ISO 19880-1, Hydrogen Fueling Station and Vehicle Interface Safety Technical Report (ICHS # 116)

Authors: Schneider, J.[1]; Dang-Nhu, G.[2]; Hart, N.[3]; Groth, K.[4]

[1] Bayerische Motoren Werke Aktiengesellschaft (BMW AG), Petuelring 130, 80809 München, Germany
[2] Air Liquide, 2 Rue de Clémencière, 38360 Sassenage, France
[3] ITM Power, 22 Atlas Way, Sheffield, South Yorkshire S4 7QQ, United Kingdom
[4] Sandia National Laboratories, 1515 Eubank, Albuquerque, NM 87123

1. Introduction

Hydrogen Infrastructures are currently being built up to support the initial commercialization of the fuel cell vehicle by multiple automakers. Three primary markets are presently coordinating a large buildup of hydrogen stations: Japan; USA; and Europe to support this. Hydrogen Fueling Station General Safety and Performance Considerations are important to establish before a wide scale infrastructure is established.

This document introduces the ISO Technical Report 19880-1 and summarizes main elements of the proposed standard. Note: this ICHS paper is based on the draft TR 19880-1 and is subject to change when the document is published in 2015.

International Standards Organisation (ISO) Technical Committee (TC) 197, Working Group (WG) 24, has been tasked with the preparation of the ISO standard 19880-1, to define the minimum requirements considered applicable worldwide for the hydrogen and electrical safety of hydrogen stations. This report includes safety considerations for hydrogen station equipment and components, control systems and operation. The following systems are covered specifically in the document as shown in Figure 1:

- H2 production / supply delivery system
- Compression
- Gaseous hydrogen buffer storage;
- Pre-cooling device;
- Gaseous hydrogen dispensers.
- Hydrogen Fueling, Vehicle Interface

The draft TR 19880-1 (and current plan for the standard) also gives guidance for the fueling validation with safety considerations relevant to the interaction between the hydrogen station and hydrogen road vehicles (during fueling).. Through a cross-industry risk assessment carried out between OEMs, Hydrogen Suppliers and existing vehicle fuelling station providers & operators (e.g. oil and industrial gas companies) the hydrogen fueling protocol SAE J2601 and associated dispenser hardware was evaluated.

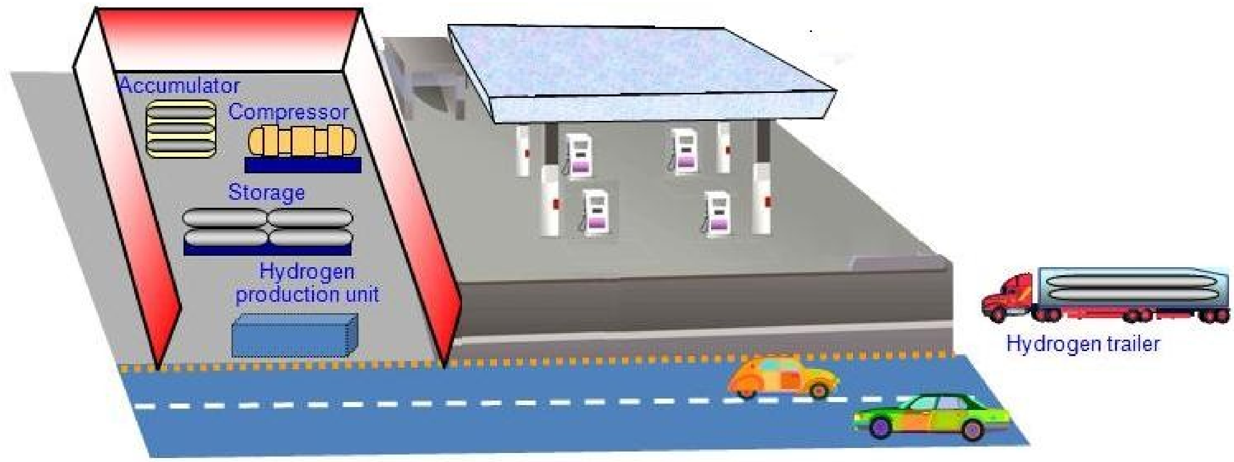


Figure 1 —Example hydrogen Fueling station illustrating scope of SO TR-19880

Currently, the expected level of quality supplied at the nozzle of the dispenser is defined in the standard ISO 14687-2 (Hydrogen fuel — Product specification — Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles).
In addition, ISO TR 19880-1 has examples for hydrogen quality control, to enabling stations to reduce the amount of testing needed to validate hydrogen fuel against ISO 14687-2 based on the hydrogen source.

Finally, in an informative annex of the TR 19880-1 the safety distances currently applied is documented with examples.

2. The Standardization Process

The ISO Technical Report (TR) 19880-1, Gaseous hydrogen — Fueling stations, published in 2015, is a first step towards standardizing the hydrogen station, and providing more up-to-date guidance than that developed as ISO TS 20100, published in 2008. The goal of the ISO TC 197 WG24 is to create an all encompassing guideline for the station and the interface between the vehicle and the hydrogen fueling station, including validation of the fueling process.

