

Underground Gas Storage Safety

CONTENTS

1	Underground Gas Storage (UGS) facilities are key assets for European Energy market	3
2	Different types of UGS technologies well known for decades	4
2.1	Pore storage	4
2.1.1	Storage in former oil and gas fields	4
2.1.2	Aquifers	5
2.2	Caverns	6
2.2.1	Salt caverns	6
2.2.2	Rock caverns/Abandoned mines	7
3	How UGS facilities work	8
3.1	Key elements of a storage facility	8
3.2	Function principle	8
4	Safety - SEVESO III directive	10
5	Safety - UGS integrity	12
5.1	Sufficient knowledge of the subsurface and proper design of operating parameters to insure confinement	12
5.2	Well integrity management	12
5.3	Monitoring Plan	13
5.4	Operation and Monitoring of Surface Facilities	14
6	Conclusion	14
7	European Standards on Underground Gas Storage	14

1 UNDERGROUND GAS STORAGE (UGS) FACILITIES ARE KEY ASSETS FOR EUROPEAN ENERGY MARKET

Underground Gas Storage facilities provide value to gas customers in four different ways.

1) Physical adjustment of seasonal and peak demand

The main function of gas storage is to smooth out seasonal fluctuation in gas demand but also to meet peak daily demand.

2) Ensuring security of supply

Gas storages play also a vital role in avoiding risks to security of supply and extreme prices driven by factors such as weather, asset failures, and political events.

3) Optimizing the natural gas system and contributing strongly to security of supply

Gas storage allows the network to operate at high load factors year-round despite wide swings in seasonal demand as pipeline systems integrated with gas storage can be sized optimally, resulting in lower cost for the end-consumers.

4) Facilitating the development of renewable gases

Gas storage allows the storage of wind and solar energy up to seasonal scale.

The global capacity of energy storage provided by Underground Gas Storage (UGS) facilities in Europe is huge¹: 1978 TWh i.e. around 180 Bcm (billions of cubic meters of gas in standard conditions)

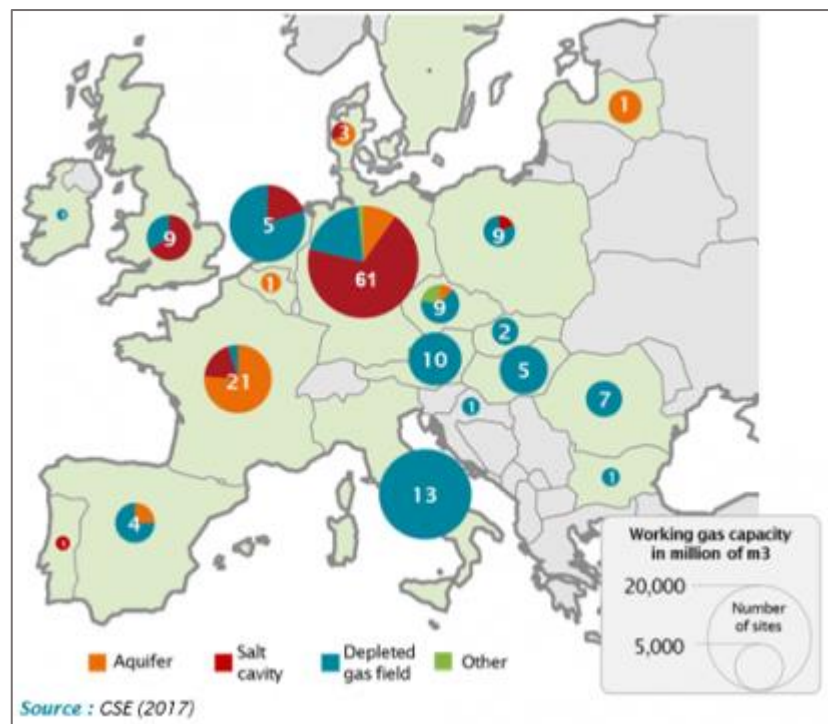


Figure 1: Number and capacity of underground gas storage facilities in Europe (Source: GIE-GSE, 2017)

¹ According to GIE 2018 data-base

2 DIFFERENT TYPES OF UGS TECHNOLOGIES WELL KNOWN FOR DECADES

There are several types of Underground Gas Storage facilities which differ by geological formation and storage mechanism. The different types are developed according to the local geological conditions.

2.1 Pore storage

The gas is stored in the porous reservoirs as sandstones. The working gas volume (i.e. the gas volume that could be injected and withdrawn during a campaign) and the deliverability (maximum gas flow rate to be injected or to be withdrawn) of these facilities depend, among other parameters, on reservoir characteristics (permeability and porosity).

