BS EN 1918-2:2016

BSI Standards Publication

Gas infrastructure — Underground gas storage

Part 2: Functional recommendations for storage in oil and gas fields

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National foreword

This British Standard is the UK implementation of EN 1918-2:2016. It supersedes BS EN 1918-2:1998 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GSE/33, Gas supply.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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This European Standard was approved by CEN on 10 January 2016.

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European foreword

This document (EN 1918-2:2016) has been prepared by Technical Committee CEN/TC 234 “Gas infrastructure”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2016 and conflicting national standards shall be withdrawn at the latest by September 2016.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 1918-2:1998.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

For a list of significant technical changes between this European Standard and EN 1918-2:1998, see Annex B.

This document is Part 2 of a European Standard on “Gas infrastructure - Underground gas storage” which includes the five following parts:

— *Part 1: Functional recommendations for storage in aquifers*;

— *Part 2: Functional recommendations for storage in oil and gas fields*;

— *Part 3: Functional recommendations for storage in solution-mined salt caverns*;

— *Part 4: Functional recommendations for storage in rock caverns*;

— *Part 5: Functional recommendations for surface facilities.*

Directive 2009/73/EC concerning common rules for the internal market in natural gas and the related Regulation (EC) No 715/2009 on conditions for access to the natural gas transmission networks also aim at technical safety including technical reliability of the European gas system. These aspects are also in the scope of CEN/TC 234 standardization. In this respect CEN/TC 234 evaluated the indicated EU legislation and amended this technical standard accordingly, where required and appropriate.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard covers the functional recommendations for design, construction, testing, commissioning, operation, maintenance and abandonment of underground gas storage (UGS) facilities in oil and gas fields up to and including the wellhead.

It specifies practices which are safe and environmentally acceptable.

For necessary surface facilities for underground gas storage, EN 1918-5 applies.

In this context "gas" is any hydrocarbon fuel:

— which is in a gaseous state at a temperature of 15 °C and under a pressure of 0,1 MPa (this includes natural gas, compressed natural gas (CNG) and liquefied petroleum gas (LPG). The stored product is also named fluid);

— which meets specific quality requirements in order to maintain underground storage integrity, performance, environmental compatibility and fulfils contractual requirements.

This European Standard specifies common basic principles for underground gas storage facilities. Users of this European Standard should be aware that more detailed standards and/or codes of practice exist. A non-exhaustive list of relevant standards can be found in Annex A.

This European Standard is intended to be applied in association with these national standards and/or codes of practice and does not replace them.

In the event of conflicts in terms of more restrictive requirements in the national legislation/regulation with the requirements of this European Standard, the national legislation/regulation takes precedence as illustrated in CEN/TR 13737 (all parts).

NOTE CEN/TR 13737 (all parts) contains:

— clarification of relevant legislation/regulations applicable in a country;

— if appropriate, more restrictive national requirements;

— national contact point for the latest information.

This European Standard is not intended to be applied retrospectively to existing facilities.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1918-5, *Gas infrastructure - Underground gas storage - Part 5: Functional recommendations for surface facilities*

3 Terms and definitions

3.1 Terms and definitions common to parts 1 to 4 of EN 1918

For the purposes of this document, the following terms and definitions apply. They are common to parts 1 to 4 of EN 1918.

3.1.1
abandoned well
well permanently out of operation and permanently plugged including removed surface facilities

3.1.2
annulus
space between two strings of pipes or between the casing and the borehole

3.1.3
aquifer
reservoir, group of reservoirs or a part thereof that is fully water-bearing and displaying differing permeability/porosity

3.1.4
auxiliary well
well completed for other purposes than gas injection/withdrawal, e.g. water disposal

3.1.5
casing
pipe or set of pipes that are screwed or welded together to form a string, which is placed in the borehole for the purpose of supporting the borehole and to act as a barrier preventing subsurface migration of fluids when the annulus between it and the borehole has been cemented and to connect the storage reservoir respectively cavern to surface

3.1.6
casing shoe
bottom end of a casing

3.1.7
cementing
operation whereby usually a cement slurry is pumped and circulated down a cementation string within the casing and then upwards into the annulus between the casing and the open or cased hole

3.1.8
completion
technical equipment inside the last cemented casing of a well

3.1.9
containment
capability of the storage reservoir or cavern and the storage wells to resist leakage or migration of the fluids contained therein

Note 1 to entry: This is also known as the integrity of a storage facility.

