Section 3.3 to precede

3.4 Hydrogen installations

Hydrogen is typically stored as a compressed gas in pressurised vessels such as cylinders or tube trailers at pressures between 350 and 700 barg. Due to its small molecular size, it also has the potential to diffuse through containment structures. It has a very wide flammability range (4–75%) and extremely low minimum ignition energy.

Hydrogen is very readily ignitable (even by static spark from a person or by phenomenon such as shockwave auto ignition, where high pressure releases can self-ignite with no obvious sources of ignition) and can ignite at a wide range of concentrations and therefore, an ignition probability of 100% is considered to be a reasonable assumption for the purposes of land use planning relating to major accidental releases.

A particular focus should be given to vapour cloud explosion (VCE) consequences for hydrogen as these are expected to be more severe than other ignited events with their effects much further reaching. Explosions are also proven to be much more prevalent in hydrogen incident recordings than other types of events in comparison to conventional fuel releases.

Due to the emerging nature of the industrial scale storage and use of hydrogen, it is recommended to use equipment failure frequencies described in this section, until a robust dataset specific for hydrogen is developed.

This section does not address jetty operations, or hydrogen stored as a liquid or in any other form than compressed gas.

3.4.1 Fixed Installations

For fixed hydrogen installations located outdoors (including, but not limited to, bulk storage vessels) the following scenarios should be modelled:

LOC Scenario	LOC Scenario Frequency (yr^{-1})	Consequence	Consequence Frequency (yr^{-1})
Instantaneous failure	5×10^{-6}	VCE/Fireball	5×10^{-6}
Continuous leak over 10 minutes (total inventory)	1×10^{-5}	VCE	1.2×10^{-6}
10 mm pipe leak over 10 minutes	5×10^{-4}	VCE	6×10^{-5}

Table D-1: Event Frequencies for Outdoors Bulk Hydrogen Storage (per Vessel)

The consequence frequencies in Table D-1 for continuous leaks and pipe leaks are based upon a 30% probability of delayed ignition (given that hydrogen is best described as an Ignition 0 (high reactivity) gas) and a 40% probability of a VCE occurring instead of a flash fire scenario (RIVM[1], 2020 guidance).

1 National Institute of Public Health and the Environment (RIVM 2020) Reference Manual Bevi Risk Assessments, version 4.2. Bilthoven: National Institute of Public Health and the Environment

2 https://www.hsa.ie/eng/publications_and_forms/publications/chemical_and_hazardous_substances/guidance-on-technical-land-use-planning-advice.pdf

For fixed hydrogen installations located indoors (including equipment such as electrolysers, heat exchangers, and compressors) the following scenarios should be modelled:

LOC Scenario	LOC Scenario Frequency (yr^{-1})	Consequence	Consequence Frequency (yr^{-1})
Instantaneous failure	5×10^{-6}	VCE/Fireball	5×10^{-6}
Continuous leak over 10 minutes (total inventory)	1×10^{-5}	VCE	3×10^{-6}
10 mm pipe leak over 10 minutes	5×10^{-4}	VCE	1.5×10^{-4}

Table D-2: Event Frequencies for Indoor Hydrogen Equipment Releases (per Vessel / Equipment)

The consequence frequencies in Table D-2 are again based upon a 30% probability of delayed ignition (given that hydrogen is best described as an Ignition 0 (high reactivity) gas) and 100% probability of VCE occurring instead of a flash fire scenario (which is considered reasonable given the large explosivity range of hydrogen).

For TLUP purposes, the VCE and fireball events are located at the source. In addition, only VCE events are required for modelling as the consequences of these events would dominate other potential scenarios (such as associated jet fires or flash fires).

It is noted that the frequency for the 10 mm pipe leak over 10 minutes includes allowance for failures from all associated pipework equipment and fittings, and hence it may be conservative for a simple installation.

3.4.2 Road Transport Units

For compressed gaseous hydrogen transported in cylinder arrays by road transport units (RTUs), the scenarios are:

LOC Scenario	LOC Scenario Frequency (yr^{-1})	Consequence	Consequence Frequency (yr^{-1})
Instantaneous failure	$N \times (5 \times 10^{-7})$	VCE/Fireball	$N \times (5 \times 10^{-7})$
Loss of entire contents through largest connection	$N \times (5 \times 10^{-7})$	VCE	$N \times (1.2 \times 10^{-7})$

Table D-3: Event Frequencies for Road Transport Units On-Site (per Pressurised Cylinder Array with 'N' Cylinders)

The frequencies should be adjusted for the proportion of the year that the laden RTU is present. The consequence frequencies given in Table D-3 are also applicable for hydrogen storage cylinder arrays which are not stored on RTUs.

The consequence frequencies in Table D-3 for continuous releases are based upon a 60% probability of delayed ignition (in line with "Flammability 0, instantaneous" event for RTUs in Table 21 of current TLUP Guidance Document[2]) and a 40% probability of VCE occurring instead of a flash fire scenario (RIVM, 2020 guidance[1]).

In addition to the risks associated with the presence of an RTU, as described above, there will also be risks associated with the on-site loading / unloading of hydrogen as detailed below:

LOC Scenario	Frequency (hr^{-1})	
	Arm	Hose
Rupture of loading / unloading arm/hose	3×10^{-8}	4×10^{-6}
Leak of loading / unloading arm/hose (10% diameter)	3×10^{-7}	4×10^{-5}

Table D-4: Event Frequencies for Hydrogen Loading / Unloading Operations

3.4.3 Pipelines

Loss Of Containment (LOC) scenarios for hydrogen pipelines are considered to be analogous to that of natural gas (NG) due to the similarities in the way the fluids are carried in the pipeline and the likely causes of failure which could lead to pipeline LOC.

Refer to Table 36 and Table 37 of current TLUP Guidance Document[2] covering LOC scenarios for over ground and underground NG pipelines within an establishment respectively.

However, consequence frequencies should assume a 100% ignition probability, 30% probability of delayed ignition, and a 40% probability of VCE occurring instead of a flash fire scenario as per Table D-1 concerning outdoor releases from bulk hydrogen storage.

3.4.4 Hydrogen Explosion Modelling Guidance

Given the ignitability of hydrogen (especially if it is released at high pressures), it is recommended to assume that all releases would be ignited.

The likelihood of a significant detonation (with blast overpressures exceeding 10 bar in the near field) is much greater for hydrogen than for methane or Liquified Petroleum Gas (LPG). Therefore, it is recommended to model a VCE of ignition strength 7 (with respect to the TNO multi-energy method (Van den Berg, 1985)) for 40% of the total flammable cloud volume (or using a site specific estimate of volume) in an outdoors environment (i.e. representative of the outdoor scenarios listed in Table D-1, Table D-3, and Table D-4).

The magnitude of an overpressure generated inside an enclosed space (i.e. representative of the scenarios listed in Table D-2) should be based upon the entire volume of the enclosure filled at a flammable (stoichiometric) concentration with ignition strength of 7. There is potential for even small releases from hydrogen systems to fill enclosures to flammable levels especially given the high pressure at which the systems are maintained giving high release rates and hydrogen's large flammability range.

END 3.4