

Report: Internal Safety Distances for PGS 35

Version: 1.0

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1. General introduction

In 2013 the PGS 35 team started the development of PGS 35, a new document in the '*Publicatiereeks gevaarlijke stoffen*' (Hazardous Substances Series). These documents are intended as guidelines for the authorities who will be making decisions about locations and details of (small) industrial installations in the public domain. PGS 35 relates to hydrogen refuelling stations (HRS) and its title is 'Hydrogen: installations for delivery of hydrogen to road vehicles'.

Following the publication of PGS 35 and its translation into English, a working group was subsequently formed by the PGS Programme Council to determine the **internal** safety distances which were to be used in PGS 35. This group consisted of members of the PGS 35 team who have particular experience with hydrogen properties, dispersion and effect monitoring and HRS design. The members of this working group are listed in section 8.

In this report the outcomes are given of the working group's assessment of internal safety distances for hydrogen refuelling stations. It is intended as a background document to be used for reference alongside PGS 35.

External safety distances for PGS 35 will be established using a quantitative risk assessment process, as is mandated by Dutch law. The government institute RIVM is leading this process.

In this document no reference is made to ATEX zoning.



2. Internal safety distances: Definitions and assumptions

The definitions used in this report for internal safety distances and related concepts are derived from those used by the European Industrial Gases Association (EIGA) in their 2007 report, IGC Doc 75/07/E 'Determination of safety distances'.

An internal safety distance is the minimal separation distance between a potential hazard source (e.g. equipment involving dangerous substances) and an object (human, equipment or environment), which will mitigate the effect of a likely foreseeable incident and prevent a minor incident escalating into a larger incident (also known as *domino effect*). The provision of adequate internal safety distances is thus a fundamental consideration for safe layout of hydrogen refuelling stations.

For the purposes of this document, a likely foreseeable incident is an incident that can occur during normal operation and with a frequency greater than 10^{-5} per year. The scenarios considered in this document are therefore based on leakages rather than on (less frequent) events such as catastrophic failure or major release. The safety distance is not intended to provide protection against such events, which should be addressed by other means to reduce the frequency and/or consequences to an acceptable level.

Similarly, the effect of external hazards which occur less frequently is also considered as being beyond the scope of this document.

It is also recognised that HRS equipment may be installed at an establishment where other fuels (e.g. petrol, diesel, compressed natural gas, liquefied natural gas or liquefied petroleum gas) are also dispensed. The safety distances (already) determined and set out in the relevant PGS documents for the delivery of other fuels shall also be applied.

Further explanation of concepts and figures mentioned here is given in section 5 '*Rationale for selection of incidents*'.



3. Internal Safety Distances: Methodology

3.1 Introduction

For calculation of safety distances, the programme SAFETI-NL NL v6.5.4 (including proposals from the Dutch safety and certification company DNV GL for hydrogen) was used; SAFETI-NL is the software tool used for quantitative risk assessment calculations in the Netherlands. In order to make SAFETI-NL suitable for calculations involving hydrogen, DNV GL proposed some changes with regard to the discharge parameters used by the programme.

The approach used to calculate the safety distances was further based largely on that described in EIGA 75/07/E (2007)(see section 9).

3.2 EIGA 2007: Summary of approach

This EIGA report describes how a full assessment of the nature of the hazard, the frequency of the event and its potential consequence is essential for understanding which risks can be reasonably mitigated by a safety distance.

If the resultant safety distance is too large, additional mitigation or prevention measures should be considered and the safety distance re-calculated. Examples of alternatives to implementing the full safety distances include the installation of barriers or protection measures (e.g. firewalls) to reduce escalation, or the alteration of equipment design and/or operating conditions to reduce the severity and/or likelihood of the incident.

EIGA uses an individual harm exposure threshold value (or range of values) as the criterion for selecting the incidents to be included in safety distance calculations. This threshold value is in the form of an incident frequency termed F_t , a number of events per annum, and internal safety distances must be established for incidents occurring more often than F_t . This threshold value is derived from national risk management policy data in the Netherlands and in the UK and is given by EIGA as $F_t = 3.5 \times 10^{-5}$. For events whose frequency is lower than F_t , no safety distance criteria need be established.

