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BSI Standards Publication

Gaseous hydrogen — Fuelling stations

Part 1: General requirements



National foreword

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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 on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword – Supplementary information](#).

The committee responsible for this document is ISO/TC 197, *Hydrogen technologies*.

ISO/TS 19880-1 has been prepared with the ultimate goal of developing an International Standard and it replaces ISO/TS 20100:2008, on the same subject, which was withdrawn in 2015.

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

Gaseous hydrogen — Fuelling stations —

Part 1: General requirements

1 Scope

This document recommends the minimum design characteristics for safety and, where appropriate, for performance of public and non-public fuelling stations that dispense gaseous hydrogen to light duty land vehicles (e.g. Fuel Cell Electric Vehicles).

NOTE These recommendations are in addition to applicable national regulations and codes, which can prohibit certain aspects of this document.

This document is applicable to fuelling for light duty hydrogen land vehicles, but it can also be used as guidance for fuelling buses, trams, motorcycles and fork-lift truck applications, with hydrogen storage capacities outside of current published fuelling protocol standards, such as SAE J2601.

Residential applications to fuel land vehicles and non-public demonstration fuelling stations are not included in this Technical Specification.

This Technical Specification provides 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 dispensers.

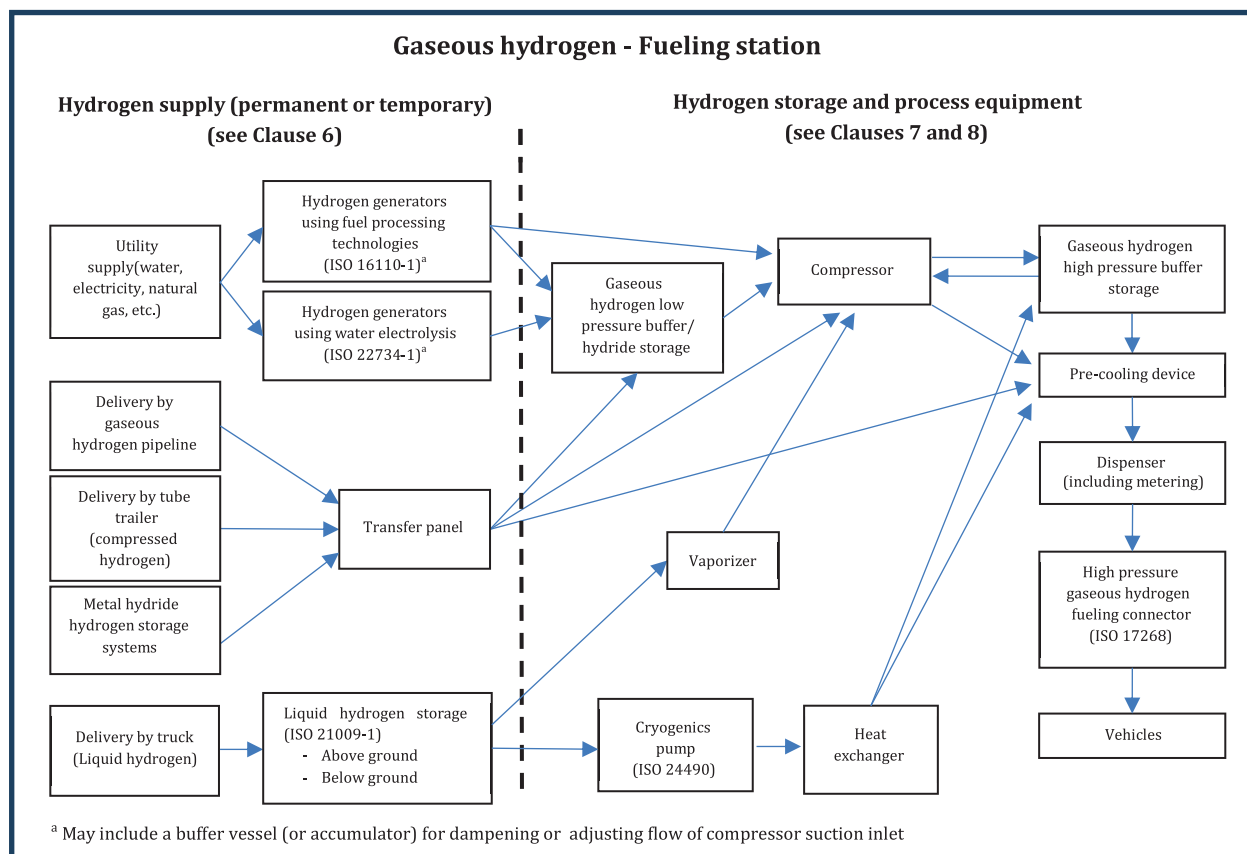


Figure 1 — Example of typical elements in a hydrogen fuelling station, including the hydrogen supply