The goal is to then finalize the ISO standard 19880-1 by the end of 2016 in order to align with the need for adoption of the standard worldwide as well as with regulations in place / being prepared around the world. Specifically, the Alternative Fuels

Infrastructure Directive, 2014/94/EU, from the European Union is planning to reference a coming ISO EN IS 19880-1 for the specification for hydrogen fueling stations as part of the deployment of a hydrogen fueling station infrastructure in Europe.

3. Hydrogen dispensing

3.1 Hydrogen Station Dispensing description

Hydrogen fuel cell electric vehicles (FCEVs) can be fueled using dispensers that resemble conventional fuel dispensers, with similar start, payment and even nozzle ergonomics. The hydrogen and fuel cell vehicle industries are worked towards the goal of making the hydrogen fueling experience "like today" targeting a similar fueling time (less than five minutes) and resulting vehicle range (~500km or 300miles) such as with the SAE J2601[1] and SAE J2799[2] standards. The station safety expectation according to ISO 19880-1 will also give at least an equivalent level of safety to that of fueling with conventional fuels.

ISO TR 19880-1 currently assumes FCEV fueling will be done at either 35MPa or 70MPa pressures. Other applications -such as forklifts- (not covered in the present scope) may use other pressures for fueling.

Figure 2 below describes an example of a fueling station dispenser, also showing the fuel cell electric vehicle compressed hydrogen storage systems (CHSS), with sensors as well as pressure relief device(s). The CHSS has a thermally activated pressure relief device(s) (TPRD) to protect against bursting of the tank if there were to be a fire.

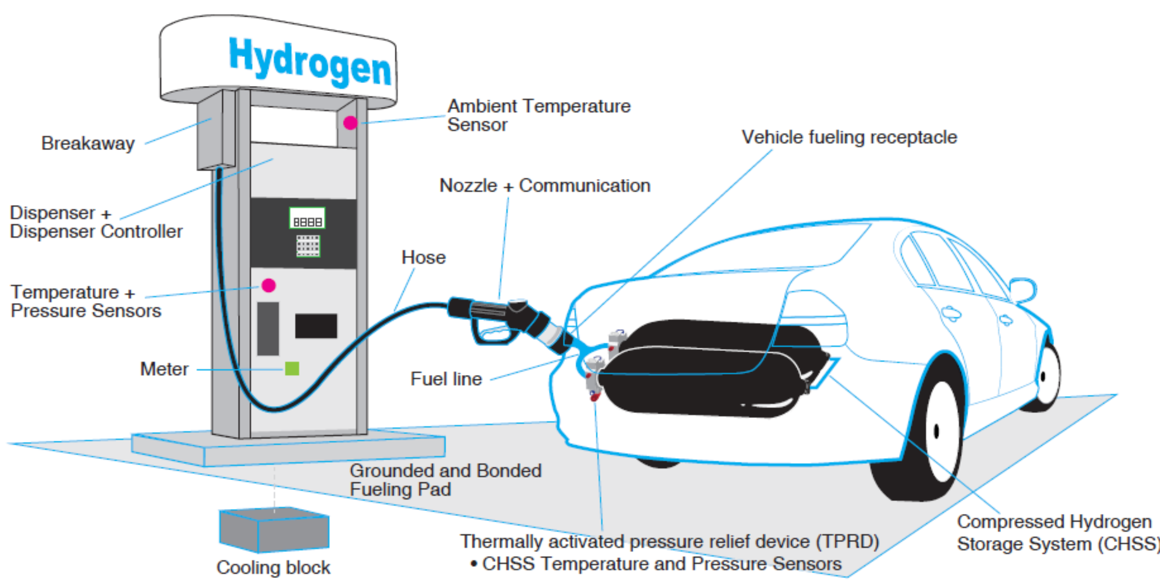


Figure 2: Station dispenser example with FCEV CHSS (from ISO 19880-1)

On the station side, there is an automated control system, such as a Programmable Logic Controller (PLC), where the Fueling control including Fueling protocol, fault procedures, etc. is programmed into the software. There is also a pressure safety-relief valve (PSV) to protect against over pressurization of the dispenser and vehicle. The dispensed hydrogen temperature and pressure should be monitored by the station, along with the ambient temperature. Where appropriate, the hydrogen dispensed should be metered in the station. A dispenser fueling assembly contains a breakaway, hose(s) and a dispensing nozzle, which may contain a communications receiver than can receive communication for the vehicle (such as the SAE J2799 standard).

The vehicle CHSS can be fueled after connecting the station dispenser to the vehicle receptacle, after the startup procedure from the dispenser.

3.2 Dispenser safety devices

General considerations

The dispensing control system should be capable, at any point in time during the fueling process, of detecting a deviation that could be indicative of a fault that leads to a hazardous condition (e.g. over temperature and over pressure for the CHSS), and executing countermeasures that will mitigate the hazard.

These safety measures are intended to prevent a hazardous situation in case of a failure of the dispensing control system hardware or software. The required reliability, defined through safety integrity level (SIL) or Performance Level (PL), as defined in IEC 61508, IEC 61511, IEC 62308, IEC 31010, ISO 13849-1 and/or ISO 12100 should be determined through quantitative or semi-quantitative risk assessment.