3.1.10
core sample
sample of rock taken during coring operation in order e.g. to determine various parameters by laboratory testing and/or for a geological description

3.1.11
cushion gas volume
gas volume required in a storage for reservoir management purpose and to maintain an adequate minimum storage pressure for meeting working gas volume delivery with a required withdrawal profile and in addition in caverns also for stability reasons

Note 1 to entry: The cushion gas volume of storages in oil and gas fields may consist of recoverable and non-recoverable in-situ gas volumes and/or injected gas volumes.

3.1.12
drilling
all technical activities connected with the construction of a well

3.1.13
exploration
all technical activities connected with the investigation of potential storage locations for the assessment of storage feasibility and derivation of design parameters

3.1.14
formation
body of rock mass characterized by a degree of homogeneous lithology which forms an identifiable geologic unit

3.1.15
gas injection
gas delivery from gas transport system into the reservoir/cavern through surface facilities and wells

3.1.16
gas inventory
total of working and cushion gas volumes contained in UGS

3.1.17
gas withdrawal
gas delivery from the reservoir or cavern through wells and surface facilities to a gas transport system

3.1.18
geological modelling
generating the image of a structure from the information gathered

3.1.19
indicator horizon
horizon overlying the caprock in the storage area and used for monitoring

3.1.20
landing nipple
device in a tubing string with an internal profile to provide for latching and sealing various types of plugs or valves

3.1.21
liner
casing installed within last cemented casing in the lowermost section of the well without extension to surface

3.1.22
lithology
characteristics of rocks based on description of colour, rock fabrics, mineral composition, grain characteristics, and crystallization

3.1.23
logging
measurement of physical parameters versus depth in a well

3.1.24
master valve
valve at the wellhead designed to close off the well for operational reasons and in case of emergency or maintenance

3.1.25
maximum operating pressure
MOP
maximum pressure of the storage reservoir or cavern, normally at maximum inventory of gas in storage, which has not to be exceeded in order to ensure the integrity of the UGS and is based on the outcome of geological/technical engineering and is approved by authorities

Note 1 to entry: The maximum operating pressure is related to a datum depth and in caverns usually to the casing shoe of the last cemented casing.

3.1.26
minimum operating pressure
minimum pressure of the storage reservoir or cavern, normally reached at the end of the decline phase of the withdrawal profile and for caverns is based on geomechanical investigations to ensure stability and to limit the effect of subsidence and normally has to be approved by authorities and has not to be underrun

Note 1 to entry: The minimum pressure is related to a datum depth.

3.1.27
monitoring well
observation well
well for purposes of monitoring the storage horizon and/or overlying or underlying horizons for subsurface phenomena such as pressure fluctuation, fluid flow and qualities, temperature, etc.

3.1.28
operating well
well used for gas withdrawal and/or injection

3.1.29
overburden
all sediments or rock that overlie a geological formation

3.1.30
permeability
capacity of a rock to allow fluids to flow through its pores

Note 1 to entry: Permeability is usually expressed in Darcy. In the SI Unit system permeability is measured in m^2.

3.1.31
porosity
volume of the pore space (voids) within a rock formation expressed as a percentage of its total volume

3.1.32
reservoir
porous and permeable (in some cases naturally fractured) formation having area- and depth-related boundaries based on physical and geological factors

Note 1 to entry: It contains fluids which are internally in pressure communication.