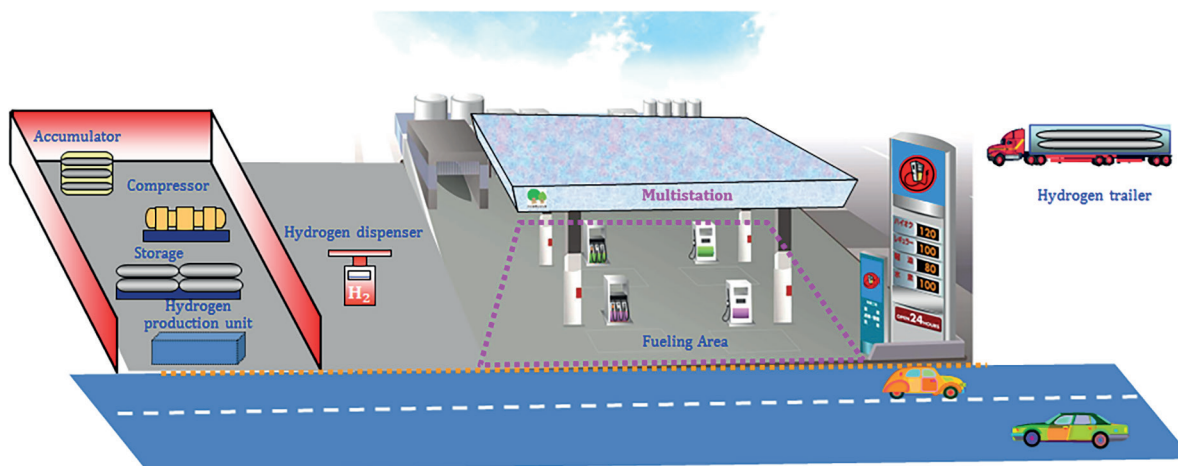


Figure 2 — Image of an example hydrogen fuelling station

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

There are no normative references in this document.

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:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

accessory

device with an operational function

3.2

authority having jurisdiction

AHJ

organization, office or individual responsible for approving a facility along with an equipment, an installation or a procedure

3.3

bleed venting

expiration or inspiration of air or gas from, or to, one side of a diaphragm of any accessory, component, or equipment such as a valve, pressure regulator or switch

3.4

breakaway device

device installed on a dispensing hose that separates when a given pull force is applied and closes the flow of hydrogen to prevent gas leakage and protect the dispenser from damage from vehicles driving away

3.5

buffer storage tanks

pressurized tanks, 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 dispenser for accumulation of pressurized gas supply for vehicle fuelling

3.6

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

3.7

connector

joined assembly of nozzle and receptacle which permits the transfer of hydrogen

[SOURCE: ISO 17268:2012, 3.1]

3.8

dispenser

parts of the pressurised-gas fuelling station via which the pressurised gas is dispensed to vehicles

Note 1 to entry: As an example, the dispenser may include a dispenser cabinet, gas flow meter, a fueling hose and fueling nozzle attachments.

3.9

dispenser cabinet

protective housing that encloses process piping and may also enclose measurement, control and ancillary dispenser equipment

3.10

dispensing system

system comprising all equipment necessary to carry out the vehicle fuelling operation, downstream of the hydrogen supply system

3.11

enclosure

protective housing that may enclose, or partially enclose, equipment in order to protect it from the environment, provide noise attenuation, or provide safety to the areas surrounding the equipment

3.12

frequency

rate of occurrence of events, e.g., how many time the event occurs in a specified time or number of opportunities

3.13

fail-safe

design feature that ensures that safe operating conditions are maintained in the event of a malfunction of control devices or an interruption of a supply source

3.14

fitting

connector used to join any pressure retaining components in the system

3.15

forecourt

surfaced area where vehicle dispensing operations are conducted including the fuelling pad and any area underneath a canopy

3.16

fuel temperature

temperature of the hydrogen fuel, measured less than 1 m upstream of the dispenser hose breakaway

3.17

fuelling assembly

part of the dispenser providing the interface between the hydrogen fuelling station and the vehicle - an assembly consisting of a breakaway device, a hose(s), a nozzle and connectors between these components

3.18

fuelling hose

flexible conduit used for dispensing gaseous hydrogen to vehicles through a fuelling nozzle

3.19

fuelling pad

area adjacent to the hydrogen dispensers, where customers park their vehicles for fuelling

3.20

fuelling station

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

3.21

standalone

independent facility for the dispensing of compressed hydrogen only

Note 1 to entry: This is a type of *fuelling station* ([3.20](#)).

3.22

integrated

facility for the dispensing of compressed hydrogen integrated into an existing, or new build, conventional fuelling station

Note 1 to entry: This is a type of *fuelling station* (3.20).