For deviations which are likely to occur during normal operation (e.g. venting), the safety distance should be calculated or mitigation provided to produce a no harm effect. The 'harm criteria' are defined as approximately a 1% chance of individual risk of serious injury or fatality, meaning that events which have a likelihood above F_t and below $100 \times F_t$ may contribute to an unacceptable risk frequency. For such events the criteria for the safety distance should be the no harm effect, as further detailed in the EIGA document. Figure 1 and Figure 2 further illustrate the EIGA approach.



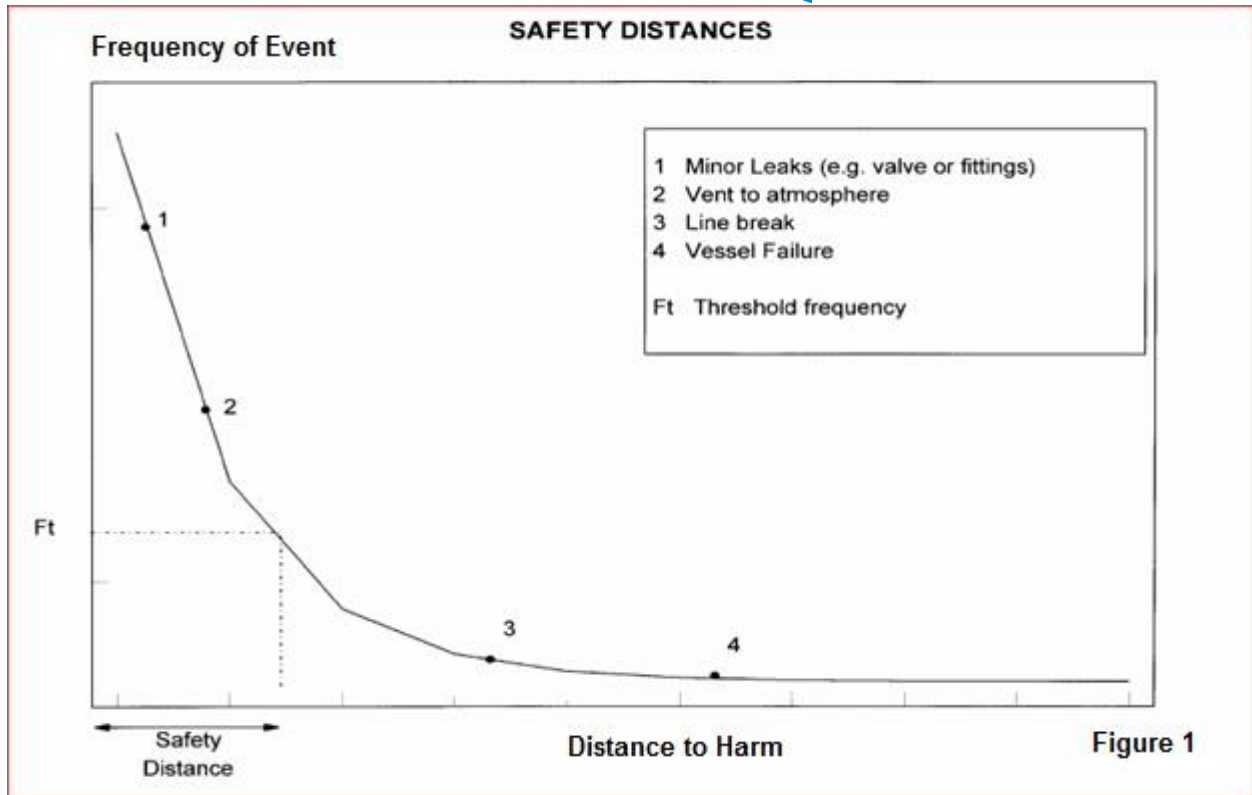


Figure 1: Example of Ft for a pressure vessel and connecting pipework

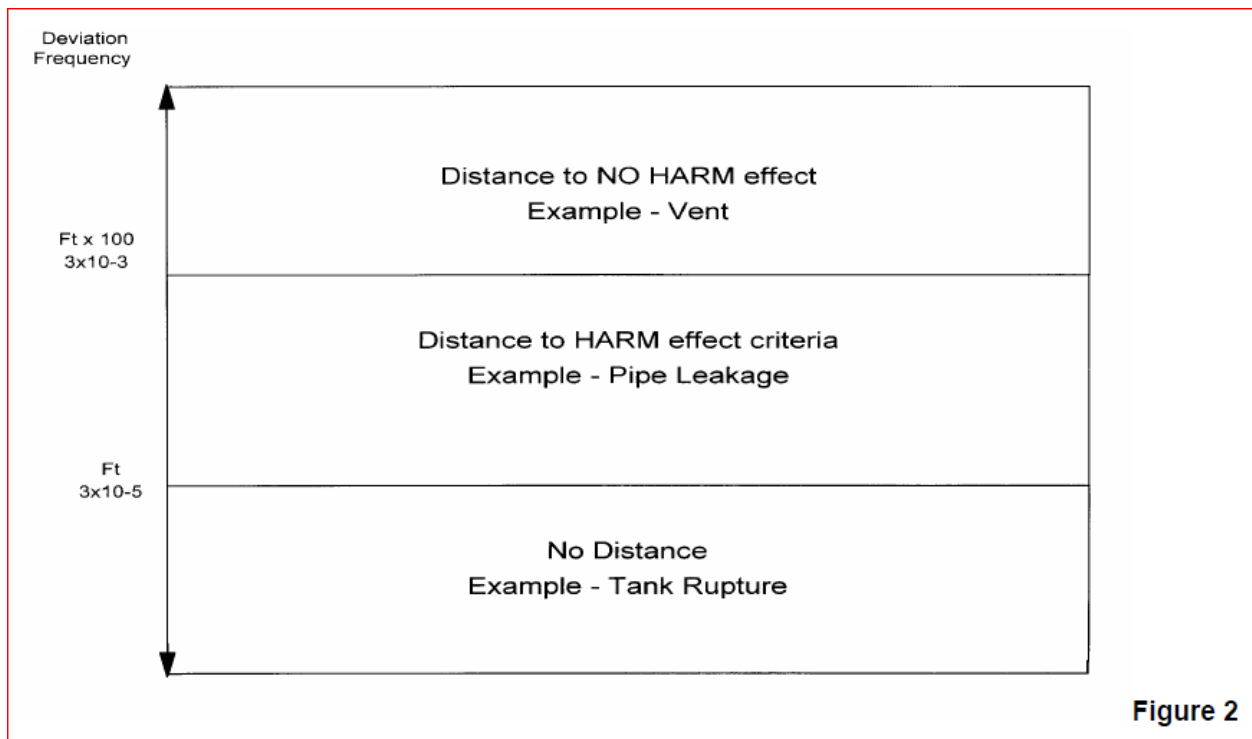


Figure 2: Illustration of the significance of Ft



4. Damage / Harm criteria for hydrogen

Hazardous property	Phase	Damage - harm effect	Maximum permitted heat radiation	Effect	Receiver / Target
Flammable	gas	Thermal radiation from jet fire (direct ignition)	10 kW/m ²	1% lethality	Persons
Flammable	gas	Thermal radiation from jet fire (direct ignition)	3 kW/m ²	Acceptable thermal radiation level to member of the public outside the establishment	Protection of public outside establishment (site boundary)
			10 kW/m ²	Failure	Buildings, unprotected installations and cables
			35 kW/m ²	Failure	Protected installations and cables (including load-bearing constructions)

Table 1: Damage and harm criteria for hydrogen

5. Rationale for selection of incidents

Based on the experience and knowhow of the members of the PGS 35 working group, a shortlist was drawn up of the most significant potential incidents on a hydrogen filling station for which safety distances should be calculated. Where appropriate, the methodology was based on that used for liquid natural gas (LNG) in PGS 33.

