STORAGE OF HYDROGEN IN SYSTEMS LOCATED UNDERGROUND

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Amendments to 171/12

Section	Change
2	Updated scope
3	New term and definition added
5.6	Major update in leak prevention

Note: Significant technical changes from the previous edition are underlined

1 Introduction

This document addresses the safety issues that are specific to the storage of hydrogen in systems located underground.

This form of installation may be needed when it is beneficial to keep above ground areas free of equipment, such as may be the case for hydrogen vehicle refuelling stations.

However, it is preferable that wherever possible, hydrogen storage and related equipment is located above ground in the open air in a well ventilated area.

2 Scope

This document covers the requirements specific to the installation of a hydrogen storage system covering

- liquid hydrogen storage and ancillary systems,
- compressed hydrogen storage composed of a single container, or multiple cylinders or tubes

in an underground space with top or side access, hereafter called a vault or directly buried in the ground.

Periodic inspection of buried gaseous storage systems is not addressed in this document.

This document does not address the generic design, materials and construction aspects of hydrogen pressure vessels.

This document does not address the following cases:

- massive storage of hydrogen in caverns
- underground pipelines
- underground parking of hydrogen vehicles
- any hydrogen system used for mining application
- tunnels for vehicles traffic
- hydrogen systems used under water

3 Definitions

Double block and bleed isolation: isolation system that consists of two block valves plus a bleed valve connected to the pipe section between the two block valves.

Fail-close isolation valve: valve that will go to closed position in case of control signal or instrument air failure.

Lock-out/tag-out: safety procedure to ensure that equipment is shut off, isolated from power sources and not started up again before the completion of maintenance work.

Safety ventilation: ventilation activated upon detection of hydrogen to prevent the hydrogen concentration from exceeding a specified limit.

Lower Flammability Limit (LFL): the lowest concentration of a gas or vapor in air that is capable of producing a flash of fire in presence of an ignition source.

4 Buried liquid hydrogen storage

The following means of protection should be assessed in the design of a buried liquid hydrogen storage system. UKLPG *Code of Practice 1: Part 4 - Bulk LPG Storage at Fixed Installations: Buried/Mounded LPG Storage Vessels (January 2021)* provides detailed guidance on installation requirements.

- Protection against corrosion including cathodic protection: design and monitoring;
- Inspection of tank condition before burial;
- Precautionary measures during burial;

- Maintenance and inspection access;
- Design against the effects of flooding;
- Prevention of subsidence / soil erosion / excessive settling;
- Avoidance of excessive loads from activities at ground level;
- Prevention of damage from neighbouring vegetation.

Note: Corrosion mechanisms specific to burial need to be assessed, such as cavernous corrosion and corrosion in deaerated environments.

If circulation of vehicles is permitted above the storage, the installation shall be designed to withstand the weight of any vehicle that may pass over it.

All buried hydrogen piping connection shall be welded. Valves, flanges, instrumentation, and filling ports shall be located above ground or in well ventilated spaces to avoid formation of a flammable atmosphere. Such equipment can be installed in a vault.

Below ground migration of leaked hydrogen to other systems (e.g. water drainage, cable ducts) and buildings shall be prevented.

Support and anchorage of the storage system shall be designed to withstand exposure to cryogenic temperatures that may arise due to loss of vacuum or leaks.

Above ground equipment, piping and vent systems connected to the buried storage shall be protected against mechanical impact.

Specific attention shall be given to the prevention of accidental damage to any buried part from excavation works in the facility.

Leak detection by hydrogen detection at ground level above the storage system shall be performed periodically with a portable detector.

5 Liquid or gaseous hydrogen systems located in a vault

5.1 Measures to be taken above ground

Above ground equipment, piping and vent systems shall be protected against mechanical impact.

If the vault cover is not designed to bear the load of vehicles, the vault shall be installed in an area where vehicular access is prevented by provision of substantial kerbs, barriers or bollards.

Above ground areas where a flammable atmosphere is likely to be present in case of a release of hydrogen inside the vault shall be identified and kept free of ignition sources, as well as of above ground activity and passageways.

Visible signage shall be present to identify the presence of an underground storage of hydrogen.