3.23

fuelling station operator

person or organisation responsible for the safe operation, maintenance and housekeeping of the fuelling station

3.24

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 may be called casing, cover, screen, door, enclosed guard, etc.

3.25

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]

3.26

harmonised standard

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

Note 1 to entry: harmonized standards are created following a request from the European Commission to one of these organisations. Manufacturers, other economic operators, or conformity assessment bodies can use harmonised standards to demonstrate that products, services, or processes comply with relevant EU legislation.

3.27

hazard

potential source of harm

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

3.28

hose assembly

includes the hose, appropriate end connectors (couplings or fittings), bend restrictors (if necessary), and appropriate markings

3.29

housing

section of a system that encloses, and is intended to protect, operating parts, control mechanisms, or other components that need not be accessible during normal operation

3.30

hydrogen purifier

equipment to remove undesired constituents from the hydrogen

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

3.31

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.

3.32
maximum allowable working pressure
MAWP

maximum pressure that a component may experience in service, including upset conditions, independent of temperature, before initiating mitigation options, typically the basis for the set point of the pressure relief device protecting the vessel or piping system

Note 1 to entry: The maximum allowable working pressure may 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: Further guidance on pressure terminology is included in [Annex D](#).

3.33
maximum operating pressure
MOP

highest pressure that is expected for a component or system during normal operation

Note 1 to entry: This is the pressure from which hydrogen at a temperature of 85 °C would settle at the NWP at a temperature of 15 °C.

Note 2 to entry: Further guidance on pressure terminology is included in [Annex D](#).

3.34
mechanically actuating safety equipment

mechanically actuating equipment that prevents the fuelling station operation outside specified acceptable maximum or minimum operating pressures or that prevents a gas leakage in the event of an incident

3.35
mitigation

combination of the measures incorporated at the design stage, and those measures required to be implemented by the station operator, dispenser operator, or others involved with the operation and maintenance of the fuelling station

3.36
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 uses a different definition.

[SOURCE: ISO 10286:2015, 2.2.1]

3.37
nominal working pressure
NWP

pressure for which the dispenser is intended to be operated for a given gas temperature of 15 °C

Note 1 to entry: This defines a full vehicle tank gas density, of either 35 MPa or 70 MPa at 15 °C.

Note 2 to entry: Further guidance on pressure terminology is included in [Annex D](#).

3.38
non-public fuelling station

fuelling station ([3.20](#)) that does not sell or dispense gaseous hydrogen to the general public

EXAMPLE private or municipal vehicle fleet operation

3.39

nozzle

device connected to a fuel dispensing system, which permits the quick connect and disconnect of fuel supply to the vehicle or storage system

[SOURCE: ISO 17268:2012, 3.8]

3.40

outdoors

location outside of any building or structure, or locations under a roof, weather shelter or canopy provided this area is not enclosed on more than two sides

3.41

plinth

raised area on the forecourt, supporting and protecting the dispensers and associated equipment

3.42

positive isolation

provision of a safe environment for performing maintenance, repair or replacement operations on process facilities

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

Note 3 to entry: A blind or a spade is an alternative way to provide positive isolation.

3.43

pre-cooling

process of cooling hydrogen fuel temperature prior to dispensing

3.44

pressure relief device

PRD

device designed to release pressure in order to prevent a rise in pressure above a specified value due to emergency or abnormal conditions

Note 1 to entry: PRDs can be activated by pressure or another parameter, such as temperature, and may 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 burst and re-closes when the pressure falls below the set point.
- Temperature-activated Pressure Relief Device (TPRD) — a PRD that opens at a specified temperature to protect a system from burst and remains open.

3.45

probability

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

3.46

public fuelling station

fuelling station ([3.20](#)) that sells gaseous hydrogen to the general public

3.47

receptacle

device connected to a vehicle or storage system which receives the nozzle

[SOURCE: ISO 17268:2012, 3.11]

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

3.48

risk

combination of the probability of occurrence of harm and the severity of that harm; encompassing both the uncertainty about and severity of the harm

[SOURCE: ISO/IEC Guide 51: 2014, 3.9 – added part from “encompassing” to “severity of the harm” and Note 1 to entry removed]

3.49

risk assessment

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

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

3.50

risk (acceptance) criteria

terms of reference by which the significance of risk is assessed

[SOURCE: ISO/IEC Guide 73:2009, 3.3.1.3]

3.51

risk level

the assessed magnitude of the risk

3.52

safeguarding

use of specific technical means to protect persons from the hazards which cannot reasonably be removed or sufficiently limited by design

3.53

safety

freedom from unacceptable risk

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

3.54

safety device

device other than a guard, which eliminates or reduces risk, alone or associated with the guard

3.55

safety distance

distance to acceptable risk level or minimum risk-informed distance between a hazard source and a target (human, equipment or environment), which will mitigate the effect of a likely foreseeable incident and prevent a minor incident escalating into a larger incident

Note 1 to entry: Safety distances are split into Restriction distances, Clearance distances, Installation layout distances, Protection distances and External risk zone. See [5.8.2](#) for further details.