The reservoir formation is overlaid by a tight formation "caprock" with impermeable rocks which ensure the confinement of gas.

2.1.1 Storage in former oil and gas fields

Most UGS facilities in the world were developed in hydrocarbon fields, converted into Underground Gas Storage at the end of their production life. The economically recoverable reserves have usually been nearly or completely produced prior to the conversion of the reservoir to gas storage operations. It means that natural gas could be injected in a geological structure within a reservoir formation which already contained oil or gas for millions of years previously.

In the case of former oil and gas fields, their ability to contain the gas has been proven over a geological period of time and at a given level of pressure (initial pressure)

With specific tests to prove confinement, the maximum operating pressure may be higher than the initial reservoir pressure.

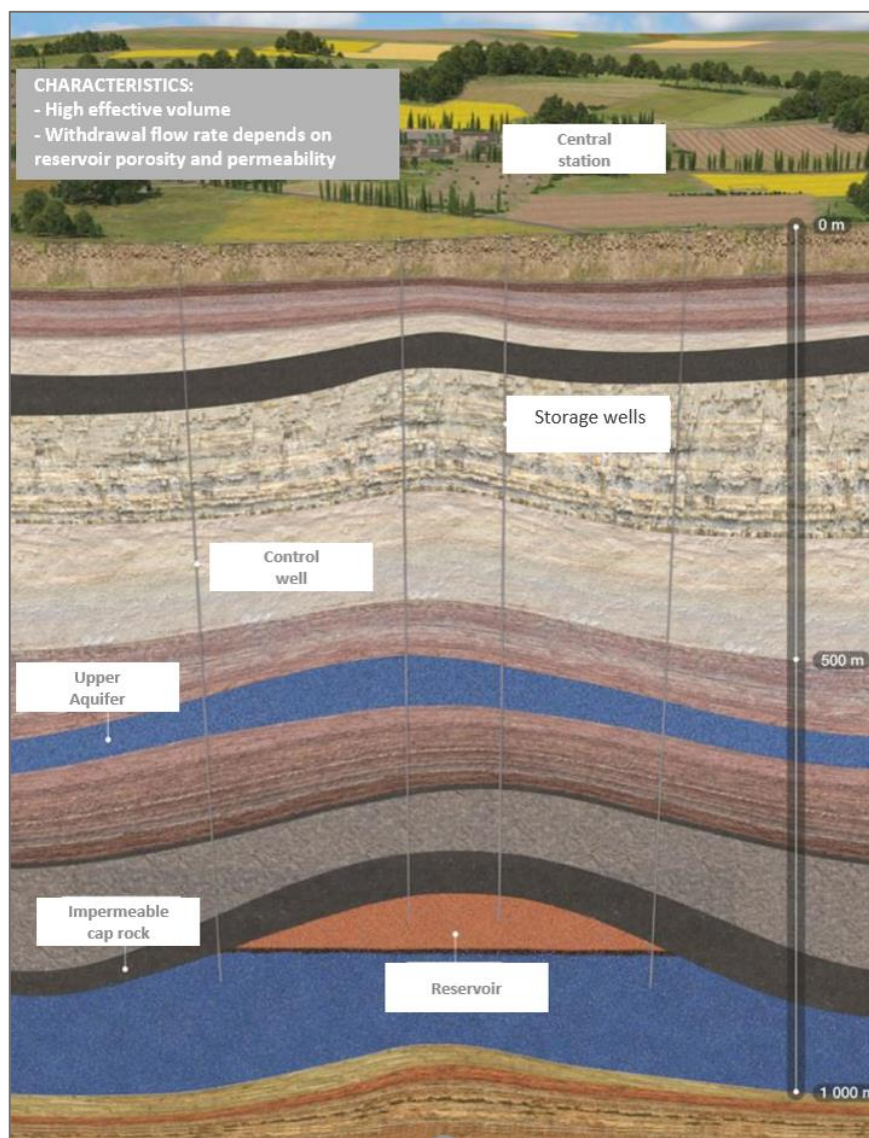


Figure 2: Former gas field converted into storage (Source: Storengy)

2.1.2 Aquifers

Storage in aquifer geological layers, in which gas reservoirs are installed up artificially in an originally water bearing formation, have a similar geological structure (porous reservoir, geological trap and cap-rocks) as depleted hydrocarbon fields (see §2.1.1, above). Progressively gas displaces water from the reservoir formation without any modification of the underground reservoir structure. With the injection of gas, the reservoir pressure is increased above the initial hydrostatic pressure, and water is progressively pushed out of the structure.