5.2 Prevention of an asphyxiating atmosphere in the vault

All gases shall be vented outside of the vault to a safe location. Whenever possible compressed air is preferable as instrument gas.

If an inert gas is used for pneumatic control systems (“instrument air/gas”) or for emergency inerting, the following requirements shall be respected:

- Permanent ventilation shall be ensured by active or passive means in order to avoid accumulation and persistence of an asphyxiating atmosphere in normal or foreseeable operating conditions (e.g. instrument nitrogen venting from control valves).

- The atmosphere in the vault shall be monitored for oxygen deficiency, specifically where inert gas is most likely to be present. Oxygen deficiency shall activate a light signalling system located outside the vault at the point of entry. The system shall be checked periodically in accordance with manufacturer's recommendations.
- Means to isolate the supply of inert gas shall be installed outside of the vault.
- The vault shall also include a permanently installed means of ventilation, capable of fully restoring a breathable atmosphere after a foreseeable release of inert gas (see 5.7 for definition of foreseeable release).
- The consumption of inert gas by pneumatic control systems should be checked periodically for abnormally high usage.
- The risk of asphyxiation due to the presence of hydrogen shall be assessed during the development of Operating Procedures.

5.3 Access and exit

The installation shall be such as to allow its complete inspection.

Because of the potential of having an oxygen depleted atmosphere within the vault due to hydrogen or inert gas leaks, the vault shall be considered to be a confined space and, as such, confined space access and egress measures shall be applied.

Unauthorized access shall be prevented by physical means, such as permanently locked access ways.

Exit doors shall be visibly marked and equipped with an anti-panic exit device.

An asphyxiation risk warning sign shall be permanently posted at all access ways.

A flammable atmosphere warning sign shall be permanently posted at all access ways.

Personnel shall carry a portable atmosphere detection system when entering and working in the vault. This portable detector shall detect oxygen deficiency, the presence of hydrogen, and the presence of carbon dioxide if carbon dioxide is used as an emergency inerting agent.

Equipment lay-out and vault exit location(s) shall allow an easy exit from the vault in the event of a hazardous situation inside the vault. Multiple exit routes may be necessary depending on the system design.

Exit routes shall be kept clear of obstructions at all times.

In case of entry from the top with a ladder special care should be taken to ensure the vault is well ventilated before entry.

Maintenance operations inside the vault are subject to specific safety requirements specified in section 5.10.

5.4 Emergency inerting system

If such a system is used, it shall be deactivated when personnel are present. For deactivation a lock-out tag-out procedure shall be in place to prevent the use and operation of the Hydrogen system until emergency inerting has been reactivated.

Activation of the inerting system shall be indicated by an audible alarm and a warning light located outside at all points of personnel entry. Instructions prohibiting entrance in such case shall be posted.

5.5 Prevention of/protection from ingress of water and other fluids

Ingress of water and other fluids from the ground surface (e.g. rain water, melted snow, fire-fighting water, flooding, accidentally released fuel and liquids) shall be prevented by assessment of location, by kerbs and means of sealing and by protection of ventilation inlets/outlets and other openings.

Ingress of ground water shall be prevented.

Access ways (staircase) shall be protected from accumulation of rain and surface water, by channelling and means of drainage.

A drainage system that will prevent flooding (which may include a sump pump) shall be provided for the vault. The drainage system shall be maintained and periodically tested. Collection of fluids in a location where they can be pumped in case of failure of the drainage system shall be provided.

Electrical equipment shall be protected against the possible ingress of fluids, to limit damage risks to the equipment, as well as to ensure personnel safety in case water is present.

Means should be provided to visually inspect a vault from the entrance for the accumulation of water or other liquids. Otherwise, means should be provided to automatically detect the presence of liquids in the vault.

Storage vessels shall be anchored securely.

Support and anchorage of the storage system shall be designed to withstand exposure to cryogenic temperatures that may arise due to loss of vacuum or leaks.

Ingress of hydrogen and of other system fluids potentially released into the drainage system shall be prevented.

5.6 Prevention of hydrogen leaks

It shall be possible to isolate the supply of hydrogen to the vault from outside the vault.

The number of fittings or joints shall be minimised.