Countermeasures should be provided to ensure that no single or two faults result in a hazardous situation in the dispensing area. If the fueling ramp rate is determined from the result of a measurement by the fueling station or information communicated to the fueling station, then this function should be shown to be sufficiently reliable to effectively avoid an unacceptable risk of overfill, over-temperature or over-pressure in the vehicle CHSS.

3.3 Dispensing safety systems

The dispenser control should operate in conjunction with an emergency shutdown function that can cut off the flow of hydrogen gas to the dispenser and vehicle by closing the automatic isolation valves. The emergency shutdown function should be available at all times to override all other dispenser functions and operating modes to protect people in the dispensing area as well as equipment in the dispenser or on the vehicle being fueled.

Fueling is classified by its nominal working pressure (NWP) of a full vehicle tank at 15C, such as 70 MPa. Normal fueling operation should stop at maximum 125% times this NWP. As part of the emergency shutdown function, a means should be provided to detect a failure of the dispenser pressure sensor(s) or pressure control function, and, if necessary, stop fueling. Additionally, a pressure safety-relief valve should be provided to prevent over-pressurization. This over-pressure protection has two purposes:

1) to protect the vehicle tank and associated hydrogen pipework
2) to protect components in the dispensing system

Ideally, the dispenser components will be rated for use at the MAWP and tested at least to ITP for their pressure class as shown in Table 1. The target is such that the PSV(s) can be set to not interfere with the normal fueling operation described above. However, if components in the dispensing system are less than the maximum allowable working pressure shown in Table 1, then the set point of the PSV should be lowered to protect lowest rated component in the relevant pressure system. The fueling protocol should also take this restriction into account and, if necessary, adjusted to minimize the likelihood of over-pressurization of the dispenser.

Table 1: ISO 19880-1 Pressure Definitions Table

Pressure Class	NWP (Nominal Working Pressure)	MOP (Maximum Operating Pressure) Highest pressure permitted during normal fuelling	MAWP [C] (Maximum Allowable Working Pressure) Minimum pressure to which component is rated Target dispenser PSV set-point	ITP [A,B] (Integrity Test Pressure) Minimum pressure to which component is tested
	1.00xNWP	*1.25xNWP*	*1.38xNWP*	*1.50xNWP*
H25	25 MPa	31.25 MPa	34.4 MPa	37.5 MPa
H35 [D]	35 MPa	43.75 MPa	48.1 MPa	52.5 MPa
H50	50 MPa	62.5 MPa	68.8 MPa	75.0 MPa
H70 [D]	70 MPa	87.5 MPa	96.3 MPa	105.0 MPa

Notes:

A. The proposed test level matches the maximum pressure expected during PSV relieving;
B. Other test pressure may be required according to national regulations;

C. Component rating needs to be valid at maximum and minimum allowable material temperatures;
D. Pressures used for hydrogen road vehicle fueling in this document.

3.4 Station Acceptance Testing

ISO 19880-1 give guidance for station acceptance (at factory or on site) for hydrogen providers, inspectors and automakers. The technical report has a chapter which gives example checklists of items which should be taken into consideration in order to accept a station for use with vehicles. See Figure 3 below.

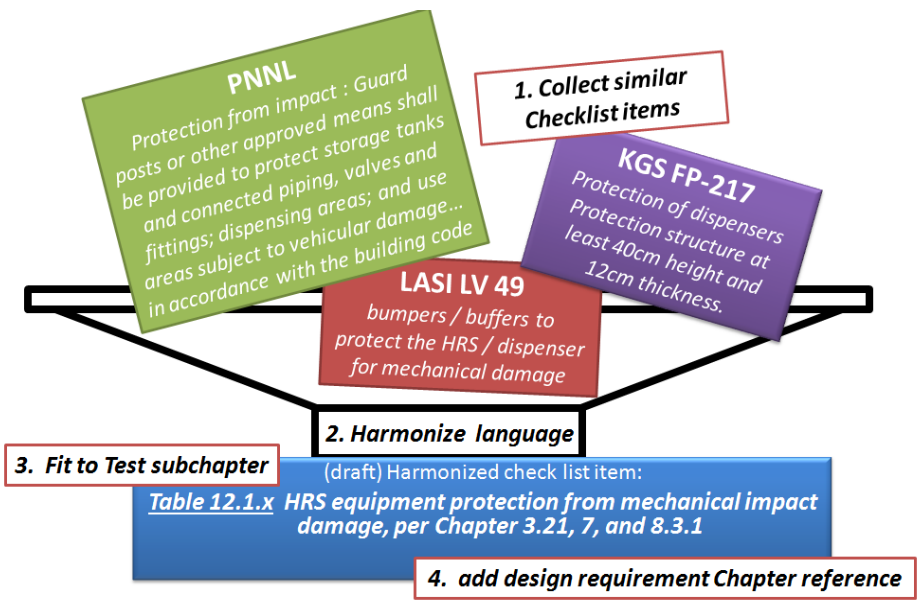


Figure 3: Example of a Station Acceptance Checklist Item from ISO 19880-1

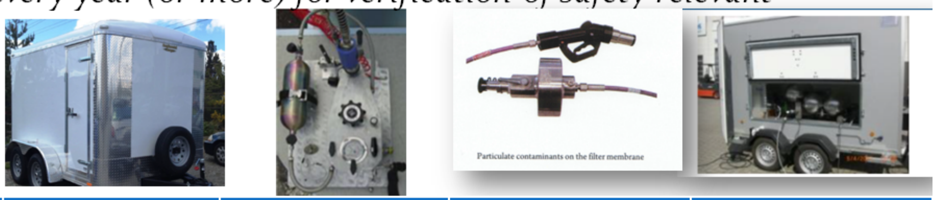
In addition, there is also technical guidance for validation of the safety functionality and performance of hydrogen fuelling stations. Shown in Figure 4, there are primarily four types of station acceptance testing related to the hydrogen fueling:

