safe operation of such fuelling stations are not addressed in this document.

This document provides requirements for and guidance on the following elements of a fuelling station (see Figure 1 and Figure 2):

— hydrogen production/delivery system:

  — delivery of hydrogen by pipeline, trucked in gaseous and/or liquid hydrogen, or metal hydride storage trailers;

  — on-site hydrogen generators using water electrolysis process or hydrogen generators using fuel processing technologies;

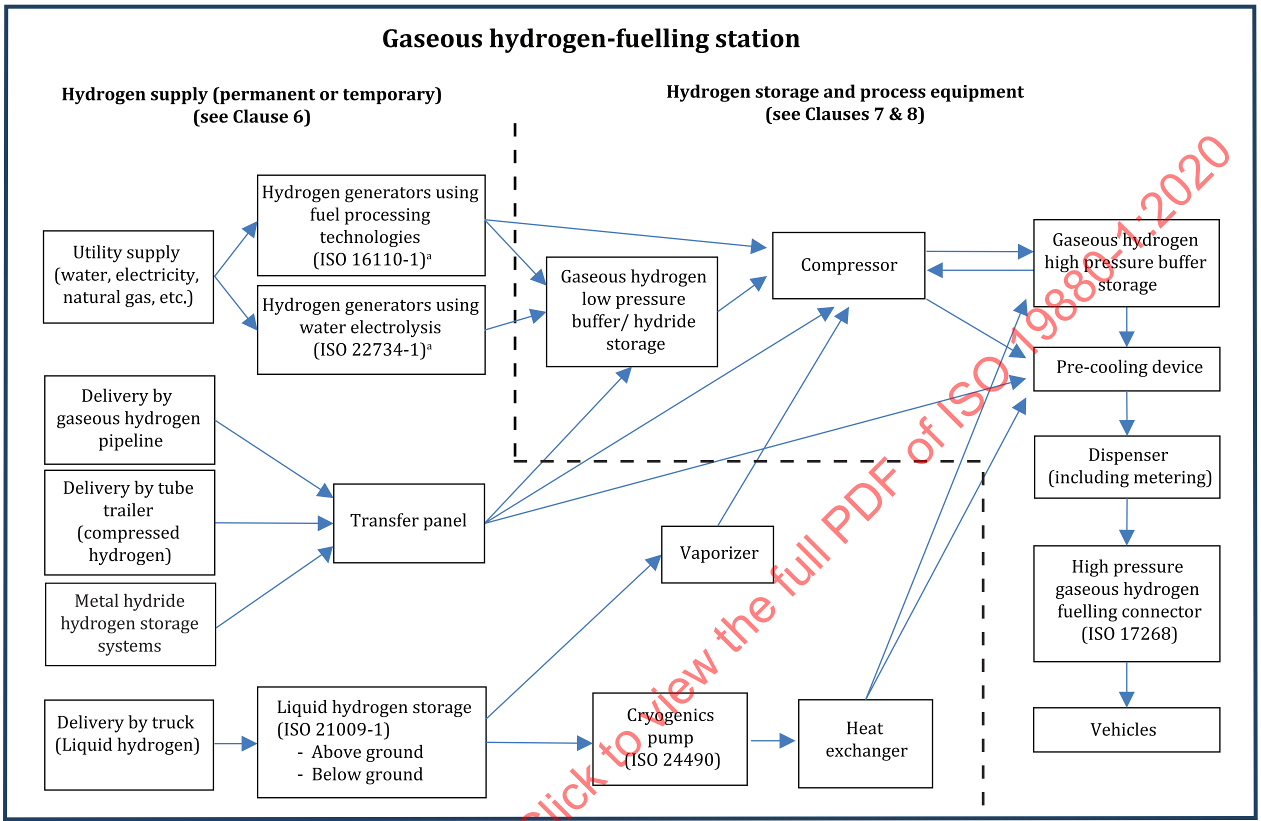
  — liquid hydrogen storage;

  — hydrogen purification systems, as applicable;

— compression:

  — gaseous hydrogen compression;

  — pumps and vaporizers;
- — gaseous hydrogen buffer storage;
- — pre-cooling device;
- — gaseous hydrogen dispensing systems.



[a] May include a buffer vessel (or accumulator) for dampening or adjusting flow of compressor suction inlet.

Figure 1 — Example of typical elements that a fuelling station consists of, including hydrogen supply

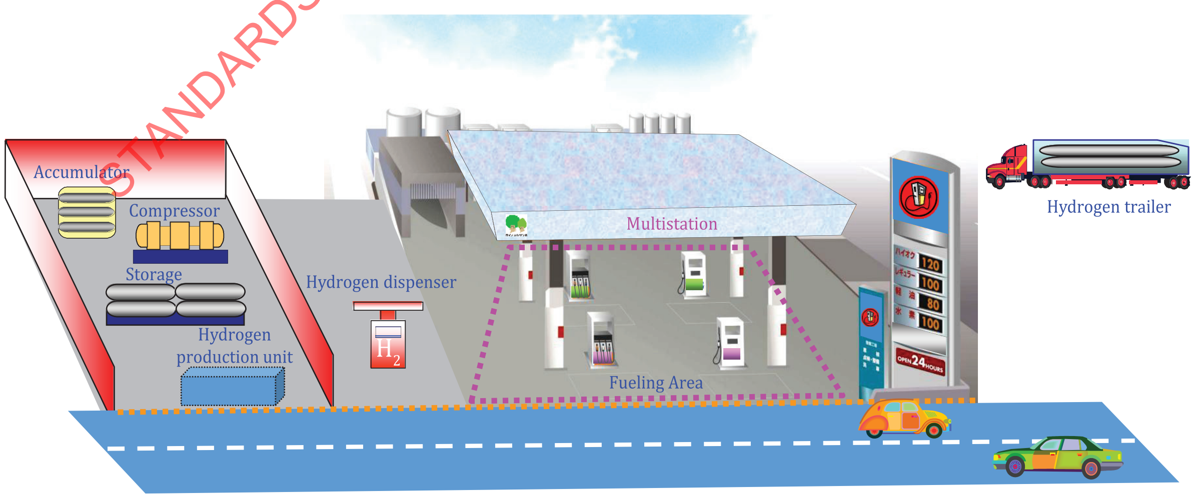


Figure 2 — Image of an example hydrogen fuelling station

2 Normative references

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

ISO 13850, *Safety of machinery — Emergency stop function — Principles for design*

ISO 14687, *Hydrogen fuel — Product specification*

ISO 15649, *Petroleum and natural gas industries — Piping*

ISO 17268, *Gaseous hydrogen land vehicle refuelling connection devices*

ISO 19880-8, *Gaseous hydrogen — Fuelling stations — Part 8: Hydrogen quality control*

ISO 21013-1, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves*

ISO 21013-2, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 2: Non-reclosable pressure-relief devices*

ISO 21013-3, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination*

ISO 22734, *Hydrogen generators using water electrolysis*

ISO/IEC 80079 (all parts), *Explosive atmospheres*

IEC 60079 (all parts), *Explosive atmospheres*

IEC 60204-1:2005, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 62282-3-100, *Fuel cell technologies. Stationary fuel cell power systems. Safety*

EN 13445-5, *Unfired pressure vessels. Inspection and testing*

SAE J2600: 2015-08, *Compressed Hydrogen Surface Vehicle Fuelling Connection Devices*

3 Terms and definitions

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

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

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

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

3.1
acceptance criteria
<risk or harm > acceptable level of risk or *harm* (3.34), locally defined as:

— a tolerable risk value; or

— a specified harm level; or

— requirements in a prescriptive document

3.2
accessory
device with an operational function

3.3
bleed
<venting> intentional expiration of a fluid from a fluid system

3.4
basic process control system
BPCS
system which responds to input signals from the process, its associated equipment, other programmable systems and/or an operator and generates output signals causing the process and its associated equipment to operate in the desired manner but which does not perform any safety-instrumented functions with a claimed *SIL* (3.73) ≥ 1

[SOURCE: IEC 61511-1:2004, 3.2.3]

3.5
breakaway device
device on the *fuelling hose* (3.27) that disconnects the hose from the *dispenser* (3.13) when a tension limit is exceeded and blocks the flow of hydrogen from the dispenser, e.g. if the vehicle moves away with the fuelling hose connected to the vehicle

3.6
buffer storage vessels
pressure vessels designed for the purpose of storing compressed hydrogen, which can be located between a hydrogen generator and a compressor for an even flow of gas to the compressor or between the compressor and *dispensing system* (3.17) for accumulation of pressurized gas supply for vehicle fuelling

3.7
building
structure, usually enclosed by walls and a roof, constructed to provide support or shelter for intended occupancy

3.8
canopy
roof, overhead shelter, or hood which affords a degree of weather protection

3.9
compressed hydrogen storage system
CHSS
hydrogen storage on-board vehicle, as defined in the GTR#13

3.10
component pressure rating
maximum pressure at which it is permissible to operate a component as specified by the manufacturer at a specified temperature

Note 1 to entry: Components designed with a maximum allowable pressure per the European PED represent the component pressure rating by the manufacturer that as indicated by the value of "PS".

Note 2 to entry: This is sometimes referred to as the *maximum allowable working pressure* (3.45) for the component, for example for vessels.

Note 3 to entry: In addition to the specification of the maximum temperature, the manufacturer can define an allowable minimum temperature or temperature range expected for service. For additional thermal conditions and risks potentially experiences during *fires* (3.23), see 5.3.6.4.

Note 4 to entry: Pressures up to 10 % above the rating can occur during fault management by PSV. See E.3 regarding limited cycle testing to 110 % of the rating as part of verification testing to demonstrate capability of the component.

Note 5 to entry: See Annex E for discussion of pressure terminology and its application to *dispensing systems* (3.17) and *fuelling stations* (3.29) in general.

3.11
control system
system which responds to input signals from the process and/or from an operator and generates output signals causing the process to operate in the desired manner

Note 1 to entry: Also see *safety-instrumented system (SIS)* (3.72) and *basic process control system (BPCS)* (3.4).

3.12
connector
matching parts (such as male and female parts) that can be put together to form a "connection" which permits the transfer of fluids, electric power, or control signals

Note 1 to entry: *Fittings* (3.24) are a type of connector used in piping systems.

Note 2 to entry: Examples of connectors commonly used in hydrogen systems are as follows:

a) The fuelling *nozzle* (3.53) “connector” mates with the *receptacle* (3.64) “connector” on the vehicle to form the connection for transfer of compressed hydrogen between the *dispenser* (3.13) and the vehicle, as defined in ISO 17268 for this specific application;

b) The hose assemblies have connectors on each end that allow coupling to the hoses and connection to the piping system, e.g. hose *breakaway device* (3.5) or fuelling nozzle;

c) *Control systems* (3.11) often use electrical connectors to allow rapid and secure assembly or replacement.

3.13
dispenser
equipment in the *dispensing system* (3.17), including the *dispenser cabinet(s)* (3.14) and support structure, that is physically located in the fuelling area

Note 1 to entry: The hydrogen dispenser typically includes, as a minimum, the *fuelling assembly* (3.26), required temperature and pressure instrumentation, filters, and the user interface to conduct vehicle fuelling.

Note 2 to entry: The manufacturer of the hydrogen dispenser can elect to include additional equipment in the dispenser, including the possibility of all equipment in the dispensing system.

3.14
dispenser cabinet
protective *housing* (3.40) that encloses process piping and can also enclose measurement, control and ancillary *dispenser* (3.13) equipment

3.15
dispenser fuel pressure
pressure of the hydrogen gas supplied to the vehicle by the station

Note 1 to entry: See Annex E for discussion of pressure terminology and its application to *dispensing systems* (3.17).

3.16
dispenser fuel temperature
temperature of the hydrogen gas supplied to the vehicle by the station

3.17
dispensing system
system downstream of the hydrogen supply system comprising all equipment necessary to carry out the vehicle fuelling operation, through which the compressed hydrogen is supplied to the vehicle

3.18
enclosure
structure, protective *housing* (3.40), container, machine cabinet, etc. which encloses or partially encloses equipment of a station that may have access for maintenance but is not intended to be occupied

Note 1 to entry: The use of an enclosure could be to protect equipment from the environment, provide noise attenuation, or provide *safety* (3.69) to the areas surrounding the equipment.

Note 2 to entry: A *canopy* (3.8) without walls is not regarded as an enclosure in this context.

3.19
explosion
ignition and rapid combustion that causes an over-pressure

Note 1 to entry: A rapid deflagration and/or a detonation are explosions.

Note 2 to entry: Slow deflagrations or jet flames do not create an over-pressure and are therefore not considered to be explosions.

3.20
explosive gas atmosphere
mixture with air, under atmospheric conditions, of flammable substances in the form of gas or vapour, which, after ignition, permits self-sustaining flame propagation

Note 1 to entry: Although a mixture which has a concentration above the upper flammable limit (UFL) is not an explosive gas atmosphere, it can readily become so and, generally for area classification purposes, it is advisable to consider it as an explosive gas atmosphere.

[SOURCE: IEC 60079-10-1:2015, 3.2]

3.21
factory acceptance testing
FAT
tests performed in the factory on *fuelling station* (3.29) equipment or systems to verify functionality and/or integrity prior to shipment to the site, (or an appropriate alternative type acceptance methodology)

3.22
fallback
back-up control strategy, for example in the fuelling protocol when the anticipated precooling of hydrogen to within a specified range of temperatures is not achieved, however fuelling is able to continue, typically at a different fuelling rate

3.23
fire
non-premixed combustion process of a solid, liquid pool, or a jet plume of flammable substance

Note 1 to entry: A fire is the combustion of a solid or liquid of a process first of pyrolysis or evaporation to a combustible gas where a non-premixed combustion process ensues. Also, a non-premixed combustion of a flammable plume (jet fire) is also covered by this definition as is combustion of metals and of hydrogen released by a metal hydride. A fire as defined here does not create an over-pressure therefore is not an *explosion* (3.19), nor is it a deflagration or a detonation which are premixed combustion phenomena.

3.24
fitting
part or design feature on a component used to join (i.e. connect) any pressure retaining components in the system

3.25
forecourt
surfaced area where vehicle dispensing operations are conducted including the *fuelling pad* (3.28) and any area underneath a *canopy* (3.8)

3.26
fuelling assembly
part of the *dispenser* (3.13) providing the interface between the *hydrogen fuelling station* (3.29) and the vehicle - an assembly consisting of a hose *breakaway device* (3.5), a hose(s), a *nozzle* (3.53) and connections between these components

Note 1 to entry: The fuelling assembly can include, or not, a nozzle vent line (with hose breakaway device and hose) depending on the type of nozzle, and communications, if used.

3.27
fuelling hose
flexible conduit used for dispensing gaseous hydrogen to vehicles through a fuelling *nozzle* (3.53)

3.28
fuelling pad
area with special construction requirements adjacent to the hydrogen *dispensers* (3.13), where customers park their vehicles during fuelling

3.29
hydrogen fuelling station
fuelling station
facility for the dispensing of compressed hydrogen vehicle fuel, often referred to as a hydrogen refuelling station (HRS) or hydrogen filling station, including the supply of hydrogen, and hydrogen compression, storage, and *dispensing systems* (3.17)

3.30
stand-alone
<hydrogen fuelling station or dispenser> independent for the dispensing of compressed hydrogen only

3.31
integrated
<hydrogen fuelling station or dispenser> being part of an existing, or new build, conventional *fuelling station* (3.29) for the dispensing of compressed hydrogen

3.32
fuelling station operator
person or organization responsible for the safe operation, maintenance and housekeeping of the *fuelling station* (3.29)

3.33
guard
part of a machine specially used to provide protection by means of a physical barrier

Note 1 to entry: Depending on its construction, a guard can be called casing, cover, screen, door, enclosed guard, etc.

3.34
harm
physical injury or damage to the health of people, or damage to property or the environment

[SOURCE: ISO/IEC Guide 51:2014, 3.1, modified — The word "physical" has been added.]

3.35
harmonised standard
European standard developed by a recognised European Standards Organization (CEN, CENELEC, or ETSI), in line with a European Directive

3.36
hazard
potential source of *harm* (3.34)

[SOURCE: ISO/IEC Guide 51: 2014, 3.2]

3.37
hazard distance
distance from the *hazard* (3.36) to a determined physical effect value that can lead to a range of *harm* (3.34) to people, equipment or environment

Note 1 to entry: It can be used as an input to quantitative *risk assessment* (3.66) to, for example, estimate the risk of injury or fatality to people (e.g. via probit functions).

Note 2 to entry: Hazards include, for example, physical, thermal, or pressure effects that can cause harm and can be determined by physical or numerical modelling, experience, or by a regulation.

3.38
hazardous area
classified area
<explosive gas atmospheres> area in which an *explosive gas atmosphere* (3.20) is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment

Note 1 to entry: The interior of many items of process equipment are commonly considered as a hazardous area even though a flammable atmosphere may not normally be present to account for the possibility of air entering the equipment. Where specific controls such as inerting are used the interior of process equipment may not need to be classified as a hazardous area.

[SOURCE: IEC 60079-10-1:2015, 3.3.1, modified — The alternative preferred term "classified area" has been added.]

3.39
hose assembly
assembly which includes the hose and end connections, including any necessary *fittings* (3.24), bend restrictors, and appropriate markings.

3.40
housing
guard (3.33) or *enclosure* (3.18) for operating parts, control mechanisms, or other components, that need not be accessible during normal operation

3.41
hydrogen purifier
equipment to remove undesired constituents from the hydrogen

Note 1 to entry: Hydrogen purifiers can comprise purification vessels, dryers, filters and separators.

3.42
hydrogen service level
HSL
pressure level in MPa used to characterize the hydrogen service of the *dispensing system* (3.17) based on the *NWP* (3.51) of the vehicle.

Note 1 to entry: The numerical value of HSL also matches the number after the “H” in the *pressure class* (3.58) (see Table 1).

Note 2 to entry: See Annex E for application of pressure terminology to hydrogen dispensing systems and vehicles.

3.43
incident
any unplanned event that resulted in injury or ill health of people, or damage or loss to property, plant, materials or the environment or a loss of business opportunity

Note 1 to entry: The use of the term incident is intended to include the term accident.

3.44
lower flammable limit
LFL
concentration of flammable gas, vapour or mist in air below which an *explosive gas atmosphere* (3.20) will not be formed

[SOURCE: IEC 60079-10-1:2015, 3.6.12]

3.45
maximum allowable working pressure
MAWP
maximum pressure permissible in a system at the temperature specified for the pressure

Note 1 to entry: The maximum allowable working pressure can also be defined as the design pressure, the maximum allowable operating pressure, the maximum permissible working pressure, or the maximum allowable pressure for the rating of pressure vessels and equipment manufactured in accordance with national pressure vessel codes.

Note 2 to entry: See Annex E for discussion of pressure terminology and its application to *dispensing systems* (3.17) and *fuelling stations* (3.29) in general.

3.46
maximum fuelling pressure
MFP
maximum pressure expected during a normal (fault-free) vehicle fuelling

Note 1 to entry: Per the GTR#13, the maximum fuelling pressure is 125 % *NWP* (3.51) (see Annex D).

Note 2 to entry: Also referred to as Maximum Fill Pressure.

Note 3 to entry: See Annex E for discussion of pressure terminology and its application to *dispensing systems* (3.17) and *fuelling stations* (3.29) in general.

3.47
maximum operating pressure
MOP
highest pressure that is expected for a component or system during normal operation including anticipated transients

Note 1 to entry: In the case of the *dispensing system* (3.17), the MOP is equivalent to the *maximum fuelling pressure* (3.46) of the vehicle.

Note 2 to entry: See Annex E for discussion of pressure terminology and its application to dispensing systems and *fuelling stations* (3.29) in general.

3.48
mitigation
combination of the measures incorporated at the design stage and the measures required to be implemented by the station operator, *dispenser* (3.13) operator, or others involved with the operation and maintenance of the *fuelling station* (3.29) to reduce the *probability* (3.60) or severity of an *incident* (3.43)

3.49
mobile storage
multiple-element gas container (3.50) or liquid hydrogen tank fixture mounted on a vehicle or trailer and used for the transportation of hydrogen to *hydrogen fuelling stations* (3.29)

3.50
multiple-element gas container
MEGC
multimodal assembly of cylinders, tubes or bundles of cylinders which are interconnected by a manifold and assembled within a framework, including service equipment and structural equipment necessary for the transport of gases

Note 1 to entry: This definition is taken from the UN Model Regulations. ADR[79] uses a different definition.

[SOURCE: ISO 10286:2015, 2.2.1, 210]

3.51
nominal working pressure
NWP
pressure of a vehicle *CHSS* (3.9) at 100 % *SOC* (3.78) at a gas temperature of 15 ºC

Note 1 to entry: See GTR#13 clause II-3.37, on page 54.

Note 2 to entry: For road vehicles, this is typically 35 MPa or 70 MPa.

Note 3 to entry: See Annex E for discussion of pressure terminology and the correspondence between vehicle terminology and *dispensing systems* (3.17).

Note 4 to entry: Also known as "settled pressure" in ISO 10286.

3.52
non-public fuelling station
fuelling station (3.29) that does not sell or dispense gaseous hydrogen to the general public

EXAMPLE Private or municipal vehicle fleet operation.

3.53
nozzle
device connected to a fuel *dispensing system* (3.17), which permits the quick connect and disconnect of fuel supply to the vehicle storage system

[SOURCE: ISO 17268:2012, 3.8]

3.54
outdoors
location outside of any *building* (3.7) or structure, or location under a roof, weather shelter, or *canopy* (3.8) provided this area is not enclosed on more than two sides

3.55
plinth
raised area on the *forecourt* (3.25), supporting and protecting the *dispensers* (3.13) and associated equipment

3.56
positive isolation
complete separation of one part of the plant or equipment from other parts of the system

Note 1 to entry: Positive isolation can be provided to equipment or piping items for maintenance purposes using various arrangements depending on following factors, as piping rating, equipment in shutdown or equipment under service.

Note 2 to entry: Physical disconnection, for example, spool removal, or use of a blind or a spade are typical ways to provide positive isolation.

Note 3 to entry: Alternatively, *proved isolation* (3.61) can be deemed acceptable based on *risk assessment* (3.66).

Note 4 to entry: Further information can be found in HSG253.

3.57
pre-cooling
process of cooling hydrogen fuel temperature prior to dispensing

3.58
pressure class
non-dimensional rating of components designed to dispense hydrogen to road vehicles at the required pressure and temperature

Note 1 to entry: The numbers following 'H' in the pressure class are numerically the same as *HSL* (3.42), but the HSL identifies only the level of the dispensing service whereas the pressure class designation shows the component are fully capable of meeting the pressure and temperature requirements for dispensing hydrogen at the indicated service level.

Note 2 to entry: See Annex E for discussion of pressure terminology and its application to *dispensing systems* (3.17) and *fuelling stations* (3.29) in general.

Note 3 to entry: Additional examples of pressure class come from ISO 15649; e.g. "600", "3000" or "6000".

3.59
pressure relief device
PRD
safety (3.69) device that releases gases or liquids above a specified pressure value in cases of emergency or abnormal conditions

Note 1 to entry: PRDs can be activated by pressure or another parameter, such as temperature, and can be either re-closing devices (such as valves) or non-re-closing devices (such as rupture disks and fusible plugs). Common designations for these specific types of PRDs are as follows:

— Pressure safety valve (PSV) — pressure activated valve that opens at specified set point to protect a system from rupture and re-closes when the pressure falls below the set point. Requirements for PRVs used in *dispensing systems* (3.17) can be found in 8.2.2.3. PSVs protecting the dispensing system can reclose above the *MOP* (3.47).

— Thermally-activated pressure relief device (TPRD) — a PRD that opens at a specified temperature to protect a system from rupture and remains open.

Note 2 to entry: See Annex E for discussion of pressure terminology and its application to pressure protection of the dispensing system and *fuelling stations* (3.29) in general.

3.60
probability
expression of the chance (likelihood) that a considered event will take place to property, system, business or to the environment

3.61
proved isolation
valved isolation where the effectiveness of valves closure can be confirmed via vent or *bleed* (3.3) points

Note 1 to entry: Proved isolation can often be used instead of *positive isolation* (3.56), where this is deemed acceptable based on *risk assessment* (3.66).

Note 2 to entry: An assembly commonly referred to as Double Block and Bleed is often used. For such systems, two block valves are required for additional isolation between the operational process side and the device requiring maintenance. A bleed valve is used to drain or vent the fluids trapped between the two block valves.

Note 3 to entry: Further information can be found in HSG253.

3.62
public fuelling station
fuelling station (3.29) that sells gaseous hydrogen to the general public

3.63
qualified personnel
personnel with knowledge or abilities, gained through training and/or experience as measured against established requirements, standards or tests, that enable the individual to perform a required function

[SOURCE: ISO 10417:2004, 3.13, modified — The word "characteristics" has been replaced with "knowledge".]

3.64
receptacle
device connected to a vehicle storage system which receives the *nozzle* (3.53)

Note 1 to entry: This can also be referred to as a fuelling inlet or gas filling port in other documents.

[SOURCE: ISO 17268:2012, 3.11]

3.65
risk
combination of the *probability* (3.60) of occurrence of *harm* (3.34) and the severity of that harm; encompassing both the uncertainty about and severity of the harm

[SOURCE: ISO/IEC Guide 51:2014, 3.9, modified — The part "encompassing both the uncertainty about and severity of the harm" has been added; Note 1 to entry has been removed.]

3.66
risk assessment
determination of quantitative or qualitative value of risk related to a specific situation and a recognised threat (also called *hazard* (3.36))

Note 1 to entry: Based on national requirements, a review of a risk analysis or a *safety* (3.69) concept by third party is sometimes required.

3.67
risk level
assessed magnitude of the risk

3.68
safeguarding
instruments or final elements related to *safety-instrumented system, SIS* (3.72), or *pressure relief device, PRD* (3.59)

Note 1 to entry: Safeguarding can be instrumental safeguarding or mechanical safeguarding.

3.69
safety
freedom from unacceptable risk

[SOURCE: ISO/IEC Guide 51:2014, 3.14]

3.70
safety distance
separation distance
safe distance
setback distance
distance to acceptable *risk level* (3.67) or minimum risk-informed distance between a *hazard* (3.36) source and a target (human, equipment or environment), which will mitigate the effect of a likely foreseeable *incident* (3.43) and prevent a minor incident escalating into a larger incident

Note 1 to entry: Safety distances could be split into Restriction distances, Clearance distances, Installation layout distances, Protection distances and External risk zone. See A.5.2 for further details.

3.71
safety function
function to be implemented by a *safety-instrumented system* (3.72), which is intended to achieve or maintain a safe state for the process, with respect to a specific hazardous situation

Note 1 to entry: Other technologies or risk reduction measures have a safety function not achieved through a safety-instrumented system, however validation of these measures is equally important.

3.72
safety-instrumented system
SIS
instrumented system used to implement one or more safety-instrumented functions

Note 1 to entry: A safety-instrumented system is composed of any combination of sensors, logic solvers, and final elements.

Note 2 to entry: A separate safety-instrumented system (SIS), typically with a greater reliability than the more *basic process control system (BPCS)* (3.4), can be required, according to the manufacturer's *risk assessment* (3.66), to respond solely to safety critical alarms. Further information is provided by IEC 61508 and IEC 61511.

3.73
safety integrity level
SIL
discrete level (one out of a possible four), corresponding to a range of safety integrity values, where safety integrity level 4 has the highest level of safety integrity and safety integrity level 1 has the lowest

Note 1 to entry: The target failure measures (see IEC 61508-4) for the four safety integrity levels are specified in IEC 61508-1:2010, Tables 2 and 3.

Note 2 to entry: Safety integrity levels are used for specifying the safety integrity requirements of the *safety functions* (3.71) to be allocated to the E/E/PE *safety-related systems* (3.74).

Note 3 to entry: A safety integrity level (SIL) is not a property of a system, subsystem, element or component. The correct interpretation of the phrase "SIL n safety-related system" (where n is 1, 2, 3 or 4) is that the system is potentially capable of supporting safety functions with a safety integrity level up to n.

Note 4 to entry: See 8.2.

[SOURCE: IEC 61508-4:2010, 3.5.8, modified — Note 4 to entry has been added.]

3.74
safety-related system
designated system that both implements the required *safety functions* (3.71) necessary to achieve or maintain a safe state for the EUC and is intended to achieve, on its own or with other E/E/PE safety-related systems, other technology safety-related systems or external risk reduction facilities, the necessary safety integrity for the required safety functions

Note 1 to entry: The term refers to those systems, designated as safety-related systems, that are intended to achieve, together with the external risk reduction facilities (IEC 61508-5:2010, 3.4.3), the necessary risk reduction in order to meet the required tolerable risk (IEC 61508-5:2010, 3.1.6 and Annex A).

Note 2 to entry: The safety-related systems are designed to prevent the EUC from going into a dangerous state by taking appropriate action on receipt of commands. The failure of a safety-related system would be included in the events leading to the determined *hazard* (3.36) or hazards. Although there can be other systems having safety functions, it is the safety-related systems that have been designated to achieve, in their own right, the required tolerable risk. Safety-related systems can broadly be divided into safety-related *control systems* (3.11) and safety-related protection systems, and have two modes of operation (IEC 61508-5:2010, 3.5.12).

Note 3 to entry: Safety-related systems are potentially an integral part of the EUC control system or interface with the EUC by sensors and/or actuators. That is, the required *safety integrity level* (3.73) is achieved by implementing the safety functions in the EUC control system (and possibly by additional separate and independent systems as well) or the safety functions can be implemented by separate and independent systems dedicated to safety.

Note 4 to entry: A safety-related system is designed:

a) to prevent a hazardous event (i.e. if the safety-related systems perform their safety functions then no hazardous event arises);

b) to mitigate the effects of the hazardous event, thereby reducing the risk by reducing the consequences;

c) to achieve a combination of a) and b).

3.75
site acceptance testing
SAT
tests performed after installation of the *fuelling station* (3.29) at the site to verify functionality and/or integrity

3.76
skid
process system contained within a frame that allows the process system to be easily transported and installed for operation

3.77
standards development organization
SDO
industry- or sector-based standards organizations that develop and publish industry specific standards

Note 1 to entry: In some cases, international industry-based SDOs may have direct liaisons with international standards organizations. SDOs are differentiated from standards setting organizations (SSOs) in that SDOs may be accredited to develop standards using open and transparent processes.

Note 2 to entry: In the European Union, only standards created by CEN, CENELEC, and ETSI are recognized as European standards, and member states are required to notify the European Commission and each other about all the draft technical regulations. These rules were laid down in Directive 2015/1535/EU with the goal of providing transparency and control with regard to technical regulations.

3.78
state of charge
SOC
density (or mass) ratio of hydrogen in the *compressed hydrogen storage system (CHSS)* (3.9) between the actual CHSS condition and the capacity at *NWP* (3.51) when the system is equilibrated at 15 °C

Note 1 to entry: SOC is expressed as a percentage and is computed based on the gas density according to formula below.

Note 2 to entry: The accuracy of the NIST formula has been quantified to be to within 0,01 % from 255 K to 1 000 K with pressures to 120 MPa at the publishing of this document.

Note 3 to entry: (%) can be calculated as follows:

$$\frac{\rho_1}{\rho_2} \times 100$$

where

ρ_1 is the density of hydrogen under the specific gas conditions;

ρ_2 is the density of hydrogen at the nominal working pressure at a gas temperature of 15 °C.

The hydrogen densities at the two major nominal working pressures are:

— density of H_2 at 35 MPa and 15 °C = 24,0 g/l

— density of H_2 at 70 MPa and 15 °C = 40,2 g/l

Note 4 to entry: The ρ_1 function for hydrogen is available from the National Institute of Standards and Technology (NIST) at https://nvlpubs.nist.gov/nistpubs/jres/113/6/V113.N06.A05.pdf.

3.79
target pressure
dispenser (3.13) fuel pressure that the hydrogen fuelling protocol targets for the end of fuelling

Note 1 to entry: Further guidance on pressure terminology is included in Annex E.

3.80
vaporizer
device, other than a tank, that receives hydrogen in a liquid form and adds sufficient heat to convert the liquid to a gaseous state

3.81
maximum developed pressure
maximum accumulated pressure
highest pressure expected during fault management by the *dispensing system* (3.17)

Note 1 to entry: Per the GTR, the maximum developed pressure is 1,50 × NWP. See Annex D.

Note 2 to entry: The estimate of maximum developed pressure is based on a "worst case" assumptions — the highest possible setpoint for the pressure protection and maximum allowable values for setpoint accuracy and "lift" to open the PSV for full relieving.

4 Abbreviated terms

AiCHE	American Institute of Chemical Engineers
ALARP	as low as reasonably practicable
API	American Petroleum Institute
APRR	average pressure ramp rate
CABF	conformity assessment bodies forum
CENELEC	French: Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization)
CFD	computational fluid dynamics
CGA	Compressed Gas Association
DDT	deflagration to detonation transition
E/E/PE	electrical/electronic/programmable electronic
ERP	emergency response plan
ESReDA	European Safety, Reliability and Data Association
ETSI	European Telecommunications Standards Institute
EUC	equipment under control
FCEV	fuel cell electric vehicle
FEMA	failure modes and effects analysis
H35	indication for 35 MPa NWP hydrogen fuelling as defined in ISO 17268

H70 indication for 70 MPa NWP hydrogen fuelling as defined in ISO 17268

HAZOP hazard and operability study

HSG health and safety guidance

IrDA Infrared Data Association

LFL lower flammability limit

MEGC multiple element gas containers

OREDA offshore and onshore reliability data

P&I piping and instrumentation

P&ID piping and instrumentation diagram

PELV protective extra-low voltage

PFP passive fire protection

PLC programmable logic controller

PPE personal protective equipment

PSV pressure safety valve

QRA quantitative risk assessment

RoHS restriction of hazardous substances

SAE Society of Automotive Engineers

SELV safety extra-low voltage

SIF safety-instrumented function

TPRD temperature-activated pressure relief device

5 Risk management

5.1 Hydrogen fuelling station safety recommendations

The hydrogen fuelling station installation should be sited to minimise risk to users, operating personnel, properties, and the environment to an acceptable level.

The following elements of a hydrogen fuelling station shall be considered potential hazard sources:

— on-site hydrogen production unit as applicable;

— hydrogen delivery system, including mobile storage and remote fill points as applicable;

— compressors;

— storage;

— piping connections (non-welded);

— dispensers.

The hydrogen fuelling station shall include measures to reduce the risk of harm from fires, deflagrations, detonations and blast waves to an acceptable level.

Example mitigation strategies are covered in greater detail in the 5.3 and 5.4.

Hazards on the fuelling station unrelated to hydrogen fires shall also be addressed (if applicable). An example list can be found in 5.5.

5.2 Risk assessment

Risk assessment is the overall process of risk identification, risk analysis, risk evaluation, and risk mitigation. Use of risk assessment may allow station owners and designers to flexibly define station-specific mitigations that achieve an equal or better level of risk to those of prescriptive recommendations or to relax existing prescriptive mitigation measures as long as the total system risk remains below the selected tolerability threshold (risk acceptance criteria).

A risk assessment shall be performed for the hydrogen fuelling station except when the stations comply with prescriptive regulations that address relevant risks. See standards such as ISO 31000, IEC 31010, and/or ISO 12100 for guidance in conducting risk assessment. The risk assessment should demonstrate that the mitigation measures employed are appropriate to achieve the desired level of risk of the station (see Clause 11).

It is recommended that the risk assessment carried out for the hydrogen fuelling station should be quantitative or semi-quantitative. Further recommendations for semi-quantitative or quantitative risk assessment of hydrogen fuelling stations can be found in Annex A.

NOTE 1 Recommendations for the method, degree of detail, and source of information used in the assessment when carried out specifically for a hydrogen fuelling station are included in A.1.

NOTE 2 An example of a quantitative risk assessment toolkit to facilitate the performance of a specific station is given in A.2.

NOTE 3 Annex B includes the recommendations generated from an example fuelling process risk assessment.

If a quantitative risk assessment (QRA) is used, non-hydrogen hazards, as defined in 5.5, shall be covered.

5.3 Mitigation measures to improve system safety

5.3.1 General

The risk assessment should demonstrate that the mitigation measures are appropriate to achieve the desired reduction of the probability and/or consequences of each scenario.

Several mitigation features affect the probability and/or impact of multiple aspects of the analysis (e.g., use of enclosures can reduce the probability of ignition, but it could potentially increase the consequence of deflagrations); when credit is taken for a mitigation, the entire analysis should be re-run to ensure that total risk is sufficiently low.

5.3.2 Mitigations which reduce the potential for the formation of a flammable mixture

5.3.2.1 General

Hydrogen fuelling stations shall be designed and operated such that, where an intentional or unintentional release of flammable gas occurs during normal operation, the formation of a flammable mixture is prevented, minimised, detected, or controlled. Further detailed information is available from the IEC 60079 series.

Examples on how to reduce the potential for the formation of a flammable mixture can be found in Annex B.

5.3.2.2 Safety and emergency shut-off systems

In order to minimise the magnitude of an unintentional release, or to minimise the duration of the flammable mixtures, isolation valves that can shut-off the hydrogen supply from the hydrogen storage to other areas of the hydrogen fuelling station shall be installed (see 11.2).

The position to which automatic valves in hydrogen lines move in the event of power or pneumatic pressure loss should be defined by risk assessment and implemented accordingly.

5.3.2.3 Pressure relief devices for gaseous hydrogen systems

When required, the pressurized gaseous hydrogen systems and equipment shall be protected from over-pressure e.g. by use of one or more PRD(s), or by other appropriate means.

Over-pressure protection shall be set at, or below, the MAWP of the pressure system that it is protecting.

The MAWP of the system shall not be greater than the lowest component pressure rating in the system.

A PRD can be of the resealable type, such as spring-loaded pressure actuated safety valves (PSVs), or of the non-resealable pressure actuated safety device (PSD) type, such as rupture disks and diaphragms (see 7.2.2). The risk associated with non-reclosing types of PRDs should be considered in the design and layout of the station (see 7.8).

The equipment should be protected against excessive pressure at all times. Consideration should be given in the design of the installation to facilitate the periodic testing and maintenance of the PRDs (see 15.4).

NOTE EN 764-7 provides guidance on the isolation of relieving safety systems.

5.3.3 Mitigation for the formation of a flammable mixture in enclosures

The formation of hazardous atmospheres resulting from anticipated hydrogen leaks or releases in enclosures should be minimised when practical.

Annex B gives examples on how this can be achieved; associated requirements can be found in 7.11.

NOTE 1 When this is not practical, see 7.4 for guidance on classifying hazardous areas and controlling ignition sources within the hazardous area.