Note 2 to entry: The term “safety distance” may also be referred to as “safe distance,” “separation distance,” or “setback distance.”

3.56

safety function

function to be implemented by a control system or safety-instrumented system, 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 control system, however validation of these measures is equally important.

3.57

safety-instrumented system

instrumented system used to implement one or more safety instrumented functions

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

3.58

safety-related system

designated system that both implements the required safety functions 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 or hazards. Although there may 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 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 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 may 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).

3.59

state of charge

SOC

ratio of compressed hydrogen storage system (CHSS) hydrogen density to the density at maximum operating pressure rated at the standard temperature 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.

$$SOC(\%) = \frac{\rho(P, T)}{\rho(NWP, 15^{\circ}C)} \times 100$$

Note 3 to entry: The hydrogen densities at the two major nominal working pressures are:

- density of H₂ at 35 MPa and 15 °C and = 24,0 g/l
- density of H₂ at 70 MPa and 15 °C and = 40,2 g/l

Note 4 to entry: The $\rho(P,T)$ function for hydrogen is available from the National Institute of Standards and Technology (NIST) at <http://www.boulder.nist.gov/div838/Hydrogen/PDFs/Lemmon.2008.pV113.N06.A05.pdf>

3.60 **station pressure**

pressure of the hydrogen gas supplied to the vehicle by the station, measured near the hose breakaway

3.61 **target pressure**

station pressure that the hydrogen fuelling protocol targets for the end of fuelling

3.62 **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

4 Abbreviated terms

AHJ	Authority Having Jurisdiction
AiCHE	American Institute of Chemical Engineers (AIChE)
ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
CEN	French: Comité Européen de Normalisation (European Committee for Standardization)
CENELEC	French: Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization)
CFD	Computational Fluid Dynamics
CHSS	Compressed Hydrogen Storage System
ESReDA	European Safety, Reliability and Data Association
ETSI	European Telecommunications Standards Institute
LFL	Lower Flammability Limit
MAWP	Maximum Allowable Working Pressure
MEGC	Multiple Element Gas Containers
MOP	Maximum Operating Pressure
NWP	Nominal Working Pressure
OGP	Oil and Gas Producers
OREDA	Offshore and onshore REliability DAta
QRA	Quantitative Risk Assessment
PRD	Pressure Relief Device

PSD	Pressure Safety Device
PSV	Pressure Safety Valve
SOC	State of Charge
TPRD	Temperature-activated Pressure Relief Device
VCE	Vapour Cloud Explosion

5 General safety recommendations

5.1 Hydrogen fuelling station safety recommendations

The hydrogen fuelling station installation should be sited to minimize risk to users, operating personnel, properties, and the environment. The following elements of a hydrogen fuelling station should be considered potential hazard sources:

- on-site hydrogen production unit;
- hydrogen delivery system, including remote fill points as applicable;
- compressors;
- storage;
- piping;
- dispensing units.

More specifically, the hydrogen fuelling station should include measures to reduce harm from the following hazards:

- fires, deflagrations, detonations and blast waves;
- asphyxiation hazard (due to release of gaseous hydrogen or inert gases in confined spaces);
- cryogenic burns (liquid hydrogen supply);
- impact from pressure / debris;
- any additional hazards associated with the system, including:
 - electrocution hazards;
 - working at heights (e.g. roof mounted equipment);
 - injury from moving equipment / hose whip.

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).

In general, the following mitigation strategies should be considered:

- minimization of the potential for the formation of a flammable or explosive mixture;
- minimization of the potential for ignition (from both piloted and spontaneous ignition sources);
- mitigation of the effects of a fire or explosion 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 strength potential of explosive atmosphere generated by potential leaks or releases.

5.2 Risk assessment

Risk assessment may be used as a flexible compliance option. Use of risk assessment allows station owners and designers to flexibly define station-specific mitigations that achieve an equal or better level of safety to those of prescriptive recommendations.

Risk assessment is the overall process of risk identification, risk analysis, risk evaluation and risk mitigation. Risks can be assessed at an organizational level, at a departmental level, for projects, individual activities or specific risks. A risk assessment should be performed for the hydrogen fuelling station in accordance with one of the following standards: ISO 31000, ISO/IEC 31010, and/or ISO 12100.

Methods used in assessing risks can be qualitative, semi-quantitative or quantitative. The degree of detail required will depend upon the particular application, the availability of reliable data and the decision-making needs of the organization. Some methods and the degree of detail of the analysis may be prescribed by legislation.