Storage systems located inside the vault shall include automatic fail-close safety isolation valve(s) mounted directly on the storage system. It shall be possible to fully depressurize the vessel in case of a leak from outside the vault.

To prevent hydrogen leaks, systematic preventive routine checks of fitting shall be done.
This includes mechanical checks as well as soap water test and sniffing techniques.
Leak detection systems such as acoustic detection may be used additionally. More recent technologies such as chemochromic hydrogen sensors (tapes that change colour when in contact with hydrogen) are currently tested and can be used for hydrogen leak detection at connections and flanges by visual inspection.

In case of a detection, appropriate corrective actions shall be taken towards their elimination. These actions include stopping the leak by tightening the connection, repairing or replacing leaking parts.
Note : avoid tightening under pressure as this could lead to additional hazard.
In case of major leaks isolation, alarming and eventual evacuation shall be performed. See details in chapter 5.7.5 “Summary of requirements with regards to the prevention of flammable atmospheres”.
Note: at 100%” LFL the emergency inerting system (if aplicable) will be activated (§5.7.3) resulting in risk of anoxia.

5.7 Prevention of flammable atmospheres

Preventing a flammable atmosphere will prevent the occurrence of an explosive atmosphere.

All gases shall be vented outside of the vault in a safe location.

Electrical and piping conduits exiting the vault shall be constructed to prevent the egress of hydrogen along the conduit.

Facility lay out shall be such that there is no risk of accumulation in buildings or overhangs of flammable mixtures exiting the vault following a release.

Potential leaks and releases shall be identified, evaluated and categorized depending on their expected frequency.

The requirements laid out in this section refer to frequency categories defined as follows:

- Expected: reasonably likely to happen during the lifetime of the system.
- Foreseeable: resulting from foreseeable accidental circumstances (cumulative probability < 10^{-2}/yr).
- Conceivable: resulting from accidental circumstances that are conceivable but rare (cumulative probability < 10^{-4}/yr).
- Unlikely: sufficiently unlikely not to be considered for the definition of the required mitigation measures (cumulative probability < 10^{-6}/yr).

The expected and foreseeable leaks respectively coincide with the primary grade and secondary grade releases considered for classification of hazardous areas in accordance with IEC 60079-10.

5.7.1 Hydrogen detection

The vault shall include a hydrogen detection system. This detection system shall activate an alarm and shall activate isolation of hydrogen sources and de-energization of all energy sources except safety ventilation and other safety devices.

It is best practice to detect hydrogen inside the vault at the point of highest elevation, with a relevant number of sensors according to the size and shape of the vault.

5.7.2 Limitation by design of the effects of expected and foreseeable hydrogen releases

For compressed gas storage systems composed of multiple cylinders or tubes, the total water volume of interconnected capacities isolated by a single automatic safety isolation valve shall not exceed 5000 L.

Storage system safety valves shall be mounted as close as possible to the storage system.

Means of ventilation and mitigation shall be provided to prevent the accumulation of a flammable atmosphere from any *expected* or *foreseeable* leaks or releases in the vault.

Ventilation fans shall comply with the requirements of EN 14986 - Design of fans working in potentially explosive atmospheres.

Accumulation of a flammable hydrogen air mixture from *expected* leaks and releases shall be prevented by highly reliable means such as:

- natural ventilation;
- or permanently monitored active ventilation, with automatic shut-down and isolation of hydrogen supply in case of loss of ventilation.

Prevention of accumulation of a flammable hydrogen air mixture from *foreseeable* leaks and releases may be achieved by the same means as above or by a hydrogen detection system which activates *both*:

- a safety ventilation system, and

- an emergency isolation system shutting off the supply of hydrogen as close as possible to the source of hydrogen.

The means of ventilation described in this section shall be sized to prevent the hydrogen concentration from exceeding 25% of the LFL of hydrogen.

Activation of emergency isolation shall also de-energize all machinery, except safety ventilation and other safety devices (emergency shut-down).

Ventilation openings shall be periodically inspected and kept free of obstacles and obstructions. Activation of the safety ventilation due to elevated hydrogen concentrations shall activate a specific alarm signal and - if existing - safety ventilation or other safety means (see §5.7.6 and §5.9).