- The hydrogen fueling station vehicle filling safety and performance, which can be measured by a Hydrogen Station Test Apparatus (examples of which are described in more detail in the ISO TR 19880-1).
- The hydrogen gas quality and particulate measurement which is measured from two separate sampling devices.
- There is may also be a need to confirm the mass transfer according to national regulations through a measurement device.

Figure 2 shows an example of these devices and whether these are performance or safety relevant topics.

19880-1 Station Acceptance Tests

- At Factory "Factory Acceptance Test" to test safety functions before shipment
- On-site "Field test" to validate normal operation of fueling and station
- periodic - e.g. every year (or more) for verification of safety relevant



	H2 Fueling with HSTA	H2 Gas Quality / & Control	Particulate Measurement	Mass Transfer Measurement
Existing Standard	No, Guidelines	Some (ASTM)	Yes (ASTM)	No, Guidelines
Goal to test or verify (parameter)	p, T in vehicle tank	To collect sample gas	Particle identification	Verification of mass transfer
Safety relevant for interface HRS-FCHV	**YES**	No (except for vehicle shutoff)	Yes	Yes
min. requirement = part of ch. 12	**YES**	**YES**	**YES**	**YES**

Figure 5: Example of the Station Acceptance Testing[3] needed and examples of the devices that can facilitate this testing, as discussed in ISO 19880-1.

3.5 Hydrogen Station Test Apparatus (HSTA)

In order to validate that the station operates properly before commissioning for use with FCEVs, the concept of using a hydrogen station test apparatus (HSTA[3]) is introduced in ISO TR 19880-1. The HSTA has an onboard CHSS with a control system to simulate a vehicle fueling with recording capability. Figure 6 shows an example of a HSTA in operation with the Clean Energy Partnership in Germany.

Hydrogen dispenser functional operation can be validated with an HSTA at new hydrogen fueling stations to ensure the following:

A. Vehicle fueling safety parameters (including CHSS limits) are not exceeded
B. The performance and safety targets for fueling, including average pressure ramp rate and cooling capacity, etc. are met,
C. The fueling protocol, such as SAE J2601, has been properly implemented.

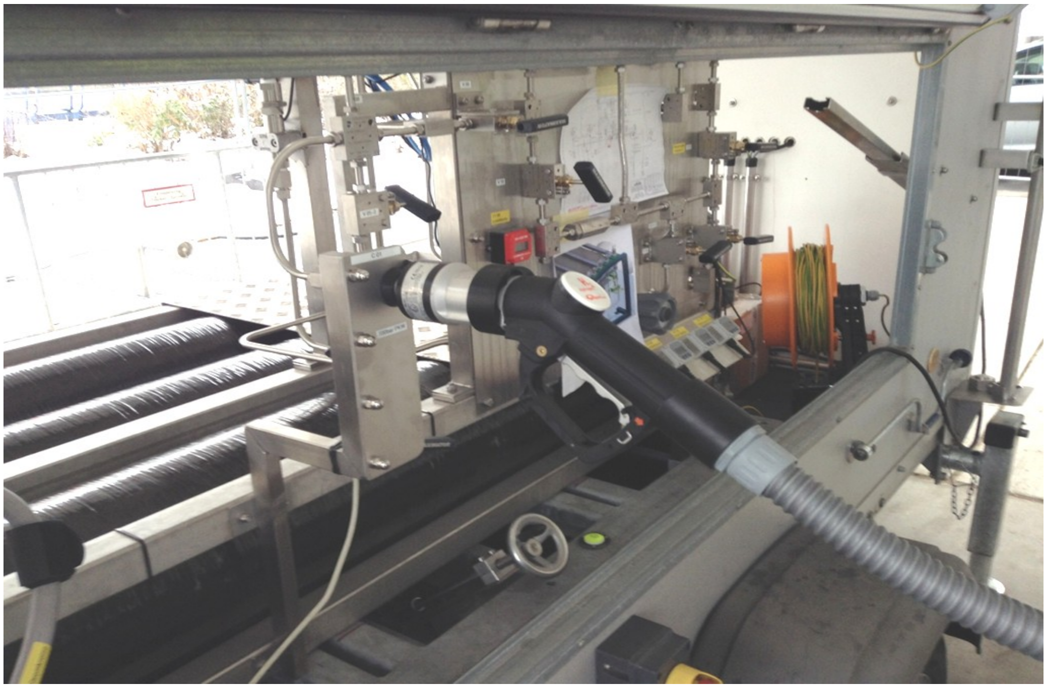


Figure 6: Example of a hydrogen station test apparatus (HSTA)

It is anticipated that, in most cases, the hydrogen station manufacturer would carry out design validation testing before the dispenser system is deployed and site acceptance is performed. ISO TR 19880-1 lists the elements of dispenser testing that should be completed for all stations brought into service, giving guidance on those typically performed as Factory Acceptance Testing (F.A.T.) or when the station is installed on site with Site Acceptance Testing (S.A.T).