This is why aquifer storage needs delta-pressuring above the hydrostatic pressure gradient in order to displace the formation water.

While the containment requirements and the geology of aquifer storages are similar to former hydrocarbon production fields there are still some additional differences. Aquifer storages require usually more cushion gas than former gas fields, as the gas phase is

brought in artificially and more extensive monitoring for ensuring storage containment and optimisation of storage performance.

Production rates may be enhanced by the presence of an active aquifer.

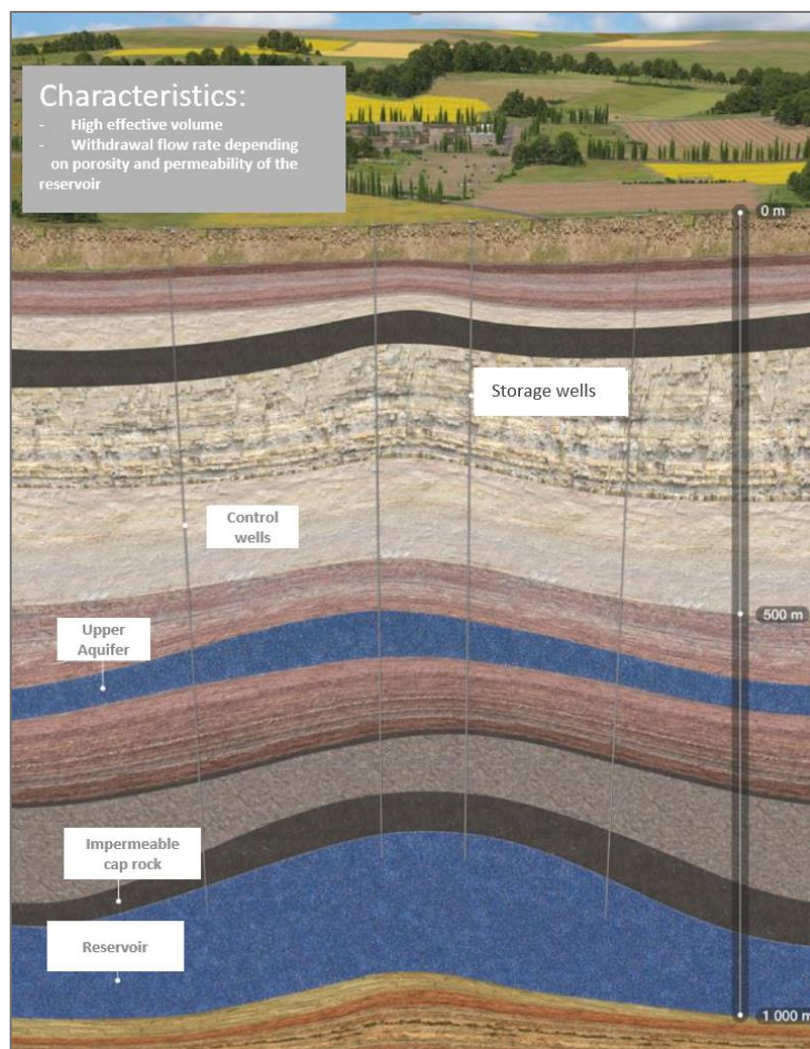


Figure 3: Aquifer storage (Source: Storengy)

2.2 Caverns

2.2.1 Salt caverns

Salt caverns are widely used for high deliverability UGS, as they are marked by high production / injection, flow rates compared to the working gas volumes. A salt cavern or cavity is created by dissolving, "leaching" the salt of a geological layer using solution mining techniques. Salt formation is considered gas tight but the stability of the cavern under pressures, covering all range of operation, must be secured.