3.1.33
saturation
percentages of pore space occupied by fluids

3.1.34
seismic technology
technology to characterize the subsurface image with respect to extent, geometry, fault pattern and fluid content applying acoustic waves, impressed by sources near to surface in the subsurface strata, which pass through strata with different seismic responses and filtering effects back to surface, where they are recorded and analysed

3.1.35
string
entity of casing or tubing plus additional equipment, screwed or welded together as parts of a well respectively completion

3.1.36
subsurface safety valve
valve installed in casing and/or tubing beneath the wellhead or the lower end of the tubing for the purpose of stopping the flow of gas in case of emergency

3.1.37
tubing
pipe or set of pipes that are screwed or welded together to form a string, through which fluids are injected or withdrawn or which can be used for monitoring

3.1.38
well
borehole and its technical equipment including the wellhead

3.1.39
well integrity
well condition without uncontrolled release of fluids throughout the life cycle

3.1.40
well integrity management
complete system necessary to ensure well integrity at all times throughout the life cycle of the well, which comprises dedicated personnel, assets including subsurface and surface installations, and processes provided by the operator to monitor and assess well integrity

3.1.41
wellhead
equipment supported by the top of the casing including tubing hanger, shut off and flow valves, flanges and auxiliary equipment, which provides the control and closing-off of the well at the upper end of the well at the surface

3.1.42
working gas volume
volume of gas in the storage above the designed level of cushion gas volume, which can be withdrawn/injected with installed subsurface and surface facilities (wells, flow lines, etc.) subject to legal and technical limitations (pressures, gas velocities, flowrates, etc.)

Note 1 to entry: Depending on local site conditions (injection/withdrawal rates, utilization hours, etc.), the working gas volume may be cycled more than once a year.

3.1.43
workover
well intervention to restore or increase production, repair or change the completion of a well or the leaching equipment of a cavern

3.2 Terms and definitions not common to parts 1 to 4 of EN 1918

For the purposes of this document, the following terms and definitions apply, which are common to part 2 of EN 1918 only.

3.2.1
boundary fault
fault, which forms the physical border in some storage reservoirs

3.2.2
capillary pressure
pressure difference between the non-wetting phase and the wetting phase in a porous rock

3.2.3
capillary threshold pressure
pressure needed to overcome the property of a porous rock saturated with a wetting phase (water) to block the flow of a non-wetting phase (gas)

3.2.4
caprock
sealing barrier for fluids overlying the pore storage reservoir

3.2.5
closure
vertical distance between the top of the structure and the spill point

3.2.6
gas oil contact
interface between the gas and the oil phase in a reservoir

3.2.7
gas water contact
interface between the gas and water in a reservoir

3.2.8
hanger
device for supporting the weight of pipes and to assure the pressure tightness of the annulus

3.2.9
material balance
calculation method based on the fluids withdrawn from or injected into a reservoir and the fluids remaining in the reservoir excluding the displacement process in the reservoir

3.2.10
initial reservoir pressure
pressure existing in a reservoir before any change due to operation of the reservoir or due to operation in the surrounding area

Note 1 to entry: The initial reservoir pressure is related to a datum depth.

3.2.11
reservoir simulation
numerical modelling of a reservoir to predict or to monitor the behaviour and movement of the fluids in the formation and in general the reservoir behaviour with respect to rates, pressures and saturation distribution

Note 1 to entry: A reservoir model may be calibrated against historical data through the history match process.

3.2.12
sand screen
filters placed at the level of the storage formation in order to avoid the entrainment of sand particles and fines during withdrawal

3.2.13
spill point
structural point within a reservoir, where hydrocarbons could leak and migrate out of the storage structure

3.2.14
well testing
taking pressure and flow rate measurements during flowing and shut-in periods of operating wells to provide information about the characteristics of the storage and the capacity of the wells

4 Requirements for underground gas storage

4.1 General

This clause gives general requirements for underground gas storage. More specific requirements for underground gas storage in oil and gas fields are given in Clauses 5, 6, 7, 8 and 9.

4.2 Underground gas storage

4.2.1 Overview and functionality of underground gas storage

The EN 1918 covers storage of natural gas, Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG). Because of the relevance of underground gas storage of CNG the major part of this introduction is related to the storage of this.