Some F.A.T. tests may be representative of multiple stations, for example where identical control software is used and do not need performing on each identical station.

Site acceptance testing uses an HSTA to validate the “final” performance and safety operation just before commissioning. Table 1 below gives an overview of the Factory Acceptance Test (F.A.T.) and site acceptance testing (S.A.T.) which should be completed before stations are brought into service. Table 2. shows an example overview of the F.A.T and S.A.T. applications from ISO TR 19880-1.

Table 2: Hydrogen Station Dispenser function tests

Dispenser function Tests	F.A.T.	S.A.T.
Confirmation that tables are correctly programmed into PLC through software means.	Yes	No
Fault Simulation Testing However Abort Signal to also be tested in both F.A.T. and S.A.T.	Yes	No
S.A.T. using an HSTA including 1-2 top off from low start pressure Verification that Measured Fueling performance Parameter are within limits Gas Temperature Window, Flow Rate and Pressure targets are within bounds of Fueling protocol	No	Yes

ISO TR 19880-1 has a Hydrogen Fueling Validation annex with a number of tests considered the minimum to confirm that the fueling meets the expectations of SAE J2601, should this fueling protocol be used.

This annex introduces the concept of carrying out field tests to confirm that the temperature; pressure limits, etc. are met using a hydrogen station test apparatus (HSTA). This would ideally have the equivalent of a FCEV CHSS with data recording capability, etc. Figure 6 shows an example of a HSTA validating the 70 MPa hydrogen fueling protocol at a fueling station.

3.6 Hydrogen quality and hydrogen quality control

Hydrogen fueling stations are used for fuel cell electric vehicles which are powered by PEM fuel cells. Fuel cells are sensitive to some critical impurities, and without control of these impurities, there could be significant performance and durability issues.

The hydrogen quality requirements for hydrogen dispensed at a hydrogen fueling station are defined in ISO 14687-2.

ISO TR 19880-1 introduces the concept of assuring the quality of hydrogen either supplied to a hydrogen station, or dispensed from the station, by taking into account the likely contaminants that could be expected to be present according to the methods used, recognizing that not all impurities need be tested for at all times.

Since the likelihood of contamination depends crucially on the hydrogen supply chain (from source to nozzle, including transport and compression), analysis of the whole supply chain will allow station operators to identify quality risks and relax testing recommendations, while maintaining the same quality assurance and limits. The specific list of impurity constituents should also take into account the impurities that could occur in the fueling station operation and maintenance processes.