5.7.3 Limitation of the effects of a conceivable accidental release

An emergency inerting system shall be installed if the ventilation system is not sized to prevent the hydrogen concentration from exceeding 2% (50% of LFL) in the event of any conceivable release.

Note: the ventilation system used for the latter purpose may be same as the one specified in section 5.7.2 with regards to *expected* or *foreseeable* leaks.

The following measures shall be applied when a vault emergency inerting system is installed:

- the activation of vault emergency inerting system shall shut down the ventilation;
- the reliability on demand of the emergency inerting activation system shall be specified in order for the residual risk to be below a threshold which shall be specified;
- it shall be ensured by design that only limited amounts of inert gas are entrained with the released hydrogen, so that this outflow can be compensated by continuous supply from the inerting system until the hydrogen release has ceased;
- the threshold for activation of the emergency inerting system should be at detection of hydrogen content in vault below 4%
- the activation of the vault emergency inerting system shall also activate a dedicated alarm;
- the activation of the vault emergency inerting system shall also activate the facility emergency response plan;
- the vault shall be equipped with a hydrogen detection system capable of measuring the hydrogen concentration in presence of an inert gas;
- the quantity of inert gas stored on-site to control a hazardous situation shall be calculated based on the estimated duration of such a situation and the time required to replenish the inert gas storage;
- a procedure shall be defined for permitting re-entry after activation of the vault emergency inerting system.

5.7.4 Safety system inspection and testing frequency

Natural ventilation openings shall be inspected on regular basis.

Activation of ventilation and isolation shall be tested at least once a year.

Activation of emergency inerting, when installed, shall be tested at least once every three years.

5.7.5 Summary of requirements with regards to the prevention of flammable atmospheres

	Type of release		
	Expected	**Foreseeable**	**Conceivable**
Ventilation type	Natural or Continuously operating forced ventilation including detection of loss of ventilation with automatic shut-down and isolation of hydrogen supply in case of loss of ventilation	Same as for expected leaks or Safety ventilation activated by the hydrogen detector Sized for foreseeable leaks	Same as for foreseeable leaks Sized for conceivable leaks
Ventilation sizing	To prevent exceeding 25% of LFL in case of expected leaks	To prevent exceeding 25% of LFL in case of foreseeable leaks	To prevent exceeding 50% of LFL in case of conceivable leaks
H2 detection	Required		
H2 detection alarm	25% of LFL at the most		
Activation of safety ventilation	25% of LFL at the most		
De-energization and isolation	40% of LFL at the most		
Activation of inerting system	100% of LFL at the most		
Testing of H2 detection and activation of alarm, safety ventilation	According to manufacturer recommendations, but at least once a year		
Testing of inerting system	At least every three years		

Note: *Unlikely* releases do not require additional measures beyond those specified for conceivable releases.

5.8 Prevention of ignition of accidental releases, and associated hazards

The vault shall be classified as a hazardous area and hazardous area classification shall be performed in accordance with IEC 60079-10 to cover also vent discharge, ventilation openings, and points of access. Electrical equipment installed inside the vault shall be specified for use in such hazardous areas. All other equipment shall be selected with the aim of avoiding ignition sources.

Neither flammable nor oxidising fluids other than hydrogen shall be stored or used in the vault.

When installing or protecting critical equipment, such as gaseous hydrogen storage systems and emergency isolation valves, consideration shall be taken to limit exposure to an ignited leak. Emergency isolation valves that are potentially exposed shall be designed to withstand fire conditions.

The vault shall include a hydrogen fire detection means (such as UV/IR or heat detection). Detection shall activate a specific alarm signal and emergency isolation.

The storage system shall include means to activate shut off valves and emergency venting from a safe location.

If composite cylinders such as type 4 are used, the residual pressure should be kept at minimum level specified by the manufacture to prevent a blistering effect / collapsing of the liner.

The facility emergency response plan shall include the measures necessary to prevent ignition of the released hydrogen outside of the vault, and to protect people and equipment in case of ignition.

5.9 Gas and fire detection signalling

Detection of oxygen deficiency shall activate a visual signal outside the vault at all points of entry.