The underground gas storage (UGS) is an efficient proven common technology and is in use since 1915. UGS became an essential indispensable link in the gas supply chain for adjusting supply to meet short-term and seasonal changes in demand.

Natural gas produced from oil and gas fields is increasingly being used to supply energy requirements. As the gas supply from these fields does not match with the variable market demand natural gas is injected into subsurface storage reservoirs when market demand falls below the level of gas delivery or if there is an economic incentive for injection. Gas is withdrawn from storage facilities to supplement the supply if demand exceeds that supply or withdrawal is economically attractive.

The primary function of UGS is to ensure that supply is adjusted for peak and seasonal demand. Apart from this, the storage facilities can provide stand-by reserves in case of interruption of the planned supply. Increasingly UGS is applied for commercial storage services.

Thus, in summary underground gas storage facilities can be used for:

- security of supply;
- providing flexibilities;
- balancing of seasonal demand variabilities;
- structuring of gas supply;
- provision of balancing energy for the optimization of transport grids;
- trading and arbitrage purpose;
- stand-by provisions and strategic reserves;
- structuring renewable energy sources – power to gas;
- storage of associated gas as service for production optimization and resultant environmental conservation.

4.2.2 Types of UGS

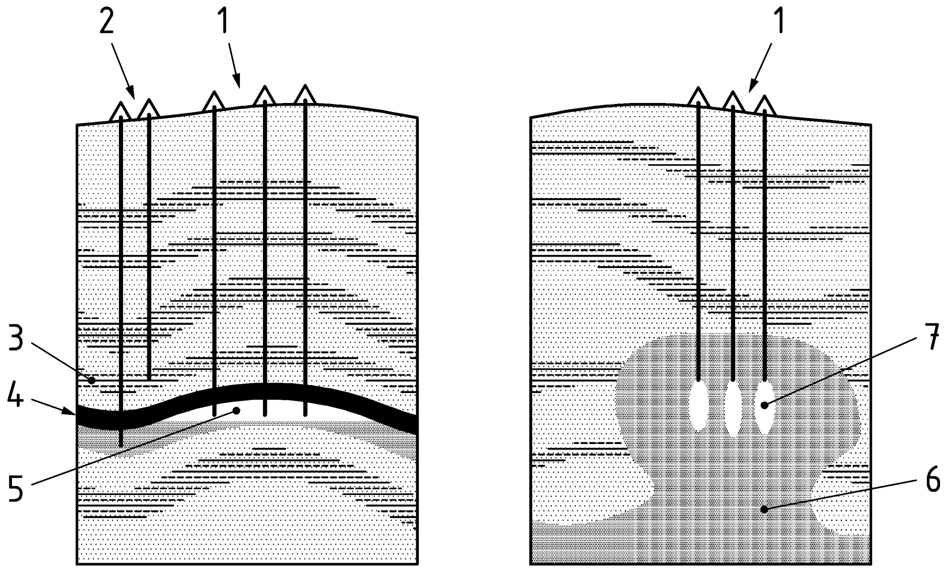
For storage of natural gas several types of underground gas storage facilities can be used, which differ by storage formation and storage mechanism (see Figure 1):

- pore storage:
  - storage in aquifers;
  - storage in former gas fields;
  - storage in former oil fields.
- caverns:

— storage in salt caverns;

— storage in rock caverns (including lined rock caverns);

— storage in abandoned mines.



Key

1 operating wells

2 monitoring wells

3 indicator horizon

4 caprock

5 storage reservoir and stored gas

6 salt dome

7 cavern

Figure 1 — Storage in aquifers, oil and gas fields, solution mined salt caverns

For LPG storage only salt or rock caverns can be applied.

The UGS type applied is dependent on the geological conditions and prerequisites as well on the designed capacity layout.

4.2.3 General characterization of UGS

UGS are naturally or artificially developed reservoirs respectively artifically developed caverns in subsurface geological formations used for the storage of natural gas (or LPG). A UGS consists of all subsurface and surface facilities required for the storage and for the withdrawal and injection of natural gas (or storage of LPG). Several subsurface storage reservoirs or caverns may be connected to one or several common surface facilities.