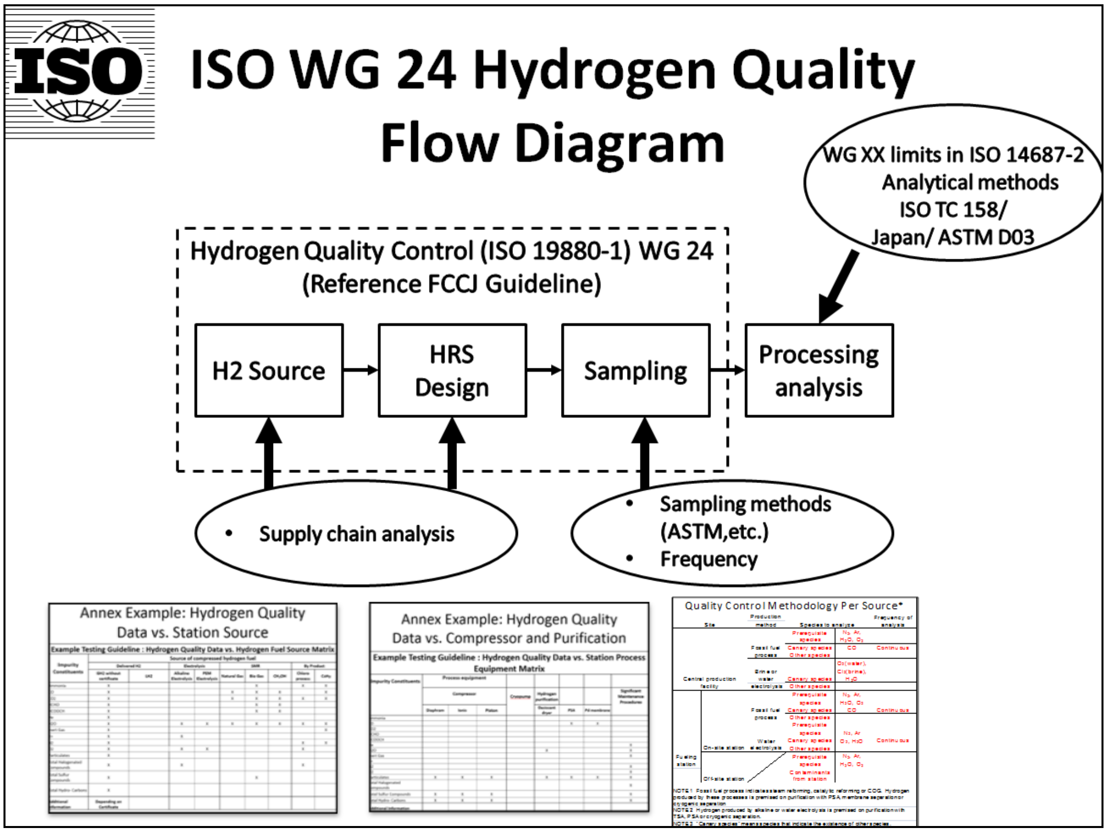


Figure 7: Hydrogen Quality Flow Diagram including examples of hydrogen quality control.

ISO TR 19880-1 provides guidance to facilitate following a quality control methodology, including the recommendations below:

Hydrogen quality measuring for impurities relevant to the supply chain, whether delivered or produced on site, should be carried out as part of the onsite fueling station acceptance test and repeated after an appropriate period. Following the initial acceptance test, a suggestion is that the testing frequency should be repeated as a minimum annually.

Fueling stations with onsite hydrogen production or purification equipment should have a continuous monitoring of the main critical impurities (for example defined through an appropriate risk assessment) or process control system to ensure that the hydrogen gas meets the purity specification of ISO 14687-2.

Hydrogen quality measuring should be conducted according to risk assessment after maintenance which may cause contamination of hydrogen fuel.

If the fueling station cannot meet the quality, corrective action should be taken before other vehicles are permitted to fuel. Corrective measures should be put in place and fuel quality assessment conducted until the hydrogen is again within required specification.

The inclusion of filters in the dispenser, upstream of the hose breakaway device, is discussed in ISO TR 19880-1 to prevent hydrogen containing function-impairing impurities (i.e. particulates) that would affect the high pressure hydrogen system of FCV, specifically the vehicle CHSS valves. ISO TR 19880-1 includes a recommendation for either the filter size (5 micron) or the efficiency of the filter to remove 5 micron particulates (99%). This should filter out the particulate concentration in the hydrogen as per ISO 14687-2.

Further development of a risk assessment approach to the list of impurities and their thresholds specified in ISO 14687-2 is the target for future work on the hydrogen quality assurance methodology, taking into account:

- Proven detrimental effect to the performance of fuel cell vehicle systems;
- Feasibility of measurement of very low concentrations;
- Complexity of appropriate purification, sampling and analysis.
- The experience from the initial HFS and vehicles deployments

4. Summary of Risk Assessment Methodology

Based on the extensive understanding and experience of ISO TC 197 WG24 experts, led by experts from Sandia National Laboratories, an aim of ISO 19880-1 is to provide a methodology for the use of risk assessment tools (e.g. semi-quantitative and quantitative risk assessment) to demonstrate the safety of a hydrogen fueling station based on robust science and engineering models.