NOTE 2 Sudden and catastrophic failure of vessels or piping systems doesn't need to be considered in this analysis when protection against such failures has already been contemplated in the vessel and piping design.

Area classification determined as per 7.4 and the protection recommendations for equipment in hazardous areas may be adjusted taking into account the means of ventilation and the means of flammable gas detection that are present. In all cases, electrical and mechanical apparatus operating in dilution volume that can exist near potential sources of release (leaks points) should be protected in accordance with 7.4.

Enclosures should be designed so as to minimise high points (or locally high points) where hydrogen can accumulate.

Flows from vents and safety relief equipment shall be piped to an appropriate location. See 5.4.2 for further information.

5.3.4 Mitigation for the formation of a flammable mixture under a canopy

The formation of hazardous atmospheres resulting from anticipated hydrogen leaks or releases under canopies should be minimised when practical.

NOTE When this is not practical, see 10.2 for guidance on classifying hazardous areas and controlling ignition sources within the hazardous area.

Area classification determined as per 10.2.2 and the protection recommendations for equipment in hazardous areas may be adjusted taking into account the availability of ventilation and the means of flammable gas detection that are present. In all cases, electrical apparatus operating in dilution volume that can exist near potential sources of release (leaks points) should be protected in accordance with 10.2.2.

Where the hazardous area above a dispenser or other hydrogen installation reaches up to a canopy, the canopy shall be designed to prevent the accumulation of hydrogen in pockets or between the canopy ceiling and roof, unless other means of protection have been taken.

Canopies should be designed so as to minimise high points where hydrogen can accumulate.

5.3.5 Mitigations which reduce the potential for ignition

5.3.5.1 General

Measures can be taken to reduce the potential for ignition. See 7.4, 7.11 and 10.2 for requirements, and Annex B for examples.

5.3.5.2 Areas subject to restriction of activity

Equipment or areas of the hydrogen fuelling station in which flammable materials are handled or stored shall be designed, operated, and maintained so that any releases of flammable material, and consequently the extent of potentially flammable atmospheres, are kept to a minimum with regard to frequency, duration, and quantity, whether in normal operation or otherwise.

In a situation in which there may be an explosive gas atmosphere, the following steps shall be taken:

— minimise the likelihood of an explosive gas atmosphere occurring around the existing sources of ignition;

— minimise the likelihood of potential sources of ignition being present.

This may be achieved through the control of ignition sources in the potentially explosive atmospheres by the restriction of activities within defined distances, referred to as "restriction distances", and by the implementation of a hazardous area, as classified according to IEC 60079-10-1, in which electrical and mechanical equipment should be appropriately classified (see 7.4 and 7.4.2).

Areas where restrictions on ignition sources should be implemented are applicable from points of potential releases of hydrogen and/or other flammable fluids, or from the exhaust of passive or active ventilation of enclosures around equipment containing flammable fluids. In some cases, the distances from the potential release source where activities should be restricted (restriction distances) are equivalent to the hazardous area as defined according to IEC 60079-10-1; in other cases, the restriction distances may be determined by other methodologies.

Only authorized persons should be allowed to enter such areas. They should be trained and aware of the hazards potentially encountered and the relevant emergency procedures.

NOTE Restriction of activity does not apply to the dispenser area, for which specific risk assessment can allow access to dispensers without any restrictions.

All portable equipment which can generate an ignition source when brought into the restricted access area (i.e. portable lamps, flashlights, communication devices) should comply with the safety recommendations for use in hazardous areas.

Requirements for grounding and bonding to prevent electric shock and electrostatic discharge are provided in 10.1.3 or 10.2.3 as applicable.

5.3.6 Mitigation of the escalation and/or impact of a fire or explosion originating from the fuelling installation

5.3.6.1 General

A list of possible mitigations is provided in Annex B.

5.3.6.2 Flame or fire detection systems

Where identified by the hydrogen fuelling station risk assessment, direct or indirect means of detection of hydrogen fires should be provided to avoid escalation due to flame impingement on neighbouring equipment by taking an appropriate action.

When detection equipment is used, this shall be set up in such a way that its functionality can be easily inspected.

5.3.6.3 Over-pressure protection of enclosures and buildings containing hydrogen systems

Enclosures and buildings containing hydrogen systems or other flammable systems shall comply with 7.11.

A risk assessment shall be conducted on enclosures and buildings containing hydrogen systems to determine the need for over-pressure protection. The risk assessment shall consider potential leak rate(s) and their frequency, extent of formation of flammable mixtures within the enclosure with consideration of ventilation, possibility of ignition, and the resultant over-pressure due to either high flow rate from pressurized systems or the ignition of flammable mixtures, including the effect of the pressure peaking phenomenon.

Where required by the risk assessment, enclosure design shall address either withstanding or venting over-pressure events as defined in 7.11.6.

NOTE Such analysis can necessitate the use of CFD, for further guidance, see NFPA 68, and for examples of CFD tools, see A.4.2.

If venting is required for over-pressure protection, then the risk assessment needs to be extended to determine the necessary area of vent openings in exterior walls or the roof of the enclosure or building.

Over-pressure venting shall be provided in exterior walls or the roof, and may consist of any one or any combination of the following:

— lightly fastened hatch covers;

— lightly fastened, outward-opening, swinging doors and/or suitable pressure relief windows in exterior walls;

— lightly fastened walls or roofs;

— walls of light material;

— continuously open vents in the exterior walls or roof of the enclosure.

Where applicable, snow loads should be considered.

The consequences of explosion relief e.g. over-pressure and possibly flying projectiles outside the opening shall be considered by risk assessment.

5.3.6.4 Emergency release of gas from hydrogen storage vessels under fire conditions

If hydrogen storage vessels are exposed to fire conditions (from inside or outside the storage area or compartment) that could lead to rupture, the station risk assessment should consider the need for thermally or pressure activated (non-reclosing) and/or manually activated valves to safely vent all the content of the hydrogen storage (see 7.8). Where such a valve needs manual activation, this should be possible from an appropriate location.

5.3.7 Mitigation of the effect of an external fire/events on the fuelling station installation

5.3.7.1 General

Measures should be taken to minimise the effect of events that have potential to take place in the vicinity of the fuelling station. A list of example measures can be found in Annex B.

5.3.7.2 Layout

The layout of a hydrogen fuelling station shall reduce to an acceptable level the likelihood of damage or injury from activities carried out on the fuelling station, or external to the fuelling station property.

This may include hazards from fires of stored fuel or other combustibles, including buildings, on or in the vicinity to the fuelling station, damage from impact of moving equipment/vehicles, or environmental hazards such as falling trees.

The general layout of installations for the storage, processing, and delivery of hydrogen should allow unhindered access and exit for the fuelling station operator, maintenance personnel, suppliers, and emergency services as appropriate.

Attention shall be paid to:

— good overview of the installation for the operating staff both from the operating building (if applicable) and from the hydrogen delivery installations;

— clear arrangement of access roads, exits and site surfacing with a view to collision hazards;

— accessibility to the installation in case of fighting any fire;

— evacuation facilities in case of incidents.

Installations should be kept free of vegetation debris and other flammable materials.

No flammable liquids shall be able to accumulate under the hydrogen storage vessels.

5.3.7.3 Fire barrier recommendations

A fire barrier may be used as a mitigation option to reduce safety distances. A list of possible mitigation measures can be found in Annex B.

If a fire barrier is used as a mitigation option, it shall be made of appropriately fire-resistant materials.

NOTE There are no appropriate ISO testing documents that cover this topic for hydrogen combustion (flames). ISO 22899-1 and ISO 834-1 include guidance on how to measure the fire resistance, however, ISO 22899-1 was derived for highly sooty and thus highly radiative hydrocarbon combustion. Hydrogen combustion does not produce soot and thus are weakly radiating compared to hydrocarbon combustion. Hence, the testing defined in ISO 22899-1 can over predict the heat load, thus represent a very conservative test, resulting in an overly designed barrier.

Consideration should be taken for the overpressure effects generated around the barrier by an unignited or ignited release. Walls intended as mitigation against fires or over-pressure should have requirements defined by risk assessment.

Any walls intended to function as a fire barrier should not include means of overpressure relief.

When used in conjunction with an outdoor storage system, the fire barrier should not generate additional risks for operating personnel in case of foreseeable incidents (see 5.3.7.6).

5.3.7.4 Mitigating against vehicular impact

Hydrogen storage and dispensers should not be located in a direct line of traffic, e.g. entrance or exit to station, or should be suitably protected against vehicular impact. The fuelling station operator shall assess impact hazards in the fuelling station risk assessment, and vehicular impact protection should be appropriate for the anticipated type and speed of vehicles in the vicinity of the hydrogen equipment.

NOTE 1 Further guidance on the protection of dispensers from vehicle traffic is included in Annex G.

NOTE 2 Plinths of adequate height and bollards of sufficient strength strategically placed are techniques typically used.

The station design shall minimise the need for vehicle manoeuvres in order to reduce to an acceptable level the risk of an unsafe situation arising through, for example, the need for vehicle reversing. Vehicle movement on the station should be clearly identified by means of signs and markings.

If deemed appropriate or necessary by risk assessment, vehicular impact protection should be supplemented by the dispensing system control protection defined in 8.2.2.8 that detects physical disturbance of the dispenser, for example by vehicle collision.

Procedural measures or vehicular impact protection should be considered to protect delivery vehicles as appropriate.

5.3.7.5 Firefighting systems

The location and quantity of firefighting equipment shall be determined based on the size of the hydrogen fuelling station and in consultation with the local fire authorities.

Where water is required for firefighting, this shall be available in adequate volume and pressure for fire protection (firefighting and cooling of fire affected equipment) as determined in consultation with the local fire authorities.

For firefighting purposes, suitable fire-extinguishing appliances shall be placed in readiness in the vicinity of hazardous areas. Details are to be co-ordinated with the local fire authorities.

Hydrogen fires should never be extinguished while allowing a release to persist. The escaping hydrogen should be shut off where possible. Where the source of hydrogen cannot be isolated from the point of the leak, hydrogen fires should be allowed to burn until the hydrogen fuel is completely consumed. Extinguishing a hydrogen fire before the hydrogen fuel is completely consumed could lead to a flammable mixture. The firefighting equipment should only be used to prevent the spread of a hydrogen fire, e.g. for cooling surrounding equipment or for cooling down the hydrogen storage to avoid rupture of the vessels. Water from the firefighting system should not be directed at or introduced into a hydrogen system vent stack. After a fire, the hydrogen system vent stack(s) should be drained of any accumulated water and inspected for damage prior to release for use.

5.3.7.6 Emergency principles and operations

Suitable roadways or other means of access for emergency equipment, such as fire department apparatus shall be provided.

The installation shall be designed so that authorised personnel have easy access at all times and have adequate means of escape in the case of emergency. Access to critical equipment (for example, operating valves) shall be restricted to authorised persons. Emergency exits shall be kept clear at all times.

Where fencing is provided to prevent access of unauthorised persons, and a passage way is necessary to allow unhindered access to and escape from the enclosure, the minimum clearance between the fence and hydrogen equipment shall be 0,8 m. Timber or other readily combustible materials shall not be used for fencing.

The gates shall be wide enough to provide for easy access and exit of authorized personnel. Gates shall not allow entry without a key or similar locking mechanism during normal operation. Gates should have access outwards and if equipped with a latch, should be equipped on the inside with fast release hardware that can be operated without a key. The fast release shall not be accessible from outside of the fence.

Consideration shall be given to the provision of an additional emergency exit where the size of fenced area or equipment location necessitates this. In cases where authorized personnel can be trapped inside fenced areas, there shall be at least two separate outward opening points of egress, remote from each other, that are strategically placed in relation to the hazard considered.

Full emergency procedures shall be established for each particular fuelling station in consultation with local fire authorities.

Where critical hydrogen equipment can be exposed to fires, which may originate from non-hydrogen related equipment, at least one of the following safety systems should be considered:

a) water sprinklers or remote watering system for cooling of equipment exposed to fire (see 5.3.7.5);

b) means for the emergency venting of hydrogen storage vessels as per 5.3.6.4.

5.3.8 Mitigation of risk to the high pressure hydrogen storage system of the vehicle being fuelled

Adequate measures shall be taken to reduce the risk of subjecting the vehicle high pressure hydrogen system to unsafe conditions, such as those outside of the operating range defined in GTR#13 (see 8.2 and Annex E).

A risk assessment shall establish the level of safeguarding needed to address the limits outlined in 8.2.1.

5.4 Safety distances

5.4.1 General

The hydrogen fuelling station layout shall incorporate adequate safety distances. The safety distance is the distance to an acceptable risk level or the minimum risk-informed separation between a hazard source and an object (human, equipment, or environment) that will mitigate the effect of a likely foreseeable incident and prevent a minor incident from escalating into a larger incident (considering all mitigation and safety measures implemented). This includes effects from hazard sources beyond the boundaries of the fuelling station.

In various regulations and industrial practices, the term "safety distance" often includes many types of distances, such as: protection distances, clearance distances, installation lay-out distances, distances to external risk sources, and distances within which restrictions apply (restriction distances).

NOTE 1 An example of safety distance definitions is given in A.5.

These safety distances are not intended to provide complete protection against catastrophic events. Protection against such events is fundamentally provided by other requirements or through an emergency response plan.

For standard equipment and events, safety distances can be prescribed by national regulations, and/or may be determined through quantitative risk assessment of a generic design. For any given fuelling station, one may also conduct a quantitative risk assessment, which can be used to understand the risks and the effects of station-specific mitigations; the result of the analysis may result in a recalculation of the safety distance to result in station-specific safety distances. If the safety distance is too large, additional mitigation or prevention measures should be considered and the safety distances may be re-calculated using a quantitative analysis.

NOTE 2 The benefit of conducting quantitative analysis is that it generates safety distances that are specific to the fuelling station/site that is analysed.

NOTE 3 The quantitative analysis is used to demonstrate that the fuelling station does not pose unacceptable risk to specific targets, taking into account the design and mitigation features of the actual installation. Acceptable quantitative techniques include quantitative risk assessment (QRA) and consequence modelling (i.e., a QRA without quantification of the probability of scenarios). The analysis uses a combination of information and data regarding the fuelling station design and operation, validated physical models, and probabilistic models that meet the criteria discussed in the remainder of this clause.

Use of a common toolkit, preferably validated for hydrogen, is recommended.

NOTE 4 Examples of safety distance toolkits are given in Annex A. One such toolkit has been used to prepare a series of example risk assessments to iteratively determine safety distances for example fuelling stations with varied country specific inputs (see A.6).

5.4.2 Safety distances relating to hydrogen vent stack outlets

The vent outlet location (height; distance to exposures) shall be such that the limits for thermal radiation and over-pressure effects of ignited vented gas are not exceeded under any foreseeable venting situation considering unfavourable expected wind conditions. The safety distances for vented gas from liquid hydrogen systems shall take into consideration the density of the gas.

The thermal radiation and overpressure effects of ignited vented gas (immediate or delayed ignition) shall be considered for the anticipated vented gas.

Hydrogen concentration at windows, openings, air intakes and at locations where persons or personnel may be present should not exceed 4 % in air (100 % LFL), unless a lower concentration of hydrogen in air is required by risk assessment.

NOTE 1 Calculations can be performed according to the risk assessment toolkits detailed in A.4.

NOTE 2 See 7.8 for further requirements relating to hydrogen vent stacks.

5.5 Protection measures for non-hydrogen hazards

5.5.1 General

In addition to the hazards related to hydrogen supply, storage and dispensing on the fuelling station site, other non-hydrogen hazards shall be addressed. The risk assessment should identify measures taken to protect against the specific hazards listed below, where applicable:

— working at heights (see 7.3.3.4);

— asphyxiation (see 5.5.2);

— emergency egress routes out of enclosures or vaults (see 5.5.3);

— electrocution (see 10.1);

— moving machinery (see IEC 60204-1);

— anti-whip measures for hoses (see 5.5.5);

— noise (see 5.5.6).

Additional examples of non-hydrogen hazards typically encountered at fuelling stations are listed in B.5. These hazards, as well as any other hazards unique to a particular fuelling station system or site should be considered and addressed when appropriate.

5.5.2 Protection measures for asphyxiation hazard in an enclosure (confined space)

When an enclosure is intended to be entered and contains or is connected to a source of hydrogen or inert gases, that compartment shall be evaluated for the potential of an oxygen deficient atmosphere during normal or off-normal conditions.

When the potential exists for an oxygen deficient atmosphere, procedures shall be put in place to prevent this occurring while personnel are present in or entering into the compartment, or detection and notification appliances shall be provided to warn personnel of an oxygen-deficient atmosphere.

Where fixed detection and notification appliances are used, notification appliances shall produce a distinctive audible and/or visual alarm and be located outside the entrance to all locations that where the oxygen-deficient condition could exist.

Where portable detection and notification appliances are used, a means of testing the gas composition inside the container (main enclosure) without opening the container door should be provided. This can be, for example, a set of external connection points to attach a gas detector sensitive to oxygen concentration (asphyxiation), hydrogen concentration (flammable mixtures), and, if necessary, other constituents likely to be present in the process. These external connection points should be routed inside the container to locations where these constituents would be likely to be present.

Hydrogen piping and equipment shall be isolated, depressurized and made safe prior to repair or replacement of components. Vent gas and purge gas shall be exhausted outside of the hydrogen compartment before and after replacement or service work requiring hydrogen depressurization and purge.

5.5.3 Protection measures for emergency egress from enclosed spaces

Exterior access doors should be secured against unauthorized entry.

NOTE 1 This can be done globally by securing the perimeter fence access, or locally by securing the enclosure(s). Refer to IEC 60204-1, the national electrical code and/or the national occupational safety code for local requirements.

Locks or latches on emergency doors shall not require the use of a key or a tool for the operation from the egress side. Where access into enclosed spaces e.g. equipment containers or vaults (see 7.3.3.3) is possible, a personnel access way with adequate space to ensure a permanent escape route shall be provided. The travel distance from points of maintenance inside an enclosed space to an emergency egress point should be appropriately minimised to be consistent with risk assessment, otherwise multiple means of egress should be provided.

NOTE 2 Egress recommendations are not applicable when all operation and maintenance-related work is performed from the exterior of the enclosure.

5.5.4 Ingress protection measures

The potential hazards and risks due to ingress of water, dirt/dust, or people into enclosures shall be assessed. If such potential hazards or risks exist, then, according to 7.11, the enclosure shall meet appropriate measures of IEC 60529 to mitigate these hazards and risks. The rating shall be verified per the test methods in IEC 60529.

NOTE 1 Components and equipment individually protected to the levels defined by this assessment do not need to be enclosed, and subsequently enclosures not intended to provide weather and personnel protection can be exempt from meeting an IP rating.

NOTE 2 IEC 60529 does not directly address ice, sleet, snow, saline atmosphere, or other conditions that can be encountered in outdoor applications. A "W" in the third character of the IP code indicates "weather conditions", however no specific requirements are provided. IEC 60068-1 contains additional guidance on environmental testing.

5.5.5 Protection measures for hose whip

For working pressures in excess of 4 MPa, hoses assembled shall be provided with a suitable restraining cable, sleeve, or device, properly fitted to an anchor point on each end of the hose to restrain the hose in the event of a hose assembly failure. Guidance is available from ISO 14113.

Other anti-whip measures, for example, identifying failure of a hose assembly through the control system and isolating the supply of gas (see 8.2.2.5) may be used in place of restraining devices where appropriate.

5.5.6 Protection measures for noise

It is presupposed that the sound pressure level and sound power level under normal operating conditions do not exceed relevant local limitations. Events such as the opening of a relief valve, or separation of the hose break-away device in the case of a drive-away event, etc. are not considered normal operation.

5.5.7 Protection against exposure to extremely cold or hot temperatures

Processes within the hydrogen fuelling station may operate at extremely cold temperatures or very hot temperatures.

Liquid hydrogen storage and processing systems operate below −250 °C, and hydrogen dispensing system precooling systems (including refrigerant systems, if used) typically operate at temperatures below −40 °C. Conversely, hot surfaces may be encountered on processing equipment (i.e., compressors and pumps) or due to solar exposure.

In addition to possible exposure of workers during maintenance, the risk to the general public in the dispensing area shall be assessed, particularly with fuelling assembly which is handled as part of vehicle fuelling. If people come in contact with surfaces at these extremely cold temperatures, injury may occur, so this potential hazard shall be considered as part of the risk analysis.

NOTE See ISO 13732 for further guidance.

Examples of countermeasures to prevent exposure to cold temperatures are (but not limited to) the following:

a) protective coverings or insulation on piping or components with cold surfaces;

b) fences, guards, cabinets, or enclosures on hydrogen systems operating at cold temperatures;

c) appropriate PPE (gloves, etc.) for workers;

d) signage, as appropriate (see 13.2).

6 Hydrogen supply safety and operation

6.1 On site generation

6.1.1 Hydrogen generators using water electrolysis

Hydrogen generators using water electrolysis shall be installed according to the manufacturer's instructions and should comply with ISO 22734 or be designed in accordance with a suitable national/regional standard(s).

6.1.2 Hydrogen generators using fuel processing technologies

Hydrogen generators using fuel processing technologies, including ancillary hydrocarbon storage and pipework, shall be installed according to the manufacturer's instructions and should meet the requirements of ISO 16110-1 and references therein, or be designed in accordance with a suitable national/regional standard(s).

Storage of hydrocarbon fuels shall be sited to minimise risk to personnel, local population and property. Consideration should be given to the location of any potentially hazardous processes in the vicinity, which could jeopardise the integrity of the hydrocarbon and hydrogen storage installation.

6.2 Hydrogen delivery

6.2.1 Gaseous hydrogen supply by tube trailers and multiple element gas containers (MEGC)

Gaseous hydrogen can be delivered on site by tube trailers or MEGC. Trailers can either deliver to storage vessels at the fuelling station site or remain at the site and be replaced when the inventory of the hydrogen product in the trailer is low. Gaseous hydrogen may also be delivered on site in transportable gas storage devices containing hydrogen absorbed in a metal hydride storage system. In such cases, ISO 16111 should be used to ensure safety of the metal hydride storage system.

The tube trailer or MEGC stationing area should be level and shall support the front and rear ends of the tube trailer or MEGC in a designated area or unloading bay. The area shall be kept free of vegetation, debris, and combustible materials.

The foundation under a tube trailer or MEGC remaining on site should be made of reinforced concrete, or any other suitable non-combustible material.

A bump stop, such as lintels, or equivalent shall indicate normal tube trailer or MEGC position in the unloading bay when a driver needs to reverse into the bay.

A designated temporary tube trailer or MEGC parking location should be provided for carrying out tube trailer or MEGC exchange without interfering with fuelling operations, unless the fuelling activity is fully suspended during the tube trailer or MEGC exchange operation. Hydrogen tube trailers or MEGCs should not be stationed outside of the designated trailer unloading bays.

The location of the transfer panel or pressure reducing station shall be accessible only to authorized persons.

Means to bond tube trailers and MEGCs to the same potential as the fixed storage hardware shall be provided (see 10.2.3).

When the offloading hose(s) is disconnected, any gaseous hydrogen released shall be discharged through a vent stack to an appropriate location.

The delivery of gaseous hydrogen shall follow a pre-defined, written procedure.

NOTE Examples of gaseous hydrogen delivery procedures are included in the document PGS35.

A risk assessment of the hydrogen delivery process shall be carried out (see 5.2). As a minimum, the risk assessment should consider:

- the need for an emergency shutdown system that can stop the filling process once activated, including the need for interaction with air driven valves on the tube trailer as applicable;
- emergency procedures required during the delivery process;
- the need to preclude access to the public during deliveries;
- the need for isolation valves at the fill point;
- measures taken for the prevention of over-pressurisation of the hydrogen storage;
- the design of the connection points to ensure proper connection/disconnection between the transport storage and the site storage;
- detectability of leaks during the delivery process;
- measures taken for the protection against hose rupture during transfer (see 5.5.5);
- the need for hazardous areas in and around the delivery area (see 7.4);
- control of the hydrogen flow rate, if applicable; and

— the need for appropriate signage during the filling process, and at the fill connection point (see 13.2).

6.2.2 Liquid hydrogen supply by tanker

6.2.2.1 Liquid hydrogen storage layout and design features

The liquid hydrogen storage tanks should comply with ISO 21009-1 or be designed in accordance with a commonly used national/regional standard.

Above ground liquid hydrogen storage and related equipment shall be located in a well-ventilated area to minimise the consequence of an accidental leakage. If any protective structures are used to reduce the safety distances, they shall be designed to avoid escalation of an ignited hydrogen release. The consequences on overpressure in case of ignition and deflagration to detonation transition (DDT) should be assessed.

Underground liquid hydrogen storage and related equipment shall require additional measures to be taken according to the risk assessment.

Connections to bulk storage systems and equipment controls necessary for filling purposes should be located in close proximity to each other and in such a way that the storage tank fill control valves and delivery vehicle controls are accessible from the delivery vehicle operator's position.

Means shall be provided to minimise exposure of personnel to piping operating at low temperatures and to prevent air condensate from contacting piping, structural members and surfaces not suitable for cryogenic temperatures.

Uninsulated piping and equipment, which operates at below air condensation temperature, shall not be installed above asphalt surfaces or other combustible materials in order to prevent contact of liquid air with such materials. For the purposes of this document, asphalt and bitumastic paving shall be considered combustible. If expansion joints are used, fillers shall also be made of non-combustible materials. Drip pans may be installed under uninsulated piping and equipment to retain and vaporise condensed liquid air.

Surfaces located under all uninsulated pipe and pump connections carrying hydrogen at cryogenic temperature with the possibility of air condensation shall be constructed of non-combustible materials as per 7.2.2.

6.2.2.2 Hydrogen and material compatibility at cryogenic temperatures

Equipment and components that are to be used for handling liquid hydrogen and other gases under cryogenic conditions shall meet the material requirements of the equipment and component standards specified in 7.1.2. Guidance for material compatibility in cryogenic service is given in ISO/TR 15916, ISO 21010 or ISO 21028-1.

6.2.2.3 Liquid hydrogen transfer area

The delivery of liquid hydrogen shall follow a pre-defined procedure.

NOTE An example of a liquid hydrogen delivery procedure is included in the document PGS35.

The liquid hydrogen transfer area shall be clearly defined.

Means to bond liquid hydrogen delivery vehicles to the same potential as the fixed storage hardware shall be provided (see 10.2.3).

The liquid hydrogen transfer area should be designated as a "NO PARKING" area.

The connection point in the transfer area should be protected sufficiently against a vehicle crash from either the delivery vehicle, any traffic on the fuelling station or other traffic (e.g. vehicles from roads not part of the fuelling station).

A risk assessment of the hydrogen delivery process should be carried out (see 5.2).

The risk assessment should consider:

— the need for an emergency shutdown system that can stop the filling process once activated;

— emergency procedures required during the delivery process;

— the need to preclude access to the public during deliveries;

— the need for isolation valves at the fill point;

— measures taken for the prevention of over-filling or over-pressurisation of the liquid hydrogen storage;

— safe connection/disconnection of the filling hose(s); and

— the need for appropriate signage during the filling process, and at the fill connection point (see 13.2).

6.2.2.4 Tank foundation and supports

Where liquid hydrogen storage tanks are required to be elevated, the tank supports shall be non-combustible structures, with an appropriate fire resistance according to risk assessment or local requirements, capable of withstanding damage by cryogenic liquid spillage.

The foundation supporting the liquid hydrogen storage tanks shall be designed to prevent pooling of liquid hydrogen or any other liquid fuel under the tank.

The tank foundation shall be designed to withstand the weight of the liquid hydrogen storage tank, its contents and other possible loads applied by wind, snow, seismic, frost heaving, etc.

The foundation on which the liquid hydrogen storage tank is installed shall be made of concrete or any other suitable non-combustible material. The risk assessment should consider the need to direct a leak away from areas that could increase the hazard (for example buildings, occupied areas, or sewers).

The tank(s) shall be secured to the foundation, with the foundation and supports able to withstand the forces that can be anticipated for the location.

NOTE National regulations can request that the design and implementation of the foundation be reviewed and/or inspected by a third-party prior to operation.

6.2.2.5 Liquid hydrogen delivery lines

Flexible hoses used for liquid hydrogen delivery should comply with ISO 21012.

Liquid hydrogen delivery lines shall have a device, such as a non-return valve or an emergency isolating valve, preventing backflow from the ground (bulk) storage tank in case of hose rupture. Means to ensure that emergency isolation valves can be actuated in case of leaks in the hydrogen delivery lines shall be provided.

The location of safety shut off valves in liquid hydrogen service shall be such that their actuators do not risk being blocked by accumulation of ice in case of a foreseeable hydrogen leak or release.

Means to immobilize the trailer while the fuelling hose(s) is connected shall be provided.

6.2.2.6 Piping, fittings, valves, regulator for cryogenic service

Valves used for cryogenic service is should comply with ISO 21011.

6.2.2.7 Pressure relief devices

Liquid hydrogen systems and equipment shall be protected from over-pressure e.g. by use of one or more PRD(s), or by other appropriate means (see 7.2).

PSVs shall meet the requirements of ISO 21013-1 or an equivalent national/regional standard.

Non re-closing safety devices shall meet the requirements of ISO 21013-2 or an equivalent national/regional standard.

Sizing and capacity determination of liquid hydrogen system PRDs shall meet the requirements of ISO 21013-3 or be designed in accordance with a national/regional standard, such as a Harmonised standard. The different behaviour of gaseous and liquid phases shall be taken in consideration.

Pressure relief devices shall be provided to prevent over-pressure, including overpressure by thermal expansion where liquid can be trapped.

Pressure relief devices and vent piping shall be designed or located so that moisture cannot collect and freeze in a manner which would interfere with proper operation of the pressure relief device. Vent piping shall meet the requirements of 6.2.2.10.

If a three-way diverter valve is installed to accommodate two PSVs operating, either simultaneously or alternatively, the flow area of the three-way valve shall be such that the liquid hydrogen storage tank is adequately protected regardless of the position of the diverter valve.

The three-way diverter valve should be provided with a position indicator, if appropriate, showing which PSV is "on line".

Consideration should also be given in the design of the installation to facilitate the periodic inspection and testing of the pressure relief devices.

6.2.2.8 Cryogenic pumps

Each cryogenic pump shall be provided with a vent and a pressure relief valve that will prevent over-pressurizing of the pump case under all conditions, including the maximum possible rate of cool down.

Operation in presence of cavitation shall be prevented if identified as a safety relevant factor, for instance by an anti-cavitation system activating automatic shutdown of the pump.

ISO 24490 can be used as a reference for the design of cryogenic pumps.

6.2.2.9 High pressure vaporizer

The vaporizer and its piping shall be protected with pressure relief devices.

The vaporizer should be sized for the maximum flow requirement specified for cryogenic pumps. The vaporizer system should be designed as required despite accumulation of ice due to condensation of ambient moisture.

Where necessary, a device shall be installed to ensure that cold gas temperature exiting the vaporizer cannot:

— affect the dispensing process;

— cause damage to pipe work and equipment downstream.

Heat used in the vaporizer shall be indirectly supplied utilising media such as air, steam, water, or water solutions.

Means to stop flow when a low temperature downstream of the vaporizer is detected shall be installed.

The vaporizer shall be anchored or secured, for example with sliding supports. Connecting piping and supports shall be designed to provide the flexibility needed to absorb the effects of expansion and contraction due to temperature changes.

Suitable means shall be installed on the vaporizer discharge to avoid the possibility of liquid hydrogen from entering a gaseous hydrogen storage or other equipment not designed for liquid hydrogen temperatures. A device should be fitted after the hydrogen vaporizer to avoid high pressure gaseous hydrogen back flow into the liquid hydrogen system.

When a water bath or steam heated vaporizer is used, the maintenance schedule should include a regular visual examination of shell and external tube surfaces for signs of damage, excessive frosting etc. Any defects should be reported to the supplier.

6.2.2.10 Venting from a liquid hydrogen system

All vents, including those of pressure relief devices and purge valves shall be connected to a vent stack, refer to 7.8.

The various vents from the liquid hydrogen system may be connected, but connection to vents from other systems shall be avoided to prevent any back-feed from other systems into the liquid hydrogen system.

Vent piping of cryogenic hydrogen should not be insulated to allow the maximum heat transfer from atmosphere in order to reduce the probability of cold hydrogen vent gas vapor clouds. Thermal contraction shall be accounted for.

Cold hydrogen vents from liquid hydrogen storage systems, including possibly the liquid delivery tanker, may be connected as long as properly sized per 7.8.2 with consideration of possible flow from more than one source.

6.2.2.11 Purging

Cold sections (i.e. below the boiling point of nitrogen) of liquid hydrogen installations and transfer hoses should be purged with warm (i.e. above the boiling point of nitrogen) hydrogen or warm helium prior to being purged with nitrogen.

Following installation or repair work, cold sections of liquid hydrogen installations should be purged with helium or warm hydrogen. If nitrogen is used instead of helium to remove air in cryogenic sections, the nitrogen should then be purged with helium or warm hydrogen prior to cool down with cold hydrogen for start-up to prevent nitrogen solidification.

6.3 Pipeline

The interface between the hydrogen pipeline and the fuelling station may include:

— isolation for emergency and/or maintenance;

— means for safe relief of pressure;

— means for nitrogen purging;

— pressure and/or flow regulation;

— metering;

— filtration or deodorisation equipment.

NOTE 1 The interface between the hydrogen pipeline and the fuelling station is typically located within the fuelling station boundary.

The hydrogen installation shall comply with the connection conditions of the gas supply company/the pipe network operator as applicable.

Interconnecting piping systems between the pipeline and fuelling station shall meet ISO 15649 or local/state piping code.

NOTE 2 See Clause 7 for further information.

7 Equipment and Components

7.1 General recommendations

7.1.1 Hydrogen materials

Equipment shall be designed for the expected operating conditions, and specified ambient conditions.

Components that may need to be dismounted for maintenance should be installed in such a manner that dismounting and remounting does not damage or untighten other components. If a specific procedure is to be applied to avoid this, a reference to this procedure should be made by signage.

The ability to carry out maintenance using positive or proved isolation (see 3.56 and 3.61), should be considered in the design of the hydrogen installation.

All parts that may be contacted during normal servicing and operation should be free from sharp projections or edges and projecting screw ends.

All components that are routinely serviced should be accessible for servicing and functional adjustment in position and should be replaceable during normal servicing.

Valves, instruments and other equipment requiring servicing shall not be buried, and when installed underground, shall be accessible.

Isolation valves shall be used to isolate portions of the piping system in emergencies and for routine maintenance. Where manually operated emergency isolation or vent valves are included, these shall be installed at an accessible location in the hydrogen piping so that the hydrogen flow can be shut off when necessary. Means to safely relieve pressure, purge systems with inert gas for maintenance (when appropriate), and purge with hydrogen after maintenance shall be provided.

A standard operating procedure shall ensure a safe and efficient hydrogen purging of the system with high purity hydrogen after maintenance operation of all kinds and prior to use. The purpose of the hydrogen purging is to remove any chemical and particulate contamination before restarting the plant in operation. Hydrogen gas quality analysis may be required to confirm that the dispensed hydrogen quality meets the expectation defined in Clause 9 before restarting dispensing operations.

7.1.2 Material hydrogen compatibility

The materials (steels, aluminium and polymers, etc.) utilized shall be compatible with hydrogen at the temperatures and pressures utilized. Due consideration shall be given when selecting ferrous materials for hydrogen service. Further information on the selection of materials, particularly the choice of steels resistant to hydrogen embrittlement can be found in ISO/TR 15916, ISO 11114-1 and ISO 16573. ISO 11114-4 can be used to determine the test methods for selecting metallic materials resistant to hydrogen embrittlement.

NOTE Hydrogen embrittlement is commonly addressed by material selection, conservative design (avoid yielding), manufacturing process and surface finish.

Cast iron, malleable iron and grey iron pipe and fittings should not be used due to the porosity of the material making permeation of hydrogen through the pipe and fittings a possibility.

Materials used for equipment containing liquid hydrogen shall comply with 6.2.2.2.

Vent lines, where pressurised hydrogen is not expected to be present under normal operating conditions, may use other materials not suitable for hydrogen service.

7.1.3 Other material recommendations

It is presupposed that material selection is made in accordance with local environment requirements, avoiding the use of the materials listed in the Directive 2011/65/EU (RoHS).

Care should be taken to prevent contact between dissimilar metals to prevent galvanic corrosion. Metal fittings should be compatible with metal tubing materials.

7.2 Piping carrying hydrogen

7.2.1 General

Piping used to transport hydrogen in the fuelling station shall conform with ISO 15649, or with a national/regional standard, such as a Harmonised standard, and be suitable for the anticipated cycle life. See 8.3 for operating requirements of piping in dispensing systems and dispenser fuelling assemblies. Piping shall be made of materials compatible with hydrogen service (see 7.1.2).

When required, high pressure systems shall be protected against over-pressure by pressure relief devices (PRDs) or an equivalent measure (such as an instrumental safeguarding system with an appropriate SIL level) in accordance with ISO 15649 (or the selected piping standard). See Clause 5 relative to the identification of over-pressurization risks, 7.2.1 for the selection of PRDs in gaseous hydrogen systems, and 7.8 for the design of PRD venting systems.

High pressure components shall be mounted in strict compliance with the supplier's instructions, following a well-defined assembly procedure.

High pressure piping shall be welded in accordance with ISO 15649 or with a national/regional standard, such as a Harmonised standard. This includes qualification of welders, welding procedures, etc.

Piping should be installed so it is not accidentally stepped on or used for leverage, and does not present a trip hazard for users or service personnel.

Piping that might be exposed to corrosive environments (e.g. underground pipes or pipes in trenches) shall be protected from corrosion by suitable means.

7.2.2 Pipe fittings, valves, hoses, for gaseous hydrogen

The rating of pipe fittings, valves, and hoses in gaseous hydrogen systems of the fuelling station shall be consistent with its use in the piping system (as defined in 7.2). See 8.3 for operating requirements of dispensing systems and dispenser fuelling assemblies. Materials shall be compatible with hydrogen service (see 7.1.2).

PSVs should meet the requirements of ISO 4126-1 or an equivalent national/regional standard.

Non re-closing safety devices should meet the requirements of ISO 4126-2 or an equivalent national/regional standard.

See the following documents for guidance in qualifying components for high pressure hydrogen service:

— ISO 19880-3 for valves and hose breakaway devices;

— ISO 19880-5 for hoses.

The testing specified in the above documents may be waived when sufficient evidence exists that the component is acceptable for service in accordance with ISO 15649 (or selected piping standard being used).

Valve assemblies shall comply with 7.4.2.

Piping, fittings, valves, and regulators for cryogenic service shall comply with 6.2.2.6.

7.3 Hydrogen storage recommendations

7.3.1 General

Liquid hydrogen delivery and storage system requirements are defined in 6.2.2, and gaseous hydrogen storage requirements are defined below.