The suitability of subsurface geological formations have to be investigated individually for each location, in order to operate the storage facilities in an efficient, safe and environmentally compatible manner.

In order to construct a storage facility wells are used to establish a controlled connection between the reservoir or cavern and the surface facilities at the well head. The wells used for cycling the storage gas are called operating wells. In addition to the operating wells specially assigned observation wells may be used to monitor the storage performance with respect to pressures and saturations and the quality of reservoir water as well as to monitor any interference in adjacent formations.

For the handling of gas withdrawal and gas injection the surface facilities are the link between the subsurface facilities and the transport system, comprising facilities for gas dehydration/treatment, compression, process control and measurement.

Gas is injected via the operating wells into the pores of a reservoir or into a cavern, thus building up a reservoir of compressed natural gas (or LPG).

Gas is withdrawn using the operating wells. With progressing gas withdrawal, the reservoir or cavern pressure declines according to the storage characteristic. For withdrawal, re-compression may be needed.

The working gas volume can be withdrawn and injected within the pressure range between the maximum and minimum operating pressure. In order to maintain the minimum operating pressure it is inevitable that a significant quantity of gas, known as cushion gas volume, remains in the reservoir or cavern.

The storage facility comprises the following storage capacities:

— working gas volume;

— withdrawal rates;

— injection rates.

The technical storage performance is given by withdrawal and injection rate profiles versus working gas volume.

Recommendations for the design, construction, operation and abandonment of underground storage facilities are described in Clauses 5, 6, 7, 8 and 9.

Construction of a storage facility begins after the design and exploration phase and should be carried out in accordance with the storage design. It is based on proven experience from the oil and gas industry.

For specific elements of an underground gas storage facility, e.g. wells and surface installations, existing standards should be applied.

4.2.4 Storage in oil and gas fields

Storage of gas in oil and gas fields is a proven technology and is mainly used for the storage of large gas volumes.

These UGS in pore storages (see Figure 2) are developed by building up a reservoir of compressed natural gas in the pores of a subsurface structure, which was originally hydrocarbon bearing as in oil and gas fields.

For UGS in oil and gas fields (see Figure 2) the containment up to the initial pressure of these reservoirs is proven by the existence of the hydrocarbon accumulation. The essential knowledge about the reservoir behaviour and properties is available from the exploration phase and from the production period of the oil and gas field. The storage integrity has to be analysed and demonstrated when reservoir pressures above initial pressures are applied.

Special care has to be dedicated to the impact of the stored gas on adjacent strata and the interference of injected fluids with reservoir water and/or oil in contact.

Feasibility of pore storage structures requires:

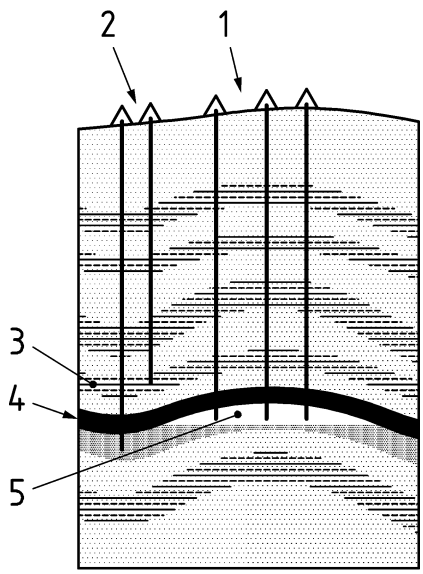
— dome-shaped structures, structural traps and/or lithological traps with an adequate closure to ensure satisfactory containment of the gas-filled zone;

— reservoirs with adequate porosity and permeability to provide the desired capacity and productivity;

— lithological, vertical and horizontal geological containment of the storage reservoir considering the structural shape, sealing caprock layers and faults, if any, in order to prevent gas leakage at anticipated operating pressures;

— especially proof of the caprock tightness at the anticipated operating pressures above initial reservoir pressure based on the capillary threshold concept;

— technical integrity of existing and abandoned wells in order to prevent gas leakage at anticipated operating pressures.