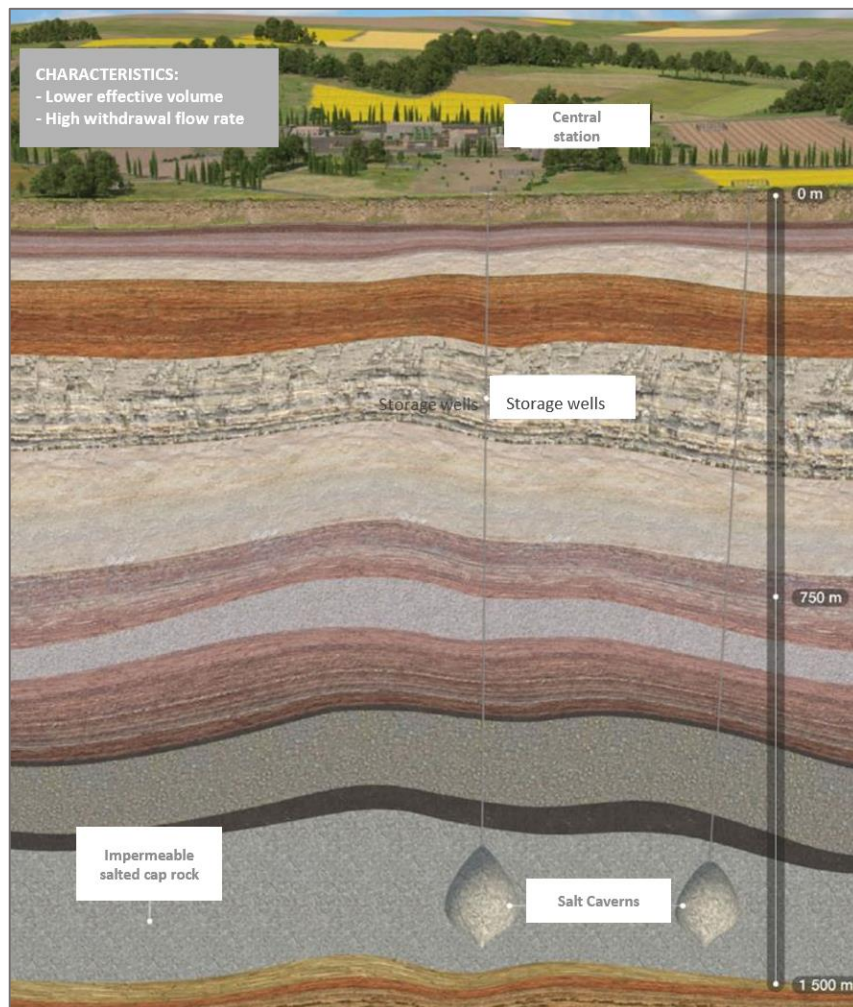


Figure 4: Cavern storage (Source: Storengy)

2.2.2 Rock caverns/Abandoned mines

A specific form of cavity storage, abandoned mines or mined hard rock caverns, which may be unlined or completed with a steel liner, can be used as UGS. Their deliverability and storage volume is limited, compared with porous and cavern UGS.

3 HOW UGS FACILITIES WORK

3.1 Key elements of a storage facility

- **Reservoir/cavern:** The geological formation in which the gas is stored.
- **Seal/caprock:** Sealing formation overlying the reservoir or the cavern which prevents gas migration. The caprock is tight under storage conditions.
- **Wells:** There are different types of wells in a gas storage:
 - o **Operating wells** connect the reservoir/cavern to the surface & subsurface facilities and isolate gas from the upper levels and atmosphere. These wells are used to withdraw/inject gas and may be used also for monitoring purposes;
 - o **Monitoring wells** are primarily used to monitor the pressure distribution of the pressure within the gas storage in order not to exceed the maximum pressure allowed. Additionally, they are used in aquifer storages to control the gas migration within the porous media. Where necessary, monitoring wells are also drilled into adjacent formations in order to monitor the tightness of the seal (cap rock);
 - o **Water disposal wells** may be used to re-inject water that is produced with the gas during withdrawal back into a geological formation.
- **Surface facilities:** Gas treatment/compressors/pipelines. The surface facilities functions are:
 - o Pipelines to transport gas between the transport grid and the central station/treatment plant and from / to the wells;
 - o Gas treatment facilities to process the gas according to the gas quality specifications;
 - o Gas pressure reduction and compression to adjust the difference in pressure between the gas grid and the UGS;
 - o Gas injection/withdrawal volumes metering to make balance of the stored / withdrawn gas.

3.2 Function principle

The gas is injected into the porous formation/caverns through the operating I wells, generally during summer.

The gas is produced from the porous formation/caverns through the operating wells, generally during winter. The withdrawn gas needs to be treated: dehydrated and in some cases, separated from hydrocarbon condensate (depleted fields) and desulfurized. In countries where the gas odorization is compulsory in the transmission network, a complementary odorization may be necessary.

Depending on the depth of the storage and depending on the operation pressure of the gas transmission network, compressors are necessary to inject and, in some cases, also produce the gas.