7.3.2 Gaseous hydrogen storage vessels

Storage vessels for the storage of hydrogen gas should be manufactured in accordance with a commonly used national/regional standard and designed for the anticipated cycle life. Buffer storage may include hydrogen absorbed in a metal hydride storage system.

If buffer storage vessels of different design pressures are interconnected, they shall be protected in such a way that vessels rated for a lower pressure cannot be over-pressurized due to any malfunction.

The design of the buffer storage installation shall include appropriate means to prevent failure in the case of fire when deemed necessary by risk assessment. Suitable prevention methods may include one or more of the following:

— product venting systems, such as thermally activated pressure relief devices (TPRDs);

— thermal shielding or fire barrier;

— inability for a flammable liquid to pool under the vessel;

— fixed firewater protection.

NOTE 1 Composite storage vessels can require increased protection compared to metallic vessels.

The vessel(s) shall be secured to the foundation, with the foundation and supports able to withstand the forces that can be anticipated for the location.

The layout design of the gaseous hydrogen buffer storage vessels and piping shall consider the risk from direct impingement of jet flames from potential leak points or vents onto an adjacent vessel. The station risk assessment shall include mitigation considerations about deflagration to detonation transition (DDT) in the compressed hydrogen storage area.

Each group of buffer storage vessels that may be isolated with manual or automatic valves, should be equipped with their own set of safety devices.

NOTE 2 When hydrogen is delivered in transportable cylinders, tube trailers or MEGCs, safety relief devices within the cylinder/group of vessels are not always included.

However, when transportable cylinders, tube trailers or MEGCs are incorporated into a fuelling station, following appropriate risk assessment that addresses the potentially different design considerations, particularly pressure cycling, any on-site compression system that may compress hydrogen into such a system should include a set of safety devices to protect the storage tube(s) from over-pressurization.

7.3.3 Gaseous hydrogen storage siting recommendations

7.3.3.1 Ground storage

When stored above ground, gaseous hydrogen buffer storage vessels or assemblies shall be situated in the open air or a suitable enclosure or building (see 5.3.6.3).

The foundation for a gaseous hydrogen storage vessel shall be appropriate to accommodate the weight of the equipment placed on it and shall be made of concrete or any other suitable non-combustible material. Foundations for gaseous hydrogen storage vessels should be designed and constructed to prevent frost heaving where applicable. In addition, if onsite hydro-testing is anticipated, then the foundation shall be designed to withstand the weight of the vessel when filled with water.

7.3.3.2 Buried underground storage

Buried hydrogen storage vessels shall be adequately protected against corrosion.

Buried process connections shall be installed in accordance with 7.2.

The design and installation of the buried hydrogen storage shall take into account requirements for maintenance and inspection (see 14.9).

7.3.3.3 Below ground vaults

It is presupposed that below-ground vaults constructed on-site are designed in accordance with a national building code. Inspections should be conducted to verify structural strength and compliance of the installation with the approved design. Consideration should be given to soil and hydrostatic loading on the floors, walls and roof, anticipated seismic forces, uplifting by ground water or flooding, and to loads imposed from above, such as traffic and equipment loading on the vault roof.

The vault walls should be higher than the gaseous hydrogen buffer storage vessels contained therein. There should be no openings in the vault enclosure except those necessary for access to, inspection of, and filling, emptying, ventilation, and venting of the gaseous hydrogen buffer storage vessels.

Ventilation or other measures shall be provided to prevent accumulation of leaked hydrogen gas.

Ingress of water shall be prevented, or a drainage system to manage water ingress shall be provided. If installed at grade and subject to vehicle loading, the top shall have a metal grating or another roof with sufficient strength to carry vehicle loading.

If manual intervention is required for safe operation or in an emergency, manually operated valves or controls should be located above ground and accessible to authorized personnel only.

There shall be sufficient clearance between the gaseous hydrogen buffer storage vessels and the vault to allow for inspection and maintenance of the vessels and their appurtenances.

Where adjacent vaults share a common wall, the common wall should be liquid and vapour tight and should be designed to withstand the load imposed when the vault on either side of the wall is filled with water.

Pressure relief devices shall be vented to an appropriate location as specified in 5.3.3.

At each entry point to a vault, a warning sign indicating the procedures for proper entry into confined spaces shall be posted. Entry points should be secured against unauthorized entry and vandalism.

7.3.3.4 Roof top or canopy installation of gaseous hydrogen systems

7.3.3.4.1 General

Where hydrogen generators, compressors, gaseous buffer storage vessels, piping systems and their related accessories are located on building or canopy roofs, the installation should meet the recommendations of 7.3.3.4.

Equipment installed at heights should have walkways and working platforms to facilitate worker access and be accessible for inspection and maintenance. Measures to address the hazards of working at heights shall be taken to protect workers from falling off the roof, and to protect persons below the equipment/elevated from falling objects.

Access to the building or canopy roof should be provided in accordance with ISO 14122.

7.3.3.4.2 Roof structural recommendations

It is presupposed that the roof structure supporting the hydrogen equipment and vessels is constructed in compliance with the local national building code with due consideration for the added weight of the equipment in addition to other static and dynamic loadings.

7.3.3.4.3 Gaseous hydrogen storage mounting

Gaseous hydrogen buffer storage vessels shall be mounted according to the manufacturer's instructions. They should be individually supported in a cradle or similar structure or within a rack that provides individual vessel support.

The vessel mounting structure shall be securely affixed to the roof.

7.3.3.4.4 Other hydrogen equipment mounting

Other hydrogen equipment shall be securely mounted on the gaseous hydrogen storage mounting structure or separately mounted to the roof.

7.3.3.4.5 Fire protection

Gaseous hydrogen equipment and buffer storage vessels on the roof of an occupied building shall meet the following recommendations to avoid escalation from a building fire:

— measures shall be provided to avoid overpressure/rupture of the hydrogen storage systems in case of fire, such as fire detection, emergency device to empty the storage, such as thermally activated pressure relief devices (TPRDs), or a sprinkler system;

— the supporting roof structure and columns below the hydrogen equipment and storage footprint area shall have a minimum fire-resistant rating, not less than that required by the type of construction for the building.

7.4 Hazardous areas (with potentially flammable mixtures)

7.4.1 General

Hazardous areas shall be identified and classified according to IEC 60079-10-1 or other regionally accepted methodologies.

Hazardous areas are applicable from points of potential releases of hydrogen and/or other flammable fluids including possibly flammable mixtures in ventilation exhausts from enclosures or building with hydrogen or processing equipment.

See 5.3.2 for identifying issues associated with the potential formation of hydrogen and/or other flammable mixtures and approaches to minimise the hazard.

A shelter or a canopy with a flat roof surface and with the sides sufficiently open to allow free passage of air through all parts should be considered well ventilated and may be treated as an outdoor area (i.e. "medium" degree and "good" availability). If the canopy is within the height of the hazardous area, the hazardous area should extend to the border of the canopy. See 5.3.4 for mitigating hazards due to the formation of flammable mixtures under canopies.

Where enclosures are placed around hydrogen equipment to contain and/or control hazardous areas, these should be in accordance with 5.3.6.3 and 7.11. The potential release of flammable fluids from either the natural or active ventilation exhausts from enclosures should be considered in the risk assessment and, if appropriate, in the classification of hazardous areas. Locations below the ventilation exhausts from enclosures may be excluded from consideration. Means to limit the quantity of hydrogen that could be released within the enclosure should be considered, for example, by the use of automatic isolation valves in the hydrogen supply to the enclosure.

The potential for flammable gases leaking from one compartment within an enclosure to another adjacent compartment (of the enclosure) shall be considered in the risk assessment and, if appropriate, in the in the classification of hazardous areas (see 7.11.4.)

Area classification around venting system outlets should be defined on the basis of a foreseeable flow rate, under normal operating conditions, but also considering reasonable potential upset or fault conditions as defined in 7.8.3, with the exception of fire conditions and voluntary, manually initiated response to emergency conditions.

7.4.2 Equipment in hazardous areas

The energy required to ignite a mixture of hydrogen and air is extremely small (see IEC 60079-20-1). Almost all electrical equipment can be an ignition source for a hydrogen/air mixture if proper protection is not implemented.

See 10.2 for bonding and grounding of equipment, the selection and installation of electrical equipment, and the protection of ignition flammables from static discharge.

In addition to the electrical ignition sources, mechanical equipment can also ignite hydrogen and other flammable fluids. Examples of such ignition sources are as follows:

— sparks from rotating fan blades; or

— hot surfaces.

Mechanical equipment and mechanical parts of electrical equipment installed in hazardous areas shall be protected in accordance with the ISO/IEC 80079 series if such parts are not protected according to the requirements in the IEC 60079 series.

NOTE As an example, it is sufficient that an explosion protected electrical fan complies with the requirements for electrical machines according to IEC 60079-0.

7.5 Hydrogen compressors

7.5.1 General

Each compressor shall be equipped with pressure relief device(s), or equivalent safety-instrumented systems to prevent overpressure.

All equipment shall comply with 7.4.2.

Compressor enclosures shall comply with 5.3.2.3 and 5.3.6.3.

The compressor and ancillary systems, where applicable, shall be consistent with use in the piping system described in 7.2. Sufficient compensation for potential vibration or movement of the compressor should be provided such that piping systems are not damaged and that leaks do not occur.

Compressors should be designed with particular reference to hydrogen service and to minimise the introduction of contaminants. The ingress of air at the inlet to the compressor shall be avoided at all times to prevent the formation of flammable mixtures.

Risks associated with installation, maintenance, and operation of compressors shall be assessed, and countermeasures shall be defined and implemented to protect equipment and prevent potentially hazardous events from occurring. Each compressor should be equipped with means to fully depressurize all parts of the system for maintenance purposes.

When the risk mitigation review of a compressor system recommends the use of an inert purge, means to purge the compressor(s) with inert gas prior to maintenance operations shall be provided, including a written procedure, to enable effective inerting.

7.5.2 Vibration and movement

Sufficient compensation for vibration and movement should be provided between interconnected systems at a hydrogen fuelling station and between the hydrogen gas supply piping and the compressor suction piping to avoid leaks caused by vibration and movement.

Any vibrations that may affect the strength of the piping, fitting and component shall not be transferred to the piping work.

7.5.3 Control and monitoring

7.5.3.1 General

Safety controls shall be installed to ensure temperature and pressure levels do not exceed or fall below set operating levels, for instance for inlet pressure, discharge temperature and pressure, with the control system instigating an alarm and/or shutdown as appropriate, or appropriate alternate measures.

In addition to the instruments and controls normally provided for gas compressing systems, the following specific safeguards for hydrogen should be considered.

7.5.3.2 Inlet pressure

Ingress of air at the inlet to the compressor shall be avoided at all times to prevent the formation of a flammable mixture. If this condition is no longer guaranteed, the compressor shall be shut down.

For example, the inlet pressure should be monitored by a pressure indicator/switch, with the control system instigating an alarm and/or shutdown as appropriate, to avoid a vacuum in the inlet line and consequent ingress of air. This pressure indicator/switch should cause the compressor to shut down before the inlet pressure reaches atmospheric pressure.

If there is a possibility of oxygen contamination under normal operating conditions due to a low inlet pressure, measurement of the oxygen content in the hydrogen can be considered as a mitigation measure during risk assessment. For example, should the oxygen content reach a volume fraction of 1 %, the compressor can be automatically shut down. Alternative means can be taken to prevent critical situations.

7.5.3.3 Discharge temperature

The temperature after the final stage of compression, or the temperature after the cooler, where fitted, shall be monitored by a temperature indicator/switch with the control system instigating an alarm and/or shutdown as appropriate at a predetermined maximum temperature.

7.5.3.4 Discharge pressure

The pressure after the final stage of compression shall be monitored by an indicator/switch with the control system instigating an alarm and/or shutdown as appropriate, or initiate alternative actions, such as recycling, at a predetermined maximum pressure which is below that of the over-pressure protection.

7.5.3.5 Cooling water alarm

The cooling water system should be monitored by an indicator/switch, with the control system instigating an alarm and/or shutdown as appropriate in case of low pressure, flow or high temperature.

7.5.3.6 Purge gas/pressurisation protection of electrical equipment

Where the motor and auxiliary equipment are purged by an inert gas, or protected by pressurisation with compressed air or an inert gas, low pressure/flow shall be indicated by an alarm, which shall be arranged to shut down the motor and auxiliaries as required by IEC 60079-2.

7.5.3.7 Purge gas/pressurisation protection of crankcases

Where the compressor crankcase is purged by an inert gas, or protected by pressurisation with compressed air or an inert gas, low pressure/flow shall be indicated by an alarm, which shall be arranged to shut down the compressor.

7.6 Instruments for gaseous hydrogen systems

Instruments shall be rated for service in the hydrogen system. The pressure and temperature ratings of the instrument casing shall comply with the requirements of the piping system (as defined in 7.2).

Instruments dedicated for various functions on the fuelling station should be verified for their intended purpose.

Instruments and gauges shall be designed and located such that, in the event of a leakage or rupture, and possible subsequent fire, the risk to personnel is minimised. Examples are the use of snubbers, safety "glass" and blowout backs on pressure gauges.

Cabinets or housings containing hydrogen control equipment should be designed to prevent any accumulation of hydrogen gas.

The installation and use of instruments shall be consistent with the electrical area classification and shall, when applicable, comply with applicable provisions of the IEC 60079 series.

7.7 Filters for gaseous hydrogen

The rating of pressure-bearing housings in gaseous hydrogen systems of the fuelling station shall be consistent with its use in the piping system (as defined in 7.2).

Filters and separators shall be sized for the maximum hydrogen gas flow and for the expected impurities in the hydrogen gas (see Clause 9), and, where appropriate, should be provided with sufficiently large sumps or collecting tanks. If possible, filters and separators should be combined in a single unit. The filters should have a specified separating capacity. Where liquids and condensation products require removal, consideration shall be given to the dew point of these liquids, relative to the temperatures to which hydrogen is cooled prior to passing through the separator, to avoid freezing and blockage.

Clogging of the filter insert in the main hydrogen gas flow shall be monitored. This may be done by regular preventive maintenance, by regular operational checks, or by monitoring equipment, e.g. differential-pressure gauges indicating a maximum value, as specified by the filter supplier.

The filters and separators shall be arranged and installed in such a way that it is possible to open and empty them in a safe manner. In the event of frequent opening and closing operations, the filters and separators should be fitted with quick opening and closing fittings.

Where a separator is needed for removing liquids and condensation products, a manual or an automatic discharging device, if applicable comprising a sump, shall be provided.

The filter shall be accessible for inspection, cleaning and replacement of the filter element.

7.8 Gaseous hydrogen vent systems

7.8.1 General

The venting of hydrogen is typical in a hydrogen fuelling station, and measures shall be taken to ensure that hazards arising from venting are minimised.

The requirements of 7.1 and 7.2 shall be applied to pressure-bearing piping of the vent system.

The vent discharge piping system shall be designed to not rupture in the event of ignition of a flammable hydrogen air mixture in the system.

The vent system shall be designed for the thrust of the discharging jet. The reaction of this thrust on the PRD nozzle forces and moments shall also be addressed to ensure that the PRD is properly supported and that the integrity of the high pressure piping system and the vent pipe are maintained.

Vent stacks shall be bonded and grounded according to 10.1.3. Vent stacks should be designed to be able to carry lightning currents without adverse effects, unless otherwise protected (see 10.1.4).

Hydrogen vent piping and associated valves/devices/systems shall be electrically grounded and bonded as required by IEC 60204-1 to give protection against the hazards of the development of electrical charges, stray electrical currents, static electricity and lightning.

Hydrogen venting systems shall be designed and sized according to 7.8.2 through 7.8.4.

Vents from high pressure systems may be connected as long as properly sized per 7.8.2 with consideration of possible flow from more than one source.

NOTE 1 For the venting of hydrogen from liquid hydrogen systems, see 6.2.2.10.

The position of hydrogen vent stacks shall be taken into account in the layout of the installation and shall be such that the vent may be used for operation, maintenance and to allow depressurisation in emergency situations [for example, when there is a fire in the vicinity (see 5.3.6.4)] without creating hazardous conditions. Consideration shall be given to the temperature of the hydrogen that is vented, and the effect that this can have on the density of the vented gas.

The vent outlet location shall be arranged to discharge to open air, and so as not to generate a hazard for persons, neighbouring structures, or personnel areas, and should consider safety distances to electrical lines and other ignition sources, air intakes, and building openings. The vent stack shall not discharge where accumulation of hydrogen can occur, such as below the eaves of buildings.

Hydrogen dispersion and radiated heat calculations shall be carried out to establish the location and height of vent stack exits. Further detail is provided in 5.4.2.

Flame arrestors are not needed for vent systems that follow the requirements of this document.

NOTE 2 Flame arrestors are typically used on combustion systems such as a pre-mixed air fuel supply to a hand torch. Flame arrestors can apply a backpressure to increase velocity at the “fire check”.

Back pressure devices used on hydrogen vent systems with gas recovery or atmosphere exclusion systems should be engineered for the specific hydrogen vent recommendations.

NOTE 3 EIGA document 211/17 and CGA G-5.5 provide further guidance.

7.8.2 Vent outlet

Outlets may be vertical upwards, horizontal, or in any direction in between. Caps should not be used.

Vent stacks shall be designed to avoid the collection of water (ice) and organic debris which may impede or impair the venting process.

Drains and water accumulation points shall be protected from freezing to avoid blockage or breaking of vent stack. Consideration shall be given in the fuelling station risk assessment to the prevention of accumulation of water, including that from condensation, in the vent stack outlet (or other requirements for protection against freezing).

Where the risk assessment deems appropriate, vent systems, particularly those with a vertical outlet, shall be equipped with a water drain valve at the bottom of the vent stack.

Hydrogen vent systems shall be protected against the hazards caused by entering of debris, animals and/or insects inside the vent pipes resulting in potential obstruction. Vent protectors equipped with wire screens (for example, mud dauber fittings) may be used provided the proper mesh size is selected to avoid flow obstruction or blockage.

For horizontal outlets (T-vent or single outlet vent), the cut plane shall not face downward if the exit velocity is sufficiently high for the direction of the release to be determined by the orientation of the cut plane.

The outlet piping may be slightly inclined downwards to avoid entry of water if measures are taken to avoid that the plume or jet will be pointing downwards, e.g. through low velocity release, or by use of a cut plane facing upwards for exit velocities that are sufficiently high for the direction of release to be determined by the orientation of the cut plane.

NOTE 1 For vertical venting, the higher the discharge velocity the smaller the necessary safety distance around the vent as the higher momentum is less effected by cross-winds to bend the flammable plume to the side or ground.

NOTE 2 For T-venting, the smaller the discharge velocity the smaller the safety distance recommendations in the axis of discharge as the lower momentum reduces the projected footprint of the potentially flammable plume.

7.8.3 Vent sizing

The vent piping diameter should not be smaller than the diameter of any pressure-relief device (PRD) outlet, and large enough that it shall not prevent the PRD from functioning properly or that it does not restrict PRD flow.

In order to calculate the pressure drop of the vent system, the maximum flow rate should be calculated as the sum of all the flows in normal operating conditions that are expected to be simultaneous, and the highest flow generated by foreseeable upset or fault conditions.

Normal operating conditions to be considered include, for example:

— for gaseous hydrogen systems:

  — venting of the fuelling assembly after fuelling a vehicle;

  — venting as part of purging or process control.

— for liquid hydrogen supply systems:

  — cool down of lines, pumps and connected equipment;

  — liquid flash and gas displacement during filling of the tank;

  — normal boil-off rate from ambient heat leak.

Foreseeable upset or fault conditions maximum flow rate should include the largest of the following independent upset conditions, such as:

— for gaseous systems:

  — emergency discharge of gaseous hydrogen buffer storage;

  — external fire;

  - malfunction of dispensing system control valve causing pressure relief valve(s) to open.
- for liquid hydrogen supply systems:
  - excessive rate of cool-down;
  - loss of vacuum;
  - malfunction of control valves in the pressure control circuits or fuelling line causing excess vapour generation in the tank;
  - venting of pumped liquid flow.

The maximum pressure drop resulting from the sum of design flows of all vent devices that could discharge into a common vent system at the same time in the worst case scenario should not exceed 10 % of the lowest set pressure of these relief valves directly at the discharge point of the affected relief valve(s), in order to prevent excessive back-pressure in the vent line from preventing the opening of the relief valve.

Limitation of noise level may need to be considered.

Back pressure devices used on hydrogen vent systems with gas recovery or atmosphere exclusion systems should be engineered for the specific hydrogen vent recommendations.

7.8.4 Multiple relief devices

Where multiple pressure relief devices (PRDs) are used, any provision made for isolating any one device (e.g. for testing or maintenance) should ensure that the remaining PRD(s) connected to the equipment provide the full relief capacity.

Acceptable methods for isolating any one of the PRDs include, but are not limited to:

- 3-way valves;
- changeover valves;
- mechanical interlocks;
- captive sequential key interlocking.

Regardless of the method used to isolate a PRD, adequate flow area of the three-way valve shall be such that the system is adequately protected regardless of the position of the diverter valve or mechanism.

A positive and obvious identification method shall indicate if a PRD is isolated from or active in the system.

Consideration should also be given in the design of the installation to facilitate the periodic testing of the pressure relief devices.

In some cases, isolation valves may be used for maintenance of pressure relief devices if the isolation valve can be locked open whenever the equipment being protected is being pressurised. Access to the lock key should be controlled and used by qualified service personnel only, with the position of the valve and the locking device checked periodically. In such cases, a bleed valve should be used to depressurize the line upstream of the PRD and ensure safety during maintenance.

7.9 Pneumatics and hydraulics

Pneumatic or hydraulic systems shall be designed so that no hazard may result from pressure losses, pressure drops.

Where applicable, all elements of the pneumatic or hydraulic systems, especially pipes and hoses, shall be protected against harmful external effects where this is required by the fuelling station risk assessment.

Instrument air from an air compressor or cylinder supply system should be supplied through control valves. A buffer volume should maintain the air pressure to allow a safe shutdown of the fuelling station should the supply lapse. Pneumatic equipment and systems should satisfy the requirements of ISO 4414.

Hydraulic control supply from pumps and pressurized supply should be supplied through control valves. Hydraulic equipment and systems should satisfy the requirements of ISO 4413.

7.10 Hydrogen purifier

The rating of pressure-bearing housings in gaseous hydrogen systems of the fuelling station shall be consistent with its use in the piping system (as defined in 7.2).

Hydrogen purification shall be provided as necessary to meet the requirements of Clause 9 under all operating conditions where vehicle fuelling is possible.

The hydrogen purifier should be designed taking into account possible contamination from the hydrogen supply system or process equipment.

7.11 Enclosures and buildings containing hydrogen equipment

7.11.1 General design

Enclosures and buildings containing hydrogen systems shall be constructed of non-combustible materials.

Requirements for the fire resistivity of the floor, walls, ceiling and any openings (doors, windows) shall be defined by risk assessment.

If the floor, walls, and ceiling are included to protect the hydrogen system from sources of fire, or to reduce safety distances from the hydrogen system to external objects due to a fire inside the enclosure, these shall have a fire-resistance rating appropriate for the scenario and, where applicable, provide time for fire brigade intervention.

The design of enclosures and buildings shall consider environmental conditions appropriate for the installation site. Where applicable, for example, the possibility of heavy rain, flooding, or snow, wind and seismic loads should be considered.

Enclosures shall meet relevant portions of IEC 60529 to prevent ingress of water or dirt/dust or exposure of people to potential hazards when the risk assessment indicates such measures are appropriate. See also IEC 60068-1 if additional environmental testing is necessary.

It is presupposed that buildings comply with applicable local building codes and regulations.

When deemed appropriate by the risk analysis in Clause 5, process vents shall be piped outside the enclosure or building and conform to 7.8.

NOTE Further guidance can be found in the outputs from the European project HyIndoor.

7.11.2 Maintenance access and possible occupancy

The design for maintenance access of hydrogen systems within enclosures and buildings shall consider risks to workers performing maintenance tasks and within the vicinity (see 5.3).

It is presupposed that buildings which are intended to be occupied during operation and/or maintenance comply with applicable local building codes and regulations.

Windows and doors should be in exterior walls and emergency exit doors shall be located so as to be readily accessible.

Access panels not designed for public access shall require tooling to open or remove.

NOTE Tooling can be as simple as an open-end box wrench.

7.11.3 Ventilation of enclosures and buildings containing hydrogen equipment

Where passive or active ventilation is relied upon for preventing ignitable mixtures, the ventilation rate should maintain a volume fraction below 25 % of the lower flammability limit (LFL), in accordance with IEC 60079-10-1. Where continuous or primary grades of release, as defined in IEC 60079-10-1, are anticipated, a lower volume fraction may be appropriate.

The equipment within dilution volumes around potential leak points, as defined in IEC 60079-10-1, shall be suitable for the area classification (see 7.4.2). The ventilation system and equipment shall comply with appropriate provisions of the IEC 60079 series.

Whenever ventilation is used, the minimum ventilation rate requirements of the system shall be determined by test and/or analysis and specified. The minimum rate of ventilation necessary to prevent the formation of a flammable mixtures due to normal and expected releases (e.g. natural leaks from fittings, or hydrogen permeation through non-metallic materials), shall be provided whenever the process contains hydrogen under pressure, whether the system is in operation or not.

NOTE 1 Leakage at welded joints is not typically considered a credible release.

Higher ventilation rates, if required to address fault management, may be provided continuously (when the system is operating) or initiated by a flammable gas detection system, for example, upon measurement of the lower activation limit complying with the recommendations of 11.2.3.

The pressure drop across the ventilation system and the maximum external pressure at the ventilation system outlet shall be taken into account as important design criteria.

Enclosures containing non-classified electrical equipment, not suitable for operation in a hazardous area, that rely on active ventilation for protection against the formation of a flammable atmosphere, shall be purged with sufficient air changes prior to the energization of such equipment.

NOTE 2 A typical start-up purge is 4 or 5 volume changes at the maximum forced ventilation rate.

Failure of active ventilation or detection of flammable gas in an enclosure at the maximum volume fraction of 25 % of the LFL of hydrogen or any other flammable gases present shall cause the shut-off of the supply of hydrogen and other flammable gases to the enclosure and the de-energization of electrical equipment not suitable for hazardous areas.

Enclosures shall be designed so as to minimise hydrogen accumulation.

Computational fluid dynamic analysis, using calculation tools validated for hydrogen, physical testing using a tracer gas, or similar methods given in IEC 60079-10-1, may be used to design the means of active and/or natural ventilation and the means/placement of hydrogen detection for providing the required protection.

7.11.4 Use of enclosures or compartments within enclosures to control hazards areas

Enclosures and compartments within enclosures may be used to separate unclassified equipment from areas housing hydrogen systems, see appropriate parts of the IEC 60079 series. Methods to prevent flammable gases from entering an adjacent area or compartment include, but are not limited to:

— maintaining the adjacent non-hazardous compartment at a relative pressure higher than the area or compartment containing the flammable gas by either pressurising the compartment to be pressurised, ventilating compartments with hydrogen systems at negative pressure, or both to achieve the required pressure differential;

— sealing between areas or compartments.

Flammable gases shall be prevented from entering adjacent compartments unless the equipment within the adjacent compartment is suitable for the resulting area classification.

When multiple purged hydrogen equipment enclosures are located in one area, the exhaust of ventilation from one hazardous area shall not be introduced into adjacent enclosure compartments without sufficient separation to sufficiently dilute potential flammables in fresh air (see 5.3.3 and A.5.2.3).

7.11.5 Electrical and mechanical equipment within enclosures and buildings containing hydrogen equipment

See 10.2 for bonding and grounding of equipment, the selection and installation of electrical equipment, and the protection of ignition due to static charge in hazardous areas.

See 7.4.2 for mechanical equipment in hazardous areas.

7.11.6 Over-pressure protection of enclosures and buildings containing hydrogen equipment

Requirements for over-pressure withstand and/or venting of the enclosure or building shall be defined by risk assessment see 5.3.6.3).

If the floor, walls, and ceiling are included to reduce safety distances from the hydrogen system to external objects due to an explosion inside the enclosure, these should have an over-pressure capability appropriate for the scenario.

Where required by risk assessment, over-pressure venting addressing the issues outlined in 5.3.6.3 shall be provided in exterior walls or the roof. Vents shall consist of any one or any combination of continuously open vents or lightly fastened covers, panels, or outward swinging doors.

Where applicable, snow loads shall be considered.

The consequences of explosion relief e.g. over-pressure and possibly flying projectiles outside the opening shall be considered by risk assessment.

8 Dispensing systems

8.1 General requirements

The hydrogen fuelling station shall have one or more dispensing systems for the transfer of hydrogen to hydrogen fuelled vehicles. The dispensing system shall prevent the allowable limits of temperature and pressure for the vehicle high pressure hydrogen system from being exceeded during fuelling.

The dispensing system shall, when necessary as determined by the dispensing system risk assessment (see 5.2), protect against faults of the control system that could result in a hazardous situation in the dispensing area or potentially damage the high pressure hydrogen system of the vehicle.

The minimum requirements for the fuelling station regarding hydrogen fuelling are specified in 8.2.

The minimum requirements for the fuelling station dispensing system piping and components, including the fuelling assembly, are specified in 8.3.

The minimum requirements for the dispensing system installation, operation, and maintenance and inspection are specified in 8.4, 8.5 and 8.6.

NOTE An example of a typical hydrogen dispenser is shown in C.1.

8.2 Hydrogen vehicle fuelling

8.2.1 Dispensing system process control

8.2.1.1 General requirements for the fuelling protocol

In order to ensure that the fuelling is conducted within the fuelling protocol process limits for vehicle compressed hydrogen storage systems (CHSS), as defined in 8.2.1.2 or 8.2.1.3 as applicable, hydrogen dispensing systems shall either:

— use an approved published fuelling protocol developed by a recognized standards development organization (SDO), such as SAE J2601 (see C.2 for further information), JPEC-S 0003;

NOTE 1 China is also developing fuelling protocol standards. The initial step in this process is documented in T/CECA-G 0018-2018.

or

— use protocols, that have been approved by the manufacturers of each vehicle to fuel at that station using that protocol. The fuelling station operator shall take measures to prevent the fuelling of vehicles where fuelling protocols are not approved by the manufacturer(s) of the vehicles using the station.

NOTE 2 Examples of countermeasures that can be employed to prevent vehicles fuelling at dispensers where the fuelling protocol has not been approved are provided in Annex F.

The station manufacturer shall ensure the nozzle and other associated dispensing system components for each fuelling point are appropriate for the hydrogen service level (HSL) (see 8.3), and the fuelling protocol being used.

The fuelling protocol shall ensure, directly or indirectly, that the maximum CHSS material temperature does not exceed 85 °C throughout the fuelling.

The fuelling protocol shall consider the possible range of temperatures of the CHSS of the vehicle prior to fuelling as well as the full range of ambient temperatures when establishing the fuelling rates to ensure that the storage system on the vehicle does not inadvertently experience an over-fill or over-temperature condition.

If necessary, the fuelling protocol shall adjust the fuelling rate and target pressure based on measured ambient and process conditions, such as dispensed hydrogen gas temperature and pressure, to ensure that the process limits listed in 8.2.1.2 and 8.2.1.3 below are maintained for the vehicle. If these conditions cannot be maintained within the limits, the fuelling shall cease.

The fuelling protocol shall include a pressure integrity check prior to fuelling (see 8.2.1.6), which may also be used to determine the pressure of hydrogen within the vehicle prior to fuelling.

The fuelling protocol should be appropriate for the range of vehicle tank capacities that are intended to be fuelled (see for example C.2).

Measures should be taken to ensure that sequential fuelling of the same vehicle does not lead to an unsafe situation, for example using different fuelling protocols, at different fuel temperatures, or certain fuelling protocols (see C.2).

The dispensing system may either conduct the fuelling using communications with the vehicle as part of the fuelling process (see 8.2.1.4) or conduct the fuelling protocol without communications with the vehicle. The fuelling protocol may have provisions for both communications and non-communications fuelling, see C.3 for an example.

8.2.1.2 Fuelling protocol process limits for light duty vehicle dispensing systems

Public hydrogen stations shall be designed in accordance with the requirements of this clause. As a minimum, the station must be safe to fuel a GTR#13 compliant vehicle (see the relevant limits in Annex D), taking into account alternative local regulations for vehicles to ascertain more stringent requirements for the station. Stations using fuelling protocols that could potentially be unsafe for such vehicles shall incorporate appropriate countermeasures.

NOTE 1 Examples of countermeasures that can be employed to prevent vehicles fuelling at dispensers where the fuelling protocol could be unsafe for GTR#13 vehicles are provided in Annex F.

Fuelling of vehicles not compliant with the GTR#13 should be addressed by risk assessment and, if necessary, the fuelling process limits defined in this clause should be revised accordingly.

During the fuelling process, the dispensing system shall meet the following fuelling protocol limits, or terminate the fuelling within 5 s (but not necessarily initiate an emergency shutdown per Clause 5):

— ambient temperature between −40 °C and +50 °C;

— dispenser fuel pressure less than the maximum operating pressure (MOP) (see Table 1);

NOTE 2 See 8.2.2.3 for over-pressure protection measures if a fault occurs.

— dispenser fuel temperature greater than −40 °C;

— fuel flow rate less than 60 g/s (excluding momentary excursions during the initial connection sequence - i.e. connecting the nozzle to the receptacle prior to the start of fuelling);

— where communications are used, a communicated CHSS temperature less than 85 °C;

— a maximum of 10 pauses during fuelling where the fuel flow rate drops below 0,6 g/s.

Additionally, the dispensing system shall also terminate the fuelling within 5 s if any of the following events occur:

— where communications are used, an abort or halt signal is received from the vehicle being fuelled;

— any deviations from the fuelling protocol (see 8.2.1.1) arise.

As a consequence of the pressure integrity check (see 8.2.1.6), a quantity of hydrogen may be transferred to the vehicle prior to the start of fuelling:

— the maximum hydrogen mass allowed to be transferred to the vehicle during this process should be 200 g;

— dispensing systems shall not fuel a vehicle which has a pressure lower than 0,5 MPa or a pressure greater than the appropriate vehicle NWP (i.e. 35 MPa or 70 MPa) after this process.

Following fuelling, the vehicle state of charge should not exceed 100 %.

The above limits shall also be considered as part of the dispensing system risk assessment (see 8.2.2.1), with the possibility that additional countermeasures (beyond normal termination of the fuelling) may be required to prevent these limits from being exceeded.

8.2.1.3 Fuelling protocol process limits for medium and heavy duty vehicle dispensing systems

Where hydrogen stations are designed to fuel medium and heavy duty vehicles, the requirements for 8.2.1.2 shall be met, with the following exception:

— when the dispenser has a high flow nozzle (see ISO 17268), which prevents connection to a standard vehicle receptacle (i.e. non high flow receptacle), the maximum fuel flow rate (excluding momentary excursions during the initial connection sequence - i.e. connecting the nozzle to the receptacle prior to the start of fuelling) may exceed 60 g/s where both the station and the vehicle are designed for the higher flow rate ;

Countermeasures shall be included to prevent vehicles that are not suitable for the fuelling protocol from being fuelled.

NOTE Examples of countermeasures that can be employed to prevent vehicles fuelling at dispensers where the fuelling protocol is not suitable are provided in Annex F.

8.2.1.4 Vehicle to station communications

For public H70 vehicle fuelling, hydrogen dispensing systems shall have the communications hardware and software to ensure that the fuelling is conducted within the fuelling protocol process limits for vehicles compressed hydrogen storage systems as defined in 8.2.1.2 and 8.2.1.3.

This is recommended for H35 dispensing systems as well, as there are some applications which use communications.

NOTE 1 H70 non-communications fuelling can still be used as required, for example, in the case of a fault in communications systems, or when a vehicle does not have communications systems.

The light duty vehicle public fuelling station H70 dispensing system shall be able to respond to an abort signal from the vehicle and halt the fuelling process.

The need to prevent further fuelling events following a number, defined by risk assessment, of consecutive shutdowns due to an abort signal from the vehicle should be considered.

Fuelling with communications shall either:

— use an approved, published communications protocol developed by a recognized standards development organization (SDO) such as SAE J2799, (see C.4), or

— use a communications protocol that has been approved by the manufacturers of each vehicle to fuel at the dispenser using that protocol. The fuelling station operator should take measures to prevent the fuelling of vehicles using a communications protocol that is:

  — not approved by the manufacturer(s) of the vehicles using the station; or

  — incompatible with the vehicle.

NOTE 2 Examples of countermeasures that can be employed to prevent vehicles fuelling at dispensers where the communications protocol has not been approved are provided in Annex F.

If the communications fail during fuelling, the station shall either terminate the fuelling within 5 s or the fuelling may continue without communications if allowed by the fuelling protocol.

8.2.1.5 Manual control of dispensing

The user of the dispenser should have the ability to initiate and stop the automatic fuelling process from the dispensing area.

8.2.1.6 Pressure integrity check (leak check)

Control systems on fuelling stations shall be designed to verify the integrity of the fuel hose, hose breakaway device, nozzle and connection to the vehicle before fuelling. Integrity shall be checked while the vehicle is connected. The integrity check shall detect a significant loss of pressure, or other indication of a leak, for example, by use of a hydrogen detection system, and shut down in the event of detection of a leak.

The inclusion of additional high pressure integrity checks during and/or after fuelling, and/or in between fuelling events should be used as an option until the dispensing system components have a demonstrated history of success.

If the pressure integrity check is not successful, the fuelling event shall be terminated. If necessary an emergency shutdown should be executed per 8.2.2.2.

8.2.1.7 Process flow measurement

When required by the fuelling protocol to calculate mass average flow of the hydrogen being dispensed, the flow meter shall measure the hydrogen flow over the operating range of flowrates and at the accuracy required by the fuelling protocol, where applicable.

Process flow measurement may also be used to collaborate process measurements being used by the fuelling protocol. See C.2 for further information.

Flow meters shall comply with 7.6.

8.2.1.8 Flow control and isolation

The dispensing system control system shall suspend or stop the fuelling process if any of the limits defined in 8.2.1.2 or 8.2.1.3 are exceeded.

NOTE See also 8.2.2 for safety-critical actions due to process deviations and faults not detected and/or mitigated by the "normal" process control.

Requirements for separate dispensing system isolation valves are included in 8.3.2.3.2.

8.2.2 Dispensing system safety devices

8.2.2.1 General considerations

As discussed in 8.2.1, a fuelling protocol shall be selected and implemented in the dispensing system control system. The control system shall be capable of properly fuelling the vehicle during normal operation and process excursions.

The dispensing system control system including programmable and/or process controllers shall comply with Clause 11.