Key

1 storage wells

2 monitoring wells

3 indicator horizon

4 caprock

5 storage reservoir and stored gas

Figure 2 — Storage in oil and gas fields

4.3 Long-term containment of stored gas

The storage facility shall be designed, constructed and operated to ensure the continuing long-term containment of the stored gas.

This presupposes:

— adequate prior knowledge of the geological formation, in which the storage is to be developed and of its geological environment;

— acquisition of all relevant information needed for specifying parameter limits for construction and operation;

— demonstration that the storage is capable of ensuring long-term containment of the stored gas through its hydraulic and mechanical integrity.

All operations adjacent to a storage facility shall be compatible with the storage activity and shall not endanger its integrity.

All new storage projects shall take into account existing adjacent activities.

4.4 Environmental conservation

4.4.1 Subsurface

The storage facility shall be designed, constructed, operated and abandoned in order to have the lowest reasonably practicable impact on the environment.

This presupposes, that the surrounding formations have been identified and their relevant characteristics determined and that they are adequately protected.

4.4.2 Surface

The storage facility shall be designed, constructed, operated and abandoned so that it has the lowest reasonably practicable impact on ground movement at the surface and on the environment.

4.5 Safety

The storage facility shall be designed, constructed, operated, maintained and abandoned to get the lowest reasonably practicable risk to the safety of the staff, the public, the environment and the facilities.

In addition to the usual safety rules and recommendations applicable to all comparable industrial installations measures shall be taken to reduce the risk and consequences of blow-out and leakages. These measures shall at least include a surface safety valve and a subsurface safety valve for gas bearing wells if technically applicable.

A safety management system should be applied.

4.6 Monitoring

In order to limit the environmental impact of storages adequate monitoring systems and procedures shall be implemented and applied.

5 Design

5.1 Design principles

Surface and subsurface installations shall be designed in an integrated way in order to achieve an environmentally, economically and technically optimized layout.

Surface and subsurface installations shall be designed to control the process and used fluids at any combination of pressure and temperature to which they may be subjected to within a determined range of operating conditions. They shall conform to existing standards for the individual part of a storage system. The key parameters and procedures at the connection with the gas transport system and the operative cooperation with the transport system operator shall be considered.

Proven technology shall be used for analysis and calculations. All relevant data should be documented.

Technology proven in the oil and gas industry should be used where possible.

The design shall be based on written procedures and shall be carried out by competent personnel and companies.

All relevant data concerning the design (such as equipment specification, operating procedures, quality assurance plan) shall be documented and made available to the owner and the operator of the storage facility.

Emergency procedures should be developed.

Adherence to the safety and environmental requirements shall be monitored.

During the design phase the following activities and reviews related to safety will be carried out, including but not limited to:

— HAZOP review or equivalent;

— risk analysis and pre-construction safety study.

The design should be summarized in a report which is sufficient for the purpose of demonstrating that adequate safety and reliability have been incorporated into the design, construction, operation and maintenance of the facility. The safety study will be updated at storage construction completion to take into account the actual facility to be operated.

5.2 Field description and storage behaviour

A review of all available information shall be conducted in order to:

— identify the trapping mechanism;

— evaluate the structure of the reservoir and its closure;

— delineate the boundaries of the proposed storage formation;

— identify the fault pattern;

— determine the sealing capacity of the boundary faults;

— determine sealing properties of caprock and if required of the surrounding formations;

— determine the sedimentology of the reservoir;

— evaluate the horizontal and vertical distribution of porosity, permeability, capillary properties and saturations;

— determine gas water, gas oil, oil water contacts;

— determine the hydrocarbons in place;

— determine type and strength of the drive mechanisms;

— determine well capacities;

— identify and assess the integrity of all existing and abandoned wells.