Flammable gas detection and fire detection shall activate a visual signal and audible alarm outside the vault at all points of entry, as well as inside to inform personnel present in the vault.

It is possible to acknowledge the acoustic alarm but is shall not be possible to turn off the visual signalling as long as the conditions for activation are present.

Gas and fire detection and signalling systems shall be tested periodically.

It is best practice to route alarms to a dispatcher.

5.10 Safety of maintenance operations

Any maintenance in the vault shall be subject to a work permit, addressing in particular

- the measures to be taken if a hazardous event occurs in the vault during maintenance;
- the hazards associated with working in a confined space
- personal trained and competed in permit to work.

When a gas detection system is installed, the corresponding detection signals and alarms shall be installed inside the vault, as well as outside.

Maintenance operations shall be well planned with the objective of avoiding the generation of a flammable hydrogen-air mixture in the vault.

Verification of the absence of a hazardous or asphyxiating atmosphere inside the vault shall be made before entering.

The section of equipment to be maintained shall be isolated, depressurised through a venting system, and purged with nitrogen or helium and residual hydrogen content shall be measured and controlled below 0.4% to allow maintenance operation.

Isolation shall be performed using a double block and bleed isolation system, with application of a lock-out/tag-out procedure.

Ventilation shall be activated and maintained throughout the maintenance operation.

If access to the vault is by ladder, the rules applicable to work in a confined space shall apply. In particular for maintenance operations, isolation from sources of hydrogen and inert gas by physical disconnection or/and a blind flange shall be implemented.

5.11 Backup power system

An independent backup power system shall be provided to ensure continuity of power supply to safety critical protection systems such as gas detection systems and active ventilation systems, for the whole potential duration of the hazardous situation generated by an accidental event (such as a hydrogen leak).

The backup power system shall be periodically tested.

5.12 Additional requirements for liquid hydrogen systems in vaults

In addition to the requirements described above the following measures shall be taken for liquid hydrogen systems.

Un-insulated surfaces on which air can liquefy and materials reactive to contact with liquefied air or liquid oxygen (lubricants, grease) shall be avoided in the vault.

The quality of the vacuum insulation of the underground system shall be periodically checked. Insulated lines shall be accessible for inspection.

All the main valves shall be accessible and regularly inspected for signs of ice interfering with their proper operation.

When made of carbon steel, the outer shell of the storage vessel shall be protected from liquid hydrogen impingement in the case of leaking valves.

High pressure equipment (such as composite containers) not designed for cryogenic temperatures shall not be installed in the same vault as a liquid hydrogen system.

The installation of critical and vulnerable equipment shall take into account the risks arising from a cryogenic leak (e.g. avoid installing them directly on the floor).

Vacuum shall be monitored and any deterioration shall be automatically detected if the vault is accessed by means of a ladder from the top. This safeguard is intended to offer an extra layer of protection entering confined space regarding the separation of air over height due to cold pipework.

The pressure relief systems shall be able to handle a complete loss of vacuum isolation in combination with fire conditions.

A means to drain the storage vessel shall be installed.

Appendix – Comparison of general characteristics of vaulted and buried storage systems

	Direct burial	Vault
Installation	Assessment of site conditions is required - in particular the local water level Requires protection against corrosion : coating and/or cathodic protection Above ground equipment needs to be protected from impact	Assessment of site conditions is required - in particular the local water level and flood risk. Above ground equipment needs to be protected from impact
Maintenance / Inspection	Storage system can not be examined externally. Need to rely on indirect indications of condition such as cathodic integrity, maintaining pressure / over pressure. To minimise activities in the vault equipment requiring maintenance should be installed separatly.	Visual inspection is feasible if access is provided but confined space entry precautions are required. Provision of suitable access for maintenance/inspection is required. Easier to prevent ingressing water from contacting the storage system.
Safety	The leakage path of any hydrogen is to open atmosphere and requires consideration for potential traffic above. Presence of buried storage should be indicated and appropiate zoning shall be applied.	Instrumentation is required to monitor for / prevent the accumulation of a hazardous atmosphere. Forced ventilation may be required. Easier to control for hydrogen leakage and subsequently vent to a safe location.