The dispensing system control system shall also be capable, at any point in time during the fuelling process, to detect a deviation that could be indicative of a fault that leads to a hazardous condition and execute countermeasures that will mitigate the hazard or stop the fuelling. If determined by the manufacturer's risk assessment, this may necessitate an automatic emergency shutdown (see 8.2.2.2). See Clause 11 for guidance in the design and maintenance of process control and safety systems.

The required reliability, or safety integrity level (SIL), of safety measures intended to prevent a hazardous situation in case of a failure of the dispensing system control system hardware or software with regards to pressure and gas temperature should be determined through risk assessment (see Clause 5). Faults and associated hazards should be considered as part of the risk assessment.

Countermeasures should be provided to ensure that no single fault results in a hazardous situation in the dispensing area evaluation or potentially damage the vehicle high pressure hydrogen system by exceeding limits defined in 8.2.1.

NOTE 1 Guidance on the definition and use of safety integrity level (SIL) can be found in IEC 61508, IEC 61511, IEC 62308, IEC 31010, ISO 13849-1 and/or ISO 12100.

NOTE 2 Annex B provides guidance with regard to fault management in dispensing systems including recommendations based on an example fuelling process risk assessment.

NOTE 3 The prevention of single faults from causing a hazardous event is equivalent to SIL 1 protection in IEC 61508. As discussed below, higher levels of protection can be required in some cases based on the findings of the risk assessment.

8.2.2.2 Dispensing system emergency shutdown

The dispensing system shall operate in conjunction with an emergency shutdown function, which may be automatically activated by the dispensing system control system or manually activated. Refer to 8.2.2.1 and 11.2.

The emergency shutdown function shall be operational at all times and override all other functions and operations in all operating modes of the dispensing system.

Activation of the emergency shutdown shall cut off the flow of hydrogen gas to the dispenser and vehicle for the dispensing system which initiated the shutdown by closing the automatic isolation valves defined in 8.3.2.3.2.

Other emergency shutdown functions that may need to be considered in the risk assessment include:

— vent any remaining gas in the dispensing system to an appropriate location;

— shut down the upstream compression systems where these systems compress hydrogen directly to the dispensing system;

— removal of power to electrical components in the vicinity of the dispenser that are not suitable for classified areas.

Other emergency stop functions may need to be considered to leave the dispensing system in a safe state.

If the forecourt incorporates multiple dispensers, the need to execute an emergency shutdown for dispensers other than the affected dispenser shall be based on the risk assessment (See 11.2).

Operation of the dispenser after the emergency shutdown is tripped shall require, as a minimum, an inspection as to the cause of the shutdown and a manual reset.

8.2.2.3 Dispensing system pressure control faults and over-pressure protection

The dispensing system control system shall stop fuelling operation when the target pressure of the fuelling protocol is reached or limits defined in 8.2.1.2 or 8.2.1.3 are exceeded. Under these circumstances, the dispenser fuel pressure can be as high as 125 % of the hydrogen service level (HSL) and thus represents the maximum operating pressure (MOP) for the dispensing system. For example, the dispenser fuel pressure of a 70 MPa dispensing system can be up to 87,5 MPa under normal conditions (see Annex E).

Means shall be provided within the dispensing system control system to detect a failure of the pressure control function or dispenser fuel pressure sensor, and, if necessary, execute an emergency shutdown per 8.2.2.2.

In addition to the fault management by the dispensing system control system, dispensing system pressure protection by a pressure safety valve (PSV) or equivalent measure (such as an instrumented safeguarding system with an appropriate SIL level) shall be provided in the dispensing system or on the hydrogen supply to the dispenser to protect against over-pressurization of the components and piping in the dispensing system (see 8.3.1) as well as the vehicle high pressure hydrogen storage system (see 8.2.1.1).

In order to avoid dispensing system over-pressurization, the setpoint for the dispensing system pressure protection shall be set no higher than 137,5 % of HSL. For example, the over-pressure protection for a 70 MPa dispensing system may be set as high as 96,25 MPa.

NOTE 1 The setting of the dispensing system control fault protection slightly above 125 % of the HSL is appropriate to avoid unwanted interaction between the normal dispensing system control functions (up to the MOP) and the controller fault management due to sensor measurement tolerances and control variations. Typically, up to 4 % is adequate.

NOTE 2 The setpoint for dispensing system pressure control fault protection is set below the PSVs, for example, to avoid unnecessary activation of PSVs and preserve a separate layer of protection.

If components in the dispensing system are rated lower than values defined in 8.3.1, then the MAWP of the dispensing system shall be lowered accordingly per 8.3.1 and the dispensing system pressure protection setpoint shall be lowered to protect the lowest rated component in the dispensing system.

The dispensing system pressure protection setpoints can also need to be lowered to satisfactorily complete the risk assessment in 8.2.1.1 or meet local/state regulatory limits.

When the setpoint of the dispensing system pressure protection is lowered below 137,5 % of HSL for any of the reasons cited above, then the target pressures and limits of the fuelling protocol and the setpoints of the dispensing system controller fault protection can also need to be lowered to avoid unwanted interactions between the normal control and protective functions.

If a dispensing system is designed to dispense hydrogen at more than one pressure level, then additional pressure protection is required to protect dispensing system components and vehicles for each nozzle delivery pressure to no higher than 137,5 % of the HSL (as defined above).

8.2.2.4 Dispensing system temperature control faults

When ambient temperature is measured for the purpose of establishing the vehicle pressurization rate or fuelling target pressure, the ambient temperature sensor shall be placed such that it is an accurate measurement of ambient temperature and not unduly influenced by solar or other effects.

If pre-cooling of the dispensed hydrogen is used, the dispensing system shall be equipped with a means to confirm that the pre-cooled dispenser fuel temperature is correct and that the control meets both the upper and lower temperature limits of the fuelling protocol (see 8.2.1.1). If the fuelling protocol uses communication of the tank temperature on the vehicle and experiences a failure of the communication, the protocol should execute a shutdown, or continue to a non-communications fuelling if that is allowed by the protocol.

NOTE An example of a fuelling protocol response to the loss of vehicle to dispenser communications is described in Annex C.

8.2.2.5 Shutdown in case of hose breakaway device activation

The disconnection of the hose breakaway device shall shut off hydrogen flow to the nozzle at or up-stream of the breakaway and terminate the fuelling process.

In addition, measures shall be taken to mitigate against the failure of the hose breakaway device to seal, see 8.2.2.6.

8.2.2.6 Limitation of hydrogen released in case of fuelling line break

A potentially hazardous leak (e.g. failure of a hose breakaway device to close, hose leak, etc.) shall be detected by the system and the volume of leaked flammable gas shall be limited. The allowable leakage volume and response time shall be determined by the risk analysis.

Examples of possible means to detect the leak and thereby meet this requirement are listed below. One or more means may be required to achieve the required level of safety based on the specific system being protected. Examples of possible means to detect the leak are:

— detection of a dispenser fuel pressure that is below the level targeted by the fuelling protocol and activation of the emergency shutdown per 8.2.2.2.

— detection of low dispenser fuel pressure and activation of the emergency shutdown per 8.2.2.2.

— detection of an unexplained reduction in dispenser fuel pressure and activation of emergency shutdown per 8.2.2.2.

— detection of a higher-than-expected dispensing flow and activation of the emergency shutdown per 8.2.2.2.

— detection of a higher-than-expected dispensing flow and closure by an excess flow valve.

8.2.2.7 Process control failure

The dispensing system control system including programmable and/or process controllers shall comply with Clause 11.

For the situation where programmable process controllers are used to control the fuelling protocol, the possibility of a hardware or software failure that would cause the controller to "lock up" and cease execution should be addressed.

A means shall be provided to detect that the controller has failed, for example, such as a watch-dog timer, and, if necessary, initiate an emergency shutdown per 8.2.2.2.

8.2.2.8 Physical disturbance of the dispenser

The risk assessment conducted per 5.2 shall consider possible vehicle impact, accidents, incidents, and seismic activity, and if physical measures are not adequate, detection of physical disturbance should be incorporated, for example using a tilt sensor, which should initiate an emergency shutdown per 8.2.2.2.

8.3 Dispensing systems

8.3.1 General design and assembly

The dispensing system shall be designed to perform compressed hydrogen fuelling according to a defined fuelling protocol that has been selected and, when necessary, protect against faults of the dispensing system control system that could result in a hazardous situation in the dispensing area or potentially damage the high pressure hydrogen system of the vehicle. The dispensing system shall, when necessary, incorporate the required critical safety equipment to safeguard the users and vehicles against any over-pressure, over-temperature, over-filling and major hydrogen release situations (see 8.2).

The dispensing system shall meet general requirements for mechanical and electrical equipment in Clauses 7 and 10. Additional requirements of the dispensing system are provided in the following sub-clauses of 8.3.

Exposure of people to extremely cold temperatures shall be considered in the risk assessment and countermeasures shall be provided when necessary to prevent injury (see 5.5.7).

8.3.2 Dispensing system hydrogen components

8.3.2.1 General

In order to achieve the MOP needed to fuel the CHSS of the hydrogen vehicle under the full range of operating conditions, the recommended minimum component pressure ratings needed for the hydrogen dispensing system relative to the dispenser hydrogen service level (HSL), the pressure class (as defined in ISO 17268), and the dispensing system MAWP are shown in Table 1. See Annex E for explanation of dispensing system pressure levels.

If components are used that are below the pressure ratings in Table 1, then the MAWP of the dispensing system shall be lowered accordingly to the component with the lowest pressure rating.

The dispensing system shall be protected against over-pressurization as defined in 8.2.2.3.

Table 1 — Dispensing system pressure levels and recommended component minimum pressure ratings

Hydrogen service level (HSL)	Pressure class	Maximum operating pressure (MOP)	Dispensing system maximum allowable working pressure (MAWP) Minimum component pressure rating for dispensing system components
Equal to NWP of vehicle being fuelled		***1,25 × HSL Highest pressure during normal fuelling***	***1,375 × HSL Highest permissible setpoint for dispensing system pressure protection in 8.2.2.3***
25 MPa	H25	31,25 MPa	34,375 MPa
35 MPa	H35	43,75 MPa	48,125 MPa
50 MPa	H50	62,5 MPa	68,75 MPa
70 MPa	H70	87,5 MPa	96,25 MPa
NOTE These are maximum values of MOP and MAWP, and recommended minimum component pressure ratings based on achieving the MOP needed to fuel the CHSS of the hydrogen vehicle over the full range of operating conditions, see 8.2.2.3.			

In addition to the pressure rating, the components in the hydrogen dispensing system should meet the following requirements:

— an ambient temperature range of −40 °C to +50 °C, unless local conditions permit or require other temperature limits;

— material compatibility of materials normally in contact with hydrogen;

— a specified cycle life before maintenance or replacement.

Target cycle life should be 100,000 cycles for the fuelling assembly, but, whether this target is met or not, the cycle life should be defined and stated so that planned maintenance activities can pre-empt a failure.

See Clause 7, 8.3.2, and 8.3.4 for additional requirements for components in the dispensing system. See Annex E for guidance in establishing verification tests for components in the dispensing system.

High pressure hydrogen dispensing system components shall be marked with the pressure class only if components are designed and verified to meet or exceed the pressure, temperature, material compatibility, and service life requirements as defined above.

High pressure components shall be mounted in strict compliance with the supplier's instructions, following a well-defined assembly procedure.

The manufacturer shall ensure that the pressure drop between the dispenser fuel pressure sensor monitoring the vehicle pressure and the nozzle does not exceed the value defined in the fuelling protocol during the hydrogen flow to the vehicle.

NOTE See Annex C for an example.

8.3.2.2 Dispensing system hydrogen piping and fittings(s)

Dispensing system piping shall comply with 7.2 and fittings shall comply with 7.2.1 using the rating information derived from 8.3.2.

8.3.2.3 Dispensing system valves

8.3.2.3.1 General

Dispensing system valves shall comply with 7.2.1 using the rating information derived from 8.3.2, and 7.4.2 when applicable.

NOTE Further guidance specific to valves for hydrogen service is available in ISO 19880-3.

8.3.2.3.2 Dispensing system hydrogen isolation valve(s)

Means to automatically isolate all hydrogen dispensers from the hydrogen supply shall be included. At least one automatic isolation valve shall be installed in the dispensing system.

The automatic isolation valve(s) shall be closed if an emergency shutdown occurs as defined in 8.2.2.2.

The automatic isolation valve(s) shall be normally closed (i.e., closed when de-energised).

The inclusion of position indicators on the automatic isolation valves should be considered.

At least one automatic isolation valve should be located in a place not accessible to public, and protected from vehicle impact.

The manufacturer's risk assessment should consider the need for an automatic isolation valve to be provided at each end of the pipe between the dispenser and the hydrogen buffer storage, dependent on the amount of hydrogen that would be released in case of a loss of containment. Where required, the automatic isolation valve(s) at the dispenser should be located such that it is protected from vehicular impact.

It should be assessed whether these automatic isolation valves are closed when no dispensing is taking place, with the exception of automated pressure integrity tests, see 8.2.1.6, or other process required operations.

While the automatic isolation valves are opened to allow dispensing, these valves shall not provide flow control as described in 8.2.1.8.

Means to provide positive or proved isolation of the dispensing system automatic isolation valve and of the dispenser, see 3.56 and 3.61, for example using manual shut-off valves, should be included where appropriate for maintenance.

A means to depressurise and/or purge the dispensing system should be provided and should be protected by a locking mechanism or permanent closure so that it is inaccessible to the public.

The leak-tightness of the automatic isolation valves should be periodically checked.

Where required by risk assessment, the automatic isolation valve body should be constructed with material that will continue to function in the case of engulfment in fire, or the valve should be adequately protected, for instance using passive fire protection (PFP) boxes and/or jackets.

8.3.2.3.3 Dispensing system hydrogen flow control valves

The dispensing system isolation valves in 8.3.2.3.2 are not to be used to control dispensing of hydrogen. A separate hydrogen flow control valve shall be used for the rate of fuelling in accordance with the selected fuelling protocol in 8.2.2.1.

8.3.2.4 Dispensing system filters

Filters in the dispensing system shall meet 7.7.

See 9.2 for performance requirements.

8.3.2.5 Dispensing system temperature and pressure sensors

The dispenser fuel temperature and pressure sensors measuring the delivery conditions of hydrogen dispensed to the vehicle shall comply with 7.6 and be located upstream of, and as close as possible to, the dispenser hose breakaway device. The piping length between the sensors and hose breakaway device shall be no greater than that defined in the requirements of the fuelling protocol, if applicable.

The ambient temperature sensor shall be placed in an appropriate location in order to give an accurate reading and should not be located in the direct sunlight, or influenced by other thermal sources.

The ambient and dispenser fuel temperature sensor tolerance shall be within ±2 °C. The dispenser fuel pressure sensor tolerance shall be within 1 % full scale.

The dispenser fuel pressure sensor placement shall insure that an accurate static pressure is detected or measured.

8.3.2.6 Metering

If required for commercial sale of motor vehicle fuel, the dispensing system shall feature a flow metering device. Flow meters shall comply with 7.6.

NOTE OIML R139 and NIST HB44 include recommendations for accuracy and the testing of metering devices and systems within hydrogen fuelling stations.

8.3.2.7 Dispenser vent system

The vent system from the dispenser shall comply with 7.8.

It is recommended that an entry point be considered to allow hydrogen sampling equipment vents, for example, from pressure relief or purge valves, to be connected in order to minimise the need for the release of hydrogen in the vicinity of the dispenser during sampling. Where included, this entry point shall be rated for the lowest dispensing temperature, and capable of the highest flow rate anticipated under fault conditions, see 7.8.3. Any limitations that affect the type of sampling equipment used shall be clearly indicated in the fuelling station operating and maintenance manual, see 14.8 and 14.9.

Any entry points to the vent system shall be appropriately blanked or capped when not in use.

8.3.3 Dispenser housings and cabinets

Dispenser housings and cabinets shall comply with enclosure requirements in 7.11 as applicable, as determined by risk assessment.

8.3.4 Dispenser fuelling assembly

A dispenser fuelling assembly shall consist of, as a minimum, a hose breakaway device, a fuelling hose assembly, a nozzle, and connectors between these components. The dispenser fuelling assembly may also contain a venting hose (and hose breakaway device).

Suitability of the fuelling assembly components for the specified service conditions and cycle life should be based on 8.3.2.

The total allowable leakage and/or permeation from the dispenser fuelling assembly throughout the specified life shall not present a hazard to people in the dispensing area. See 8.4.4.

A hose breakaway device shall be provided as part of the fuelling assembly to stop the release of high pressure hydrogen in the event of a drive-away before the fuelling nozzle is disconnected from the vehicle. The hose breakaway device should disconnect when subjected to a maximum force of 1 000 N but not less than 220 N independent of the operating pressure within the device when installed as specified by the manufacturer. This condition should be met at all operating fuelling pressures.

The hose breakaway device shall be positioned such that when the fuelling hose is pulled along its axis, it will release without damage to the dispenser cabinet, fuelling hose assembly, the venting hose assembly (if used), the nozzle, or any other connections in the dispenser hose assembly. It shall be ensured that the breakaway function is not affected by the shape and features of the dispenser, e.g. by protruding elements on which the hose can get caught, thereby preventing the hose breakaway device to function properly.

If the fuelling assembly includes a venting hose or electrical connection for communications or grounding, these shall also be fitted with a breakaway device.

The hose breakaway device on the fuelling line should incorporate shut-off features that isolate the dispenser side of the breakaway device, or both sides of the connection when uncoupled.

NOTE 1 See ISO 19880-3 for further information.

The fuelling assembly should be strong enough to withstand the loads (tensile and torsion) exerted by the user without damage. See 8.4.5 for specific installation requirements.

The fuelling assembly shall provide sufficient electrical continuity such that 8.4.6 can be met, but the outer surface shall be non-conductive.

NOTE 2 Dissipative materials are considered non-conductive so there is no conflict with also complying with 10.2.3.

The bonding resistance of the fuelling hose assembly, from end fitting to end fitting, shall be no greater than 100 kΩ.

NOTE 3 The bonding resistance of the fuelling hose assembly can be limited to 1 kΩ for manufacturing quality control.

Exposure of people to extremely cold temperatures shall be considered in the risk assessment and countermeasures shall be provided when necessary to prevent injury due to touching extremely cold fuelling assembly components or connections, see 5.5.7.

The fuelling nozzle should prevent the entry of air into the vehicle fuel system and fuelling station equipment.

A mechanism should be provided to depressurize nozzles and vent gas to an appropriate location.

The fuelling nozzle shall comply with ISO 17268 and/or SAE J2600.

NOTE 4 See ISO 19880-3 for further guidance on hose breakaway devices and other valves.

NOTE 5 See ISO 19880-5 for further guidance on fuelling hose assemblies.

8.4 Dispenser installation

8.4.1 General

The components of the dispensing system and fuelling assembly should be assembled and installed according to the manufacturer's instructions.

8.4.2 Location and protection of dispensers

The dispenser may be a stand-alone device on the fuelling station forecourt, or may be integrated as part of a hydrogen production/compression container unit. Physical protection shall be implemented as necessary to protect the dispenser from vehicular impact, according to the risk assessment.

NOTE Examples of methods that can be used to achieve adequate protection are described in Annex G.

The structural foundation of the dispenser and the fuelling area shall be constructed of non-combustible materials and shall be adequate to support all components including vehicles to be fuelled.

Dispensers should be secured against unauthorized use. Outside of normal operating hours the hydrogen supply to the dispenser should be isolated at the source, and where appropriate, at the dispenser, see 8.3.2.3.2.

Dispensers located under a canopy shall be installed according to 5.3.4.

8.4.3 Fuelling pad

The vehicle fuelling pad shall be made of non-combustible materials and designed to allow electrical grounding before the nozzle is connected to the vehicle.

The fuelling pad shall have a common ground (earth connection) with the station equipment. This requirement can be met by either:

a) use of a concrete fuelling pad, or

b) a material where an electrical resistance between the vehicle fuelling pad and the dispenser ground does not exceed 100 MΩ.

NOTE If hydrogen is integrated into a multi-fuel station, other fuels can require more stringent grounding.

The vehicle fuelling pad should be level, except for a minimal slope to provide normal surface water drainage.

8.4.4 Hazardous area around the dispenser

The hydrogen fuelling process is a “closed system” as there is no hydrogen vented to open air in the dispensing area. Per the design qualification procedures in the referenced standards of this section, the allowable leakages from the dispensing system and fuelling assembly under normal operation are very small and not ignitable. Even during the uncoupling of the nozzle from the receptacle on the vehicle, the quantity of hydrogen released in the dispensing area is also insignificant.

Additionally, the probability of a potentially hazardous leak is reduced by the utilization of the mitigation measures in 8.2.1.6, 8.2.2.5 and 8.2.2.6.

The presence of a flammable atmosphere in the dispensing area is therefore not expected during normal operation, and the need to classify portions fuelling area should be established by risk assessment based on the likelihood and extent of component failures and mitigation measures being used (see 5.3.5.2**)**.

8.4.5 Installation of the fuelling assembly to prevent damage in service

The nozzle and hose assembly should be secured between fuelling events in such a way that they are protected from damage by vehicles.

The fuelling nozzle should be securely supported and protected from the accumulation of foreign matter (e.g. snow, ice or sand) that could impede operation.

The length of the fuelling hoses shall be adequate to fuel vehicles, but should not be longer than necessary to fuel vehicles at the intended location. The hose assembly should be prevented from contacting the ground unless appropriate measures are taken to protect the hose from any damage resulting from contact with the ground.

The hose assembly should be prevented from being bent to the point of damaging the hose in the conditions of use that are likely to occur.

8.4.6 Electrical continuity for bonding and grounding

Electrical continuity for bonding and grounding shall be provided for the dispensing system including the fuelling assembly, see 10.1.3 and 10.2.3.

The total electrical resistance for bonding and grounding the fuelling assembly shall be less than 1 MΩ between the (vehicle) end of the fuelling nozzle to earth.

8.5 Operating considerations

When necessary, dispensers should be secured against unauthorized use. Outside of normal operating hours, the hydrogen supply to the dispenser should be isolated at the source, and where appropriate, at the dispenser.

The use of adapters shall be prohibited, with the exception of controlled situations, such as the use of specialized tooling and equipment for dispensing system operational verification or hydrogen quality sampling. The specialized tooling and equipment shall be evaluated by risk analysis and suitable for hydrogen service as defined in Clause 7 under the anticipated pressure, temperature and flow conditions as per the fuelling protocol limits of 8.2, including under fault conditions.

Hydrogen piping systems and equipment shall comply with the requirements in 7.2. Procedures shall be conducted by trained personnel (see 12.6, Annex J and Annex K).

8.6 Maintenance and inspection

Procedures shall be established for expected service and maintenance activities. If necessary, these procedures shall address proper isolation of the system for worker safety, measures required during the maintenance or service activity to prevent contamination or air ingestion into the dispensing system, and steps required to return the system to operation.

The dispensing system and fuelling assembly shall be visually inspected regularly to check that the assembly is free from damage. The fuelling hose shall be free from cuts, cracks, bulges or blisters, and kinks.

The fuelling assembly shall also be periodically tested for leaks by an appropriate method, such as bubble testing or pressure decay testing. Leak detection fluids, if used, shall be compatible with dispenser fuelling assembly components. Fuelling hose assemblies that fail visual inspection or leakage test shall be withdrawn from service. The use of protective covers and/or automatic leak tests may be considered to define the frequency of visual inspection.

Both manual and automatic isolation valves shall be periodically checked for functionality and leakage.

See Clause 15 for further guidance.

9 Hydrogen quality

9.1 General

The hydrogen quality at the nozzle shall meet the requirements of Grade D in ISO 14687. The means of assuring these requirements are met shall be based upon ISO 19880-8.

Hydrogen quality verification as part of the fuelling station acceptance testing, and ongoing operation, shall be conducted in accordance with the hydrogen quality assurance plan, see ISO 19880-8.

If the fuelling station cannot meet the above quality requirement, corrective action shall be taken before other vehicles are permitted to fuel. Corrective measures should be put in place and fuel quality assessments conducted until the hydrogen is again within specification.

Requirements for hydrogen sampling are included in 12.6.

9.2 Dispensing system fuel filters

Hydrogen filters shall be included as part of the dispensing system, preferably in the dispenser, to prevent hydrogen containing function-impairing impurities (i.e. particulates) that would affect the high pressure hydrogen system of FCEV, specifically the vehicle CHSS valves. See 7.7 for requirements for filters.

There shall be a filter with a capability to prevent particulates larger than 5 µm with a minimum removal efficiency of 99 % under expected process conditions, or alternatively a 5 µm filter. The filter shall be installed downstream of dispensing system components which could create particulates, such as a heat exchanger, flow controller, valves etc. and be as close as possible to the hose breakaway device. This shall filter out the particulate concentration in the hydrogen in accordance with the requirements of Grade D in ISO 14687.

The filter located nearest to the nozzle shall be carefully selected by taking the robustness into account (for example the durability limitations of powdered sintered metal filters).

NOTE ISO 4022 and ISO 12500-1 and ISO 12500-3 provide recommended methodologies for the testing of filter efficiencies.

Appropriate means to remove contaminants such as condensates or liquids shall be installed upstream of the dispenser unless removal of the contaminant is deemed unnecessary in accordance with either the prescriptive or risk assessment requirements of ISO 19880-8.

10 Electrical

10.1 General electrical

This clause addresses general electrical safety for hydrogen fuelling stations.

10.1.1 Components

Individual electrical components, devices or equipment assemblies that have any of the characteristics or are used in any of the ways listed below should comply with the requirements of the product safety standard(s) corresponding to that component device or assembly:

- connected to the electrical mains;
- contain, use, or are connected to hazardous voltage;
- perform a safety function.

NOTE Hazardous voltages are typically defined as greater than 50 VAC and 120 VDC in clean, dry conditions. However, much lower voltages can be hazardous in other conditions. The conditions of use should be considered when determining the hazardous voltage levels. See the SELV and PELV sections of IEC 60364-4-41, and IEC 60204-1, for more information.

If there is no product safety standard(s) corresponding to a type of equipment, the equipment should conform to IEC 60204-1.

Valves, sensors, and other individual components or devices that are connected to the equipment assemblies should also conform to IEC 60204-1.

10.1.2 Site (interconnections to and/or between equipment assemblies)

Connections between the electrical equipment of the hydrogen fuelling stations and the electrical mains, or connections between electrical equipment assemblies of the hydrogen fuelling stations should also be designed, erected, installed, connected, tested, and verified in accordance with IEC 60364.

There are many sections and subsections to IEC 60364; the electrical equipment connections should comply with all sections of IEC 60364 that apply.

NOTE In many cases the requirements of IEC 60204-1 also apply to connections between electrical equipment assemblies of the hydrogen fuelling stations.

10.1.3 Electrical bonding and grounding

Electrical equipment and associated frames and enclosures that can become energised under first fault conditions shall be bonded and grounded as defined in IEC 60204-1 to prevent electric shock.

NOTE The grounding requirement per IEC 60204-1 for electric shock protection is typically less than 100 Ω to earth and therefore significantly more stringent than the requirement in 10.2.3 for the prevention of electrostatic discharge.

Effectiveness of grounding connection should be verified at an appropriate frequency that is consistent with risk assessment.

See 10.2.3 for additional bonding and grounding requirements to prevent electrostatic discharges in hazardous areas.

10.1.4 Lightning protection

Lightning protection shall be provided when required.

NOTE The IEC 62305 series offers guidance on lightning protection, i.e. IEC 62305-1, and the other parts of IEC 62305 appropriate for the type of equipment.

In the case where vent stacks are designed to carry lightning currents, see 7.8.1, this may be considered to achieve the requirement for lightning protection.

10.2 Hazardous areas (potentially flammable mixtures)

10.2.1 General

Hazardous areas shall be defined according to 7.4.

10.2.2 Protection requirements for electrical equipment within hazardous areas

All electrical equipment in hazardous areas shall be protected in accordance with the IEC 60079 series, i.e. IEC 60079-0 and the appropriate other part of the IEC 60079 series for the type of protection used. For example an intrinsically safe electrical system should comply with IEC 60079-0, IEC 60079-11, and IEC 60079-25.

All electrical equipment in hazardous areas shall be installed in accordance with the manufacturer's instructions, and with IEC 60079-14, or regional equivalents.

Where new or existing electrical equipment is within the hazardous area surrounding hydrogen equipment, this shall also be suitable for hydrogen (for example, gas group IIC, or IIB+H_2, as defined in IEC 60079-0).

NOTE This is particularly relevant to integrated fuelling stations when existing fuel dispensing equipment is not suitable for hydrogen.

All electrical equipment installed in hazardous areas shall be inspected and maintained in accordance with the manufacturer's instructions, and with IEC 60079-17, or regional equivalents.

All electrical equipment installed in hazardous areas shall be serviced, repaired, overhauled, and reclaimed in accordance with the manufacturer's instructions, and with IEC 60079-19, or regional equivalents.

10.2.3 Protection from ignition due to accumulation of static charge

Hydrogen systems shall be equipotentially bonded and grounded to prevent build-up of electrostatic charge.

An exception to this requirement is made for hydrogen systems that normally carry current or are otherwise intended to be operated at a voltage above or below ground potential which shall either meet 10.1.3 and 10.2.2 or meet an approved product standard such as IEC 62282-3-100 or ISO 22734-1 and be installed per the manufacturer's directions.

Electrical continuity should be ensured throughout the hydrogen systems.

The electrical resistance between metallic parts connected or in contact together should be less than 10 Ω. The bonding requirement applies to, but is not limited to, the following equipment:

— conductive hydrogen tanks and vessels;

— hydrogen piping and systems including flanges and joints; and

— conductive enclosures or skids, frames and/or (metal) floors where hydrogen is stored or used.

Both halves of a joint or flange connection shall be equipotentially bonded if there is an isolating seal (for example, a polymer seal).

All hydrogen delivery vehicles shall be equipotentially bonded to the fixed storage hardware prior to flexible hose connection.

The bonded hydrogen systems shall be grounded. The grounding system resistance shall be less than 1 MΩ to earth from any part within the hydrogen system.

Grounding devices should either:

— be clearly visible or be essential to the correct functioning of the fuelling station, so that any shortcomings are quickly detected; or

— be robust and so installed that they are not affected by high resistive contamination, for example, by corrosion products or paint.

Effectiveness of grounding connection should be verified at an appropriate frequency that is consistent with risk assessment.

NOTE 1 The bonded and grounded hydrogen systems (as defined above) can also be connected to the bonding or grounding in 10.1.3 but this is not a normative requirement.

All other conductive parts in hazardous areas that are not addressed above or in 10.1.3 shall be bonded to the bonding or grounding system or separately grounded to earth in accordance with IEC 60079-14.

Other sources of static discharge shall be addressed, and measures shall be taken to remove them completely or reduce the probability of their occurrence.

NOTE 2 Electrostatic charges can occur when mechanical separation of similar or different substances takes place and also when a gas, containing droplets or dust particles, flow past the surface of a solid, e.g. valve openings, hose or pipe connections. If the accumulation of electric charges is released suddenly, the resulting electric spark can be sufficiently strong to ignite hydrogen.

Equipment and electrical sources that may unintentionally be in contact should have a common grounding.

Grounding devices should:

— either be clearly visible or be essential to the correct functioning of the fuelling station, so that any shortcomings are quickly detected;

— be robust and so installed that they are not affected by high resistive contamination, for example, by corrosion products or paint.

The use of non-conductive or non-dissipative materials should be restricted in hazardous areas.

10.3 Electromagnetic compatibility and interference (EMC)

10.3.1 General

Hydrogen fuelling stations should not emit electromagnetic noise that will interfere with other equipment at or near their sites and should not be adversely affected by electromagnetic noise at or near their sites.

The electrical equipment and systems of hydrogen fuelling stations should comply with the applicable parts of the IEC 61000 series. These standards include (but are not limited to):

— IEC PT 61000-3-1;

— IEC 61000-3-2;

— IEC 61000-3-3;

— IEC 61000-3-4;

— IEC 61000-3-5;

— IEC 61000-3-11;

— IEC 61000-3-12.

10.3.2 Industrial (EMC) Environments

The electrical equipment and systems of hydrogen fuelling stations located in industrial environments should also comply with these standards in the IEC 61000 series:

— IEC 61000-6-2;

— IEC 61000-6-4.

10.3.3 Residential, Commercial, and Light-Industrial (EMC) Environments

The electrical equipment and systems of hydrogen fuelling stations located in residential, commercial, or light-industrial environments should also comply with these standards in the IEC 61000 series:

— IEC 61000-6-1;

— IEC 61000-6-3.

11 Instrumentation and control system

11.1 General

This clause defines the minimum requirements and recommendations for the functional safety of the control and safety system.

The hydrogen fuelling station shall be equipped with a control system that enables automated operation of the station within the manufacturer's specified limits. Control systems shall maintain operating conditions within safe limits, carrying out a process shutdown as appropriate when these limits are reached and respond to any abnormal states by automatically activating mitigating measures as part of an emergency shutdown.

Electrical control systems, components of hydrogen fuelling stations, and devices determined by the manufacturer to be safety related control systems, shall comply with the requirements of IEC 60204-1 or equivalent regional standards.

The risk assessment shall determine what to do when there is a system fault on the process control or safety system.

Where the manufacturer's risk assessment requires a response to abnormal states (faults) with an increased reliability to that achievable from the control system, the fuelling station shall be equipped with an additional safety system or layer of protection. IEC 61508 and IEC 61511 can be used for specification, design, testing, operation, and maintenance of such a safety system.

The safety system could be composed of several safety functions activated manually or automatically.

The configurations of process control and safety systems shall be documented (see Clause 14).

There shall be restrictions regarding admittance to the control and safety systems, for example by using password protection. Where specific operations require safety systems to be non-functional, a risk assessment should be executed and documented before the start of the operation.

As part of the safety system, an alarm warning system may be implemented. In the case of an event, the station should default to a safe state without relying on the alarm warning system. The alarm warning system should only be used to give notification as to the status of the station.

NOTE 1 See IEC 60204-1:2016, Section 9 for control circuits and control functions and Section 10 for operator interface and machine-mounted control devices.

NOTE 2 IEC 60204-1 includes essential requirements for safety related controls that are often overlooked including:

— stop categories;

— emergency operations (Emergency stop, etc.);

— protective interlocks;

— control function in the event of failure – including references to:

  — IEC 62061

  — ISO 13849-1

  — ISO 13849-2

— protection against maloperation due to ground faults, voltage interruptions and loss of circuit continuity.

All elements which remain under pressure after isolation following a process control or safety system shutdown, or from loss of the electrical power supply, should be provided with clearly identified vent systems, and details drawing attention to the necessity of depressurizing those elements before setting or performing maintenance activity on the equipment unit should be included in the equipment manual, see 14.9.

11.2 Emergency shutdown functionality

11.2.1 General

The response to an emergency shutdown signal initiated automatically by the control or safety system, or manually by the emergency stop device(s), shall be determined according to the fuelling station risk assessment, see 5.2. The emergency shutdown function shall be so designed that, after actuation, hazardous movements and operations of the fuelling station are stopped in an appropriate manner, without creating additional hazards and without requiring any further intervention by any person, and shall comply with ISO 13850 or IEC 60204-1. Where appropriate, activation of emergency isolation valves shutting off the hydrogen supply shall be utilized.

The control or safety system performing the emergency shutdown shall override all other functions and operations that could prevent the emergency shutdown actions. Emergency safeguarding shall remain effective for all operating modes.

Provision of an overall (or global) emergency shutdown function that carries out a shutdown of the complete hydrogen system should be considered, in addition to hazards where a localised shutdown may be more appropriate.

Further detail for the emergency shutdown function specific to the dispensing system is provided in 8.2.2.2.

Control circuits shall be arranged so that, when an emergency shutdown is activated, hydrogen supply and storage systems that are shut down or isolated as appropriate, shall remain shut down until proper maintenance checks are performed and the system is manually reset. A manual operation shall be required for the dispenser to resume operation.

Control and monitoring systems that can operate safely in the hazardous situation may be left energized to provide system information.

At fuelling stations with liquid hydrogen supply, the emergency shutdown also shall shut off the liquid supply and power to the liquid hydrogen transfer equipment necessary for producing gaseous hydrogen from liquid hydrogen. Subsystems isolated by emergency shutdowns shall be provided with overpressure protection.

Where the manufacturer's safety case permits or requires equipment, such as the hydrogen gas detection system and ventilation systems, to remain energised in such an event, this shall be suitable for use in hazardous areas as per 7.4.2 or 10.2.2.

11.2.2 Manually actuated emergency stop devices

The fuelling station shall operate in conjunction with readily accessible manually actuated emergency stop devices (see IEC 60204-1) positioned in appropriate locations with consideration given to the hazardous areas initially generated by foreseeable incidents. Emergency stop devices shall be located in the vicinity of hydrogen dispensers, and at other locations where the initiation of an emergency stop may be required, such as inside the fuelling station office, where applicable, and in compressor and storage areas.

Emergency stop devices shall be clearly identified with a permanently affixed legible sign. An emergency stop device located at the dispenser, or on specific pieces of equipment, may have a different functionality to an emergency stop device for the entire hydrogen system, or for the entire fuelling station. Where the functionality of emergency stop devices differ, this shall be clearly defined.

Where emergency stop devices are located in the office of an integrated fuelling station, the function of these actuators being specific to the complete hydrogen system only, or to include other activities on the fuelling station, should be determined by risk assessment.

An emergency stop device shall be provided in the vicinity of the dispenser, but sufficiently separated from the dispensing area such that it can be safely actuated under fault conditions without entering a potentially hazardous area.

Where hydrogen is used in enclosed, or indoor areas, in addition to any emergency stop device(s) located indoors, devices shall also be provided outdoors, for example, close to the point of egress.

The possibility of inadvertent or malicious activation of emergency stop devices should be considered when locating and labelling the emergency stop device in order to avoid "false alarms" and unnecessary emergency responses.

11.2.3 Hydrogen detection systems

Hydrogen detection apparatus used in hydrogen sensing and monitoring systems should comply with, and meet the accuracy requirements of ISO 26142.

Hydrogen detection apparatus and/or hydrogen detection systems shall have a suitable range for the concentration set-points used to initiate a response through the control or safety system.

The appropriate response should be determined by the fuelling station manufacturer's risk assessment.

This may include different activation limits, for example:

— a lower activation limit, set at a maximum value of 25 % of the lower flammability limit (LFL), which instigates further mitigation measures and alerts the fuelling station operator, and other users. An alarm set point lower than 25 % LFL may be appropriate depending on the station risk assessment, for example, for enclosed areas with a high level of congestion;

— a higher activation limit, set at a maximum value of 50 % of LFL, which instigates an emergency shutdown and alerts the fuelling station operator, and other users. An alarm set point lower than 50 % LFL may be appropriate depending on the station risk assessment, for example, for enclosed areas with a high level of congestion.