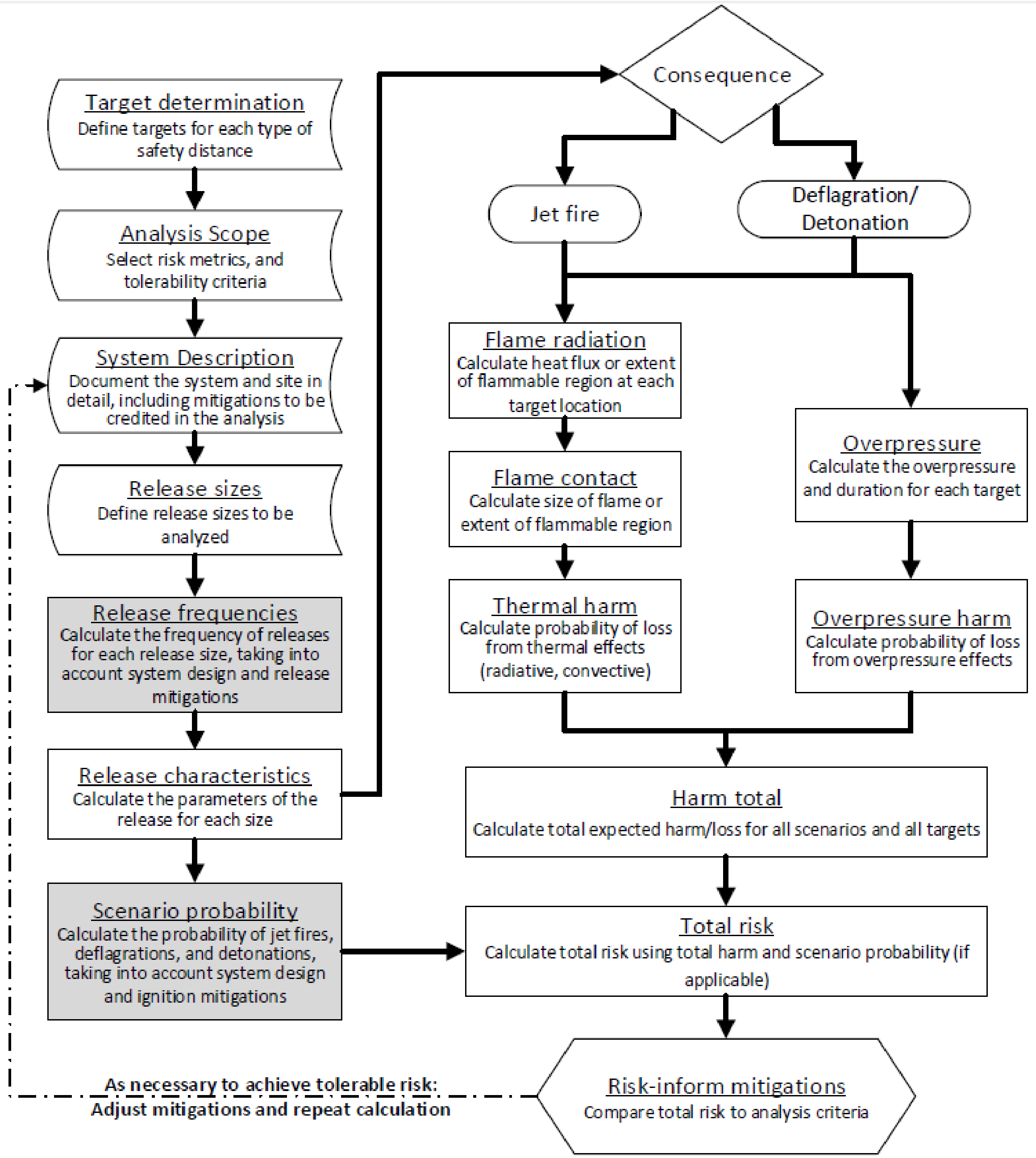
A target of WG24 is to enable the development of guidance on carrying out this analysis that can be applied world-wide, taking into account the physical characteristics of hydrogen releases and fires which are the same all around the world, whilst allowing flexibility for country specific variables (such as tolerable risk, permissible heat fluxes, hole sizes etc) and enabling the risk assessment to take account of the station specific mitigation measures. These could include the use of regular leak tests, use of leak-resistant components, hydrogen or flame sensors, fire walls, and ultimately separation (defined as safety distances) of elements within the fueling station, and between the station and sources of hazard, or people, objects, etc. which could be affected by the hydrogen station.

A flow diagram example of a general risk informed approach to safety distances and other mitigations is shown in figure 8. The process enables transparent, evidence-based safety decisions. The QRA approach is able to use a combination of probabilistic and deterministic models to evaluate potential consequences of incidents occurring at the station. 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 modeling, the probability terms are ignored, but the remainder of the analysis follows the same general methodology.

The process for risk-informing mitigations includes the following steps, as displayed in Figure 8:

- Target determination– Define the targets being protected, and as necessary, the hazard sources. provides many examples of targets;
- Analysis scoping – Select appropriate risk metric 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;
- Cause analysis – Identify and model the hazard scenarios and quantifying 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-inform mitigations -- Increase or reduce mitigations to achieve risk level within tolerability region (including consideration of uncertainty).

The general approach in Figure 8 provides general guidance for what the risk-informed approach entails; implementing this approach can be done using several different approaches, tools, and models. Sandia's HyRAM tool[4] includes a documented QRA approach along with validated physical models for various aspects of hydrogen behavior. Other documented QRA approaches include the Bow-tie method. A range of physical models relevant for hydrogen systems have been documented in recent research studies.[5,6]



- Grey shading denotes an analysis step that is used only in full-QRA approach.
- Concave rectangle denotes analysis step
- Rectangle denotes calculation step
- Diamond denotes branching

Figure 8 — Example of a risk-informed approach to safety distances

5. Fueling Risk Assessment and applied methodology

Figure 9 gives an example of a specific type of risk assessment called the "bow-tie" approach. An effort within ISO TC 197 WG24 to update the existing guidance in ISO TS 20100 on the reliability of the protection measures on the dispenser that mitigate against the over-pressurization, over-heating and over-filling of the vehicle CHSS. This has been initiated in the form of a bow-tie[9] and Layer Of Protection Analysis (LOPA). It is anticipated that this will show in a transparent format the minimum technical requirements for safe Fueling. Some of the requirements could be expressed in terms of safety integrity level (SIL) or Performance Level (PL), as defined in IEC 61508, IEC 61511, IEC 62308, IEC 31010, ISO 13849-1 and/or ISO 12100. These will be stipulated in ISO 19880-1 as minimum requirements intended to prevent a hazardous situation in case of a failure of the dispensing control system hardware or software. Other requirements might be guidance on how to maintain and inspect the Fueling system.