The assumptions used during the assessment of incidents to include are listed here.

- A threshold incident occurrence frequency of 10^{-5} was selected based on F_t from the EIGA document and on RIVM calculations.
 - A leak size of 10% of pipe diameter was used (source: RIVM, data PGS 35 workgroup members).
 - Flange leaks will be smaller in magnitude and are therefore not considered.
- Leak incidents are decisive in determining safety distances (source: RIVM, data PGS 35 workgroup members):
 - Catastrophic equipment failure is outside the scope, as already mentioned.
 - Ignition rather than explosion presents the more likely scenario.
- On-site hydrogen production by steam methane reforming (SMR) was also considered:
 - CO release was discussed but concluded not to pose a significant risk.
 - Catastrophic failure is outside the scope (incident frequency $<10^{-6}$).
- Similar conclusions were reached for electrolysis:
 - Calculations showed that high-pressure (85bar) electrolysis does not present a significantly higher risk.
 - Catastrophic failure is outside the scope (incident frequency $<10^{-6}$).
- Heat resistance of double walled vacuum insulated liquid hydrogen storage tank is assumed to be 35 kW/m².
- During hydrogen unloading at the HRS hose rupture is the most likely scenario. This means that the leak rate is determined by the diameter of the choke valve, for which values of 1mm and 3mm were used in the calculations.



5.1. Assessed incident scenarios

On the basis of the reasoning outlined above, the following incident scenarios were considered for calculation of internal safety distances:

- Scenario 1: Leakage scenario, 10% of piping diameter DN50 at 10 bar, for onsite production – steam reforming *or* Leakage scenario, 10% of piping diameter 1” at 10 bar, for onsite production – electrolysis (equivalent).
- Scenario 2: Leakage scenario, 10% of piping diameter 1” at 85 bar, for onsite production – electrolysis.
- Scenario 3a: Leakage scenario, hose failure of tube trailer, 1 mm at 200 bar.
- Scenario 3b: Leakage scenario, hose failure of tube trailer, 3 mm at 200 bar.
- Scenario 4a: Leakage scenario, hose failure of tube trailer, 1 mm at 500 bar.
- Scenario 4b: Leakage scenario, hose failure of tube trailer, 3 mm at 500 bar.
- Scenario 5: Leakage scenario, downstream compressor, 10% of piping diameter, 1 mm at 450 bar.
- Scenario 6: Leakage scenario, downstream compressor, 10% of piping diameter, 1 mm at 1000 bar.
- Scenario 7: Leakage scenario, 10% of piping diameter 0.75” at 100 bar, for gaseous hydrogen through piping.

The actual calculations were then carried out by RIVM with the modelling tool SAFETI-NL as described above, also including corrections for weather conditions. These modifications relate to the discharge parameters. The ‘atmospheric expansion method’ was changed from ‘closest to initial conditions’ to ‘conservation of energy’, meaning that the dissipation of energy by the discharge of material is now included. Furthermore, the ‘maximum release velocity’ was raised from 500m/s to 1500m/s.

5.2. Incident scenarios not included

Following discussions in the working group, a number of incident scenarios was *not* considered for internal safety distances. The reasons for this were an occurrence frequency below the threshold of 10^{-5} , or the presence of other prevention or mitigation measures which limit the harmful consequences.

Incident scenarios which were *not* assessed for the determination of internal safety distances of hydrogen refuelling stations include:

- Catastrophic failure of a hydrogen storage vessel, tube trailer or mobile storage vessel.
- Rupture of hydrogen piping or a fixed hydrogen storage / mobile storage vessel (see earlier comments on leakage).
- Failure of HRS equipment due to vehicle collision.
- Failure of HRS equipment due to a fire involving the vehicle which is refuelling.