Further mitigation measures that may be appropriate to be taken upon detection of a flammable atmosphere above the lower activation limit include, but are not limited to:

— shut-off of the hydrogen supply to the equipment within the enclosure from an isolation point outside of the container;

— depressurisation of the hydrogen equipment within the enclosure to a safe location;

— de-energization of electrical equipment not intended for use in flammable atmospheres;

— increased ventilation.

The duration of the audible and visual signals initiated by the hydrogen detection system should be determined by the station manufacturer's risk assessment. Where safe to do so, it is recommended that the visual signals should remain until the alarm condition has been corrected and the fuelling station control or safety system has been manually reset. The audible signals may be automatically reset when the concentration of hydrogen falls below a defined set-point, after a specified period of time or when the control system is manually reset.

11.3 Remote system control

A hydrogen fuelling station may be provided with the following capabilities:

1. remote monitoring and data transmission;
2. remote operation, for instance giving permission for fuelling, or restarting the station after a fault;
3. remote control code modifications (software update, flashing etc.)

These control code modifications capabilities can include, for example, the ability to:

a) modify the control parameters remotely;

b) certify an upgrade to the remote monitoring system;

c) certify a parameter change;

d) change parameters remotely;

e) upload parameters;

f) qualify the operation;

g) undo/reverse all changes;

h) test and backup documentation.

Consideration shall be taken of possible interference of remote operation with activities that may be occurring at the fuelling station at the same time.

Measures shall be taken when the station may be restarted remotely, software may be updated remotely, or control options changed remotely to ensure that the task is successfully planned, executed, and verified. This includes consideration of the need for maintenance staff onsite.

11.4 Modifications to control system

Any hardware or software changes shall be re-validated prior to use in accordance with the station's management of change process, see 12.7 and 15.6. This includes, but is not limited to, setpoints and alarm or trip settings.

12 Station inspection and tests

12.1 General

As part of commissioning prior to opening the station for use by the public, the hydrogen fuelling station shall be inspected and tested as detailed in 12.2 to 12.6 to ensure compliance with the requirements of this document.

NOTE Non-public station inspection and test requirements can differ depending on regulatory requirements, and agreements between the supplier and operator.

All inspection and test results should be retained as appropriate.

The inspections and tests shall be conducted by the hydrogen fuelling station manufacturer or integrator or, when appropriate, by suppliers of equipment for the fuelling station.

Additionally, inspections and tests typically required to assess the readiness of the station are provided in Annex I for guidance.

When appropriate, some of these tests can be performed as factory acceptance testing (FAT) (or an appropriate alternative type acceptance methodology), and accepted without the need for replication when the station is installed on-site. Where applicable, a report of the FAT shall be provided (with data, when appropriate) to confirm compliance with requirements. Tests performed within the FAT can be covered in a type approval process with an independent third party by covering an assembly certification, for example, see 1.3.2.7 of Table I.1.

If specific factory acceptance tests are not conducted, or not acceptable, these tests shall be performed as part of the site acceptance testing (SAT).

Every test activity covers the check of documentation as well as technical testing.

The commissioning of the hydrogen fuelling station is not complete until all inspection and test results demonstrate compliance with requirements as defined above.

Periodic safety retesting shall be carried out as required based on risk assessment, and periodic performance retesting should be carried out, see 12.7 and Clause 15 for further information on retesting following maintenance activities.

12.2 Pressure test

The strength and integrity of all pressure bearing parts, including joints and connections, that convey a fluid shall be pressure tested using either hydraulic or pneumatic means.

If a pneumatic test is used, air, nitrogen, helium, or non-flammable hydrogen mix, is recommended.

NOTE It is good practice to only apply paint after hydrostatic testing of components (not before).

The test procedure shall be based on a recognized standard such as ISO 15649 or EN 13445-5. No permanent deformation or mechanical failure shall be allowed.

Pressure relief valves and other pressure sensitive instruments may be removed for the test and lines capped.

Components or assemblies that have already passed required pressure tests according to local/state requirements do not need to be re-tested. Connection points of such components or subsystems of the fuelling station shall be pressure tested as necessary, see 7.2.

The pressure test(s) may be carried out either prior to delivery to the site, or on the site where the fuelling station is to be installed, however pressure testing prior to delivery to the site is recommended where possible, to minimise contamination from test fluids during on-site pressure testing. Hydraulic pressure test(s), when required, should be carried out on subsystems prior to delivery to the site where the fuelling station is to be installed, where it is easier to manage the removal of contamination than with on-site testing, in order to minimise the efforts needed to remove contamination from test fluids used.

Some types of in-field connections that do not involve welding may not require pressure testing when installation is performed by qualified personnel.

If an on-site pressure test on systems or connections is not required, then (as a minimum) a leak test in accordance with 12.3 shall be conducted to confirm basic system integrity and leak tightness.

Means of pressure indication suitable for the test pressure, where required, shall be installed before the test. Precautions shall be taken to prevent excessive pressure in the system during the test.

Following any hydraulic test of a pneumatic system, the system or equipment shall be drained and thoroughly dried out and visually examined.

High pressure hydrogen gas is much more hydroscopic than dry nitrogen and is the most effective cleaning agent for hydrogen piping and storage. Purging the fuelling station components with high quality hydrogen after replacement or atmospheric contamination of hydrogen pressure rated components is recommended in accordance with Clause 9.

12.3 Leak test

A leak test shall be conducted on hydrogen and other pressurised fluid subsystems, on the interconnections and on the whole system. The leak test should be conducted in conjunction with, or follow, the pressure test. The leak test shall verify that the system leakage is acceptable as per design of the manufacturer.

The leak test shall be carried out to at least 85 % of the MAWP.

NOTE 1 Testing to 85 % is to avoid opening pressure relief valves installed on the system.

Depending on the complexity, the leak test may be executed by splitting the system into subsystems (e.g. by closing valves) for the leak testing.

NOTE 2 For further guidance, see Annex H.

It is recommended that subsequent leak checks be carried out at the relevant operating temperatures when the system operation has been confirmed, and prior to opening the fuelling station.

12.4 Electrical testing

Electrical verification testing in accordance with IEC 60204-1:2016, Section 18 shall be performed on the hydrogen fuelling station.

This testing shall include functional tests which are safety related mitigation measures (see Clause 5).

Functional testing especially of the safety circuit(s) should be thorough, complete, and unambiguous. All inputs should be activated or simulated individually. Each device in the circuit or system should be checked individually for each input activation or simulation. Care should be taken to ensure that only the circuit under test caused the required action. Careful inspection and disconnection of other devices, circuits, or systems may be required to eliminate paths other than the one under test (ex. "sneak circuits").

Additionally the following tests can need to be carried out at the site, depending on what has already been performed as part of factory acceptance testing, or according to the station manufacturer's risk assessment, or due to regulatory requirements:

— verification of conditions for protection by automatic disconnection of supply (typically a final ground/bond test which would need to be performed on site);

— insulation resistance tests;

— voltage tests;

— protection against residual voltages;

Where a portion of the fuelling station and its associated equipment is changed or modified, that portion should be re-verified and retested, as appropriate (see IEC 60204-1:2016, 18.1).

Particular attention shall be given to the possible adverse effects that retesting can have on the equipment (for example overstressing of insulation, disconnection, or reconnection of devices).

12.5 Fuelling safety and performance functional testing

12.5.1 General

Testing shall verify that the hydrogen fuelling station meets the manufacturer's specification, the requirements in Clause 8, and the requirements of the fuelling protocol using an approved protocol validation standard such as CSA HGV 4.3, or using the guidance in Annex C to develop an approval process.

Elements critical for safety, as determined by risk assessment, and in Clause 8, shall be reviewed for correct installation and, where appropriate, tested for correct functionality.

Hydrogen fuelling safety targets shall be verified at station commissioning using a hydrogen station test apparatus (HSTA) or equivalent equipment which can perform the necessary testing. For example, where multiple dispensers are installed allowing simultaneous fuelling, simultaneous fuelling testing may also be necessary.

NOTE Annex J offers examples of hydrogen station test apparatus that could be used for acceptance testing for stations that utilise the SAE J2601 fuelling protocol.

The onsite tests shall have representative hardware that conforms with station manufacturer specifications for the SAT.

SAT and FAT capability shall include a data acquisition system and ability to test the vehicle-to-dispenser communications systems.

If a test fails, the reason for failure shall be identified, reviewed by a qualified person, fixed and re-tested until it passes. All changes made shall be documented and affected systems re-tested.

12.5.2 Fuelling protocol test

The fuelling protocol shall be tested to confirm that the dispensing system is adhering to the safety related process requirements of an approved fuelling protocol as defined in 8.2. If a standard fuelling protocol is utilized, then a protocol validation standard corresponding to the protocol standard shall be used for this testing, see Annex C.

As a minimum, fuelling protocol safety testing shall be carried out on site according to one of the options given in 12.5.4.

Testing capability shall include a data acquisition system and ability to test the vehicle-to-dispenser communications system. This assumes that access to pressure and temperature signals of the dispensing system or data from the station owner, operator, or manufacturer, as applicable, during testing will be given for the station acceptance testing.

NOTE CSA HGV 4.3 is a comprehensive fuelling protocol validation standard for use with stations implementing and SAE J2601 standard protocol. Alternatively, Annex C offers guidance and examples of the acceptance testing appropriate for stations that utilise an SAE J2601 standard fuelling protocol.

Where other fuelling protocols or different versions of SAE J2601 are used, corresponding acceptance tests should be used.

12.5.3 Test procedure

Stations shall be validated by testing to ensure that they meet the following requirements:

1. The station correctly implements the fuelling protocol being used.
2. The station terminates the fuelling within 5 s if the process limits for the fuelling protocol, as listed in Clause 8, are exceeded.
3. The station correctly implements the communications protocol and terminates the fuelling within 5 s upon receiving an abort signal, or, if an incorrect signal is sent to the station, the station terminates the fuelling or reverts to a non-communications fuelling as per Clause 8.

NOTE Refer to Annex C for an example of a test procedure to verify SAE J2601.

12.5.4 Site acceptance testing options

12.5.4.1 General

The following clauses provide two options for site acceptance testing of the fuelling protocol, one of which, as appropriate, shall be carried out before the station is opened.

12.5.4.2 SAT overview — Option 1

Table 2 defines the first option for a set of minimum site acceptance tests.

Table 2 — Option 1 for minimum site acceptance testing

Test name	Preparation to be performed	Test information	Acceptable test	Reference in Table C.2 for example where SAE J2601: 2016 is used
Ambient, fuelling pressure and temperature sensor calibration accuracy table	—	Verification of ambient and fuelling temperature sensor and fuelling pressure readings, review of calibration	Sensors show value reasonable to state of the station; calibration certificates OK	Test 3
Fault: CHSS starting pressure	CHSS with starting pressure of >70 MPa ready to be fuelled (attempted)[a]	Connect the CHSS to the station and initiate fuelling. Station shall recognize full CHSS and not start main part of fuelling	Main fuelling is not allowed to start	Test 8

[a] Testing that the dispensing system doesn't fuel a vehicle with a start pressure below 0,5 MPa is a test that can be simulated or carried out as part of FAT and doesn't need repeating at the station.

Table 2 *(continued)*

Test name	Preparation to be performed	Test information	Acceptable test	Reference in Table C.2 for example where SAE J2601: 2016 is used
Communications break	Simulated communications and then a break in communications signal, e.g. by manipulating of signal loop	Confirm that the fuelling switches to non-communications fuelling	Station switches to non-com fuelling or stops fuelling	Test 16
Fault: communications abort signal	Simulated communications abort signal, e.g. by manipulating of signal loop	To be monitored even with non-communications fuelling (if applicable)	Fuelling stop within 5 s with out-of-bounds	Test 18
Non-communications fuelling validation for each pressure level (H70 and, if applicable, H35)	Two different starting conditions	Two tests per hydrogen service level where applicable	Fuelling performed to a pressure representative of the final pressure anticipated during a fuelling, ±2 MPa, without exceeding the fuelling protocol process limits as defined in 8.2	Test 36
Communications fuelling validation	Two different starting conditions, one of which is below 2 MPa starting pressure	Two tests per hydrogen service level where applicable	Fuelling performed to an SOC or pressure representative of that anticipated during a fuelling, without exceeding the fuelling protocol process limits as defined in 8.2 with no abort signal received from the vehicle NOTE From a performance perspective, a minimum SOC of 95 % is desirable, see 12.5.5.	Test 37
Pre-cooling Capacity (PC) Test.	NOTE Recommendations for testing of the pre-cooling capacity, for instance for back-to-back fuelling are included in 12.5.5.			Test 34

[a] Testing that the dispensing system doesn't fuel a vehicle with a start pressure below 0,5 MPa is a test that can be simulated or carried out as part of FAT and doesn't need repeating at the station.

12.5.4.3 SAT Overview — Option 2

Table 3 defines the second option for a set of minimum site acceptance tests.

NOTE Further detail necessary for performing the tests below can be found in HySUT–G 0003.

Table 3 — Option 2 for minimum site acceptance testing

Test #	Test item	Initial pressure	End pressure	Main check point
1	Communication verification test	—	—	This test should be done at first. Check that a hydrogen station terminates fuelling by an abort signal.

Table 3 *(continued)*

Test #	Test item	Initial pressure	End pressure	Main check point
2	Fuelling with communications: fuelling performance test with a selected APRR	Under 10 MPa	Under 82 MPa	Check that the selected target pressure and APRR target and the control of APRR and fuel delivery temperature and the station pressure and the SOC at the end of fuelling are appropriate with the selected communication map.
3	Accuracy test of tank volume estimation	—	—	Check that the measured results have an accuracy of ±15 % against the fuel tank volume of the HSTA.
4	Fuelling with non-communications: fuelling performance test with a selected APRR	Under 10 MPa	Under 82 MPa	Check that the selected target pressure and APRR target and the control of APRR and fuel delivery temperature and the station pressure at the end of fuelling are appropriate with the selected non-communications map.
5	Test for switching from communications to non-communications fuelling	—	—	Check that the target pressure is switched to a target pressure under fuelling with non-communications upon the shutdown of communications.
6	Fuelling performance test with a high APRR (by manipulation of ambient temperature to a lower value or over-riding the APRR calculation)	About 10 MPa	To be halted about 60 MPa to protect the vessel from over-temperature	Check the control of maximum APRR and the maximum peak of mass flow at the middle pressure range. Test to be done more than 2×. Caution: The vessel temperature shall be monitored during this test to avoid overheating.
7	Fuelling performance test with a low APRR (by manipulation of ambient temperature to a higher value or over-riding the APRR calculation)	About 30 MPa	Under 82 MPa	Check the control of minimum APRR and the control of mass flow at the high pressure range. Test to be done more than 2×.
8	Fallback fuelling performance test	About 30 MPa	Under 82 MPa	To be carried out where fallback is available: Check that the selected target pressure and APRR target and the control of APRR and fuel delivery temperature are appropriate after switching to fallback fuelling.
9	Top-off fuelling performance test	Under 3 MPa	Under 82 MPa	Check that the selected target pressure and APRR target and the control of APRR and fuel delivery temperature are appropriate after switching to top-off fuelling.

12.5.5 Additional performance considerations for fuelling

As part of the process of commissioning a station, in addition to the factory and site acceptance testing, the station fuelling and cooling capacity related to back-to-back fuelling should be evaluated by analysis or test relative to the station specification. This could test:

— the minimum vehicle SOC, or equivalent, achieved by the station at the end of fuelling;

— the cooling capacity of the station; and

— the optional fallback fuelling, where applicable.

If applicable, manufacturers should prove their "rated" back-to-back fuelling capability. As a minimum, two test fuelling of 2 CHSS (including 1 within the largest category for the station) with an initial pressure of 5 MPa are recommended. The station should pass the back to back fuelling, switch to fall back or abort the fuelling.

The payment system should also be validated with actual fuelling transactions before commissioning.

12.6 Hydrogen quality testing

Hydrogen quality shall be assured in accordance with the hydrogen quality assurance plan, defined in ISO 19880-8 to ensure compliance with the requirements of Grade D in ISO 14687 for fuel cell grade hydrogen impurity threshold limits, as per Clause 9.

Gas phase impurities in the dispensed hydrogen may be captured with a sampling adapter and taken off site in a dedicated sample vessel for laboratory analysis. A representative sample from multiple fuelling station hydrogen storage banks should be taken to confirm that all storage banks have been cleaned and purged properly.

Sampling equipment used shall be evaluated by risk analysis and shall be suitable for hydrogen service as defined in Clause 7, under the process conditions defined in Clause 8, unless other safety precautions have been taken. Piping systems and other equipment comprising the hydrogen sampling apparatus shall comply with the requirements in 7.2.

Where sampling equipment uses the dispenser vent line for purging or relief venting, this shall be in accordance with 8.3.2.7.

NOTE For further guidance on hydrogen quality test apparatus that connects to the dispenser nozzle, see Annex K.

12.7 Station inspection and tests following modifications

Following any service, maintenance or repair work having an impact on the safety or hydrogen quality of the fuelling station, the fuelling station operator shall assess the need for inspection and any functional testing, as defined in Clause 12 above, to be performed after this modification. These tests should be included as part of appropriate operating and maintenance procedures.

13 Operation

13.1 General

Warning signs, operational instructions, nameplates, markings, and identification plates should be of sufficient durability to withstand the physical environment involved, including the effects of weather.

Fuelling station equipment assembly markings and warning signs should comply with the applicable clauses of ISO 7010, ISO 3864 (all parts), ISO 17398 and IEC 60417. See 13.2 for additional requirements for warning signs and 13.5 for equipment markings.

13.2 Warning signs

Warning signs shall be placed to identify hazards identified in the risk assessment of 5.2, for example including (but not limited to) the following types of hazards:

— flammable fluids;

— hazardous areas, where flammable mixtures may form;

— pressurized fluids;

— electrical hazards;

— contents from drain valves,

— hot or cold surfaces;

— mechanical hazards.

Where applicable, hazardous area signage and the following warning signs should be placed at approaches to the fuelling station site:

— "Compressed hydrogen";

— "No smoking, open flames, or other ignition sources";

— "Authorized access only".

Warning signs should be clearly displayed and visible at all times, particularly at access points.

For liquid hydrogen installations, warning signs should indicate:

— LIQUID HYDROGEN;

— FLAMMABLE LIQUID;

— NO SMOKING;

— NO SOURCES OF IGNITION (NAKED FLAME);

— DO NOT SPRAY WATER ON VENT STACK;

— AUTHORIZED PERSONS ONLY.

For gaseous hydrogen installations, warning signs should indicate:

— GASEOUS HYDROGEN;

— FLAMMABLE GAS;

— COMPRESSED GAS;

— NO SMOKING;

— NO SOURCES OF IGNITION (NAKED FLAME);

— AUTHORIZED PERSONS ONLY.

Similar, additional signage should be displayed during deliveries of gaseous or liquid hydrogen as appropriate.

The maximum filling pressure and the filling capacity, as appropriate, of the storage system shall be indicated at the fill point.

For dispensing points, warning signs should be located within 3 m of the fuelling point, and should indicate:

— NO SMOKING;

— POWER OFF AND IMMOBILISE VEHICLE DURING FUELLING;

— FLAMMABLE GAS.

13.3 Dispenser operational instructions

Instructions for use of the hydrogen fuelling station dispenser by the general public shall be included on or in the vicinity of each dispenser. The dispenser fuel (i.e. hydrogen) and pressure class, see Table 1, shall be clearly indicated. Dispenser operation instructions for dispensing hydrogen into a vehicle may be displayed as markings or as an electronic display at the dispenser.

These instructions shall include prohibitions against:

— the use of adapters (e.g. 35 MPa vehicle fuelling from 70 MPa nozzle, or alternative fuel nozzles);

— the fuelling of cylinder systems (whether in a vehicle or not) that are incompatible with the fuelling protocol employed at the station, see 8.2.

Sampling of hydrogen at the nozzle for quality purposes requires the use of adapters and the fuelling of under-sized cylinders. This should be carried out only by trained persons according to a specific risk assessment and procedure. See 8.5, Clause 9 and Annex K for further details.

13.4 Functional identification

Control devices, visual indicators, and displays (particularly those related to safety) should be clearly and durably marked with regard to their functions either on or adjacent to the item. Such markings may be as agreed between the fuelling station operator and the supplier of the equipment. Preference should be given to the use of standard symbols given in IEC 60417 and ISO 7000.

Fuelling assembly components should be appropriately marked for identification (e.g. using a P&I tag).

Requirements for the marking of piping and tubing to identify content should be determined by risk assessment. As a minimum, it is recommended that the pipes accessible to the public, or visible by the public, should be marked.

NOTE ASME A13.1 documents one scheme for the identification of piping systems.

13.5 Marking of equipment (data plate)

Where applicable, equipment should bear a data plate or combination of adjacent labels located so as to be easily read when the equipment is in a normally installed position.

Where an IEC or ISO product safety standard exists for the equipment it should be marked in accordance with that standard.

Where an IEC or ISO product safety standard does not exist for the equipment, the data plate/label(s) should include the following information, as applicable:

a) manufacturer's name, trademark, and location;

b) the model number or type;

c) serial number;

d) date of construction;

e) component or assembly process ratings

   i. pressure rating, in MPa;

   ii. temperature rating, in °C;

f) utility connections;

   i. electrical:

      — electrical input range, in volts;

      — current rating, in amperes;

      — frequency in hertz and number of phases;

    — rated nominal power input (watts or VA);

  ii. fuel:

    — type;

    — quality;

    — pressure range;

  iii. rated nominal thermal input;

g) environmental ratings:

  i. IP rating;

  ii. ambient temperature range;

  iii. if applicable, the area classification rating;

h) hydrogen output

  iv. pressure range, in MPa;

  v. temperature range of output hydrogen, in °C;

  vi. flow rate (consumption);

i) main document number (see IEC 62023).

Equipment designed to be used in hazardous areas should be marked as required by IEC 60079-0 and the appropriate parts of the IEC 60079 series for the type(s) of protection used.

13.6 Reference designations

All enclosures, assemblies, control devices, and components should be plainly identified with the same reference designation as shown in the technical documentation for example on equipment required for emergency response.

13.7 Training

Fuelling station operators, maintenance personnel, and fuelling attendants shall be trained in the operations of the fuelling station as applicable.

New employees shall be trained in emergency response plan (ERP) procedures at the start of their employment. All operations personnel should be re-trained in the ERP procedures at least once per year.

A personnel training manual shall be provided and readily available at the fuelling station for consultation by personnel.

NOTE This requirement does not apply to public users of a commercial fuelling station.

13.8 Emergency response plan

The fuelling station should have an ERP prepared in accordance with ISO 14001. This document shall be readily available to operations personnel.

Emergency instructions shall be posted at the fuelling station in locations that are highly visible. As a minimum, instructions should be provided at the compressor, at each dispenser, and in the operator or attendants office as applicable.

13.9 Emergency contact information

In order to facilitate control of an emergency, a sign with the following emergency contact information should be included at the fuelling station site:

— the station operator's name and local address;

— the station operator's local phone number;

— the phone number of the local emergency service.

Operating, maintenance, and emergency instructions should be supplied to the fuelling station owner before commissioning the installation.

14 Technical documentation

14.1 General

The information necessary for installation, operation, and maintenance of the hydrogen fuelling station equipment shall be supplied in the appropriate forms, for example, drawings, diagrams, charts, tables, instructions.

The information shall be in an appropriate language(s) for the anticipated installation, operation, and maintenance personnel.

The information provided may vary with the complexity of the equipment. For very simple equipment, the relevant information may be contained in one document, provided that the document shows all the devices of the equipment and enables the connections to the utilities to be made.

NOTE The technical documentation provided with items of electrical equipment can form part of the documentation of the hydrogen fuelling station equipment.

14.2 Information to be provided

The information provided with the hydrogen fuelling station equipment shall include a technical file of critical documentation that shall be made available to the operator.

The technical file shall include the following minimum documentation:

a) declarations of conformity/manufacturer's declarations;

b) manual(s);

c) technical specifications;

d) assembly and layout drawings;

e) component lists;

f) schematics and technical diagrams;

g) calibration certificates.

h) setpoints for alarms and trips, for example in a variable table;

i) cause and effect matrix, including a description of safety loops and critical equipment;

j) HAZOP or underlying risk assessment;

k) a description (including interconnection diagrams) of the safeguards, interlocking functions, and interlocking of guards against hazards (safeguarding memorandum), particularly for equipment operating in a coordinated manner;

l) a description of the safeguarding and of the means provided where it is necessary to suspend the safeguarding (for example for setting or maintenance).

The manufacturer and/or integrator should assemble the documentation for the hydrogen fuelling station components, subsystems, assembly compliances, intended installation environment, and maintenance and service requirements into the technical file.

This technical file should be kept after the hydrogen fuelling station is decommissioned, disassembled, and disposed of.

Changes to the documentation shall be made in accordance to a management of change process, see 15.1.

Complementary documents that should be provided as part of the technical file include:

m) a clear, comprehensive description of the equipment, installation and mounting, and the connection to the electrical supply(ies) and other utilities;

n) electrical supply(ies) and other utility requirements;

o) information on the physical environment (for example lighting, vibration, atmospheric contaminants) where appropriate;

p) overview (block) diagram(s) where appropriate;

q) circuit diagram(s);

r) information (as applicable) on:

   i. programming, as necessary for use of the equipment;

   ii. sequence of operation(s);

   iii. frequency of inspection;

   iv. frequency and method of functional testing;

   v. guidance on the adjustment, maintenance, and repair, particularly of the protective devices and circuits;

   vi. recommended spare parts list; and

   vii. list of tools supplied.

s) control diagrams supplied by the component manufacturer;

t) instructions on the procedures for securing the hydrogen fuelling station for safe maintenance; (see also 14.9);

u) information on handling, transportation, and storage;

v) information regarding load currents, peak starting currents, and permitted voltage drops, as applicable;

w) information on the residual risks due to the protection measures adopted, indication of whether any particular training is required and specification of any necessary personal protective equipment;

x) emergency contact information;

y) any relevant information, as applicable, that would be needed for the operator to prepare a hydrogen quality plan, as specified in ISO 19880-8, for the equipment supplied.

14.3 Recommendations applicable to all documentation

Unless otherwise agreed between manufacturer and fuelling station owner or operator:

a) the documentation for the electrical system should be in accordance with relevant parts of the IEC 61082 series;

b) reference designations should be in accordance with relevant parts of the IEC 61346 series;

c) instructions or manuals should be in accordance with IEC/IEEE 82079-1;

d) parts lists where provided should be in accordance with IEC 62027, class B.

For referencing of the different documents, the supplier should select one of the following methods:

e) where the documentation consists of a small number of documents (for example less than 5) each of the documents should carry as a cross-reference the document numbers of all other documents belonging to the hydrogen fuelling station equipment; or

f) for single level main documents only (see IEC 62023), all documents should be listed with document numbers and titles in a drawing or document list; or

g) all documents of a certain level (see IEC 62023) of the document structure should be listed, with document numbers and titles, in a parts list belonging to the same level.

14.4 Installation documents

14.4.1 General

The installation documents shall give all information necessary for the preliminary work of setting up the hydrogen fuelling station equipment (including commissioning). In complex cases, it may be necessary to refer to the assembly drawings for details.

The recommended position, type, and cross-sectional areas of the supply cables to be installed on site should be clearly indicated. The data necessary for choosing the type, characteristics, rated currents, and setting of the overcurrent protective device(s) for the supply conductors to the electrical equipment of the machine should be stated (see IEC 60204-1:2016, 7.2.2 on supply conductors).

Where necessary, the size, purpose, and location of any ducts in the foundation that are to be provided by the fuelling station operator should be detailed.

The size, type, and purpose of ducts, cable trays, or cable supports between the machine and the associated equipment that are to be provided by the fuelling station operator should be detailed.

Where necessary, the diagram should indicate where space is required for the removal or servicing of the hydrogen fuelling station equipment.

NOTE 1 Examples of installation diagrams can be found in IEC 61082-4.

In addition, where it is appropriate, an interconnection diagram or table should be provided. That diagram or table should give full information about all external connections. Where the electrical equipment is intended to be operated from more than one source of electrical supply, the interconnection diagram or table should indicate the modifications or interconnections required for the use of each supply.

NOTE 2 Examples of interconnection diagrams/tables can be found in IEC 61082-3.

The installation documentation should also include guidelines on:

a) equipment unpacking;

b) location and design of the foundation;

c) installation and interconnection;

d) ventilation recommendations;

e) protection from weather hazards;

f) recommended height in relation to the base flood elevation;

g) altitude;

h) security enclosure;

i) acceptable distances from exposures; and

j) protection from vehicular impact.

The installation documentation should define the services and utilities, for example drains and waste water required for operation of the hydrogen fuelling station.

14.4.2 Installation documentation for hazardous areas

The hydrogen fuelling station installation documentation shall indicate the area classification (zone) and extent of any hazardous areas, see 5.3.5.2.

The installation documentation should also include specific instructions for the proper installation of hydrogen fuelling station equipment that is designed to be installed in hazardous areas in order to ensure compliance with IEC 60079-0 and with any other parts of IEC 60079 used for protection; see especially IEC 60079-14.

The installation documentation for hydrogen fuelling station components and assemblies using active ventilation as a means to protect against the accumulation of ignitable mixtures in accordance with 5.3.2 should also include recommendations for:

a) source of ventilation air;

b) location of exhaust;

c) ducting (when used).

14.4.3 Venting documentation

The installation documentation shall provide guidelines for the proper venting of gases and the proper installation of the vent lines. The installation documentation should indicate that relieved gases should be vented to a safe area (see 5.4.2).

The ability for vent stacks to carry lightning currents shall be documented in the manufacturers' documentation pack.

14.4.4 Seismic documentation

The seismic rating and related installation information, where applicable, shall be included in the installation documentation.

14.4.5 Handling and lifting documentation

Instructions on how to safely handle and lift hydrogen fuelling station assemblies shall be provided.

Lifting point to facilitate lifting by crane, forklift or other means as may be appropriate for the size and weight of the hydrogen fuelling station assembly should be provided and identified.

14.5 Overview diagrams and function diagrams

Where it is necessary to facilitate the understanding of the principles of operation, an overview diagram shall be provided. An overview diagram symbolically represents the hydrogen fuelling station equipment together with its functional interrelationships without necessarily showing all of the interconnections.

NOTE 1 Examples of overview diagrams can be found in the IEC 61082 series.

Function diagrams may be provided as either part of, or in addition to, the overview diagram.

NOTE 2 Examples of function diagrams can be found in IEC 61082-2.

14.6 Circuit diagrams

A circuit diagram shall be provided. This diagram shall show the electrical circuits on the hydrogen fuelling station and its associated electrical equipment. Any graphical symbol not shown in IEC 60617 should be separately shown and described on the diagrams or supporting documents. The symbols and identification of components and devices should be consistent throughout all documents and on the hydrogen fuelling station.

Where appropriate, a diagram showing the terminals for interface connections should be provided. That diagram may be used in conjunction with the circuit diagram(s) for simplification. The diagram should contain a reference to the detailed circuit diagram of each unit shown.

Switch symbols should be shown on the electromechanical diagrams with all supplies turned off (for example electricity, air, water, lubricant) and with the machine and its electrical equipment ready for a normal start.

Conductors should be identified in accordance with IEC 60204-1:2016, 13.2.

Circuits should be shown in such a way as to facilitate the understanding of their function as well as maintenance and fault location. Characteristics relating to the function of the control devices and components which are not evident from their symbolic representation should be included on the diagrams adjacent to the symbol or referenced to a footnote.

14.7 Flow (P&ID) diagrams

A flow diagram shall be provided. This diagram shall show the fluid piping on the hydrogen fuelling station and its associated instruments, valves, and equipment.

ISO 10628-1 provides further guidance. Any graphical symbol not shown in ISO 10628-2 or ISO 14617 should be separately shown and described on the diagrams or supporting documents. The symbols and identification of components and devices should be consistent throughout all documents and on the hydrogen fuelling station.

Where appropriate, a diagram showing the interface connections shall be provided. That diagram may be used in conjunction with the flow diagram(s) for simplification. The diagram should contain a reference to the detailed flow of each unit shown.

Valve symbols should be shown on the flow diagrams with all supplies turned off (for example electricity, air, water, lubricant) and with the hydrogen fuelling station and its fluids equipment ready for a normal start.

Piping and circuits should be shown in such a way as to facilitate the understanding of their function as well as maintenance and fault location. Characteristics relating to the function of the control devices and components which are not evident from their symbolic representation should be included on the diagrams adjacent to the symbol or referenced to a footnote.

On P&IDs, safety critical elements should be marked accordingly.

14.8 Fuelling station operating manual

The technical documentation shall contain an operating manual detailing proper procedures for set-up and use of the hydrogen fuelling station equipment. Particular attention shall be given to the safety measures provided.

The operating manual shall indicate the hazards related to the use of the fuelling station.

The operating manual shall also include a description and explanation of all warnings and markings on the hydrogen fuelling station especially those relating to hazardous areas.

The operating manual shall be made available to the operator.

14.9 Maintenance and service manuals

Where the fuelling station operator is anticipated to carry out any maintenance or servicing, the technical documentation shall contain maintenance and service manuals detailing proper procedures for adjustment, servicing, preventive inspection, replacement of consumables and repair, including requirements for lock-out and tag-out procedures where applicable.

This manual should contain clearly defined, legible, and complete instructions for starting, shutting down, and servicing the hydrogen fuelling station. Procedures for depressurization, purging and inerting, and isolation (for instance positive or proved isolation where necessary, see 3.56 and 3.61) shall be included in the service manual where applicable.

The station manufacturer or integrator shall recommend a safety concept for the recurring inspection and testing of the vessels. This concept should work without the need for people entering the vessel.

The maintenance instructions should also include specific instructions for the proper maintenance of the hydrogen fuelling station designed to be installed in hazardous areas to ensure compliance with IEC 60079-0 and with any other parts of the IEC 60079 series used for protection in accordance with IEC 60079-17.

Recommendations on maintenance and service intervals and records should be part of that manual. Where methods for the verification of proper operation are provided (for example software testing programs), the use of those methods should be detailed.

Where the operation of the equipment can be programmed, detailed information on methods of programming, equipment required, program verification, and additional safety procedures (where required) should be provided.

If the hydrogen fuelling station is provided with the capability for remote monitoring and data transmission, remote operation, or remote control code modifications, see 11.3, the station manufacturer or integrator should supply the instructions and procedures for the operator to be able to monitor the station remotely, receive data from the station, and/or to permit fuelling from an unattended station.

NOTE The maintenance and service manual is not required to be provided to the fuelling station operator unless the fuelling station operator is expected to perform maintenance or servicing on the hydrogen fuelling station equipment.

14.10 Parts list

The parts list, where provided, should comprise, as a minimum, information necessary for ordering spare or replacement parts (for example components, devices, software, test equipment, technical documentation) required for preventive or corrective maintenance including those that are recommended to be carried in stock by the fuelling station operator.

15 Inspection and maintenance

15.1 Inspection and maintenance program

The fuelling station shall have a documented inspection and maintenance program in place.

Fuelling station operators should determine a maintenance schedule that considers the particular fuelling station design, environmental conditions, fuelling loads, operating hours, frequency of use, and other factors impacting equipment use and wear.

The maintenance schedule should include safe maintenance intervals based on fuelling station experience and inspection requirements.

Maintenance of each piece of equipment should follow the manufacturer's instructions.

The checklist of Table 4 offers guidance on hydrogen fuelling station periodic inspection and testing.

Repair or direct replacement of fuelling station components should require verification and validation as applicable per 12.7. Modifications and repairs should be carried out under appropriate change management and control systems.

NOTE See ISO 9001, ISO 14001, OSHAS 18001 and OSHAS 18002 for guidance on management of change systems.

Where hydrogen equipment is to be operated during maintenance activities, positive or proved isolation, see 3.56 and 3.61, shall be used as appropriate according to maintenance procedures and/or risk assessment.

The fuelling station maintenance record should be available for inspection as necessary.

Components shall be shipped and stored in a manner according to the manufacturer's instructions prior to installation. Where applicable, the manufacturer's shelf-lives shall be adhered to.

Table 4 — Minimum periodic hydrogen fuelling station inspection and test checklist

No.	Content/Requirement	Requirement value	Reference to ISO 19880-1 (clause)	Pass/ Fail	Link to other standards/ Remarks
	Work permit (to assess risk and safety measures required)		5.3.5.2, 15.5		Per local authority (grinding/ welding)
	Good housekeeping				
	Maintenance log up to date				
	— sensor calibration				
	— leakage test				
	— PRD within calibration date				
	— Hose within date				
	Dispensed hydrogen quality test report	ISO 14687, Grade D	12.6, 9		ISO 14687 and ISO 19880-8
	Dispensing system fuelling protocol	Per applicable standard	12.5.3 (1) 8.2		SAE J2601
	Dispensing system fuelling limit test	Per applicable standard	12.5.3 (2) 8.2		SAE J2601
	Vehicle to dispenser communications	Per applicable standard	12.5.3 (3) 8.2		SAE J 2799 and SAE J 2601
	Verify emergency and safety functions	100 %	5.3, 12.5, 14.8		
	Verify emergency communications according to the risk assessment.	100 %	13.8		Test communications with emergency responders

15.2 Maintenance and testing frequency of gas detection

The gas detection system shall be maintained in accordance with the service requirements of the manufacturer. The service frequency shall be once per year as a minimum, or more often if so specified by the manufacturer.

Maintenance shall be performed by trained persons.

The following periodic maintenance actions shall be performed as a minimum:

— each gas detector shall be calibrated with a certified gas mixture;

— the entire system shall be checked for the desired settings;

— an overall function test shall be performed including the associated actions (see 11.2);

— an operation test shall be performed.

Special attention shall be given to detectors that are in an environment where pollution is influencing the operation, or detectors that are exposed to substances which reduce the lifetime of the detector.

All maintenance operations shall be recorded in a fuelling station log.

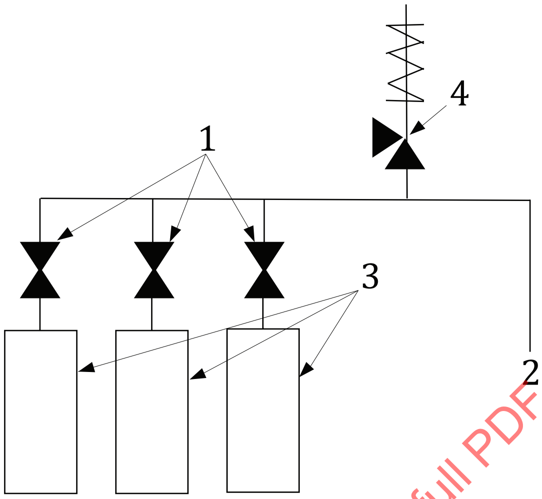
15.3 Maintenance and inspection frequency of filters

Filters for particulates and other possible fuel contaminants and operating debris (e.g. seal, gasket, desiccant materials) shall be inspected and replaced at a regular interval, according to the manufacturer's specifications. The pressure drop across dispensing system filters shall not exceed that required by the fuelling protocol, see 8.3.2.