4 SAFETY - SEVESO III DIRECTIVE

SEVESO III directive - A common framework for all UGS facilities in Europe.

In Europe, storage operations are strictly regulated by the SEVESO III directive² to avoid major accidents.

Following several major accidents in Europe, directives named "SEVESO" have been published by EC from 1976 to ensure a high level of risk management associated to technological activities like chemistry, oil and gas activities.

A second and a third European directives (SEVESO II and SEVESO III) have improved the first one and have enlarged the scope to include more industrial facilities. The directive 2012/18/EU clearly mentions Underground Gas Storage facilities as affected by the requirements.

First, operators have to draw up a document in writing, setting out a **Major-Accident Prevention Policy (MAPP)**. The MAPP is designed to ensure a high level of protection of human health and the environment. It must be proportionate to the major-accident hazards and includes the operator's overall aims and principles of action, the role and responsibility of the management, as well as the commitment towards continuously improving the control of major-accident hazards and ensuring a high level of protection. This MAPP has to be updated every five years. It demonstrates the commitment of the (storage) operator at the highest level of management. The MAPP shall be implemented by appropriate means, structures and by a **Safety Management System (SMS)**.

Due to the SEVESO III directive, each European UGS operator has to provide the authorities with a risk assessment study to describe all the risks linked to their substances and activities. Aims of this **Safety Report (SR)** are the following:

- demonstrate that a MAPP and a SMS are implemented on site;
- demonstrate that major-accident hazards and possible major-accident scenarios have been identified and all the necessary measures have been taken to prevent such accidents and to limit their consequences for human health and the environment;
- demonstrate that adequate safety and reliability have been taken into account in the design, construction, operation and maintenance of Underground Gas Storage installation, equipment and infrastructure connected with its operation, which are linked to major-accident hazards;
- demonstrate that internal emergency plans have been drawn up and supplying information to enable the external emergency plan to be drawn up;
- the safety report must take into account the "**domino effect**" on other industrial sites, surrounding storage sites, that may be impacted by major accidents due to the storage facility.

² SEVESO III directive: "Directive 2012/18/EU of the European Parliament and the Council on the control of major-accident hazards involving dangerous substances"

An important aspect of the safety management system is the **Management Of Change (MOC)** (modification of the storage facility). The operator shall review and, where necessary, updates the MAPP, the SMS and the SR and shall inform the relevant authority of the details of those updates prior to that modification.

UGS operator shall draw up an **internal emergency plan** for the measures to be taken inside the storage facility and provide information to allow public authorities to have an **external emergency plan**.

The emergency plans shall be established with the following objectives:

- containing and controlling incidents so as to minimise the effects and to limit damage to human health, the environment and property;
- implementing the necessary measures to protect human health and the environment from the effects of major accidents;
- communicating the necessary information to the public and to the services or authorities concerned in the area;
- providing the necessary information for the restoration and clean-up of the environment following a major accident.

The last principles of SEVESO directives are **public information** on major risks and **land-use planning**. That means that the objectives of preventing major accidents and limiting the consequences of such accidents for human health and the environment are taken into account in their land-use policies. These principles are crucial: they are implemented by public authorities with the information and the support of storage operators.

In the transposition of this directive, some Member States have implemented additional regulations at national level.

5 SAFETY - UGS INTEGRITY

UGS integrity - European UGS operators share a common vision.

The basic concept for the integrity of facilities of UGS, especially for subsurface, are mainly developed in the EN1918 standards. These standards, defined for the different types of UGS and the surface facilities (EN1918-1, -2, -3, -4, -5, see details in §7, p.14), have been recently updated (2016).

They give functional recommendations for design, construction, operation and abandonment.

They are not compulsory but all European operators use these requirements as a reference in their programs to upgrade their facilities.

The main principles are described in the §5.1, §5.2, §5.3, §5.4.

5.1 Sufficient knowledge of the subsurface and proper design of operating parameters to insure confinement.

It presupposes:

- Adequate prior knowledge of the geological formation in which a storage is to be developed.
- Acquisition of all relevant information needed for specifying operational constraints for construction and operation.
- Feasibility study for ensuring long-term containment of the stored gas in the storage reservoir/cavern through its hydraulic and mechanical integrity.

It has to be ensured, that all formations (hydrocarbon fields, aquifers) that could possibly be connected to the gas storage are assessed. If there are other storages or production fields in the vicinity, reference measurements are necessary to rule out the possibility of connection.

