

## **Safety Distances for Hydrogen Refuelling Station**

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## Safety Distances for Hydrogen Refuelling Station

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Safety distances are widely used for preventing incidents caused by unintended interference between two activities or for preventing harmful consequences from an incident to objects or people in the vicinity. EIGA [1] has expressed this as: *“Safety distances need to be considered as a generic means for mitigating the effect of a foreseeable incident and preventing a minor incident escalating into a larger incident.”* Some countries have specific regulations, expressing required distances based on standard equipment, while others also allow a performance based approach using guidelines or codes on how to determine safety distances. For hydrogen equipment, specific requirements for safety or separation distances are being established for Gaseous Hydrogen refuelling stations e.g. in NFPA 55: 2010 [2], in 2003 International Fire Code [3] as well as in the ISO TS 20100: 2008 [4]. There is also ongoing work on safety distances within ISO/TC197/WG11.

The challenge is to provide an approach allowing to standardize installation requirements in order to facilitate the deployment of a fuelling station infrastructure, while allowing for non standard designs and adaptation to technological progress. This paper discusses the approaches implemented in the different standards and also compares the approaches to that of the European Gas Industry Group (EIGA) guideline [1]. The EIGA safety distance procedure has been applied to a hydrogen refuelling station (Figure 1) designed by HySafe participants, to avoiding confidentiality issues. The results and recommendations are obtained from comparison and discussion of the results. The work was done by the Risk Assessment work package in the EU 6<sup>th</sup> FP HySafe NoE (HySafe).

Safety distances are determined using different methodologies. An example is the concept of consequence lengths that determines the impacts of releases and fires up to a certain harm criteria, which represents a deterministic approach. Another approach is being used in QRA where the safety distance is determined using the Individual risk (IR) and/or societal risk criteria (SRC). For determination the frequency of each failure is multiplied with the probability of a certain consequence depending on the distance to the incident location. All

products are summed to give the overall individual risk as a function of distance, that is the risk to an unprotected person placed permanently a certain distance from the accident source. The SRC is basically the same approach, but is also regarding the population density around the object of concern.

The EIGA methodology is comparable to the described for QRA. The main difference is the initial exclusion of incidents of very low frequency. The EIGA guideline uses a per incident acceptance threshold criterion of  $F_t < 3.5 \times 10^{-5}$  per annum; for each potential hazardous event the frequency shall not exceed  $3.5 \times 10^{-5}$  per annum. For events with a higher frequency, safety distances must be established. This means that for each event the tolerance criterion applied in the EIGA guideline is

- $3.5 \times 10^{-8}$  fatalities per annum
- $3.5 \times 10^{-7}$  cases of considerable material damage per annum

The European guideline for risk based safety distances for land use planning [5] suggests an acceptance criterion for individual risk of  $10^{-5}$ , with an ALARA (As Low As Reasonably Achievable) region between  $10^{-6}$  and  $10^{-5}$ . The IEA HIA Task 19 Hydrogen Safety has suggested similar criteria for hydrogen infrastructure [6]: Individual risk  $< 10^{-5}$ , with an ALARA region between  $10^{-7}$  and  $10^{-5}$ .