15.4 Maintenance of pressure relief devices

Pressure safety equipment shall be inspected and either repaired or replaced at a regular interval, according to the manufacturer's specifications.

During maintenance, isolation of pressure relieving safety accessories from the equipment which it is designed to protect should only be permitted if the source of pressure, which could lead to an unsafe condition, is simultaneously isolated from the equipment with the pressure relief device. A typical arrangement is shown in Figure 3.



Key

1 isolating valves

2 pressure source

3 pressure vessel(s)

4 safety valve(s)

NOTE This figure is reproduced from EN 764-7: 2002.

Figure 3 — Illustration of one method of simultaneous isolation

Prior to isolation the continued need to protect against external sources of overpressure such as solar radiation and fire should be addressed.

15.5 Hot work

Maintenance operations requiring the generation of an ignition source within the restriction distances while the installation is in operation or pressurized with hydrogen should only be performed in case of service necessity and the atmosphere in the work area should be continuously analysed using a portable, transportable or, if applicable, fixed, hydrogen detector. Welding and grinding should be done with the utmost care. Hydrogen pipes and equipment should be protected from welding and grinding sparks by suitable protection devices such as welding/fire blankets. Such maintenance operations should be covered by a risk assessment, with specific attention to explosion and fire risks, in which all the measures necessary for ensuring safety are pre-defined.

15.6 Modifications to the hydrogen fuelling station and associated equipment

All modifications shall be assessed for impact on process safety and follow a management of change process.

Annex A
(informative)

Safety methodologies and risk assessment

A.1 General

The requirements for permitting (as applicable) and/or the justification for the safe design of a hydrogen fuelling station differ from country to country. In some countries/regions, specific hydrogen fuelling station regulations, codes or guidance documents exist, typically detailing prescriptive requirements or recommendations to be followed in the design, installation or operation of a fuelling station. A non-comprehensive list of examples is included in A.2.

Alternatively, the justification for the safe design of a station can utilise the process of risk assessment. A.3 to A.6 provide guidance on quantitative or semi-quantitative risk assessment for hydrogen fuelling stations in the specific context of informing site specific considerations to be taken.

A.2 Regional specific permitting guidance

A.2.1 Example of existing guidance

The following are regional specific permitting guides giving guidance on safety for hydrogen fuelling stations, typically using prescriptive methods:

1) Californian GO-Biz Hydrogen Permitting Station Guidebook:

   http://business.ca.gov/Programs/Permits/HydrogenStationPermitting.aspx

2) NOW Approval Guidelines for Hydrogen Refuelling Stations:

   http://www.h2-genehmigung.de/Index/Index?lang=1

3) NREL: Regulations, Codes, and Standards (RCS) Template for California Hydrogen Dispensing Stations

   http://www.hydrogen.energy.gov/permitting/stations_related.cfm

A.2.2 Example safety distances from each country/region

ISO maintenance portal URN (https://standards.iso.org/iso/19880/-1/ed-1/en) includes a table of examples of safety distances collected by ISO/TC 197, through country representative members during the preparation of ISO/TS 19880-1, which conveys a status of country specific safety distances at that the time of publication of the ISO/TS 19880-1 (2016). It demonstrates the wide range of results that can be found for similar equipment in similar environments around the world.

This table was not an inclusive list of values internationally and is not meant to be a recommendation for these applications.

A.3 Methodology for semi-quantitative and quantitative risk assessment for assessing hydrogen installation safety

A.3.1 General

It may be possible to use quantitative risk assessment (QRA) and/or semi-quantitative (e.g., consequence-only) analysis instead of prescriptive requirements to allow the hydrogen fuelling station to use alternative methods which are of an equivalent, or higher, level of safety to the prescriptive requirements. Using QRA may allow (for instance using mitigation measures) for shorter safety distances and/or simplified station layout.

If QRA is used, this subclause provides recommendations for performing that analysis. This analysis focuses on hazards involved with the release and ignition of hydrogen mixtures and related physical effects. This does not cover non-hydrogen hazards associated with the fuelling station, see 5.5.

Developing an approach to protect against harm should consider the following factors:

— nature of the hazards (e.g., thermal, pressure, potential for asphyxiation, etc.);

— behaviour of hydrogen under the design and operating conditions;

— equipment design and operating conditions;

— installation design and location, including protection measures;

— targets (e.g., person, property, equipment) which are being protected from effects of potential hazards.

A semi-quantitative risk assessment provides an intermediary level between the textual evaluations of qualitative risk assessment and the numerical evaluation of quantitative risk assessment, by evaluating risks with a score. Semi-quantitative risk assessment provides a structured way to rank risks according to their probability, severity, or both (criticality), and for ranking risk reduction actions for their effectiveness. This is achieved through a predefined scoring system that allows one to map a perceived risk into a category, where there is a logical and explicit hierarchy between categories. Semi-quantitative risk assessment is generally used where one is attempting to optimize the allocation of available resources to minimise the impact of a group of risks.

It helps achieve this in two ways:

— first, the risks can be placed onto a sort of map so that the most important risks can be separated from the less important;

— second, by comparing the total score for one or a series of risks before and after any proposed risk reduction measures, one can get a feel for how relatively effective the mitigation strategies are and whether they merit their costs.

For performing a semi-quantitative risk assessment, a full mathematical model is not always needed. It could sometimes offer the advantage of being able to evaluate a larger number of different kind of risk issues in a limited time. Nonetheless, all forms of risk assessment require the greatest possible collection and evaluation of data available on the risk issue.

A.3.2 Summary of methodology

Risk assessment provides a framework to establish a common understanding of the system safety level based on robust science and engineering models. The process enables transparent, evidence-based safety decisions. The QRA approach uses a combination of probabilistic and deterministic models to evaluate potential consequences on the targets identified in the previous section. Risk is characterized by a set of hazard exposure scenarios, the causes associated with each scenario, the undesirable consequences associated with the scenario, and uncertainty about these elements (this uncertainty is generally expressed by probability). In consequence-only modelling, the probability term is ignored, but the remainder of the analysis follows the same methodology.

The process for risk-informing mitigations includes the following steps, as displayed in Figure A.1:

— Target determination– Define the targets being protected, and as necessary, the hazard sources.

— Table A.2 provides many examples of targets.

— Analysis scoping – Select appropriate risk type for each target and establish tolerability criteria (e.g., acceptable/unacceptable risk level) for each target.

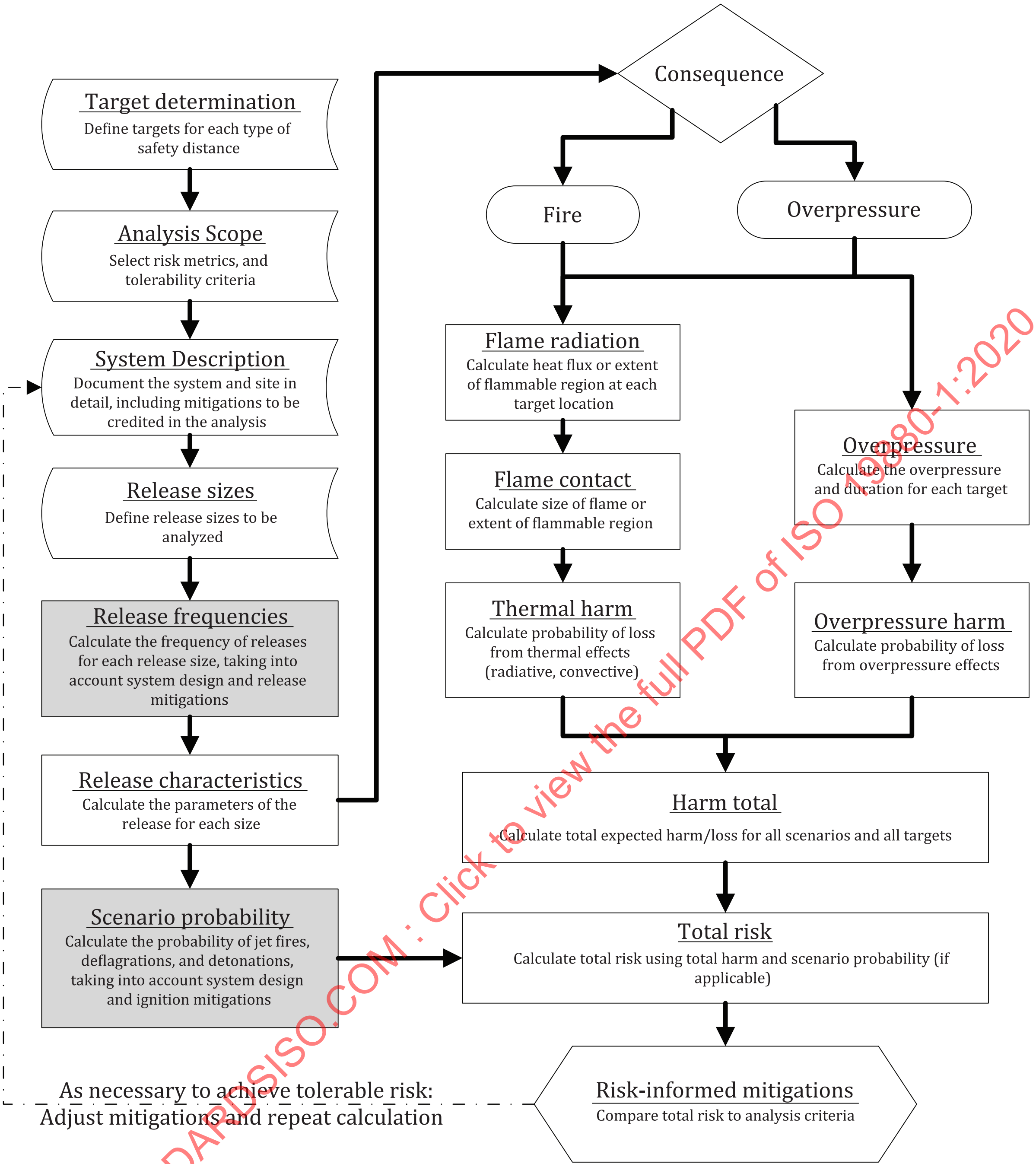
— System description – Document the system and installation being analysed, including mitigations to be credited in the analysis and which events they mitigate (see 5.1).

— Cause analysis – Identify and model the hazard scenarios and quantify the probability of each scenario in the model for each source and target.

— Consequence analysis – Identify the physical effects for each scenario, and quantify the impact of those effects on the targets.

— Risk assessment – Integrate the cause and consequence models into an assessment of the total risk; Perform sensitivity studies and changing modelling assumptions to identify appropriate combination of mitigation elements to maintain risk level within the tolerability region.

— Risk-informed mitigations – Increase or reduce mitigations to achieve risk level within tolerability region (including consideration of uncertainty).



NOTE 1 Grey shading denotes an analysis step that is used only in full-QRA approach.

NOTE 2 Concave rectangle denotes an analysis step.

NOTE 3 Rectangle denotes a calculation step.

NOTE 4 Diamond denotes branching.

Figure A.1 — Example of a risk-informed approach to safety distances

A.3.3 Analysis scoping

A.3.3.1 Target determination

Each characterisation of safety distance in Table A.1 affects one or more classes of target. Table A.3 provides many examples of targets for each type of safety distance. It is presupposed that types of safety distance are defined according to national requirements/guidance, with appropriate targets and hazards sources defined for each type of safety distance. Table A.2 provides examples of sources for the different types of safety distance.

A.3.3.2 Hazards

A.3.3.2.1 General

The primary hazards related to the use of hydrogen are the release and subsequent ignition of hydrogen. The two main hazards are thermal effects (e.g. conduction or radiation from hydrogen flames or post flame gases) and blast effects (overpressure and impulse) from deflagrations and detonations. Both of these hazards should be modelled for all sources and all targets.

A.3.3.2.2 Hazard distance

Hazard distance is a distance from the (source of) hazard to a determined (by physical or numerical modelling, or by a regulation) physical effect value (normally, thermal or pressure) that may lead to a harm condition (ranging from “no harm” to “max harm”) to people, equipment, or environment.

The calculation of hazard distances is deterministic based on a predetermined scenario (for example, a leak flow rate considered as most likely scenario or in some cases the worst-case scenario). Which means that hazard distances do not consider the probability of a hazardous event occurring. Hence, the direct use of hazard distances may lead to restriction of activities over large areas.

Thus, for practical applications, hazard distances should be used as an input to risk informed safety distances that employ both deterministic and/or probabilistic components of the QRA methodology. The probabilistic method should not underplay or underestimate the potential hazards, but take into account most scenarios, including those with a low probability of a hazardous event occurring as well as available means of protection, detection, and isolation to generate safety distances corresponding to an acceptable risk level.

A.3.3.3 Risk and harm criteria and tolerability limit selection

Risk and harm criteria are established through close interactions with stakeholders, which may include detailed surveys of existing risk benchmarks. A best practice is to ensure that risk from hydrogen fuelling should be equal to or less than the risk posed by similar activities, which could include gasoline fuelling, occupational accidents, general accident rates within the population, etc.

For personnel risk, including workers and/or members of the general public, four widely used fatality risk criteria are:

— FAR (fatal accident rate) – the number of fatalities per 100 million exposed hours;

— AIR (average individual risk) or individual risk per annum - the individual risk averaged over the population which is exposed to risk from the facility;

— PLL (potential loss of life) – the average number of fatalities (per system-year);

— F-N curves representing the expected frequency at which N or more people will be exposed to a fatal hazard (cumulative distribution function). Such curves may be used to express societal risk criteria.

Other criteria may be used, such as:

— average number of hydrogen releases per system-year;

— average number of jet fires per system-year;

— average number of deflagrations/detonations per system-year.

Consequence-based harm or damage criteria may be used, such as:

— heat flux level;

— thermal dose;

— flame temperature;

— flame length;

— peak overpressure;

— gas concentration;

— fluid temperature.

Acceptance criteria should be specified. These may be specified in terms of single values, acceptance bounds or distributions, use of ALARP (as low as reasonably practicable), option comparison, etc.

Due to the complexity and uncertainties involved in predicting performance in engineered systems, there will always be a level of subjectivity attached to any risk assessment result. This uncertainty should be considered when selecting risk and harm criteria and tolerability limits.

A.3.3.4 System description

The analysis should contain documentation of the installation and operational environments (as-built and as-operated). Documentation should contain sufficient detail to allow replication by an independent expert.

The documentation should define and identify the system, and components, their functions, and their relationships and interfaces. Block diagrams, P&IDs, and other figures should be included to facilitate understanding of the boundaries of the system, components of the system, and functions of each component in each operational environment. Installation characteristics should be described, including expected use conditions and layout diagrams. Expected operating parameters/states of hydrogen in the system should be documented.

The scope of work should capture and define the work activities and intended applications. If multiple operational environments are contained in one analysis, the work activities should be defined for each operational environment.

A.3.3.5 Cause analysis

A.3.3.5.1 General

The goal of cause analysis is to provide insight into the causes of hazardous exposures and the likelihood of those causes. This involves creating models that describe the scenarios that occur after a release of hydrogen, and quantifying these models using probability information.

A.3.3.5.2 Exposure scenarios

At a minimum, exposure scenarios should contain the following elements:

— Release of hydrogen. Release sizes that are to be modelled should be defined based on national requirements or guidance.

— Occurrence of ignition. At a minimum, ignition should be sub-divided into immediate and delayed ignition.

— Jet fires, deflagrations/detonations.

Root causes of releases should be identified qualitatively. Use of root cause information in quantification is optional. Root causes should include:

— leaks from individual components, including separation of a component or unintended operation;

— shutdown failures;

— accidents, including collisions and drive-offs;

— human errors.

Scenario and root cause models may also include:

— leak detection systems;

— system isolation;

— more detailed bifurcations of "ignition".

For QRA, exposure scenario fault expressions may be documented graphically, e.g. in Event Trees or Event Sequences Diagrams, or fault expressions can be manually specified. Root causes may be given as a list, or documented graphically, e.g. in Fault Trees, or through fault expressions.

A.3.3.5.3 Data for scenario quantification

Data used should be of sufficient quality to support decision making. Sources of data should be documented in the analysis.

Analysts should use published, hydrogen-specific data if it is available.

Non-published, hydrogen-specific data, such as proprietary company-specific data, may be used. If such data are used, it is presupposed that the data are documented and made available to the regulatory body or designated reviewer if requested. The designated reviewer should give extra scrutiny on inputs that lower probabilities below commonly used data sources.

In lieu of hydrogen-specific data, commonly accepted, published data sources (for example; OREDA, ESReDA, AiCHE API 521 or Sandia Laboratories H2 data) from similar industries and applications should be used.

A.3.3.6 Consequence analysis

A.3.3.6.1 General

This involves determining the physical effects of the scenarios, as well as the target response to those physical effects.

A.3.3.6.2 Physical effects of the accidents

The physical effects of hydrogen fires which should be modelled for a target are 1) thermal effects and 2) pressure effects. The primary physical effects relevant to ignited hydrogen releases are fire effects (for example; impinging flames, high temperature, heat flux) and explosions.

NOTE Debris effects (e.g., from over-pressurization of hydrogen vessel) are not required to be modelled.

Modelling of these required physical effects requires modelling several physical processes: release, jet flames, and deflagrations and detonations.

The physical models used should be validated for use in on hydrogen within the parameter ranges expected in the fuelling installation or specific equipment.

A.3.3.6.3 Hydrogen release characteristics

The first step in characterizing consequences is to characterize the release of hydrogen and the extent of the flammable envelope. Thermodynamic parameters of releases from high-pressure hydrogen systems can be estimated using notional nozzle models. The selected model should be validated for use in high-pressure hydrogen systems within the parameter ranges expected in the fuelling installation or specific equipment. The selected model should be specified in the analysis documentation.

A.3.3.6.4 Ignition sources

The source of ignition for an installation or the process itself should be examined. A non-comprehensive list of examples is as follows:

— lightning;

— static electricity (including clothing);

— mechanical sparks (for example; moving parts, tools not suitable for explosive atmospheres);

— naked flames;

— hot surfaces (for example; overheating by adiabatic compression);

— electrical components and installations (for example; electric sparks);

— exposed live cables.

A.3.3.6.5 Jet flame behaviour

Releases from high-pressure hydrogen systems that are ignited immediately produce momentum driven jet flames. A validated hydrogen model should be used to predict the characteristics of a jet flame necessary to meet the goals of the analysis. The selected characteristic(s) should be specified in the analysis documentation. Characteristics relevant to the goals of the analysis may include flame length, flame width, or heat flux. The position at which these characteristics are calculated should be specified in the analysis.

A.3.3.6.6 Deflagration and detonation behaviour

Releases from hydrogen systems which are not immediately ignited may accumulate and result in a flash fires or explosions.

Thermal and overpressure effects created from hydrogen deflagration or detonation can vary significantly based on the scenario.

The least significant is a flash fire when the cloud is ignited in its extremity (regions below 10 % of hydrogen). Flash fires result in thermal effects with very small overpressure.

When the cloud is important and ignition near the central stoichiometric region, the overpressure effects (and associated impulse) produced could be more important.

The turbulence in the hydrogen release, and/or the presence of objects, and/or release in a confined space can potentially result in an increase of the overpressure generated.

Blast effects may be modelled using validated software code based on computational fluids dynamics (CFD), empirical or phenomenological methods.

NOTE An example can be found in NORSOK Z013, Annex G.

A.3.3.7 Harm models

A harm or damage model or criteria is used to translate the physical effects into the harm to a person, a component, or structure. This should be done through use of either a model or criteria, including single criteria, deterministic models, probability models, probit functions. The selected criteria or model may come from reference to establish scientific information or national standard. The selected model or criteria should be specified in the analysis documentation.

A.3.3.8 Risk calculation

Some forms of risk assessment calculate risk for multiple individual scenarios and some use one calculation of risk for multiple scenarios.

When the total risk for the system is required, this should be calculated by combining the results of the scenario (cause) analysis and the consequence analysis into the total.

Risk is expressed as follows:

$$R = \sum_n (f_\mathrm{n} * c_n)$$

where

R is summed risk over all n selected scenarios;

f_n is the frequency of scenario n;

c_n is the consequence for scenario n.

Risk may be calculated separately for each type of consequence (e.g., harm, loss).

In all cases, a combination of risk analysis and consequence-only analysis may be used. For example, a regulatory body can ask for a consequence-only analysis for additional specific scenarios and can ask for a total risk analysis to include additional scenarios.

A.3.3.9 Risk-informed mitigations

The estimated risk level should be compared to the risk acceptance criteria.

If the estimated risk level is above the acceptance criteria, the analyst should implement additional mitigations or increase safety distances to reduce the risk level, and re-run the analysis.

If the estimated risk level is below the acceptance criteria, the mitigations or safety distance may be reduced.

Analysts should consider and discuss appropriate methods to account for uncertainty when comparing to risk criteria. This should be addressed through use of conservative risk criteria, or sensitivity analysis or methods to propagate uncertainties.

A.4 Quantitative risk assessment toolkits

A.4.1 General

Toolkits may be used to facilitate implementation of the methodology.

An approved toolkit should:

— contain the latest available data and models (ideally, validated for hydrogen infrastructure use) relevant to quantifying the probability of progression various hazard scenarios;

— contain the latest available data and models (ideally, validated for hydrogen infrastructure use) relevant to prediction of behaviour of hydrogen releases and ignition events, and the consequences of those events;

— calculate the representative observable quantities (e.g., physical parameters, damages, number of fatalities) relevant to decision making for safety, codes, and standards;

— facilitate relative risk comparison, sensitivity analysis, and treatment of uncertainty;

— provide default models, values and assumptions, and provide transparency about those defaults; furthermore, it allows modification of these defaults to reflect different systems and new knowledge.

A.4.2 Examples of toolkits/software tools

HyRAM: A toolkit for integrated deterministic and probabilistic risk assessment for hydrogen infrastructure.

SAFETI: SAFETI-NL is the software tool used for quantitative risk assessment calculations in the Netherlands[1)].

NOTE For calculation of safety distances used for hydrogen fuelling stations in the Netherlands, the programme SAFETI-NL NL v6.5.4 was used, with some changes (proposed by DNV GL) with regard to the discharge parameters used by the programme. The approach used to calculate the safety distances was further based largely on that described in EIGA 75/07/E (2007), section 9.

Phast/Phast Risk: A process hazard analysis software tool, available from DNV GL, for all stages of design and operation, which examines the progress of a potential incident from the initial release to far-field dispersion analysis including modelling of pool spreading and evaporation, and flammable and toxic effects.

FLACS: A CFD tool used for ventilation, gas dispersion and explosion simulations in safety analyses, including a fire module.

KFX-Exsim: A CFD tool used for ventilation, gas dispersion and fire simulations in safety analysis, including an explosion module.

NET-Tools: European e-Laboratory of Hydrogen Safety for online calculation of hazard distances for unignited releases, jet fires, blast wave and fireball after hydrogen storage tank rupture in a fire, deflagration mitigation techniques, etc.

1) Further detail is available from http://content.publicatiereeksgevaarlijkestoffen.nl/documents/PGS35/PGS_35_WG_2015_032_PGS35_Definitief%20Achtergronddocument.pdf.

A.5 Safety distances definition

A.5.1 General

This document recommends making a distinction between safety distances designed to protect against different hazards, and uses the following terms:

— restriction distances;

— clearance distances;

— installation layout distances;

— protection distances;

— external risk zone.

A.5.2 Types of safety distances

A.5.2.1 Restriction distances

The restriction distance is the minimum distance from hydrogen equipment or the area around where certain activities are restricted or subject to special precautions (e.g., no open ignition sources, like flames, hot works, electrical sparking, use of sparking tools, smoking, etc.).

NOTE This is addressed in 5.3.5.2. The remaining types of safety distances mitigate foreseen and unforeseen events other than those arising from activities restricted during normal operations.

A.5.2.2 Clearance distances

The clearance distance is the minimum distance between the fuelling station equipment and the vulnerable targets within the fuelling station site boundary. Here, the hydrogen installation is regarded to be the source, while the surrounding people/objects are considered to be the targets.

Examples of targets that may be exposed include personnel of the fuelling station, users of the fuelling station, and other facilities within the fuelling station like gasoline storage, gasoline dispensing, and delivery facilities. Additional examples are listed in Table A.3.

A.5.2.3 Installation layout distances

The installation lay-out distance is the minimum distance between the various equipment of the hydrogen installation required to prevent escalation to other equipment in case of an incident. Installation layout distances may be different combinations of hydrogen equipment.

Example of source-target pairs are dispenser and bulk storage; liquid or gaseous hydrogen storage and hydrogen venting. Additional targets are listed in Table A.3.

A.5.2.4 Protection distances

The protection distance is to prevent damage to the hydrogen installation equipment from external hazards (e.g., fires) not accounted for in the installation layout distances.

NOTE In this case, the term external refers to both off-site events and also on-site events unrelated to the hydrogen equipment.

The protection distance prevents off-site and non-hydrogen-related events from escalating to the hydrogen equipment. Protection distances may be different for specific elements of the fuelling station equipment.

External sources of hazard often involve fires and collisions. Sources include presence of combustibles (e.g., gasoline storage area), on site vehicles using non-hydrogen parts of the fuelling station, and vehicles on nearby roads; additional example sources are provided in Table A.2. Example targets are any equipment of the hydrogen fuelling station, including equipment listed in Table A.3.

A.5.2.5 External risk zone

The external risk zone is the distance (or area) outside fuelling station which is to be protected from hazards caused by the fuelling station. Here, the fuelling station is the hazard source, while people and constructions offsite are regarded to be the target(s).

Example off-site targets include members of the public residing or working near the fuelling station; additional targets are listed in Table A.3.

A.5.3 Examples of safety distances

Table A.1 — Summary of types of safety distances

Characterization of safety distance	Purpose	Source	Target(s)
Restriction distances	Minimise risk in areas adjacent to hydrogen equipment	Fuelling station equipment	Any open area adjacent to hydrogen equipment
Clearance distance	Protect persons and objects within the fuelling station from hazards associated with the fuelling station	Equipment and objects within fuelling station	Persons and other facilities within the fuelling station
Installation lay-out distance	Prevent escalation of events within fuelling installation	Fuelling station equipment	Fuelling station equipment
Protection distance	Protect the fuelling station from damage due to any external hazards	Off-site facilities and on-site things (except for the fuelling station equipment)	Fuelling station equipment
External risk zone	Mitigate off-site risks from hazards associated with the Fuelling station	Fuelling station equipment	Surrounding people/ property outside of the fuelling station

Table A.2 — Example sources for each type of safety distances

Safety distance	Example sources[a]
Clearance distance AND Installation lay-out distance AND External risk zone	Equipment of the fuelling station — Dispenser; — Compressor; — Liquid hydrogen storage; — Gaseous hydrogen storage.

[a] The information in this table is provided to facilitate identification hazard sources that could be included in the model. It is not required to establish safety distances for any of the sources in the table. It is also permissible to establish safety distances for sources not listed in this table.

Table A.2 *(continued)*

Safety distance	Example sources[a]
Protection distance	Off-site or on-site: — Presence of other combustible liquids or gases (e.g., gasoline storage, LPG storage, pipelines containing flammable gases of liquids); — Buildings of combustible materials. On-site: — Vehicles using non-hydrogen parts of the fuelling stations. Off-site: — Vehicles on nearby roads; — Specific types of industrial buildings.

[a] The information in this table is provided to facilitate identification hazard sources that could be included in the model. It is not required to establish safety distances for any of the sources in the table. It is also permissible to establish safety distances for sources not listed in this table.

Table A.3 — Example targets for each type of safety distance

Safety distance	Example targets[a]
Clearance distance	Persons: — Workers in the fuelling station (1st party); — Users of the fuelling station (2nd party); — Public and users of other facilities within the fuelling station (3rd party). Other facilities within the fuelling station: — Building such as convenience stores, carwash; — Gasoline storage; — Gasoline dispensing facilities; — Fuel delivery areas; — Building openings, air intakes.
Installation lay-out distance AND Protection distance	Equipment of the fuelling station: — Dispenser; — Compressor; — Liquid hydrogen storage; — Gaseous hydrogen storage; — Vent stack exits.

[a] The information is this table is provided to simplify target selection. It is not required to establish safety distances for any of the targets in the table. It is also permissible to establish safety distances for targets not listed in this table.

Table A.3 *(continued)*

Safety distance	Example targets[a]
External risk zone	Persons: — Public (3rd party); — Places of public assembly. Property: — Lot lines; — Parking; — Houses; — Public buildings such as schools, hospitals; — High voltage lines.

[a] The information is this table is provided to simplify target selection. It is not required to establish safety distances for any of the targets in the table. It is also permissible to establish safety distances for targets not listed in this table.

A.6 Examples of safety distances derived from risk assessment

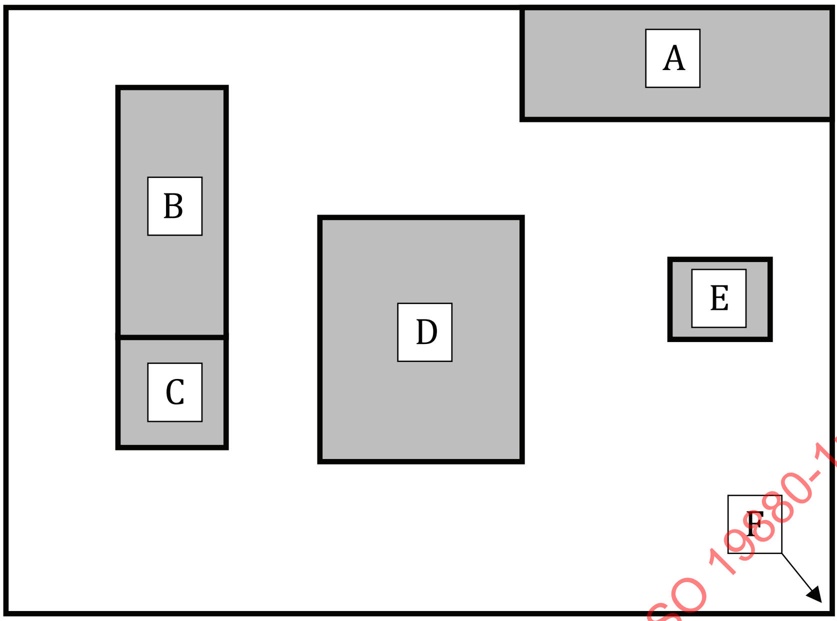
A.6.1 General

Safety distances are one of several station features designed to ensure safety. Design choices and regional and local regulations can change the safety features of the system. To make it possible to take these differences into account when calculating safety distances, a common approach is proposed in this annex. If needed this approach can be used towards local or national authorities for assessing in a detailed and appropriate manner the safety distances to be applied.

This annex can be used either for designing the station in order to improve the safety distances or for comparing the safety distances using different method: quantitative risk assessment or consequence-only modelling.

The example described in this annex illustrates how to perform an analysis to prepare a country-specific safety distances. The approach follows the methodology established Clause 5. The approach allows two methods for analysing safety of a hydrogen fuelling station: quantitative risk assessment and consequence-only modelling. Both methods are demonstrated herein.

The example system is an outdoor, publicly-accessible, compressed gaseous hydrogen station. The hydrogen supply is via tube trailer, with on-site compression and dispensing. The layout of the example system is shown in Figure A.2. The station dispenses 700 bar hydrogen, with maximum expected system pressure of 975 bar in the compressor. The station operates 24 hours per day, 365 days per year in a climate with average temperature and pressure 15 °C and 1 atm (101,325 kPa).



Key

A building/shop
B trailer module 0
C panel module 1
D station modules 2, 3, 4, 5 & 6
E dispenser
F lot line

Figure A.2 — Layout of the example hydrogen fuelling station

The example station is comprised of multiple modules. Module 0 is a trailer and module 1 is a connection cabinet. The main body of the station includes up to 5 modules: module 2 is low pressure gaseous hydrogen storage; module 3 is a compressor units; module 4 is a high-pressure hydrogen cabinet; module 5 is the high-pressure storage; and module 6 is a precooling unit. Module 7 is the dispenser.

Two station configuration options are considered in this example. For option 1, the compressed gaseous hydrogen trailer (module 0) stays on site and is used as the main hydrogen source for the hydrogen fuelling station. In this case, the low pressure storage tank (module 2) is not part of the station. For option 2, the compressed gaseous trailer will only be on site temporarily for unloading in a low pressure storage tank (module 2). In that case the low pressure storage tank will be considered as part of the station. Expected operating parameters of the modules are presented in Table A.4.

Table A.4 — Expected operating parameters of the example station

	System pressure	Ambient temperature external to system (minimum range)	Largest pipe outer diameter	Pipe wall thickness
Module 0	Up to 25 MPa	−18 °C to +40 °C	10 mm	(Not considered)
Module 1	Up to 25 MPa	−18 °C to +40 °C	10 mm	(Not considered)
Module 2	Up to 25 MPa	−18 °C to +40 °C	9,525 mm	1,587 5 mm
Module 3	Operating pressure: 70 MPa Range: 3 MPa to 97,5 MPa	−18 °C to +40 °C	9,525 mm	1,587 5 mm
Module 4	Operating pressure: 70 MPa Range: 3 MPa to 97,5 MPa	−18 °C to +40 °C	9,525 mm	1,587 5 mm
Module 5	Operating pressure: 70 MPa Range: 3 MPa to 97,5 MPa	−18 °C to +40 °C	9,525 mm	1,587 5 mm
Module 6	Operating pressure: 70 MPa Range: 3 MPa to 97,5 MPa	−18 °C to +40 °C	9,525 mm	1,587 5 mm
Module 7	Operating pressure: 70 MPa Range: 3 MPa to 97,5 MPa	−18 °C to +40 °C	9,525 mm	1,587 5 mm

A.6.2 defines a list of standard case scenarios to be considered for assessing the corresponding safety distances (corresponding to several kinds of safety distances defined in Clause 5). Then we illustrate the calculation of station-specific safety distances using several approaches and acceptance criteria.

The example calculations are performed in the HyRAM software, which is available for free download at http://hyram.sandia.gov. Calculations were performed in HyRAM version 1.0.2.766.

NOTE The example uses HyRAM tool. Other tools such as SAFETI and PhastRisk are equally suited for this kind of QRA, see A.4.2.

A.6.2 Description of scenarios for calculation of safety distances

In this example, illustrations of calculation are provided for multiple scenarios, including two external risk zones scenarios and one clearance distance scenario. Local authorities can define additional scenarios. Similar calculations could be applied to define installation layout distances, restriction distances, and protection distances.

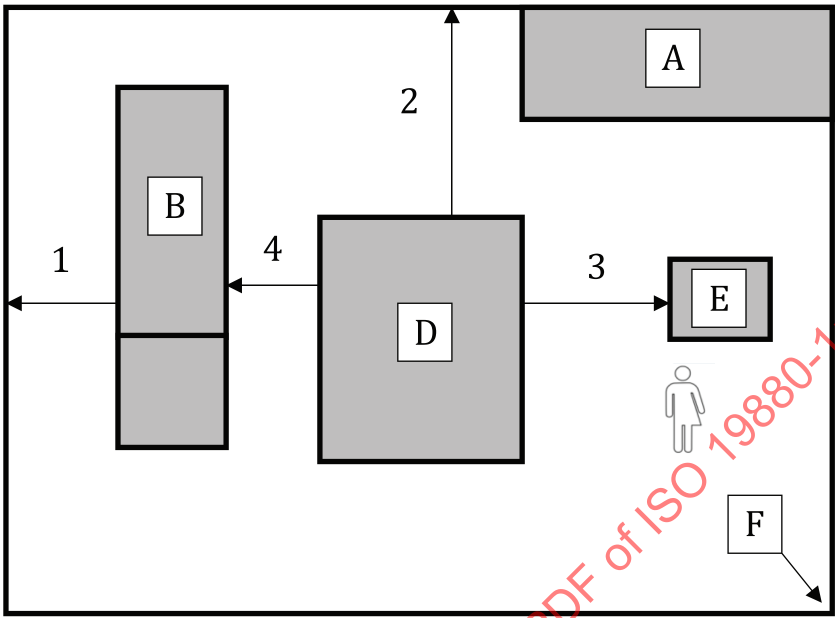
In most cases, several calculation options are demonstrated, corresponding to both calculation approaches, and different station designs and local restrictions, modelling choices, and acceptance criteria. The current example does not consider hazards related to accumulation of hydrogen in confined spaces.

Four standard cases are defined below in Table A.5. They are illustrated on the lot layout in Figure A.3.

Table A.5 — List of example cases for safety distances

Case(s)	Type of safety distance	Source	Target
Standard Case 1	*External risk zone*	Module 0 & 1 (Trailer & connection cabinet)	One person (a member of the public) standing at the lot line.
Standard Case 2	*External risk zone*	Station (Modules 2, 3, 4, 5, 6 considered together)	One person (member of the public) standing at the lot line.
Standard Case 3	*Clearance distance*	Station (Modules 2, 3, 4, 5, 6 considered together)	One person (station user) standing at the dispenser

These cases described in Table A.5 are illustrating two types of safety distances. Other kind of safety distances (defined in A.5) can be calculated by similar approach with different harm criterion or risk criteria or models.



Key

A building/shop
B trailer module 0
C panel module 1
D station modules 2, 3, 4, 5 & 6
E dispenser
F lot line

Figure A.3 — Illustration of the safety distances in the example cases

A.6.3 Analyses performed

A.6.3.1 Risk and harm acceptance criteria used within.

Risk acceptance criteria and harm acceptance criteria may come from various published sources. The following criteria are used in this analysis:

— AIR < 1e^{-6} for vulnerable external populations and 1e^{-5} for less vulnerable (Dutch source)

— AIR < 2,0e^{-5} for members of the public (Used in NFPA 2)

— AIR < 1,0e^{-4} for facility users and workers

— Thermal flux:

  — 1,26 kW/m^2 (in API 521 KHK committee document)

  — 1,577 kW/m^2 (used in NFPA 2; Originally found in SFPE guide)

  — 1,6 kW/m^2 (“irreversible effects” threshold for continuous exposure, meaning more than 60 s from API 521)

  — 3,0 kW/m^2 (“irreversible effects threshold for...how long exposure?” from API 521)

— 5,0 kW/m^2 (threshold effects on windows)

— 8,0 kW/m^2 (potential domino effects threshold)

A.6.3.2 Default parameters used in all cases

The models, data, and default values for Table A.6 are explained in more detail in the HyRAM technical reference manual \cite{HyRAMtechreport}. Additional information about the underlying scientific basis of the models and data can be found in the original sources which are cited in the HyRAM technical reference manual.