It is recommended that the risk assessment carried out for the hydrogen fuelling station should be quantitative or semi-quantitative. 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 [5.3](#) and [5.4](#).

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.

5.2.1 Methodology for semi-quantitative and quantitative risk assessment for assessing hydrogen installation safety

5.2.1.1 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 clause provides recommendations for performing that analysis. This analysis focuses on at 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 5.10.

Developing an approach to protect against harm should consider the following factors:

- nature of the hazards (e.g., thermal, pressure, toxicity, etc.);
- physical properties 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 minimize 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, so 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.

5.2.1.2 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 clause. 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.

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 process for risk-informing mitigations includes the following steps, as displayed in [Figure 3](#):

- target determination– Define the targets being protected, and as necessary, the hazard sources. Table 3 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).

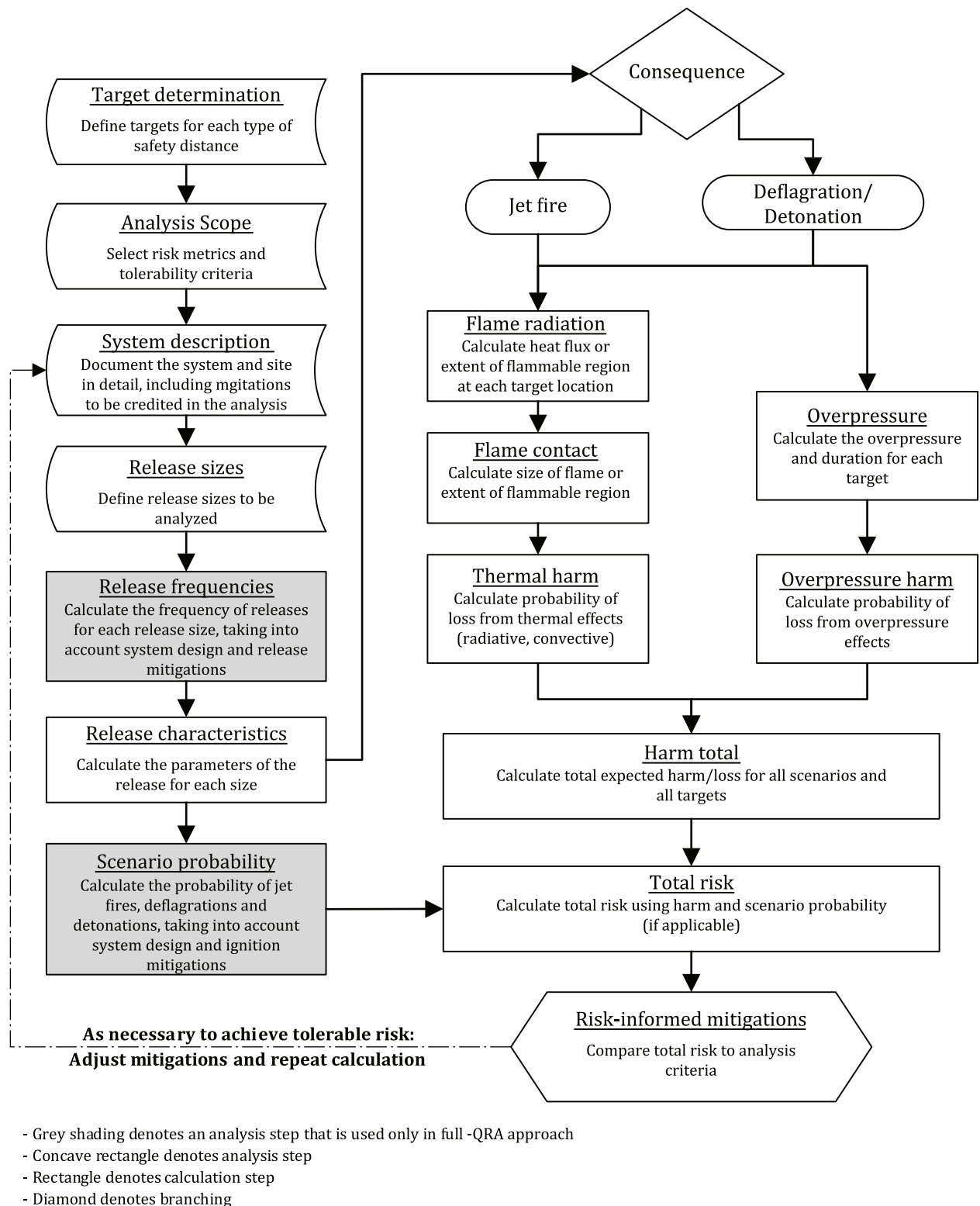


Figure 3 — Example of a risk-informed approach to safety distances

5.2.1.3 Target determination and analysis scoping

Each characterisation of safety distance in [Table 1](#), affects one or more classes of target. [Table 3](#) provides many examples of targets for each type of safety distance. Types of safety distance should be defined according to national requirements / guidance, with appropriate targets and hazards sources defined for each type of safety distance.