6. Internal Safety Distances

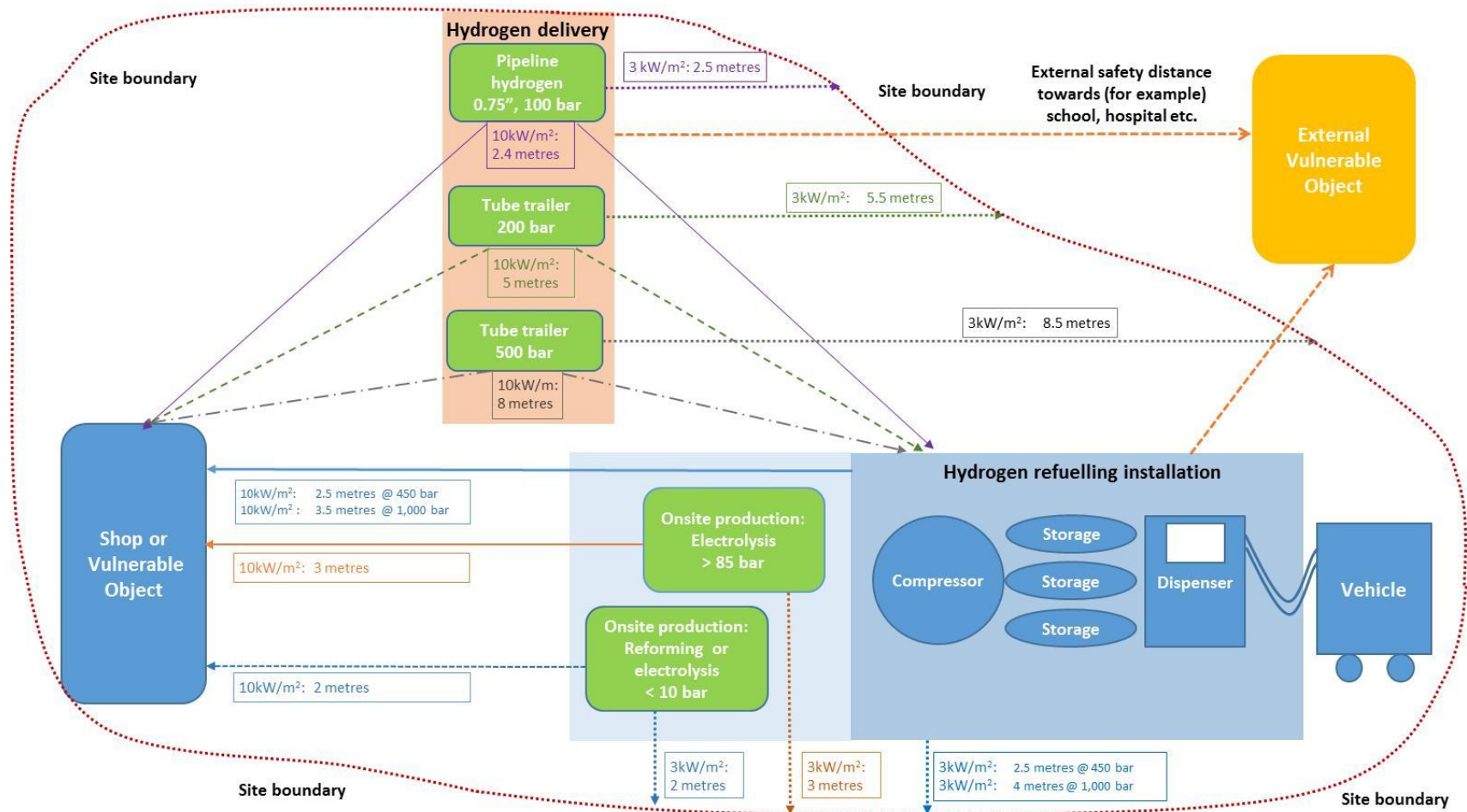
The resultant internal safety distances are listed in Table 2. See also the schematic diagram of HRS illustrating separation distances in section 7.