Table A.6 — HyRAM model and input parameters used in these analyses

HyRAM Model or Input Parameter	Value	Comments
Flame Radiation Model	Ekoto/Houf (curved flame)	
Notional Nozzle	Yuceil/Otugen	.
Radiative source model	Multiple radiation sources, integrated	
Deflagration Model	CFD With user input: P_s = [0,0,0,0,0] and Impulse = [0,0,0,0,0]	Since this station is outdoors and there is no confinement of the hydrogen, so therefore no overpressure generated by fires.
Thermal Probit	Tsao	
Thermal Exposure	60 s	
Overpressure Probit	Lung Eisenberg	
Leak frequency (for all components, all sizes)	Default values	
Ignition Probabilities	Default values	
System Parameters - Vehicles	One or more inputs on this tab should be set to 0.	This HyRAM feature is not intended to be used in this analysis. All inputs on this should be set to 0.
Gas release angle	0 degrees	
Jet flame angle	0 degrees	
Leak height from floor (y0)	1 m	
Relative humidity	0,89	
Y radiative heat flux points (m) (Vertical)	All are set to 1 m.	
Z radiative heat flux points (m) (Perpendicular to flame)	In physics mode all are set to 0 m. (Flame centerline). In QRA mode Z=X-=location distribution parameter A.	
Location distribution type	Deterministic	

A.6.3.3 to A.6.3.5 describe some illustrative examples of scenario and case description.

Examples are not inclusive of all possible cases.

A.6.3.3 Case 1 analysis

As mentioned previously, different methods can be used to assess the safety distances.

Below in Table A.7 are described the details of the different approaches. These approaches are country or region specific.

Case 1A and Case 1B use a QRA-informed approach for finding this safety distance. Cases 1C to 1E use a consequence-only approach to find this safety distance. Case 1F does not calculate a distance for this scenario. The key differences between the cases are highlighted in grey.

The consequence-only cases differ from the QRA cases in two important ways. First, the QRA cases allow the region to include consideration of the system design, safety features, and release frequency (from each part in the system) in the calculation of distance. Secondly, the QRA approach considers the full spectrum of possible release sizes: the calculation includes consequences from all possible release sizes. These consequences are weighed based on the frequency of that leak size. In the consequence-only approaches, there is no credit for the system design; the release size is chosen (this is different from the QRA approach where all release sizes are considered and weighted by the frequency of those releases based on system reliability data) and selected based on local requirements. In most regions the selected release sizes are much smaller than the largest possible release. In some regions this is specified as a required diameter (e.g., 0,2 mm, 1 mm) or a required fraction of the pipe diameter (1 % or 10 % of a pipe OD, ID, or flow area).

Case 1A considers the consequence from all possible release sizes (including the maximum possible release of 10 mm) and also considers the likelihood of those releases from each component in the system. Region A uses the published risk acceptance criteria of AIR < $1{,}0e^{-5}$.

Case 1B differs from Case 1A with one main difference: Region B requires a flow orifice on module 0; this orifice restricts the flow area in this system down to an effective diameter of 3 mm. Region B also uses a different risk acceptance criteria of AIR < $2{,}0e^{-5}$.

Case 1C uses the conservative 1,26 kW/m² harm acceptance criteria and requires analysis of a 100 % release (corresponding to a full bore rupture) from the largest pipe in the system. Case 1D uses the same harm criteria but only requires analysis of a release of 1 % of pipe diameter and requires consideration of the maximum allowable pressure (25 % more than the intended operating pressure). Region E uses a higher harm acceptance criteria of 3,0 kW/m² and requires modelling a release size of 10 % of pipe flow area.

In Case 1F, the safety distance is 0 m, because Region F does not assess this safety distance scenario in their regional requirements due to other regional requirements designed to mitigate the risk from Case 1.

Table A.7 — Case 1 HyRAM analysis results

	Case 1A	Case 1B	Case 1C	Case 1D	Case 1E	Case 1F
Calculation approach	QRA	QRA	Consequence-only	Consequence-only	Consequence-only	Region F does not consider the case 1 scenario.
Acceptance criterion	AIR < $2{,}0e^{-5}$	AIR < $1{,}0e^{-5}$	1,26 kW/m²	<1,26 kW/m²	<3,0 kW/m²	
Pipe maximum flow diameter (either the ID or effective ID based on flow restriction)	10 mm (ID from module 0)	3 mm (flow rate equivalent of a 3 mm pipe)	N/A. System design is not considered in consequence-only approaches.			
Release diameter considered	[All releases from 0,1 mm - 10 mm]	[All of releases from 0,03 mm - 3 mm]	Maximum (10 mm hole)	1 mm	10 % of flow area (3 mm)	
Internal temperature	15 °C	15 °C	15 °C	15 °C	15 °C	
Internal pressure	250 bar (25 MPa)	250 bar (25 MPa)	250 bar (25 MPa)	312,5 bar (31,25 MPa)	250 bar (25 MPa)	
External temperature	15 °C	15 °C	15 °C	15 °C	15 °C	
External pressure	1 atm (101,325 kPa)	1 atm (101,325 kPa)	1 atm (101,325 kPa)	1 atm (101,325 kPa)	1 atm (101,325 kPa)	

Table A.7 *(continued)*

	Case 1A	Case 1B	Case 1C	Case 1D	Case 1E	Case 1F
System configuration (sources of releases)	0 compressors, 0 cylinders, 23 valves, 3 instruments, 2 filters, 0 flanges, 48 (non-welded) joints, 1 hose, 10 m pipes	0 compressors, 0 cylinders, 23 valves, 3 instruments, 2 filters, 0 flanges, 48 (non-welded) joints, 1 hose, 10 m pipes	N/A. System design is not considered in consequence-only approaches.			
Credit for additional mitigations (e.g., gas or flame detection) or other documented considerations (e.g., direction of release)	0,0	0,0	N/A. System design is not considered in consequence-only approaches			
Number of exposed persons	1	1	N/A. Exposed population is not considered in consequence-only approaches.			
Person's exposed hours in 1 year	8 760	8 760	N/A. Exposed population is not considered in consequence-only approaches.			
Illustrative examples of calculated safety distance	**11,5 m**	**1 m**	**40 m**	**4,0 m**	**8,5 m**	**Not applicable**

A.6.3.4 Case 2 analysis

In Table A.8, Case 2A and Case 2B use a QRA-informed approach for finding this safety distance. Cases 2C to 2D use a consequence-only approach to find this safety distance. The key differences between the cases are highlighted in grey.

As stated before, the consequence-only cases differ from the QRA cases in two important ways. First, the QRA cases allow the region to include consideration of the system design, safety features, and release frequency (from each part in the system) in the calculation of distance. Secondly, the QRA approach considers the full spectrum of possible release sizes: the calculation includes consequences from all possible release sizes. These consequences are weighed based on the frequency of that leak size. In the consequence-only approaches, there is no credit for the system design; the release size is chosen (this is different from the QRA approach where all release sizes are considered and weighted by the frequency of those releases based on system reliability data) and selected based on local requirements. In most regions the selected release sizes are much smaller than the largest possible release. In some regions this is specified as a required diameter (e.g., 0,2 mm, 1 mm) or a required fraction of the pipe diameter (1 % or 10 % of a pipe OD, ID, or flow area).

Case 2A case considers the consequence from all possible release sizes (including the maximum possible release of 0,312 5 in) and also considers the likelihood of those releases from each component in the system. Region A uses the published risk acceptance criteria of AIR < $1{,}0e^{-5}$.

Case 2B is very similar to Case 2A, but more parts are included in the Case 2B system configuration. This is because Region B regulations prohibit an on-site trailer: instead, stations in Region B are assumed to have on-site storage (represented by Module 2 in this example).

Region C uses a harm acceptance criteria of 3,0 kW/m^2 and requires modelling a release size of 10 % of pipe flow area. Region D uses the conservative 1,26 kW/m^2 harm acceptance criteria. Both Region C and Region D require modelling of a 1 mm hole in the system.

Table A.8 — Case 2 HyRAM analysis results

	Case 2A	Case 2B	Case 2C	Case 2D	Case 2E
Calculation approach	QRA	QRA	Consequence-only	Consequence-only	Consequence-only
Acceptance criterion	AIR < 1,0e^{-5}	AIR < 1,0e^{-5}	<3,0 W/m^2	<1,26 kW/m^2	<1,26 kW/m^2
Pipe maximum flow diameter (either the ID or effective ID based on flow restriction)	0,312 5 in (ID from modules 3-5)	0,312 5 in (ID from modules 3-5)	N/A. System design is not considered in consequence-only approaches.		
Release diameter considered	[All releases from 0,003 125 in – 0,312 5 in]	[All releases from 0,003 125 in – 0,312 5 in]	1 mm	1 mm	1 mm
Internal temperature	15 °C	15 °C	15 °C	15 °C	15 °C
Internal pressure	700 bar (70 MPa)	700 bar (70 MPa)	700 bar (70 MPa)	700 bar (70 MPa)	700 bar (70 MPa)
External temperature	15 °C	15 °C	15 °C	15 °C	15 °C
External pressure	1 atm (101,325 kPa)	1 atm (101,325 kPa)	1 atm (101,325 kPa)	1 atm (101,325 kPa)	1 atm (101,325 kPa)
System configuration (sources of releases)	2 compressors, 40 cylinders, 20 valves, 8 instruments, 0 filters, 0 flanges, 24 (non-welded) joints, 0 hoses, 20 m pipes	2 compressors, 48 cylinders, 32 valves, 12 instruments, 0 filters, 0 flanges, 44 (non-welded) joints, 0 hoses, 30 m pipes.	N/A. System design is not considered in consequence-only approaches.		
Credit for additional mitigations (e.g., gas or flame detection) or other documented considerations (e.g., direction of release)	0,9 (reduction by 90 % of frequency)	0,9 (reduction by 90 % of frequency)	N/A. System design is not considered in consequence-only approaches		Region E allows safety distances to be reduced by 50 % if barrier walls added
Number of exposed persons	1	1	N/A. Exposed population is not considered in consequence-only approaches.		N/A. Exposed population is not considered in consequence-only approaches.
Person's exposed hours in 1 year	8 760	8 760	N/A. Exposed population is not considered in consequence-only approaches.		N/A. Exposed population is not considered in consequence-only approaches.
Illustrative examples of calculated safety distance	**1 m**	**2,5 m**	**4,5 m**	**5,5 m**	**2,75 m**

A.6.3.5 Case 3 analysis

In Table A.9 Case 3A, Region A uses a higher AIR criterion of 1 × 10^{-4} because the exposed person is a user of the station. Similarly, Case 3C and Case 3D use higher harm criteria.

Table A.9 — Case 3 HyRAM analysis results

	Case 3A	Case 3B	Case 3C	Case 3D
Calculation approach	QRA	Region B does not consider the case 3 scenario.	Conseq. only	Conseq. only
Acceptance criterion	AIR < 1 × 10^{-4}		<5,0 W/m^2	<3,0 kW/m^2
Pipe maximum flow diameter (either the ID or effective ID based on flow restriction)	0,312 5 in (ID from modules 3-5)		N/A. System design is not considered in consequence-only approaches.	
Release diameter considered	[All releases from 0,003 125 in – 0,312 5 in]		10 % of ID (0,031 25 in)	1 mm
Internal temperature	15 °C		15 °C	15 °C
Internal pressure	700 bar (70 MPa)		700 bar (70 MPa)	700 bar (70 MPa)
External temperature	15 °C		15 °C	15 °C
External pressure	1 atm (101,325 kPa)		1 atm (101,325 kPa)	1 atm (101,325 kPa)
System configuration (sources of releases)	2 compressors, 40 cylinders, 20 valves, 8 instruments, 0 filters, 0 flanges, 24 (non-welded) joints, 0 hoses, 20 m pipes		N/A. System design is not considered in consequence-only approaches.	
Credit for additional mitigations (e.g., gas or flame detection) or other documented considerations (e.g., direction of release)	0,0		N/A. System design is not considered in consequence-only approaches	
Number of exposed persons	1		N/A. Exposed population is not considered in consequence-only approaches.	
Person's exposed hours in 1 year	8 760		N/A. Exposed population is not considered in consequence-only approaches.	
Illustrative examples of calculated safety distance	**0,5 m**	**0 m**	**3 m**	**4 m**

Annex B
(informative)

Further guidance on risk management

B.1 General

This annex is to be used as a narrative to the Clause 5 and is intended to give valuable additional information, examples and list of items that are recommended to consider. Also, in some instances, the possible solution space is listed.

One major aim of risk assessment is to provide a description of the hazard scenarios, their causes and consequences and uncertainties (taken in part or in whole), for use in decision making (e.g., comparison against a defined risk acceptance criteria). The generated information can be used to make educated changes to the design and siting of the hydrogen fuelling station with the aim to reduce the risk posed to surrounding people, assets and the environment to a level tolerable to the society in which the station is operating.

The risk assessment can further be used to show to the authorities that an equivalent (or higher) level of safety can be reached with arrangements that deviate from the ones e.g. found in prescriptive

B.2 Hydrogen fuelling station safety recommendations for 5.1

The following general mitigation strategies should be considered:

- minimization of the potential for the formation of a flammable mixture;
- minimization of the potential for ignition (from both piloted and spontaneous ignition sources);
- mitigation of the effects of flammable gas releases originating from the fuelling station installation;
- mitigation of the impact to the fuelling station installation from an external fire;
- reduction of the physical effects of the explosion generated by potential leaks or releases;
- minimisation of confinement of hydrogen systems;
- maximisation of natural ventilation;
- safety distances.

The following three stages of safety assurance should be considered:

- prevention of accidents through a combination of the following:
  - application of state-of-the-art technology;
  - following technical standards and simple handling procedures to users and operators;
  - designing the user-machine-interfaces in a straight forward manner;
  - emphasizing training of personnel, managing competence of personnel;
  - implement Management of Change processes;

  - establishing preventative maintenance.
- mitigation strategies by combination of the following:
  - application of state-of-the-art technology;
  - barriers and layers of protection;
  - safety measures;
  - safety distances.
- structured and effective emergency response (contingency planning).

B.3 Risk assessment guidance for 5.2

Qualitative assessment defines consequence, probability, and level of risk by magnitude levels such as “high”, “medium”, and “low”, may combine consequence and probability, and evaluates the resultant level of risk against qualitative criteria.

Semi-quantitative methods use detailed models and data for either consequence or probability, and qualitative treatment for the other. One example is a consequence-only analysis which uses detailed consequence modelling and assumes the probability of a scenario is 1,0.

Quantitative analysis uses detailed models and data to estimate for consequences and their probabilities, and produces values of the level of risk using both probability and consequence. Level of risk is expressed in specific units defined when developing the context.

B.4 Guidance for 5.3

B.4.1 General

The following subsections provide guidance for addressing risks in various parts of 5.3.

B.4.2 Mitigations which reduce the potential for the formation of a flammable mixture in 5.3.1

Where possible, it may be preferable to locate hydrogen process equipment in the open air, with natural ventilation to dissipate any leaked hydrogen. Alternatively, the hydrogen equipment may be located in an enclosure to permit detection of leaks and instigate forced ventilation to prevent accumulation.

The following mitigations may reduce the frequency or probability of a release:

- equipment designs which minimise the number of connections, are leak-free by design or use inherently safe equipment design;
- control of operating pressure to prevent over-pressurisation;
- in-process leak detection such as the ability for isolated systems to hold pressure;
- regular inspections and maintenance.

The following mitigations may reduce the frequency of scenarios related to gas accumulation (delayed ignition scenarios):

- ventilation (e.g. passive or active ventilation);
- hydrogen detectors to provide detection and automatic shutdown/isolation if flammable mixtures present, particularly in enclosed spaces (see 11.2.3);
- permanent inert atmosphere (for instance, in small electrical equipment enclosures).

Where the source of release is situated outside an area or in an adjoining area, the penetration of a significant quantity of flammable gas or vapour into the area can be prevented by suitable means such as:

— physical barriers;

— maintaining a sufficient overpressure in the area relative to the adjacent hazardous areas, so preventing the ingress of the flammable gas;

purging the area with sufficient flow of fresh air, so ensuring that the air escapes from all openings where the flammable gas or vapour may enter.

B.4.3 List of examples on how to prevent the formation of flammable mixtures in enclosures for 5.3.2

A non-comprehensive list of example prevention methods is as follows:

— passive ventilation;

— active ventilation;

— flammable gas detection system (see 11.2.3);

— integrity testing (rate of pressure loss measurement) of isolated piping sections;

— other means of leak detection, such as ultrasonic gas detection.

B.4.4 Mitigations to reduce the probability of ignition in 5.3.4

The following mitigations may reduce the probability of ignition:

— restriction of activities;

— area classification;

— design by construction of components or equipment;

— electrical measures (e.g., grounding and bonding);

— equipment enclosures;

— procedures. (e.g. anti-static clothes or non-sparking tools, limited access).

B.4.5 Mitigations to reduce the effects of flammable mixtures in 5.3.5

The following mitigations may reduce the effects of flammable mixtures originating within the installation:

— flame or fire detection;

— equipment enclosures;

— access control measures (e.g., fences, walls, equipment enclosures);

— safety distances such as minimum distance between storages (see 5.4);

— explosion relief protection (see for example; API 521).

B.4.6 Mitigations against external fire or event in 5.3.6

B.4.6.1 General

These measures may include the following:

— safety distances, see 5.4;

— lightning protection;

— fire barriers;

— vehicle impact protection;

— protection against spillage of flammable fluids from other sources;

— access control measures;

— protection against external events.

B.4.6.2 Fire barrier recommendations for 5.3.6.2

A non-comprehensive list of examples of safety distances which could be reduced by use of a fire barrier is as follows:

— building of combustible material;

— flammable liquids above ground;

— stock of combustible material;

— flammable gas storage above ground;

— jet flames following ignition of hydrogen releases from the fuelling station;

— overpressure following delayed ignition of hydrogen releases from the fuelling station;

— pool fires following ignition of hydraulic oil releases.

B.5 Examples of non-hydrogen hazards for 5.5

Examples of non-hydrogen hazards that should be considered as part of 5.5 are included below.

1) Mechanical hazards due to:

   a) shape (sharp surfaces);

   b) relative location (trip/crash hazard);

   c) mass and stability (potential energy of elements which may move under the effect of gravity);

   d) mass and velocity (kinetic energy of elements in controlled or uncontrolled motion);

   e) inadequacy of mechanical strength (inadequate specification of material or geometry);

   f) fluids under pressure (over-pressurization, ejection of fluids under pressure, vacuum).

2) Electrical hazards due to:

   a) contact of persons with live parts (direct contact);

   b) contact of persons with parts that have become live under faulty conditions (indirect contact);

   c) approach to live parts under high voltage;
   d) electrostatic phenomena;
   e) electromagnetic phenomena;
   f) heat/chemical effects from short circuits, overloads;
   g) projection of molten particles.

3) Thermal hazards due to:
   a) contact of persons with surfaces at extreme high and low temperatures;
   b) release of high temperature fluids;
   c) thermal fatigue;
   d) equipment over temperature causing unsafe operation.

4) Hazards generated by materials and substances:
   a) hazards from release, venting, contact with, or inhalation of, harmful fluids, gases, mists, fumes, and dusts;
   b) fire or explosion hazard due to leak of flammable fluids;
   c) fire or explosion hazard due to internal build-up of flammable mixture;
   d) hazardous situations caused by material deterioration (for example, corrosion) or accumulation (for example, fouling);
   e) asphyxiation;
   f) reactive materials (pyrophoric).

5) Hazards generated by malfunctions:
   a) unsafe operation due to failures or inadequacy of software or control logic;
   b) unsafe operation due to failures of control circuit or protective/safety components;
   c) unsafe operation due to power outage.

6) Hazards generated by neglecting ergonomic principles:
   a) hazards due to inadequate design, location or identification of manual controls;
   b) hazards due to inadequate design or location of visual display units and warning signs;
   c) noise.

7) Hazards generated by erroneous human intervention:
   a) hazards due to deviation from correct operating;
   b) hazards due to errors of manufacturing/fitting/installation;
   c) hazards due to errors of maintenance;
   d) vandalism.

8) Environmental hazards:
   a) unsafe operation in extreme hot/cold environments;

b) rain, flooding;

c) wind;

d) earthquake;

e) external fire;

f) smoke;

g) snow, ice load;

h) attack by vermin;

i) pollution;

j) air pollution;

k) water pollution;

l) soil pollution.

Annex C
(informative)

Hydrogen dispensing and examples of fuelling and communications protocols, and corresponding verification testing

C.1 General description of dispensing

Figure C.1 describes an example of the key components of the fuelling station dispensing system including the fuel cell electric vehicle high pressure hydrogen system, comprising, amongst others, the receptacle and compressed hydrogen storage systems (CHSS) with sensors as well as pressure relief device(s). The CHSS has a thermally activated pressure relief device(s) to protect against overpressure due to a fire. On the station side, there is an automated dispensing system control system (e.g. through a PLC) for performing the fuelling (using an acceptable fuelling protocol), as well as fault detection and management procedures. The station also has an over pressure protection device such as a pressure relief device(s) or equivalent to protect against over pressurization of the dispensing system and the vehicle.

The dispenser at a public fuelling station for light duty vehicles is typically designed with separate nozzles to fuel vehicles to 35 MPa and/or 70 MPa nominal working pressures. The station fuelling nozzle may contain a communications receiver and the vehicle may contain a communications transmitter (such as SAE J2799). The vehicle IrDA communications system may use the SAE J2799 protocol to transmit the measured temperature and pressure of the compressed hydrogen storage system on the vehicle to the hydrogen dispenser. The dispensing system control system may use this data for the control system to manage the fuelling process.

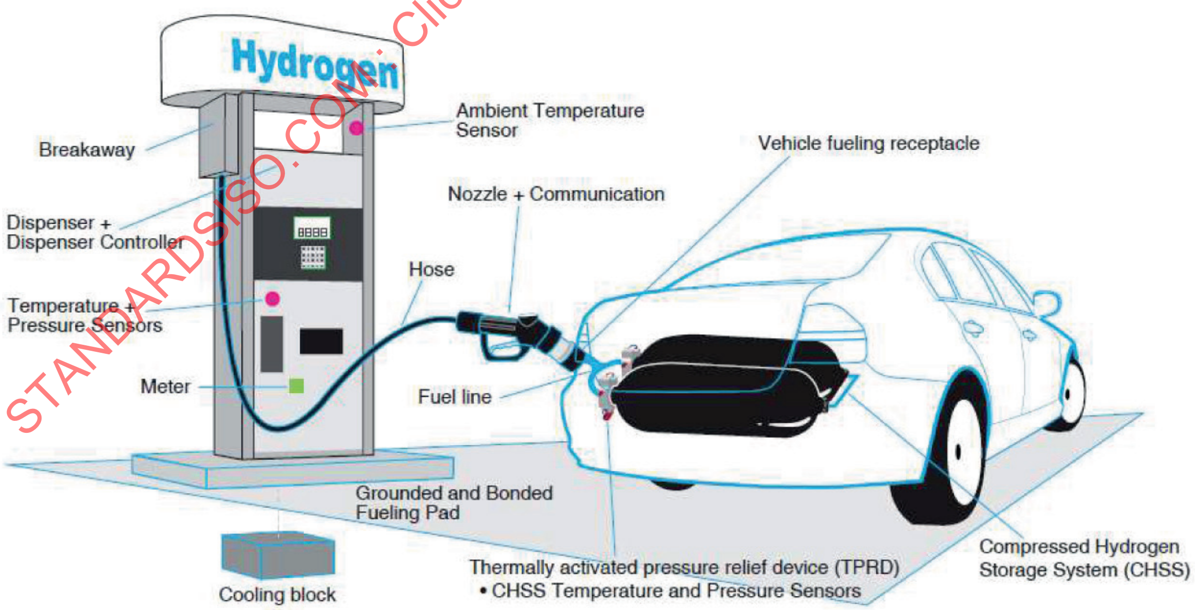


Figure C.1 — Example of the key components of the fuelling station dispensing system and the vehicle high pressure hydrogen system

C.2 Description of SAE J2601

SAE J2601 defines the protocol and process limits for hydrogen fuelling of light duty vehicles which meet the requirements of the GTR#13.

The fuelling protocols in SAE J2601 are based on a set of boundary and initial conditions which reflect CHSSs of current light duty vehicles and associated fuel delivery components in the vehicle and fuelling station that affect the fuelling. For example, SAE J2601:2014 and SAE J2601:2016 cover light-duty vehicles with CHSS volumes from 50 litres to 250 litres. Assumptions regarding the initial temperature of the CHSS are also established and incorporated into the SAE J2601 fuelling protocols.

SAE J2601 is fully compliant with the general requirements of 8.2.1.1 and with the process limits defined in 8.2.1.2.

SAE J2601 defines fuelling protocols based on either a look-up table approach utilizing a fixed pressure ramp rate, or a formula-based approach utilizing a dynamic pressure ramp rate continuously calculated throughout the fuelling. The table-based protocol provides a fixed end-of-fill pressure target, whereas the formula-based protocol calculates the end-of-fill pressure target continuously. Both protocols allow for fuelling with communications or without communications. For fuelling with communications, SAE J2601 is used in conjunction with SAE J2799.

SAE J2601 is an approved and published document. The description and information provided in this annex is based on the 2016 revision to SAE J2601. Periodically, technical updates and expansions in scope are made through the ANSI-approved document revision process. It is recommended that the dispensing system hardware and software remain current with regard to revisions, particularly when revisions effect specific applications of that dispensing system as it may effect overall safety of the dispensing process. This situation is specifically noteworthy with regard to the 2010 version of SAE J2601 which was published as a Technical Information Report (TIR) and superseded twice by approved revisions at the Standard level.

NOTE A significant limitation of the SAE TIR J2601: 2010 is that it does not address the requirement of 8.2.1.1 dealing with safety of consecutive fuelling, unless further mitigation measures are taken.

Future publications of SAE J2601 are also expected to include methodologies to detect a potential error in pressure, temperature, or mass flow measurements that are being used by fuelling protocol. In addition to the use redundant or collaborative measurements of process parameters, mass balances over the fill process can be used in conjunction with the equation of state to confirm that the CHSS process conditions are consistent with each other. Such a feature should be very valuable in providing confidence in the reliability and integrity of the fuelling process.

For hydrogen stations intended for the fuelling of heavy duty vehicles, SAE J2601-2 is available. The SAE J2601-2: 2016 fuelling protocol is compliant with 8.2.1.2 except as noted in 8.2.1.3 to accommodate larger storage capacities of these types of vehicles.

C.3 Use of vehicle-to-station communications

The use of vehicle-to-station communications enhances the fuelling process by providing information about the CHSS being fuelled, which the dispensing system would not otherwise know, such as the CHSS nominal working pressure (e.g. H70, H35), the CHSS volume, the CHSS gas pressure, and the CHSS gas temperature. It also provides a fuelling command signal, which informs the dispensing system if it is "ok to fuel" or if the fuelling should be aborted. Although these data provide an additional layer of safety, they are not used for primary control of the fuelling process, as a reliability requirement has not been established for the vehicle data measurements and for the communication link. In SAE J2601, the data communicated to the station may be used for secondary confirmation of the CHSS nominal working pressure, for determining the CHSS volume, and for determining when to end the fuelling based on a target SOC of 95 % to 100 %. The data communicated does not influence the pressure ramp rate the dispensing system utilizes – the pressure ramp rate is the same for communications fuelling and for non-communications fuelling for a given CHSS volume.

C.4 Description of SAE J2799

SAE J2799 fulfils the functionality defined in 8.2.1.4. SAE J2799 specifies the communication hardware and software requirements for fuelling hydrogen surface vehicles (HSV). SAE J2799 is intended to be used in conjunction with SAE J2601 and with SAE J2600.

SAE J2799 utilizes one-way communication and provides error-checking that can identify faults with the data transfer. If a sufficient error in communication is detected, or if communication is lost, the dispensing system control either switches to the non-com fuelling protocol or stop fuelling as defined in 8.2.

SAE J2799 is an approved and published document. The description and information provided in this annex is based on the 2014 revision to J2799. Periodically, technical updates and expansions in scope are made through the ANSI-approved document revision process. It is recommended that the dispensing system hardware and software remain current with regard to revisions, particularly when revisions effect specific applications of that dispensing system as it may effect overall safety of the dispensing process.

C.5 Validation of the fuelling protocol and vehicle-to-station communications

C.5.1 General

It is important that the fuelling station be validated that it is correctly applying the fuelling protocol and vehicle-to-station communications, as outlined in 12.5. This validation can be conducted through the use of factory acceptance testing, through the use of site acceptance testing, or a combination of both. For validation of fuelling stations employing SAE J2601 and SAE J2799, an approved validation standard, such as CSA HGV 4.3, HYSUT-G 0003 or the "CEP hydrogen fuelling validation test protocol", should be used.

Validation of the fuelling protocol is intended to test that the dispensing system is:

a) applying the control parameters correctly;

b) responding to process limit violations correctly;

c) able to meet a certain level of fuelling performance (i.e. completing fuelling without exceeding process limits and achieving an acceptable ending SOC in the CHSS.

Validation of the vehicle-to-station communications is intended to test that the dispensing system:

a) receives and interprets the communicated data correctly;

b) responds correctly to data values which are outside the allowed bounds;

c) responds correctly to bad data packets;

d) responds properly to data which should terminate the fuelling:

- an "abort" command;
- CHSS gas temperature equal to or greater than 85 C;
- CHSS SOC ≥ 100 %.

C.5.2 Acceptance criteria of testing (as per SAE J2601:2016)

Table C.1 below lists the acceptance criteria for the fuelling at a hydrogen station along with the reference clauses in SAE J2601:2016.

Table C.1 — Global acceptance criteria for all hydrogen fuelling testing to SAE J2601 (both SAT and FAT)

Criteria	Fuelling limits	SAE J2601:2016 Clause reference
Ambient temperature of operation Ambient temperature sensor	−40 °C < T_{amb} < +50 °C	6.2.2
Vehicle tank starting pressure monitoring	<0,5 MPa < P_0 < NWP	6.3.1
Maximum flow rate Dispensing system flow sensor	Flow rate ≤60 g/s	6.4.2
Fuel delivery temperature Dispenser fuel temperature sensor	−40 °C < T_{fuel}	6.2.3
Vehicle CHSS gas temperature	−40 °C < $T_{vehicle}$ ≤ 85 °C	6.2.4
Maximum mass of hydrogen allowed during start-up	Total H_2 mass prior to start of fuelling <200 g (measured at HSTA, flow meter, etc)	6.4.3
CHSS capacity	CHSS volume determined to be within the allowed range of 49,7 litres to 248,6 litres. If CHSS volume is measured, SAE J2601:2016 requires a measurement accuracy of ±15 %.	Table-based protocol – Section 8.2 MC formula protocol – Section 9.2
Fuel delivery start-up requirement (measured by dispenser fuel temperature sensor)	Table-based frotocol: T_{fuel} < $T_{fuel\ category\ max}$ within 30 s from the start of the main fuelling time MC formula protocol: T_{fuel} shall always be ≥−40 °C, and after a total of 30 seconds of mass flow have elapsed, MAT_{30} shall be ≤−17,5 °C.	Table-based Protocol – Section 8.1.2.1 MC formula protocol – Section 9.1.2.1
Fuel delivery temperature tolerance (measured by dispenser fuel temperature sensor)	Table-based protocol: $T_{fuel\ category\ min}$ < T_{fuel} < $T_{fuel\ category\ max}$ (if not met, fallback is allowed) MC formula protocol: Tfuel shall always be ≥−40 °C, and after a total of 30 seconds of mass flow have elapsed, MAT_{30} shall be ≤−17,5 °C.	Table-based protocol – Section 8.1.2.2 MC formula protocol – Section 9.1.2.1

[a] In a fault condition, it is permissible to have up to 115 % SOC only with communications.

Table C.1 *(continued)*

Criteria	Fuelling limits	SAE J2601:2014 Clause Reference
Table-based protocol only and for communications fuelling only: Fallback test (where option exists)	— Communication fills only — Follow the fallback procedure — Stations shall not use the fallback procedure to switch to a colder fuel delivery temperature (and faster APRR), including switching back to the original APRR if the station returns to the initial fuel delivery temperature category. — The fallback procedure can only be used once during a fuelling and the station shall terminate the fuelling (as soon as possible but within five seconds) if the fuel delivery temperature exceeds a fallback fuel delivery temperature upper limit.	8.10
Upper station pressure tolerances (measured by dispenser fuel pressure sensor)	Table-based protocol: $P_{station} \leq P_0 + (APRR_{target})(t_{fuelling}) + \Delta P_{upper}$, where ΔP_{upper} = 7,0 MPa MC formula protocol: $P_{station} \leq P_{limit\_high}$ where $P_{limit\_high} = P_{ramp} + \Delta P_{tol\_high}$, where ΔP_{tol_high} = 7,0 MPa	Table-based protocol – Section 8.3.2 MC formula protocol – Section 9.3.2
Lower station pressure tolerances (measured by dispenser fuel pressure sensor)	Table-based protocol: $P_{station} \geq P_0 + \text{Max}\ [((APRR_{target})(t_{fuelling}) - \Delta P_{lower}), 0]$, where ΔP_{lower} = 2,5 MPa (A 5 second allowance is given for the station pressure to get back above the lower pressure tolerance after an intended non-fuelling event) MC formula protocol: $P_{station} \geq P_{limit\_low}$ where $P_{limit\_low} = \text{Max}\ [P_{initial}, P_{ramp} - \Delta P_{tol\_low}]$, where ΔP_{tol_low} = 2,5 MPa (A 5 second allowance is given for the station pressure to get back above the lower pressure tolerance after an intended non-fuelling event)	Table-based protocol – Section 8.3.2 MC formula protocol – Section 9.3.2
Cycle control (ensure software has a counter for unintentional fuel stopping events)	Fuel flow stoppage (below 0,6 g/s) may not happen more than 10 times during a fuelling event	Table-based protocol – Section 8.4 MC formula protocol – Section 9.4

[a] In a fault condition, it is permissible to have up to 115 % SOC only with communications.

Table C.1 *(continued)*

Communication end of fuelling	Table-based protocol: Fuelling stops when $P_{station} = P_{target}$, and/or 100 % < $SOC_{vehicle}$[a] MC formula protocol: Fuelling stops when ($P_{station}$ or $P_{vehicle}$) = Minimum (P_{target_comm}, P_{limit_comm})	Table-based protocol – Section 8.9.6 MC formula protocol – Section 9.9.5
Non-communication end of fuelling	Table-based protocol: Fuelling stops when $P_{station} \equiv P_{target}$ MC formula protocol: Fuelling stops when $P_{station} \equiv P_{target\_non\_comm}$	Table-based protocol – Section 8.8.2 MC formula protocol – Section 9.8.2
Maximum pressure (measured by dispenser fuel pressure sensor or communicated vehicle pressure, MP, from IrDA)	$P_{vehicle} \leq$ 125 % NWP	6.3.3
Maximum vehicle state of charge under communications fuelling	$SOC_{vehicle} \leq$ 100 % (measured at HSTA or in vehicle CHSS)	6.4.1

[a] In a fault condition, it is permissible to have up to 115 % SOC only with communications.

C.5.3 FAT and SAT specification

C.5.3.1 FAT description

The FAT of dispensing systems is expected to be carried out before the fuelling station is commissioned in order to prove the functionality of the safety and performance systems of the fuelling station according to SAE J2601. This could take place in a simulated environment to evaluate that the dispensing system applies the protocol correctly under a wide range of conditions, and that it responds properly to out-of-bounds conditions (upset conditions) which cannot be replicated in the field. This should include simulated software testing and hardware-in-the-loop testing, or can optionally include hydrogen fuelling with a hydrogen station testing apparatus (HSTA). The hardware and software of the station should be specified and should not be changed between the FAT and SAT tests. In addition, the manufacturer should provide minimum installation specifications to ensure that the station will perform the same during the FAT and SAT tests.

NOTE In a mature production situation, if the design and manufacturing processing have been established and are under configuration management control, then the necessary type and frequency of tests can be adjusted as supported by production quality plan to ensure the performance consistency of each unit produced.

The factory acceptance tests are mainly focused on the minimum safety tests as described in the 12.5. The station owner/operator should provide the necessary data from the dispensing system in order to properly evaluate the tests.

C.5.3.2 SAT description

The site acceptance testing should include representative tests according to the dispensing system capability. For example, if there are two pressure levels, 35 MPa and 70 MPa, but one dispensing system fuel delivery temperature category, such as T40, tests should be conducted to evaluate that the dispensing system fuels according to SAE J2601 and responds properly to process limit violations. In addition the performance of fuelling with (if available) and without communications should be evaluated. Testing should evaluate the ability of the dispensing system to fuel compressed hydrogen storage system (CHSS) of the different capacity categories (2 kg to 4 kg, 4 kg to 7 kg, 7 kg to 10 kg) according to the dispensing system capability. All fuelling stations should be tested at each dispenser and each nozzle connection (e.g. H35 and H70), see 12.5.5.

It is assumed that the necessary dispensing system data (or access it) will be provided from the station owner/operator and the HSTA. The data should be recorded, from the start of connection to end of fuelling, at a minimum rate of 1 Hz. The minimum station data required depends on the protocol utilized.

Table-based protocol minimum data requirement:

— Time

— The station measured ambient temperature (T_{amb})

— Dispenser outlet H2 temperature (T_{fuel}) – two values if dual measurements used

— Dispenser outlet pressure ($P_{station}$)

— Accumulated mass flow and $T_{fuelave}$ or $T_{fuelaveroll}$ (if $T_{fuelave}$ or $T_{fuelaveroll}$ are used)

— An indication of where the main fuelling time begins and ends

— An indication of intended non-fuelling time

— An indication of where Top-off begins

— An indication of where Fallback begins (if utilized)

— Measured pressure (MP), measured temperature (MT) and fuelling command (FC) from IR data

MC Formula protocol minimum data requirement:

— Time

— The station measured ambient temperature (T_{amb})

— Dispenser outlet H2 temperature (T_{fuel}) used for MAT – two values if dual measurements used

— Dispenser outlet H2 temperature (T_{fuel}) used for h_{ave} – two values if dual measurements used

— Dispenser outlet pressure ($P_{station}$)

— Accumulated mass flow (m)

— Control pressure offset value (ΔP_{offset})

— An indication of where the main fuelling time begins and ends

— An indication of intended non-fuelling time

— Indicator cons RR (flag variable in SAE J2601)

— Indicator comm fill (flag variable in SAE J2601)

— P_{limit_high} and P_{limit_low}

— $P_{target\_non\_comm}$, P_{target_comm}, P_{limit_comm}

— Measured pressure (MP), measured temperature (MT) and fuelling command (FC) from IR data

There should be site acceptance testing of the fuelling function with the HSTA or equivalent, as per Clause 12. The goal is to test the fuelling functionality with no station modification in order to confirm the fuelling parameters are within fuelling limits under normal operation. Pass/Fail criteria to be based on the dispensing system staying within, or responding properly to, the limits defined in Table C.2 below. Discretion is allowed in meeting performance-related criteria listed (i.e. the dispensing system's ability to complete a fuelling while staying within the fuelling limits) when the deviation is due to a recognized and accepted limitation of a particular filing station design or application. If applicable, at least one test should be done for each different CHSS size category.