Similarly, in case of caverns, the gas tightness conditions and cavern stability have to be ensured. This requires implementing hydrogeological investigations and studies (valid for unlined rock caverns) and rock mechanics investigations and studies (valid for unlined rock caverns, mines and salt caverns).

5.2 Well integrity management

The well integrity policy adopted by most of the European Underground Gas Storage operators, according to EN1918 standards, is based on the **"two barriers" principle** for operating wells. Both independent barriers would have to fail at the same time for a leak to occur. A well barrier is an envelope made of a set of combined elements that prevent any uncontrolled flow of fluids or gases from or to the well as well as within the well. Barriers prevent any unintentional flow of fluids from the storage reservoir to overlying formation or the surface.

Typically, the first barrier is composed of packer (sealing element between casing and tubing), gas tight production tubing and a subsurface safety valve. The second barrier is composed of a cemented production casing and a well head with different valves, including the master valve.

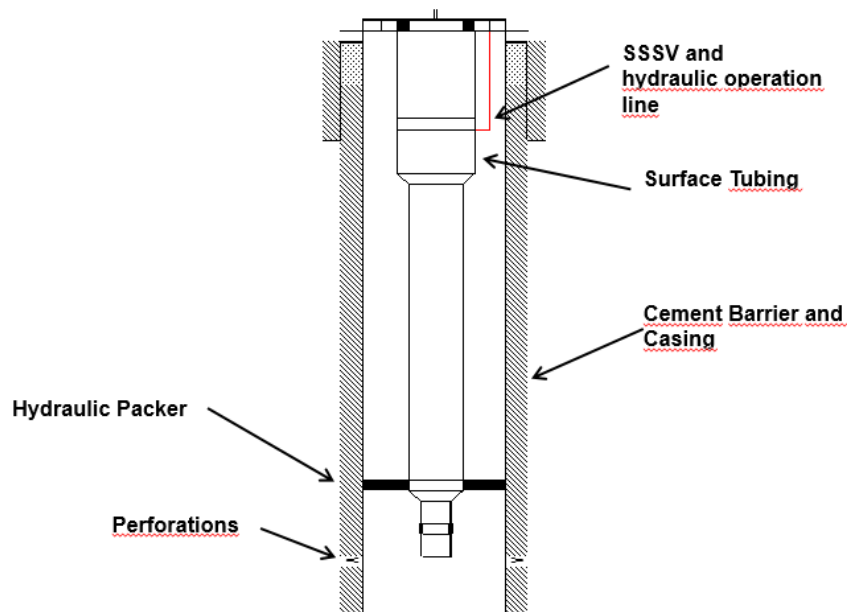


Figure 5: Schematic of a storage well (Source: RAG)

These two barriers should be guaranteed through all the stages of the well lifecycle, including work-overs (i.e. heavy maintenance on wells).

5.3 Monitoring Plan

The subsurface monitoring plan is adapted to each facility. The surveillance includes:

- The monitoring of the storage formation or the caverns;
- If required (relevant for aquifer storages), the monitoring of an upper aquifer as indicator of the containment provided by the cap-rock;
- Specific monitoring action according to the specific situation of each UGS: water quality of the aquifer, subsidence of the ground above cavern, seismicity of the zone, ...
- The monitoring of the water disposal wells, if any, including the water quality and the possible pressure response in other formations;
- The monitoring of the storage wells including the annuli: between the two barriers and the cemented ones;
- The monitoring of the gas qualities injected into or withdrawn from the reservoir.

5.4 Operation and Monitoring of Surface Facilities

Measures to operate safely surface facilities and monitor their integrity are defined through Seveso requirements (see §4) and Pressure Equipment Directive (2014/68/UE replacing 97/23/EC).

6 CONCLUSION

These standards and regulations have ensured European storages to operate without any major accident since several decades and to guarantee the security of gas supply in Europe.

The safety management system ensures a continuous improvement of the practices.

7 EUROPEAN STANDARDS ON UNDERGROUND GAS STORAGE

- EN 1918-1:2016: Gas infrastructures – Underground gas storage – Part 1: functional recommendations for storage in aquifers
- EN 1918-2:2016: Gas infrastructures – Underground gas storage – Part 2: functional recommendations for storage in oil and gas fields
- EN 1918-3:2016: Gas infrastructures – Underground gas storage – Part 3: Functional recommendations for storage in solution-mined salt caverns
- EN 1918-4:2016: Gas infrastructures – Underground gas storage – Part 4: Functional recommendations for storage in rock caverns
- EN 1918-5:2016: Gas infrastructures – Underground gas storage – Part 5: functional recommendations for surface facilities

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