	Accident scenario	Applicable effect	Leakage flow	Protection value	Internal safety distance in m
SC 1	Leakage scenario, 10% of piping diameter DN50 at 10 bar, for onsite production – steam reforming or electrolysis	Flare	12 g/s	3 kW/m ²	2.2
		Flare	12 g/s	10 kW/m ²	2.1
		Flare	12 g/s	35 kW/m ²	0
SC 2	Leakage scenario, 10% of piping diameter 1" at 85 bar, for onsite production – electrolysis	Flare	23 g/s	3 kW/m ²	3.1
		Flare	23 g/s	10 kW/m ²	2.9
		Flare	23 g/s	35 kW/m ²	n/a
SC 3a	Leakage scenario, hose failure of tube trailer, 1 mm at 200 bar	Flare	8 g/s	3 kW/m ²	2.9
		Flare	8 g/s	10 kW/m ²	1.8
		Flare	8 g/s	35 kW/m ²	n/a
SC 3b	Leakage scenario, hose failure of tube trailer, 3 mm at 200 bar	Flare	75 g/s	3 kW/m ²	5.5
		Flare	75 g/s	10 kW/m ²	5
		Flare	75 g/s	35 kW/m ²	4.7
SC 4a	Leakage scenario, hose failure of tube trailer, 1 mm at 500 bar	Flare	20 g/s	3 kW/m ²	2.9
		Flare	20 g/s	10 kW/m ²	2.7
		Flare	20 g/s	35 kW/m ²	n/a
SC 4b	Leakage scenario, hose failure of tube trailer, 3 mm at 500 bar	Flare	178 g/s	3 kW/m ²	8.5
		Flare	178 g/s	10 kW/m ²	7.8
		Flare	178g/s	35 kW/m ²	7
SC 5	Leakage scenario, downstream compressor , 10% of piping diameter 1 mm at 450	Flare	18 g/s	3 kW/m ²	2.7
		Flare	18 g/s	10 kW/m ²	2.6
		Flare	18 g/s	35 kW/m ²	n/a
SC 6	Leakage scenario, downstream compressor , 10% of piping diameter 1 mm at 1000 bar	Flare	36 g/s	3 kW/m ²	3.9
		Flare	36 g/s	10 kW/m ²	3.6
		Flare	36 g/s	35 kW/m ²	3.3
SC 7	Leakage scenario, 10% of piping diameter 0.75" at 100 bar, for gaseous hydrogen through piping	Flare	16 g/s	3 kW/m ²	2.5
		Flare	16 g/s	10 kW/m ²	2.4
		Flare	16 g/s	35 kW/m ²	n/a

Table 2: Internal Safety Distances



7. Schematic diagram of HRS illustrating separation distances



Remarks:

- Not to scale.
- Distances rounded to nearest 0.5 metres.

8. List of Working Group members

Remarks:

- Approved by the PGS Programme Council.
- * = Guest.

On behalf of	Name and employer
Chairman	Erik BÜthker (LNG 24/CNG Net)
Secretary	Indra te Ronde (NEN)
IPO	Luc Vijgen (Dienst Centraal Milieubeheer Rijnmond, DCMR)
International Cooperation Agency of the Association of Netherlands Municipalities (VNG)	Peter Pasman (Omgevingsdienst, Arnhem region)
The Netherlands Fire Service (Brandweer Nederland)	Ferry El-Aaidi (Fire Service Amsterdam Amstelland)
VFIG	Peter Bout (Air Products) Hans Martens (AirLiquide)
VNO-NCW	Alice Elliott (Shell Global Solutions) John de Bont (Linde) Erik van de Keulen (Shell Global Solutions)*
Inspection	n/a
I-SZW	n/a
Ministry of Infrastructure and Environment	Marcel van der Ploeg (Rijkswaterstaat)
National Institute for Public Health and the environment, RIVM	Piet Timmers (RIVM)
European Commission, Joint Research Centre	Michel Honselaar*

Table 3: List of members of working group on Internal Safety Distances for PGS 35

9. References

- SAFETI NL, 6.5.4 (including proposals from DNV GL for hydrogen).
- EIGA report 75/07/E 'Determination of safety distances', 2007.
- PGS 35 Hydrogen 'Installations for delivery of hydrogen to road vehicles - Hazardous Substances Publication Series 35: version 1.0', April 2015.