The dispensing system should be tested to validate that fuelling rate is dependent upon ambient temperature. While it is not possible to control the ambient environment at a fuelling station, tests should be conducted as close as possible to the high and low ambient temperatures for a given day.

The SAT should be done for each dispenser at the station for multiple CHSS volume categories (e.g. 2 kg to 4 kg, 4 kg to 7 kg, and 7 kg to 10 kg).

Table C.2 — Recommended FAT and SAT matrix for the validation of a dispensing system using the SAE J2601:2016 protocol

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
Pre tests	1	Correct communications protocol	Tests according to SAE J2799	Check functionality of all IrDa signals according to SAE J2799	Able to send and receive all IrDa commands, as defined in SAE J2799	S	YES	YES
	2	Correct table implementation	Confirmation report of software implementation	Confirmation in writing using “independent verification”	Table-based protocol: Correct values for all implemented tables (including communications, non-communications and optional cold dispenser) MC formula protocol: Correct values for all implemented tables (t_{final} coefficient tables, ending pressure tables, if used), and for all parameter values which are constants	S	YES	NO
	3	Accounting for sensor error (ambient temperature, fuel delivery temperature and station pressure sensors	Confirmation report of software implementation	Confirmation in writing using “independent verification”	Dispensing system accounts for all sensor errors in the implementation of the fuelling protocol utilized. See Sections 6.2 and 6.3 of SAE J2601	S	YES	YES[b]
	4	Cold dispenser implementation (if used by dispensing system)	Confirmation report of software and hardware implementation	Confirmation in writing using “independent verification”	If the cold dispenser (CD) fuelling option is implemented, the appropriate SIL level and the approach used to satisfy this requirement should be confirmed (according to IEC 61508/ IEC 61511 or equivalent). See SAE J2601, Section 8.12 (table-based) or Section 9.10 (MC formula)	S	YES	NO

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
Fault tests	5	Extreme ambient test	Influence T_{amb} measurement to <−40 °C, e.g. by manipulation of transmitter signal loop	Not sensor calibration, this is a fault test with either signal modification or actual temperature modification.	Main fuelling does not begin (see definition of main fuelling in SAE J2601)	S	YES	YES
	6		Influence T_{amb} measurement to >50 °C, e.g. by manipulation of transmitter signal loop			S	YES	YES
	7	Fault: CHSS starting pressure	Prepare HSTA with <0,5 MPa pressure in the CHSS. Use the largest CHSS volume possible within the range allowed by SAE J2601 for light duty fuelling	Initiate a fuelling in non-comm and comm mode.	Main fuelling does not begin (see definition of main fuelling in SAE J2601)	S	YES	YES
	8		Prepare HSTA with slightly >HSL (i.e. slightly >70 MPa for testing an H70 dispenser, and slightly >35 MPa for an H35 dispenser)			S	YES	YES
	9	Fault: maximum mass of hydrogen allowed during start-up	For each fuelling test conducted, ensure that dispenser is not dispensing more than 200 grams of hydrogen during the start-up phase	This is not a specific test, but rather a monitoring of each fuelling test conducted. The testing agency should devise a method of accurately determining the mass of hydrogen dispensed during the start-up phase of fuelling (see definition of start-up in SAE J2601)	Less than 200 grams dispensed during start-up or if the dispenser does dispense >200 grams during start-up: Main fuelling does not begin (see definition of main fuelling in SAE J2601)	S	NO	YES

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
	10	Fault: excess hydrogen flow	Either produce a signal greater than 60 g/s, or provide report confirming mechanical means	Hydrogen mass flow signal manipulation to be more than 60 g/s after the start-up phase, or a confirmation of mechanical flow limitation (such as flow orifice) over fuelling range	If non-mechanical means is used, Fuelling Stop within 5 seconds of the point in the fuelling where 60 g/s of mass flow occurred	S	YES	NO
	11	Fault: dispenser only absolute hydrogen delivery temperature	Manipulation of dispenser fuel delivery signal to below −40 °C	Use a methodology which causes the hydrogen fuel delivery temperature signal read by the dispenser to drop below −40 °C	Fuelling Stop within 5 seconds of the point in the fuelling where the fuel delivery temperature dropped below −40 °C	S	YES	YES
	12		For T30 and T20 stations using the table-based protocol, manipulation of dispenser fuel delivery signal to below the relevant limit (i.e. −33 °C and −26 °C respectively) Note that this test is not applicable to the MC Formula based protocol	Use a methodology which causes the hydrogen fuel delivery temperature signal read by the dispenser to drop below the relevant limit (i.e. −33 °C and −26 °C respectively)	Fuelling Stop within 5 seconds of the point in the fuelling where the fuel delivery temperature dropped below the relevant limit (i.e. −33 °C and −26 °C respectively)	S	YES	NO

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
	13	Fault: hydrogen delivery temperature monitoring	Manipulation of dispenser fuel delivery temperature or mass average of fuel delivery temperature. For table-based protocol, dispenser to indicate if it uses T_{fuel} or T_{fuel_ave} as criteria for fuel delivery temperature criteria	Table-based protocol: *Tfuel* method: After a period of >35 s of continuous mass flow, the testing agency should use a means which causes the T_{fuel} signal read by the dispenser to rise above the upper boundary of the fuel delivery temperature category (e.g. −33 °C for T40) T_{fuel_ave} method: After a period of >35 s of continuous mass flow, the testing agency should use a means which causes the T_{fuel_ave} signal read by the dispenser to rise above the upper boundary of the fuel delivery temperature category (e.g. −33 °C for T40) MC formula protocol: After a period of > 35 s of continuous mass flow, the testing agency should use a means which causes the MAT_30 signal read by the dispenser to rise above the upper boundary temperature of −17,5 °C	Table-based protocol: Either (i) Fuelling Stop, or (ii) switch to fallback APRR where applicable, within 5 seconds after the point in the fuelling where the upper boundary of the fuel delivery temperature category was breached MC formula protocol: Fuelling Stop after the point in the fuelling where MAT_30 exceeded the upper boundary temperature of −17,5 °C.	S	YES	NO

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
	14	Invalid communications signal test	Transmit incorrect, CRC, “non standard” and “out of range” SAE J2799 parameters to station by manipulation of IrDA transmitter.	1) Transmit incorrect CRC value for > 500 ms (5 × 100 ms per packet) 2) Transmit “non-standard” signals (e.g. STAT for FC command) 3) Transmit “out of range” values for each parameter (e.g. MP = 110)	Station switches to non-com fuelling or stops fuelling within 5 seconds.	S	YES	YES
	15	Out of bounds test for CHSS size	Comm test only: Transmit SAE J2799 parameter TV < 49,7 and TV > 248,6 via IrDA	Send signals outside of the range of the station specification	Station does not initiate fuelling	S	YES	YES
	16	Break in communication test	Manipulation of IrDA transmission signal	Cause the communications signal to disappear for more than 0,6 seconds	Station switches to non-com fuelling or stops fuelling within 5 seconds	S	YES	YES
	17	Fault: halt signal	Transmit SAE J2799 fuelling command “Halt” via IrDA	Fuelling should be paused when the fault command is received. Fuelling should be terminated if the Halt command is received for more than 60 seconds	Fuelling Pause within 5 s of signal being received Fuelling Stop within 5 s if signal received for 60 s	S	YES	YES
	18	Fault: communications abort signal	Transmit SAE J2799 fuelling command “Abort” via IrDA	Create an abort signal. To be monitored even with non-communications fuelling (if applicable)	Fuelling Stop within 5 s of signal being received	S	YES	YES
	19	Fault: CHSS Max temperature	Transmit SAE J2799 measured temperature MT > 358,15 K (which corresponds to 85 °C)	Create a MT signal greater than 358,15 K	Fuelling Stop within 5 s of signal being received	S	YES	YES

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
	20	Fault: max CHSS and dispenser pressure	a) Cause $P_{station}$ to be >125 % NWP b) Transmit SAE J2799 measured pressure MP > 125 % NWP (e.g. 87,5 MPa for H70)	Create a $P_{station}$ signal greater than 125 % NWP Create an MP signal greater than 125 % NWP	Fuelling Stop within 5 s of signal being received	S	YES	YES (MP only)
	21	Fault: maximum state of charge	Cause SAE J2799 parameter measured temperature (MT) to be a value, which when combined with the measured pressure (MP) creates an $SOC_{vehicle}$ larger than 100 %.	After 30 seconds of fuelling, set the communications signal MT so that $SOC_{station}$ or $SOC_{vehicle}$ is greater than 100 %. Note that the dispenser may have a safeguard to stop fuelling if MT < 233,15 K (−40 °C). To ensure that the dispenser is stopping based on SOC and not a minimum MT threshold, execute the test at a high enough pressure such that MT is greater than 233,15 K	Fuelling Stop within 5 s of signal being received	S	YES	YES
Response tests	22	Cycle control: (ensure software has a counter for unintentional fuel stopping events)	Fuel flow stoppage (below 0,6 g/s) may not happen more than 10 times during a fuelling event, e.g. by manipulation of signal loop	Software only confirmation that fuel stoppage of >10 times shuts down fuelling (hardware test not recommended)	Fuelling Stop within 5 s of this conditions occurring	S	YES	NO

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
	23	Hydrogen delivery pressure monitoring	Cause the fuel delivery pressure $P_{station}$ to exceed the upper and lower limits of the pressure corridor during fuelling (this can be done in simulation mode) Two tests for each – one in communications mode and one in non-communications mode	During a simulated fuelling, manipulate $P_{station}$ to exceed the upper limit of the pressure corridor	Fuelling Stop within 5 s of the limit being exceeded.	S	YES	NO
	24			During a simulated fuelling, manipulate $P_{station}$ to exceed the lower limit of the pressure corridor (while mass flow is >0,6 g/s)		S	YES	NO
	25	Hydrogen delivery pressure target	Manually (or using software) calculate expected target pressure based on observed starting conditions Two tests - one in communications mode and one in non-communications mode	Perform a non-communications fuelling	Fuelling Stop at target pressure	S	YES	NO
	26			Perform a communications fuelling Disregard stop criteria based on IrDa values	Fuelling Stop at target pressure	S	YES	NO
	27	CHSS size determination	Possible to determine size ±15 % or conservative lookup	Test HSTA or equivalent the range of fuelling to confirm the volume accuracy within ±15 %	If the volume is not within ±15 %, the main fuelling part should default to the most conservative fuelling tables (table-based protocol) or set indicator cons RR flag variable to TRUE (MC formula), or stop fuelling.	S	YES	YES

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
Optional implementations	28	Fallback test (for table-based protocol only and communications fuelling only. implementation of Fallback is optional)	Calculate expected APRR and target pressure based on observed starting conditions and expected precooling fallback category	Influence hydrogen delivery temperature above the intended temperature corridor	Confirm Fallback corridor is implemented correctly	S	YES	NO
	29			Influence hydrogen delivery temperature above the intended temperature corridor, and then remove influence	Confirm Fallback corridor is implemented correctly and APRR doesn't switch back to previous APRR	S	YES	NO
	30			Influence hydrogen delivery temperature above the intended temperature corridor Then further influence hydrogen delivery temperature above the fallback precooling temperature corridor (i.e. −26 °C for T30 or 17,5 °C for T20)	Fuelling Stop within 5 s with out-of-bounds	S	YES	NO
	31			Influence hydrogen delivery temperature above the intended temperature corridor After Fallback switch, disrupt IrDa communication	Fuelling Stop within 5 s after signal disruption	S	YES	NO
	32	Top-off fuelling (for table-based protocol only and for communications fuelling only)	Condition the HSTA with an initial pressure <3 MPa. Calculate expected APRR and target pressure based on station measured starting conditions (e.g. T_{amb} and P_0)	Conduct a fuelling test	Confirm Top-off APRR and pressure corridor is implemented correctly	S	YES	YES
	33	Cold dispenser	If applicable: verify 2 cold table-based fuelling in ambient condition		Verify Fuelling is within bounds	S	YES	YES

Table C.2 *(continued)*

Category	Test no.	Function	Preparation	Test info	Acceptable criteria	Safety (S)/Performance (P)	FAT	SAT[a]
Capacity tests	34	Pre-cooling (PC) capacity test. Ensure that the T-category rating e.g. T40 can be used at site	HSTA to test multiple tanks or multiple vehicles	If applicable, manufacturers should prove their "rated" back-to-back fuelling per report in advance. As a minimum, two test fuelling of 2 CHSS (including 1 within the largest category for the station) with an initial pressure of 5 MPa should be shown[c]	Monitor the hydrogen delivery temperature in the station during the fuelling ensuring the temperature is within limits of the anticipated T-rating and volume categories	P	YES	YES
	35	Testing that all CHSS capacity classes can be filled	Check for which categories station has been designed. At least one fuelling	2 kg to 4 kg, 4 kg to 7 kg, 7 kg to 10 kg CHSS volume categories as applicable	Station performs as per design intent, with expected fill level reached and no limits breached	P	YES	YES
SAT fuelling tests	36	Non com fuelling validation	Two different starting conditions[d]	Two tests	Fuelling did not exceed any process limits, fuelled at the correct APRR and terminated the fuelling at the non-comm pressure target ±2 MPa	S	NO	YES
	37	Com fuelling validation	Two different starting conditions[d]	Two tests, one of which is below 2 MPa start[e]	Fuelling did not exceed any process limits, fuelled at the correct APRR and terminated the fuelling with an ending SOC in the HSTA of between 95 % to 100 %.	S	NO	YES

[a] If this test has been carried out as part of FAT, and the entry in the SAT column says no, this test does not need to be repeated as part of SAT.

[b] SAT testing is verification that signal is reasonable at ambient conditions.

[c] If it cannot be demonstrated, that the physical conditions between factory and site are identical this test can be included in SAT.

[d] It is recommended that, if possible, these tests are carried out at different times of the day to validate performance at different average pressure ramp rates.

[e] Fuelling can be ended by the station on reaching target pressure or target SOC. If fuelling is stopped by abort signal, it needs to be shown that fuelling was still in bounds and the abort signal was triggered by sensor tolerance overlap.

C.6 Test descriptions and checklists — Additional fuelling tolerances

The following are additional fuelling tolerances based on experiences in the field to date.

Storage bank switches can be difficult to detect with a test device. Thus, perceived failures to stay within the pressure corridor can be incorrect. SAE J2601 includes an allowance of 5 seconds for the station pressure to rise above the lower limit of the pressure corridor after an intended non-fuelling event (such as bank switching). The station should account for its tolerances in applying this fuelling protocol. Tolerances should be applied to ensure that the pressure ramp rate and ending pressure remain within their specified boundaries or limits. An acceptable tolerance for non-communications fuellings to stop at the target pressure is ±2 MPa.

Annex D
(informative)

Reference fuelling limits of hydrogen and fuel cell vehicles

A complete set of hydrogen limits and extreme validation testing for the vehicle high pressure hydrogen system can be found in the GTR#13, in addition to other requirements for the vehicle.

One considerable element of this that influences requirements for the fuelling protocol are the requirements of the CHSS.

NOTE 1 See Figure 1 in the GTR to see the scope of a typical compressed hydrogen storage system (CHSS).

Ideally, the hydrogen dispensing is to be conducted such that pressure of the CHSS equals the NWP when the tank has settled (stabilized) to 15C. At this condition, the CHSS is at 100 % state of charge (SOC).

The following items describe key parameters that effect the dispensing of fuel to a vehicle that is compliant with GTR#13:

— The minimum number of full pressure hydraulic qualification test cycles for hydrogen storage systems is set at 5 500 based on leakage, but storage systems are qualified to at least 22 000 cycles based on the more severe failure (rupture). See GTR paragraph 57 on page 17 and paragraph 58 on pages 17 and 18.

— The CHSS component complies with the external leakage test at the appropriate maximum material temperature (−40 °C to +85 °C) at the completion of the high temperature cycles (GTR section 7.4.4.3.5).

  NOTE 2 Compressed hydrogen storage system materials are qualified to 85°C in the GTR durability test protocol. The liner temperature has been demonstrated to be lower than the gas temperature during “fast fills” using fuelling protocols such as SAE J2601 that are based on bulk gas temperature measurements (see SAE 2011-01-1342). This provides margin to manage measurement errors and the transient thermal conditions during fuelling.

— The maximum pressure at the end of “fault free” fuelling is 125 % of NWP (the maximum fuelling pressure and therefore the dispensing system maximum operating pressure (MOP), see Annex E). See GTR#13 clause I-D-1-33, on page 12.

— Assurance of capability to sustain multiple occurrences of over-pressurization over the lifetime of the vehicle due to fuelling station failure is provided by the CHSS requirement to demonstrate absence of leak in 10 exposures to 150 % NWP fuelling, followed by long-term leak-free parking and subsequent fuelling/de-fuelling. See GTR#13 paragraph 61-(f)-(i) on page 13.

  NOTE 3 150 % NWP is equivalent to the maximum developed pressure (MDP) of 1,5 × HSL as used in Annex E.

  NOTE 4 Per Annex E, the MDP of 150 % of HSL is consistent with dispensing system pressure protection set to 137,5 % of HSL.

In addition to the simulation of vehicle fuelling under both normal and “worst case” fault conditions as described above, the test protocols in GTR#13 address all requirements expected during road service including extreme conditions and use as well as the possibility of vehicle crash so that the vehicle can be verified and certified for road service. These verification tests and requirements, however, are unique to road service and not necessarily consistent with requirements for vessels and components that are permanently in installed in pressurized systems as application and risks are entirely different.

Annex E
(informative)

Pressure level application to design verification requirements for hydrogen dispensing systems and compressed hydrogen storage systems

E.1 Explanation of pressure terminology

Figure E.1 shows the relationship between the pressure terminology used for hydrogen vehicles in GTR#13 and the terminology adopted for hydrogen dispensing systems.

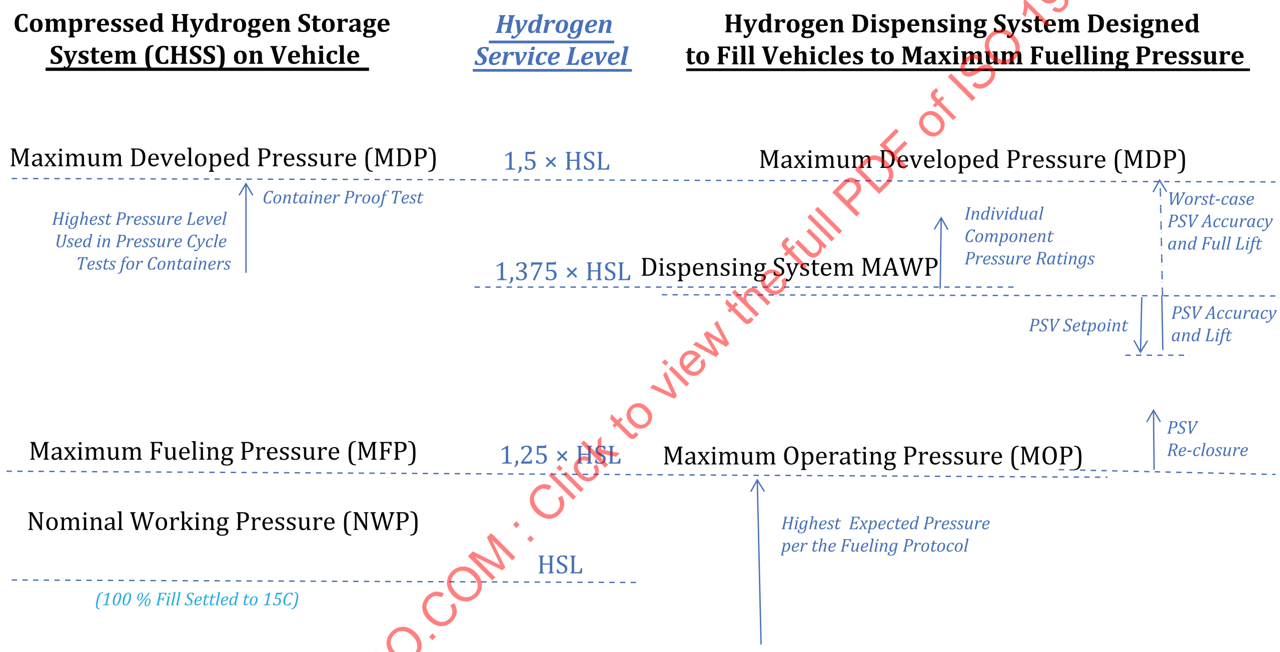


Figure E.1 — Comparison of pressure design parameters for dispensing systems designed to fuel vehicles to maximum fuelling pressure

The key parameter for hydrogen vehicles is the nominal working pressure (NWP) of the high pressure hydrogen system.

In order to avoid confusion between the "NWP" of the hydrogen vehicle with "NWP" in the Japanese hydrogen pressure code, the Hydrogen Service Level (HSL) is used for dispensing systems. As depicted in Figure E.1, the HSL of the dispensing system is equal to NWP of the vehicle.

Maximum operating pressure (MOP) is equal to maximum fuelling pressure of the hydrogen vehicle as it is the highest expected pressure during normal (no fault) operation including over-shoots, if any. For dispensing system control systems, the target pressure (including any overshoots that are expected to typically occur) and limits defined in 8.2.1 for the protocol should be addressed at or below the MOP.

Typically, following standard engineering practice, the design pressure of components is set at least 10 % above the MOP in order to create opportunity to exercise additional fault management by the dispensing system control system and provide margin to prevent inadvertent operation by the mechanically-independent pressure protection (PSVs) to open and reclose. The MAWP for the dispensing system is ideally therefore 1,375 × HSL.

Even if all the components in the dispensing system are rated above 1,375 × HSL, the dispensing system pressure protection should not be set any higher than 137,5 % of HSL as this is limit needed to ensure that the MDP does not exceed 1,5 × HSL for the hydrogen vehicle being fuelled. See Annex D.

All dispensing system components in the hydrogen system need to be designed and rated at or above 137,5 % of HSL for the dispensing system to have a MAWP of 137,5 % of HSL. If any components in the dispensing system are rated below 137,5 % of HSL , then the dispensing system MAWP is lowered to at least the lowest component rating (see 8.2.2.3). Per most piping codes used globally, the pressure protection for the dispensing system (whether provided on the hydrogen supply in the hydrogen compressed storage system or the dispensing system) needs to be set at or below the dispensing system MAWP in order to protect the dispensing system including nozzles, hoses, flowmeters, and all other components within the dispensing system.

Pressurized systems are protected by PSVs or equivalent SIL-rated pressure protection. The PSVs for the dispensing system are no higher than the dispensing system MAWP (as determined above) so that the lowest-rated component is protected.

The maximum developed pressure is the highest expected to occur during fault management. It is based highest possible setpoint of the PSV and “worst case” values for setpoint tolerance and valve lift.

E.2 Guidance for defining verification tests of dispensing system components

Figure E.2 depicts the type of verification tests to be considered when establishing qualification tests components for the dispensing system.

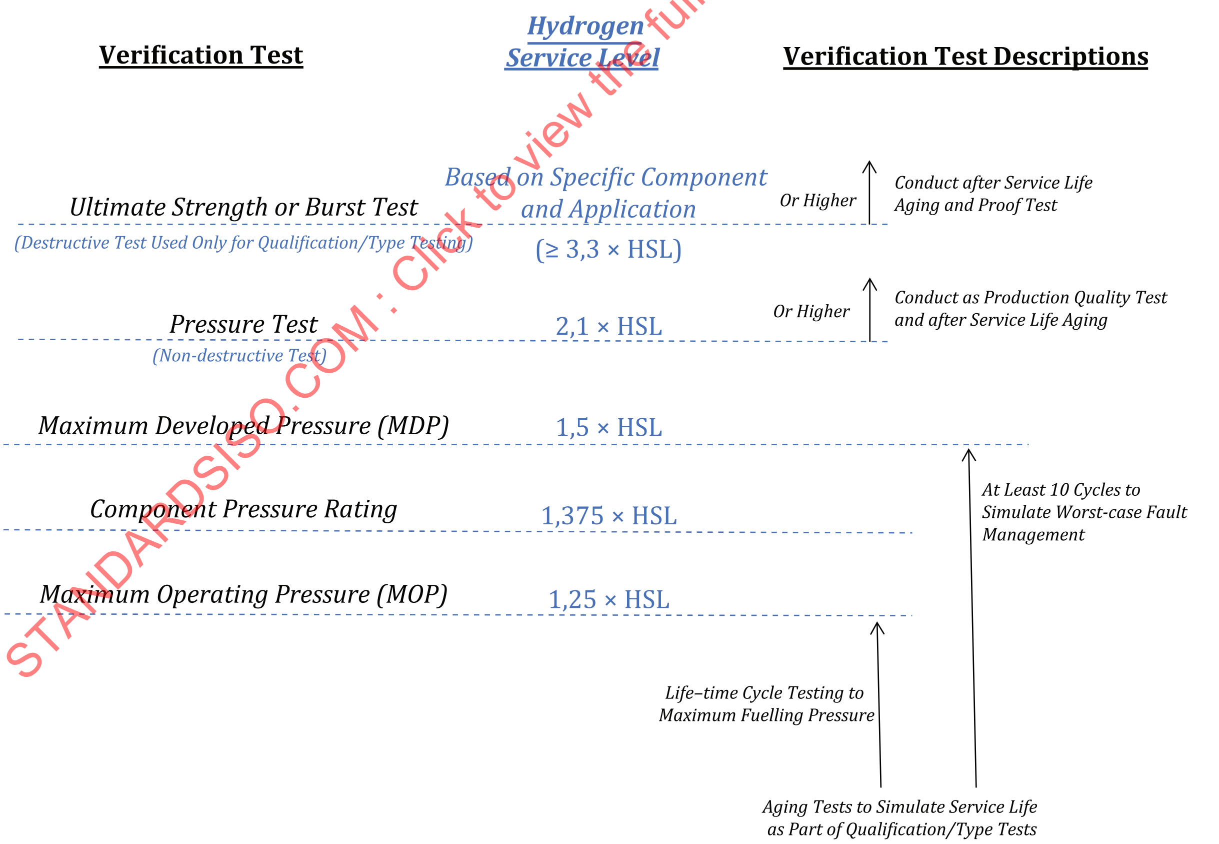


Figure E.2 — Guidance for verification of dispensing system components

Components submitted for verification testing should be representative of production. Quality checks including leak tests and pressure tests should be performed (and passed). The following tests should be considered as part of the verification testing:

1) The brunt of the aging test should be spent simulating the pressure cycling over normal operation to at least 125 % of HSL. The number of cycles should meet or exceed the manufacturer's specification and should consider extremes in both ambient and hydrogen dispensing temperatures. In order to ensure that the verification tests consider compatibility of materials with compressed hydrogen, the cycling should be performed with compressed hydrogen.

2) Aging tests should also consider fault management by cycling the components at least 10 times to MDP (150 % of HSL).

3) Following aging tests, the total discharge of hydrogen (leakage plus permeation) should be determined for acceptability and then the components should be (hydraulically or pneumatically) pressure tested to 210 % of HSL. No physical deformation should occur and the components should be expected to functional after the test.

4) An ultimate strength or burst pressure test should also be conducted to demonstrate adequate mechanical strength against rupture following the aging tests. The test level should consider the specific component and target application but should be conducted to at least 330 % of HSL. If the ultimate strength or burst pressure is less than 300 % of MOP (375 % of HSL), then it is recommended that a detailed design of the dispensing system component be conducted with consideration of hydrogen material compatibility and cycle fatigue.

Since the key design parameter of stationary pressurized equipment is the component rating, verification tests should be referenced to the component (as opposed to the HSL as done for dedicated dispensing system components). See Figure E.3 for an illustration of this translation.

Finally, since the dispensing system duty is a highly specific application, verification of components that can be used generally in hydrogen systems should consider more aggressive verification test conditions to cover situations that can typically addressed by the pressurized piping codes. See E.3 for guidance. It is acceptable, however, that components (such as fuelling nozzles, hose breakaway devices for drive-away protection, and dispensing system flow meters) with specialized functions within the dispensing system that are unlikely to be used in other hydrogen systems use E.2.

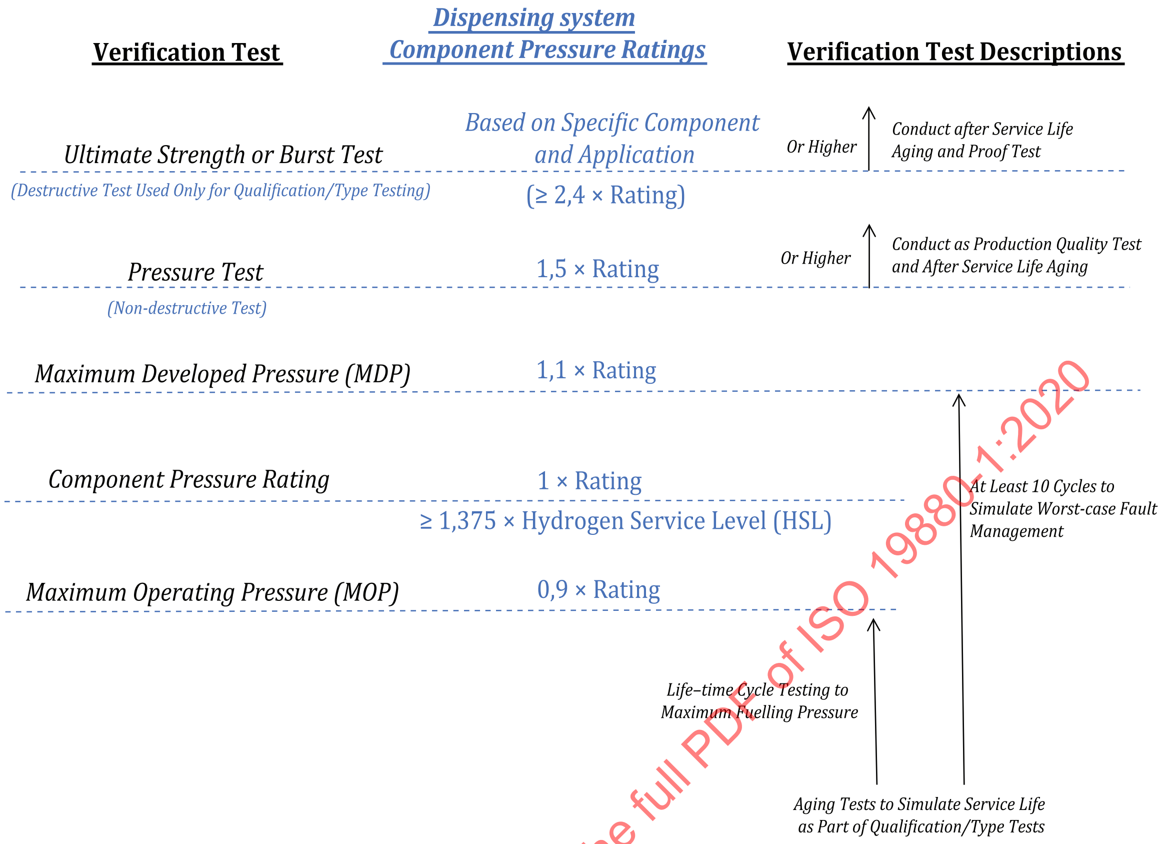


Figure E.3 — Guidance for verification of dispensing system components relative to component pressure rating

E.3 Generalization of verification test requirements for hydrogen service

Valves and perhaps hoses within the dispensing system are likely to be generally throughout the fuelling station and not restricted to the dispensing system. Since the operating conditions in other hydrogen systems could be more aggressive than captured for the dispensing system in E.2, these components should be verified to the more aggressive conditions that could occur in these systems within the component ratings (as indicated by the pressure class).

Verification of components to the more aggressive conditions will simplify development, reduce spare parts inventory, and help prevent replacement errors during maintenance.

The following guidance should therefore be used to verification tests for generalize usage of components such as valves (other than hose breakaway devices) and hoses in hydrogen systems:

1) Normal cycling in the aging tests should be performed up to the component rating.

2) Cycling to simulate “worst case” fault management should be to 110 % of the component rating.

3) The pressure test should be performed to 150 % of the component rating.

4) The ultimate or burst test level should consider the specific component and target application but typically 3 - 10 times the component rating (with 240 % of PS as a minimum).

If the ultimate strength or burst pressure is less than 300 % of the minimum required component pressure rating (equivalent to the system MAWP), then it is recommended that a detailed design of the dispensing system component be conducted with consideration of hydrogen material compatibility and cycle fatigue.

The above guidance is depicted in Figure E.4. This guidance may be used to define general requirements for specific components in hydrogen systems. The information can also be used to better understand the expected duty cycles and operating requirements for components in hydrogen service which can be used per 7.2.1 to waive testing when sufficient evidence exists that the component is acceptable for service in accordance with ISO 15649 (or selected piping standard being used).

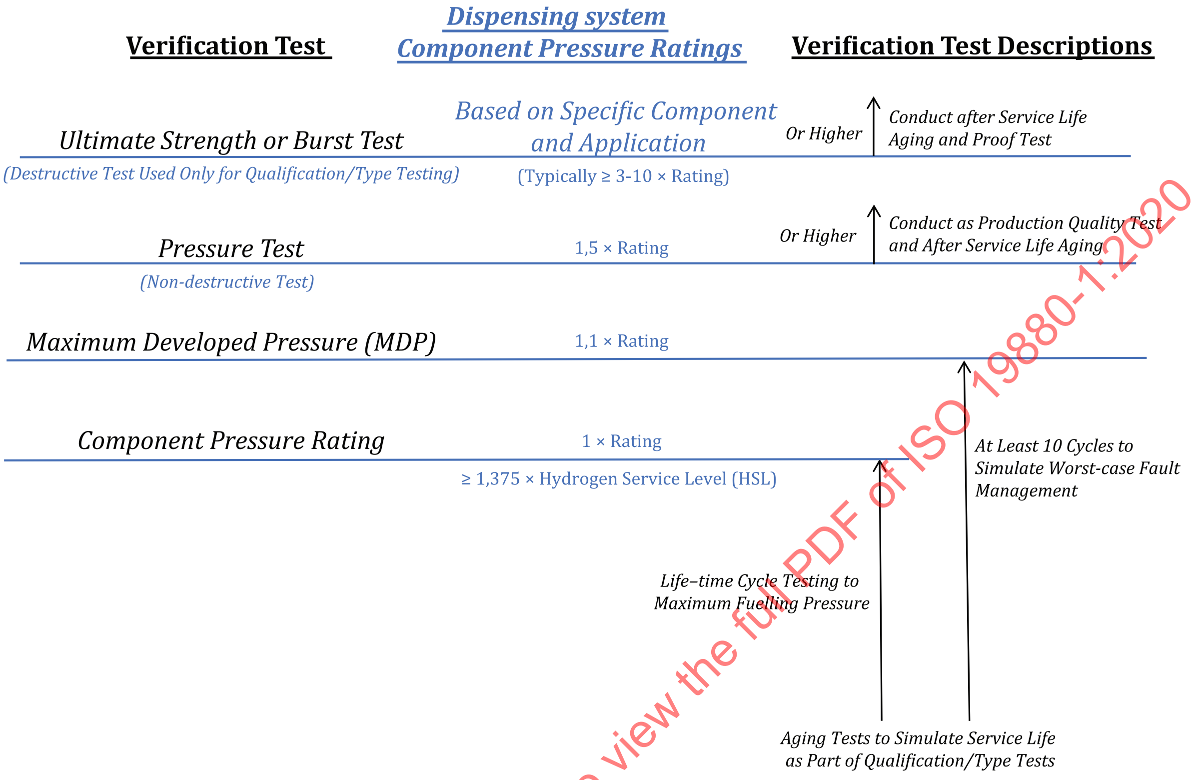


Figure E.4 — Guidance for verification of components for general applications relative to component pressure rating

Annex F
(informative)

Countermeasures for unsuitable hydrogen fuelling protocols

F.1 General

The following are examples of countermeasures for hydrogen fuelling stations that can be used in order to avoid damage to vehicles using the station, for example, the overheating of light duty hydrogen vehicles (CHSS) from non-standard protocols, etc., or damage to the vehicle high pressure hydrogen system due to unsuitable flow rates.

Human factors should be taken into account when defining countermeasures against fuelling protocols that deviate from recognised standards.

F.2 "Lock Out" countermeasure examples

Below are some "Lock Out" countermeasure examples for fuelling hydrogen vehicles:

— Software authorisation (e.g., pin access to use dispenser) or hardware authorization (e.g., lock and key), or by limiting public access to the dispenser (e.g. fence) and only allowing the use of the station by trained personnel. Human factors should be taken into account when defining authorisation/countermeasures that that can be traded among users;

— Forklift fuelling: For forklift fuelling using communications (such as wired communications) for a captive fleet of vehicles, the dispensing system should default to a conservative fuelling by a recognized SDO in the event that a road certified FCEV presents at the dispenser or stop fuelling when the fork lift communications signal is not available. For non-communications fork lift dispensers there should be a physical lockout to ensure that a FCEV cannot fuel or a conservative fuelling should be done according to SDOs;

— Heavy duty fuelling: For fuelling dedicated to a 35 MPa heavy duty vehicle station without precooling, which may have flow rates up to 120 g/s (or more), an ISO 17268 high flow nozzle H35HF lockout should be used to eliminate the possibility of a light duty vehicle (with safety limits of 60 g/s) using the same nozzle;

— Sequential fuelling of a vehicle: If the station operator determines there may be a potential risk of an unsafe condition, such as overheating the CHSS due to fuelling at, for example, an H70 dispenser subsequent to fuelling at an H35 dispenser, the station operator should take appropriate measures, such as software or hardware authorisation requirements for access to the H35 dispenser in addition to training;

— Communication: A unique identifier on the communications signal can be used to validate the communications protocol. For SAE J2799, the protocol identifier (ID= SAE J2799) can be used to identify the communications protocol.