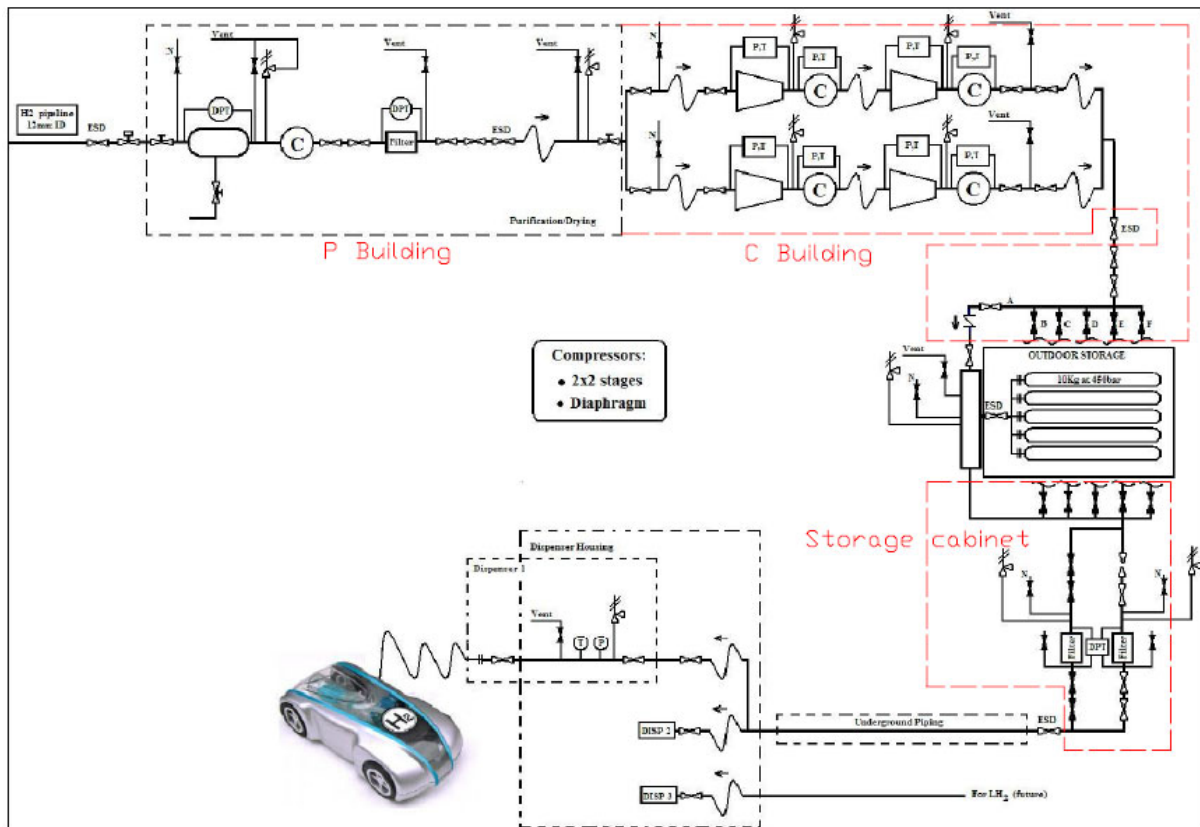
In comparison, the EIGA guideline criterion appears to be more strict, but as the contribution from major accidents with a frequency less than  $3.5 \times 10^{-5}$  is not included, the criterion can be said to be line with generally accepted levels for tolerable risk.

"Harm" and "no harm" criteria for fire and explosions proposed for calculations of safety distances in the guideline are given in the table below.

**Table 1: Criteria for fire and explosions.**

Hazard	target	"no harm" criterion events likely during lifetime	"harm" criterion events not likely during lifetime
Fire	people	$1.6 \text{ kW/m}^2$	$9.5 \text{ kW/m}^2$ (sustained fire)
Fire	equipment		$37.5 \text{ kW/m}^2$
flash fire		$\frac{1}{2}$ LFL	LFL
explosion	people	2 kPa	7 kPa
explosion	equipment		20 kPa

The "no harm" criteria are rather strict: The radiation criterion ( $1.6 \text{ kW/m}^2$ ) which is comparable to solar radiation on a bright day and is the level defined as acceptable maximum for continuous exposure (from a flare) in API 521 [7]. The explosion criterion is far below what is reported as harmful for humans, except for secondary effects from broken glass. In this study the criteria are applied as recommend though.



**Figure 1: Hydrogen refuelling station evaluated.**

In total more than 50 hazards were identified. For most of these risk reducing measures are already recommended practice: E.g. for ventilation failure for the hydrogen compressor building: The control system will shut down the container (compressor and all electrical equipment inside the container) in case of ventilation failure (or failure of air flow confirmation signal). In addition, the safety system will give an alarm if hydrogen is detected at 10 % of flammable level shut down the container at 25 %. The frequency of a ventilation failure causing a potentially harmful effect was thus evaluated as well below  $3.5 \times 10^{-5}$ .

Safety distances were done for the scenarios listed:

**Scenario 1A:** Small leak in outside storage bank valves. Leak, and if ignited, exposure of storage bottles. A total content of 50 kg (5 tanks 10 kg each) of hydrogen means this could lead to a fire of very long duration. The leak is modelled in PHAST [8] as a 0.5 mm hole size, which will give a leak of 4.4 g/s and a jet fire length of 1.3 meters. The modelled range of radiation above 1.6 kW/m<sup>2</sup> (no harm) is similar to the range of the jet. Within the jet flame envelope the temperature will be sufficient to cause damage to exposed equipment as well as harm to people.

**Scenario 1B:** Escalation of 1A by tension cracks and possibly rupture of exposed bottle(s). Release of content of one storage bank and immediate ignition of release. Atex (zone 2) classification of equipment will reduce (but not eliminate) ignition probability. This event (rupture of exposed bottle) is evaluated as not likely to occur during the lifetime of the project,

and the safety distance is thus calculated for “harm” criteria: radiation of 9.5 kW/m<sup>3</sup> for people and 37.5 kW/m<sup>3</sup> for equipment.