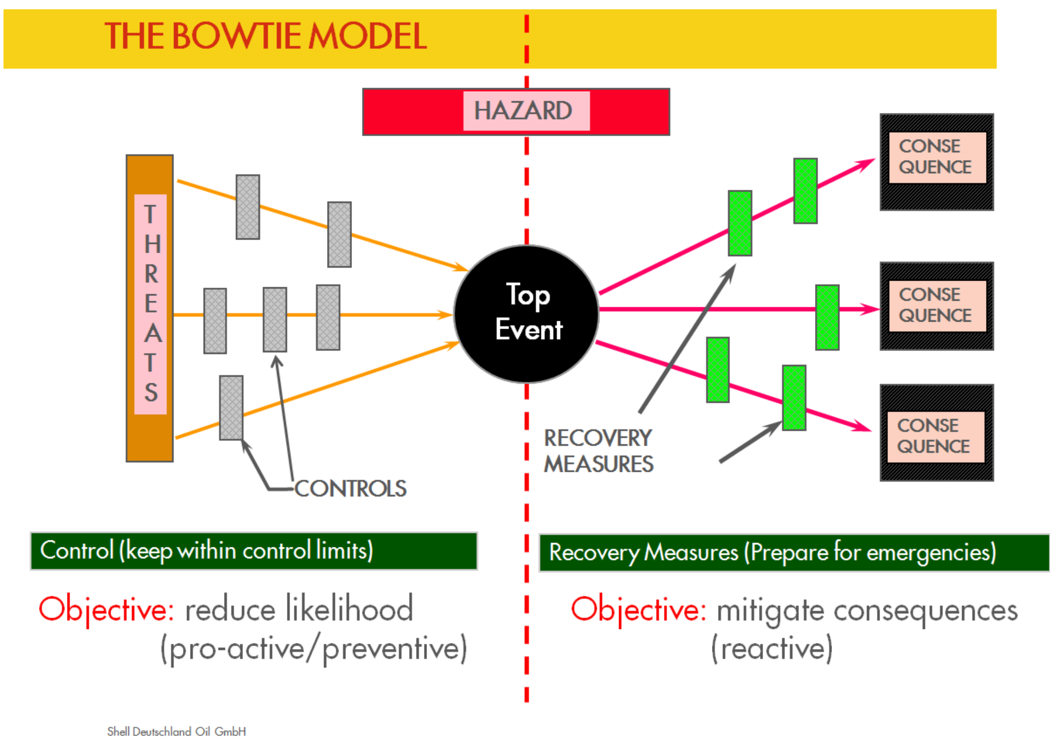


Figure 9 — Example of a "Bow-tie" Risk Assessment

6. Risk Informed Safety distances

One of the aims of the future ISO standard 19880-1 would be to create a common methodology for determining applicable safety distances based on local requirements and conventions.

The safety distance is the minimum 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 Fueling station. See figure 9 for the definitions of types of safety distances

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 the extent of hazardous areas. The term 'safety distance' may also be referred to as "safe distance," "separation distance," or "setback distance."

For standard equipment and events, safety distances may be prescribed by national regulations and/or may be determined through quantitative analysis of a generic design. For any given Fueling station, one may also conduct a quantitative analysis, 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.

The quantitative analysis is used to demonstrate that the Fueling 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 modeling (i.e., a QRA without quantification of the probability of scenarios). The analysis uses a combination of information and data regarding the Fueling station design and operation, validated physical models, and probabilistic models that meet the criteria discussed in the remainder of this section.

The development of a common, ISO standard toolkit would be a beneficial resource for the hydrogen fueling industry (as it doesn't exist today).

This technical report 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

Table 3 — Definitions of Types of Safety Distances

Characterization of safety distance	Purpose	Source	Target(s)
Restriction distances	Minimize risk in areas adjacent to hydrogen equipment	Fueling station equipment	Any open area adjacent to hydrogen equipment
Clearance distance	Protect persons and objects within the establishment from hazards associated with the fueling station	Equipment and objects within fueling station	Persons and other facilities within the establishment
Installation lay-out distance	Prevent escalation of events within fueling installation	Fueling station equipment	Fueling station equipment
Protection distance	Protect the fueling station from damage due to any external hazards	Off-site facilities and on-site things (except for the fueling station equipment)	Fueling station equipment
External risk zone	Mitigate off-site risks from hazards associated with the Fueling station	Fueling station equipment	Surrounding people/property outside of the establishment

The wide diversity of applied methodologies for defining safety distances in all countries could represent a major impediment to wider infrastructure development, by recommending over-prescriptive requirements.

The technical report 19880-1 gives a comparison of different set of safety distances currently defined in local or national regulation and enforced in the corresponding countries. This will help to understand and compare the applied rationale and should help to harmonize in a medium term the approach among all countries.

7. Conclusion:

The ISO TR 19880-1 establishes a guideline for the minimum criteria for hydrogen fueling station safety and performance from the perspectives of station layout design, commissioning, site acceptance checklists, testing and operation. The document also aligns the pressure ratings for hydrogen fueling components.

ISO TR 19880-1 describes a methodology that facilitates a risk-based approach to guidance for safety systems, with development of this to enable the definition of appropriate safety distances anticipated in the next stage, the development of the ISO standard ISO 19880-1. A proposal to facilitate validation of hydrogen fueling in accordance with SAE J2601 is also described in the report. This ISO technical report, and the subsequent ISO standard is being developed to be a baseline for station designers to use as guideline for developing the next generation of hydrogen fueling stations worldwide.

8. Acknowledgements:

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8. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the 9 U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
9. http://www.cgerisk.com/knowledge-base/risk-assessment/thebowtiemethod

CONTACT INFORMATION

Email Contact: Jesse.Schneider@bmw.de / @web.de