5.2.1.4 Hazards

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.

5.2.1.5 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.

5.2.1.6 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.

5.2.1.7 Cause analysis

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.

5.2.1.8 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.

5.2.1.9 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, the data should be documented and should be made available to the AHJ 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 (OREDA, ESReDA, AiCHE or API 521) from similar industries and applications should be used.

5.2.1.10 Consequence analysis

This involves determining the physical effects of the scenarios, as well as the target response to those physical effects.

5.2.1.11 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 explosion effects such as pressure and impulse waves.

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.

5.2.1.12 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.

5.2.1.13 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

5.2.1.14 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.

5.2.1.15 Deflagration and detonation behaviour

Releases from hydrogen systems which are not immediately ignited may accumulate and result in a flash fire, blast or vapour cloud explosion (VCE) when ignited with thermal and pressure effects.

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 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.

5.2.1.16 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.

5.2.1.17 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:

$$Risk = \sum_n (f_n * C_n)$$

where risk is summed over all n selected scenarios, f_n is the frequency of scenario n, and 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, an AHJ may ask for a consequence only analysis for additional specific scenario and an AHJ may ask for a total risk analysis to include additional scenario.

5.2.1.18 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/discussion 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.

5.3 Mitigation measures to improve system safety

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. Mitigations which improve overall safety of the system (as demonstrated by use of the quantitative risk assessment process defined above) may be used to:

- reduce prescriptive safety distances through the risk-informed safety distance process;
- relax existing prescriptive mitigation measures by carrying out a semi-quantitative or quantitative risk assessment.

As long as total system risk remains below the selected tolerability threshold (Risk acceptance criteria).

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.

5.4 Mitigations which reduce the potential for the formation of a flammable or explosive mixture

5.4.1 General

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

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 minimize the number of connections, are leak-free by design or use inherently safe equipment design;
- permanent inert atmosphere;
- 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)

- hydrogen detectors to provide detection and automatic shutdown/isolation if flammable mixtures present, particularly in enclosed spaces;
- ventilation (e.g. passive or active ventilation).

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 explosive gas atmosphere;
- 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.

5.4.2 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 should have a suitable range for the concentration set-points used to initiate a response through the control or safety system.

When used, hydrogen detection apparatus should be installed where it has the highest likelihood of detecting the foreseeable leaks, such as:

- upstream of the ventilation system;
- where the released hydrogen is most likely to accumulate.

The appropriate response should be determined by the 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 instigated by the hydrogen detection system should be determined by the 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 extinguished 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.

5.4.3 Safety and emergency shut-off systems

In order to minimise the magnitude of an unintentional release, or to minimise the duration of the flammable or explosive atmosphere, emergency isolation valves that can safely shut-off the hydrogen supply from the hydrogen storage to other areas of the hydrogen fuelling station should be installed.

The fail-safe position of automatic valves in liquid hydrogen lines in the event of power or pneumatic pressure loss should be defined by risk assessment and implemented accordingly.

5.4.4 Mitigation for the formation of a flammable or explosive mixture in enclosures

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

NOTE 1 When this is not practical, see [10.2](#) for guidance on classifying hazardous areas and controlling ignition sources within the hazardous area.

A non-comprehensive list of example prevention methods is as follows:

- passive ventilation;
- active ventilation;
- flammable gas detection system or ultrasonic gas detection;
- integrity testing (rate of pressure loss measurement) of isolated piping sections;
- other means of leak detection.

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) of hydrogen or any other flammable gases (see [5.4.2](#)). Where continuous or primary grades of release, as defined in IEC 60079-10-1, are anticipated, a lower volume fraction may be appropriate.

Small dilution volumes where the structural integrity of the enclosure would not be affected in case of ignition, based on the maximum anticipated flammable gas leak rate into the enclosure as determined by the manufacturer, may be exempted from this requirement. The manufacturer should demonstrate that the equipment is fit for the purpose.

This rate of ventilation need not be permanently present if it is initiated by a flammable gas detection system upon measurement of the lower activation limit complying to the recommendations of [5.4.2](#). However, the rate of ventilation necessary to prevent the formation of an explosive atmosphere due to normal and expected releases (e.g. natural leaks from fittings, or hydrogen permeation through non-metallic materials), should be maintained whenever the process contains hydrogen under pressure, whether the system is in operation or not.

Whenever active ventilation is used, the minimum required ventilation rate of the ventilation system should be specified. The pressure drop across the ventilation system and the maximum outlet pressure of the ventilation system should 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 should be purged with sufficient air changes prior to the energization of such equipment.