Each storage bank consisting of 5 10 kg bottles connected with 8 mm pipes. Modelling the release in PHAST [8] gives a leak rate of 1 kg/s and a maximum jet fire length of 15 meters, which also is the range of radiation levels above 37.5 kW/m<sup>3</sup>. Radiation above 9.5 kW/m<sup>3</sup> has a range of 20 meters.

Preventing scenario 1A from escalating into scenario 1B cannot be achieved by increasing the distance. One will thus either have to implement measures to reduce the frequency of scenario 1B below the Ft or base the safety distancing on scenario 1B.

**Scenario 2:** GH2 leakage, most likely caused by vehicle drive away. Safeguards: Flow restriction in filling line, limiting the flow to 6 grams per second and EXV valve (flow actuated normally open shut off valve) close to dispenser. Modelling the release in PHAST gives a jet fire length of 1.5 meters for an ignited leak and the estimated maximum extent of a flash fire (distance to ½ LEL) of 5 meters. The EXV will limit the duration of the leak and the probability of a delayed ignition and a flash fire. For a jet fire the “no harm” safety distance should thus be set to 1.5 meters. For the less likely event of a flash fire the “harm” criterion may be applied – which gives a distance of 3 meters.

**Scenario 3:** Refuelling started with (undetected) minor leak. Pressure drop too small for EXV valve to close (assumed leak rate of 10 % of maximum filling rate). Flow restriction will work. Modelling the release in PHAST gives a jet fire length of 0.5 meters for an ignited leak and an estimated maximum extent of a flash fire of 2 meters.

**Scenario 4:** GH2 leak inside compressor enclosure. Small quantity of hydrogen within process equipment. Release rate will decay immediately after detection and shutdown. Safeguards: Gas detection, alarm, automatic shut down if 0.25 LEL or ventilation failure. Relief panels opening at 0.1 bar overpressure. Frequency for an overpressure exceeding 0.1 bar is less than  $3.5 \times 10^{-5}$ . Utilising the Multi Energy Method [9] this gives a resulting overpressure below 7 kPa (harm criterion) at 6 meters distance.

The distances are compared to recommended distances from the HyApproval [10] project in the table below.

**Table 2: Comparison of safety distance with HyApproval distance.**

Case	Frequency	Effect	Criterion	Safety distance	HyApproval distance
1A	Likely	jet fire	no harm	1.3 m	
1B	< proj. life	jet fire	harm	20 m (people) 15 m (material)	“L2 large jet” 21 m
2	likely	jet fire	no harm	1.5 m	-
2	unlikely	flash fire	harm	3 m	6 m
3	likely	jet fire	no harm	0.5 m	-
3	likely	flash fire	no harm	2 m	-
4	unlikely	Explosion	harm	6 m	6 m

The seen variations in calculated distances are related to different hole size and to different operational pressures.

Comparing the distances to separation distances or “setback” distances in different fire codes is done in the table below.

**Table 3: Comparison of the distances to separation distances.**

Case	Safety distance	ISO/TS 20100 [4] V>10 000 l	International Fire Code[3](V<120m <sup>3</sup> )	NFPA 55 [2]
1A	1.3 m	4 m to sidewalk	1.5 m	0 m (workers)
1B	20 m (people) 15 m (material)	8 m to public area 6 m (combustible)	1.5 m	4.6 m (public/cust.) 3 m (equipment)
		P<=45 MPa		
2	3 m	3m (sidewalk) 4m (public area)	0	0
3	2 m	3m (sidewalk) 4m (public area)	0	0
4	6 m	3m (sidewalk) 4m (public area)	0	0

All the codes reviewed recommends distances for storage of hydrogen. ISO TS 20100 [4] also give recommendations for filling, but the options for taking safeguards into account is limited; this is demonstrated clearly by Case 1A/1B.

The determination of frequencies and the modelling of the resulting consequences involve a degree of uncertainty that will influence the resulting safety distances. This has been addressed in the ASSURANCE project [11]. E. g. for an ammonia plant the predicted radius at IR = 10<sup>-6</sup> per year ranged from 820 to 1325 m. It was found that the determination of frequencies was considerable more uncertain than the results of the modelled consequences. In practice and especially for the new hydrogen economy it is difficult to find specific reliability data. For the determination of reasonable safety distances (in standard development as well as in installation specific calculations) it is very important to continuously collect and file appropriate safety data and to make commonly agreed data available for the stakeholders.

One conclusion from this study and the comparison is that safety distance calculations specific to the solutions chosen for an installation is worth the effort as general recommendations can not reflect all possible variations in technical solutions. The EIGA method also has a potential for standardised recommendations for a specific station design: Comparing the “HyApproval station” to this station, the variation in safety distances is related to differences in pipe diameters, operational pressure and assumed safety equipment. It would however be recommendable to do a thorough review of the harm criteria and bring them more in line with recent research and accident experience.

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