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 should cause the shut-off of the supply of hydrogen and other flammable gases to the enclosure and the de-energization of non-classified electrical equipment.

Computational fluid dynamics 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 passive ventilation and the means of hydrogen detection for providing the required protection.

NOTE 2 Sudden and catastrophic failure of vessels or piping systems need not be considered a leak scenario in this analysis when protection against such failures has already been contemplated in the tank and piping design.

Area classification determined according to [10.2](#) and the protection recommendations for equipment in classified 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 apparatus operating in dilution volume that can exist near potential sources of release (leaks points) should be protected in accordance with [10.2.2](#).

Enclosures should be designed so as to avoid high points where hydrogen can accumulate undetected.

5.4.5 General requirement hydrogen venting for mitigation for the formation of a flammable or explosive mixture

Flows from vents and safety relief equipment should be piped outdoors to a safe location to avoid formation of a flammable or explosive mixture in hydrogen equipment enclosures or other locations where the consequences of ignition of the vented hydrogen would pose a hazard.

The position of hydrogen vent stacks should be taken into account in the layout of the installation and should be such that the vent may be used for operation, maintenance and emergency response without creating hazardous conditions. Consideration should 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 should be arranged to discharge to open air, and so as not to generate a hazard for persons or neighbouring structures, away from personnel areas, electrical lines and other ignition sources, air intakes and building openings. The vent stack should not discharge where accumulation of hydrogen can occur, such as below the eaves of buildings.

Hydrogen dispersion and radiated heat calculations should be carried out to establish the location and height of vent stack exits. Further detail is provided in [5.8.4](#).

The outlet of the vent stacks should not be equipped with devices that deflect the direction of the vented hydrogen downwards.

5.5 Mitigations which reduce the potential for ignition

5.5.1 General

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)

5.5.2 Areas subject to restriction of activity

Equipment or areas of the hydrogen fuelling station in which flammable materials are handled or stored should be designed, operated and maintained so that any releases of flammable material, and consequently the extent of potentially explosive 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 should be taken:

- minimise the likelihood of an explosive gas atmosphere occurring around the source 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 fixed electrical equipment should be appropriately classified, see [10.2.2](#).

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 aware of the hazards potentially encountered and the relevant emergency procedures.

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

All portable equipment which may 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.

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 where hydrogen presence in the atmosphere is not likely under normal conditions. During such operations, the atmosphere in the work area should be continuously analysed using a portable analyser. 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.

Further information on electrical grounding and bonding to prevent ignition sources is provided in [10.1.4](#).

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

5.6.1 General

The following mitigations may reduce the effects of fires or explosions 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 [5.8.1](#));
- explosion relief protection [see for example; API 521 Guide for pressure-relieving and depressurising systems].

5.6.2 Flame detection systems

Where identified by the hydrogen fuelling station risk assessment, means of detection of hydrogen fires should be provided to avoid escalation due to flame impingement on neighbouring equipment.

Infra-red, ultra-violet emission or thermal sensors may be used for hydrogen fire detection.

Means should also be provided to detect fires (e.g. smoke detectors) in equipment that have particular fire hazards (e.g. high current electrical equipment) if such fires can directly affect hydrogen storage systems.

5.6.3 Enclosures containing hydrogen systems

Enclosures containing hydrogen systems should be constructed of non-combustible materials.

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

Requirements for the fire resistivity of the floor, walls, ceiling and any openings (doors, windows) should 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 should have a fire-resistance rating appropriate for the scenario and, where applicable, provide time for fire brigade intervention.

Requirements for over-pressure relief should be defined by risk assessment.

Where required, explosion venting should be provided in exterior walls or the roof only. Vents should 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 outside the opening, projectiles, movement of doors or hatches should be considered by risk assessment.

Requirements for the over-pressure resistance of the floor, walls, ceiling and any openings (doors, windows), where not intended for explosion relief, should be defined by risk assessment.

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.

5.6.4 Emergency release of gas from hydrogen storage tanks under fire conditions

If hydrogen storage tanks may be exposed to fire conditions (from inside or outside the storage area or compartment) that could lead to rupture, thermally activated (non-reclosing) and/or manually activated valves should be provided to safely vent all the content of the hydrogen storage. Where such a

valve needs manual activation, this should be possible from a safe location. In this case, the vent system should be designed accordingly, see [9.14.5](#).

NOTE National regulations can prohibit the use of manually activated valves.

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

5.7.1 General

Measures should be taken to minimize the effect of events that have potential to take place in the vicinity of the fuelling station. These measures may include the following:

- safety distances;
- lightning protection;
- fire barriers;
- vehicle impact protection;
- protection against spillage of flammable fluids from other sources;
- access control measures;
- protection against external events.

5.7.2 Layout

The layout of a hydrogen fuelling station should minimise the likelihood of damage 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.

Hydrogen installations should be kept free of debris and other flammable waste.

No flammable liquids should be able to accumulate under the hydrogen storage tanks.

5.7.3 Fire barrier recommendations

A fire barrier may be used as a mitigation option to reduce safety distances. A non-comprehensive list of example safety distances for which a fire barrier could be used 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.

If a fire barrier is used as a mitigation option, it should be made of suitable non-combustible materials and have a minimum fire resistance rating of 30 min, as measured according to ISO 834-1. Consideration should be taken for the overpressure effects generated around the barrier by an unignited or ignited

release. Walls intended as mitigation against fires / 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, also see [5.7.6](#).

5.7.4 Mitigating against vehicular impact

Hydrogen storage and dispensers should not be located in a direct line of traffic, e.g. entrance / exit to station. Further details for the protection of dispensers from traffic are included in [9.10.1](#).

The station design should minimise the need for vehicle manoeuvres as far as is reasonably practical, in order to reduce 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. The fuelling station operator should conduct an impact assessment that takes into account the vehicle movements within the fuelling station.

Vehicular impact protection should be appropriate for the anticipated type and speed of vehicles in the vicinity of the hydrogen equipment.

NOTE Further guidance on examples of how to achieve this is included as [Annex E](#).

5.7.5 Firefighting systems

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

Water should be made 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 fire-fighting purposes, suitable fire-extinguishing appliances should 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 whilst allowing a release to persist. 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 an explosion in the event of a re-ignition of the hydrogen. 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 bursting of the vessels. Water from the firefighting system should not be directed at or introduced into a hydrogen system vent stack.

5.7.6 Emergency principles and operations

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

The installation should be designed so that authorised personnel have easy access at all times and have adequate means of escape in the case of emergency. Access should be prevented to all unauthorised persons. Emergency exits should 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 should be 0,8 m. Timber or other readily combustible materials should not be used for fencing.

All gates should comply with the local fire and building codes. The gates should be wide enough to provide for easy access and exit of authorized personnel. Gates should 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.

Consideration should 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 compounds, there should be at least two separate outward opening exits, remote from each other, that are strategically placed in relation to the hazard considered.

Full emergency procedures should be established for each particular fuelling station in consultation with local fire authorities. Periodic drills should be carried out.

Where a risk remains that critical hydrogen equipment can be dangerously exposed to fire conditions, which may originate from non-hydrogen related equipment, despite all the means that can reasonably be taken at design level, the following safety systems should be considered:

- water sprinklers for cooling of equipment exposed to fire, see [5.7.5](#);
- means for the emergency venting of hydrogen storage tanks according to [5.6.4](#).

5.8 Safety distances

5.8.1 General

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. 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 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 may be prescribed by national regulations, see examples presented in [Annex A, Table A.1](#) 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.

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, ISO standard toolkit is strongly suggested.

NOTE 3 An example of a safety distance toolkit is given in [Annex A](#).

This Technical Specification 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

5.8.2 Types of safety distances

5.8.2.1 Restriction distances

The restriction distance is the minimum distance from hydrogen equipment or 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 [5.5.2](#). The remaining types of safety distances mitigate foreseen and unforeseen events other than those arising from activities restricted during normal operations.

5.8.2.2 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 3](#).

5.8.2.3 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 3](#).

5.8.2.4 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 2](#). Example targets are any equipment of the hydrogen fuelling station, including equipment listed in [Table 3](#).

5.8.2.5 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 3](#).

5.8.3 Examples of safety distances

Table 1 — Summary of types of safety distances

Characterization of safety distance	Purpose	Source	Target(s)
Restriction distances	Minimize 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 2 — Example sources for each type of safety distances.

Safety distance	Example sources
Clearance distance AND Installation lay-out distance AND External risk zone	Equipment of the fuelling station • Dispenser; • Compressor; • Liquid hydrogen storage; • Gaseous hydrogen storage.
Protection distance	Off-site or on-site: • Presence of other combustible liquids or gases (e.g., gasoline storage, LPG storage, pipelines containing flammable gases or 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.

NOTE The information in this table is provided to facilitate identification of 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 possible to establish safety distances for sources not listed in this table.

Table 3 — Example targets for each type of safety distance.

Safety distance	Example targets
Clearance distance	Persons: - Workers in the fuelling station (1st party); - Users of the fuelling station (clients, 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.
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.
NOTE The information in 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 possible to establish safety distances for targets not listed in the table.	

5.8.4 Safety distances relating to hydrogen vent stack outlets

The vent outlet location (height; distance to exposures) should 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 wind conditions. The safety distances for vented gas from liquid hydrogen systems should take into consideration the density of the gas.

The thermal radiation and overpressure effects of ignited vented gas (immediate or delayed ignition) should 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 national regulations or by risk assessment.