The field description shall include a set of maps showing clearly the depth contour lines and the thickness of the proposed storage formation, faults, fluid contacts and all existing wells, as well as stratigraphic correlations.

If the design of the storage facility could cause the gas phase to extend beyond the original gas water, oil water contacts, the structure and caprock should be defined in the area the gas may spread. Any spill-point situation or insufficient confinement should be identified.

If data from wells and other available data are not sufficient to give an adequate description of the field and the overburden or if this description is questionable, additional data should be collected, e.g. by geophysical work, logging, testing, drilling or coring. Should the storage be operated above initial reservoir pressure, then particular care in this area should be taken.

Well test information, pressure and production history data from the proposed storage and surrounding formations shall be analysed to estimate the capacity of the storage reservoir. Its reservoir dynamic properties should be determined by a material balance study, numerical simulation or other means. The future pressure performance and the maximum possible future migration of the hydrocarbons should be evaluated.

The operator shall obtain the physical and chemical properties of the native hydrocarbons and of the gas to be stored, i.e. composition, density, viscosity and pressure-volume-temperature behaviour.

The rock pore volume available for storage shall be evaluated.

5.3 Determination of the maximum operating pressure

Based on the overall description of the caprock, the overburden, the structural situation, the sealing capacity of faults and the technical situation of all wells penetrating the storage formation, the maximum operating pressure for the storage facility shall be determined so that the following is avoided:

— mechanical disturbance;

— gas migration through the caprock;

— uncontrolled lateral spread of gas;

— jeopardizing the integrity of all existing wells that have penetrated the storage reservoir.

For the anticipated maximum operating pressure the existence and the continuity of a gastight caprock shall be proved by a detailed investigation. Consideration should be given to recovering cores from the caprock for gas tightness tests especially when exceeding initial reservoir pressure. As the geological containment up to initial reservoir pressures is proven due to the existence of an oil and gas field, investigations for storages at pressures up to the initial pressure are mainly focused on the technical integrity of wells.

The characterization of the caprock should specify:

— the lithology;

— the petrophysical and hydraulical characteristics and, if applicable, the capillary threshold pressure and the permeability;

— the geometry with respect to structure, thickness and lateral extension;

— geological discontinuities or other features, which may affect the containment above initial reservoir pressure;

— fracture gradients.

Based on these investigations about the caprock, the overburden and the technical integrity, the maximum operating pressure of the reservoir shall be evaluated at the following locations:

— the most sensitive position in the storage reservoir;

— structural locations, which are in hydraulic communication with the storage.

This will enable the following to be avoided:

— mechanical disturbance of the caprock by fracturing;

— gas migration into the caprock by displacing water out of the caprock, via faults in the formations or due to leakages in wells.

The maximum operating pressure (MOP) of the reservoir is limited by the lowest pressure value from:

— the fracture pressure of the caprock;

— the pressure at which the well integrity could be affected;

— the calculated pressure resulting from the pressure in the caprock plus the threshold capillary pressure of the caprock if applicable.

5.4 Wells

5.4.1 General

For the operation of an underground storage facility in oil and gas fields three types of wells are used:

— operating wells, used for the injection and withdrawal of the storage gas and also for monitoring purposes;

— monitoring wells in the storage formation and indicator horizon such as upper aquifers or oil and gas fields;

— auxiliary wells for water supply or for disposal of water.

The design of a well is focused on:

— the drilling platform, well site and wellhead area;

— the equipment of the well, especially the casing and the completion (see Figure 3);

and this design shall take into account:

— the integrity of the storage reservoir;

— the gas tightness of the subsurface installations;

— the flow rates, pressures and temperatures, that will be applied to the well, especially for the cyclic operation of the storage facility;

— the composition of the gas, noting corrosive components;

— corrosion prevention, e.g. by inhibiting fluids in the casing/tubing annulus;

— protection of the formations (e.g. water aquifers, oil fields), which have been penetrated by the well;

— subsurface measurement requirements;

— the planned lifetime of the well;

— use of existing wells, if applicable;

— location of the well;

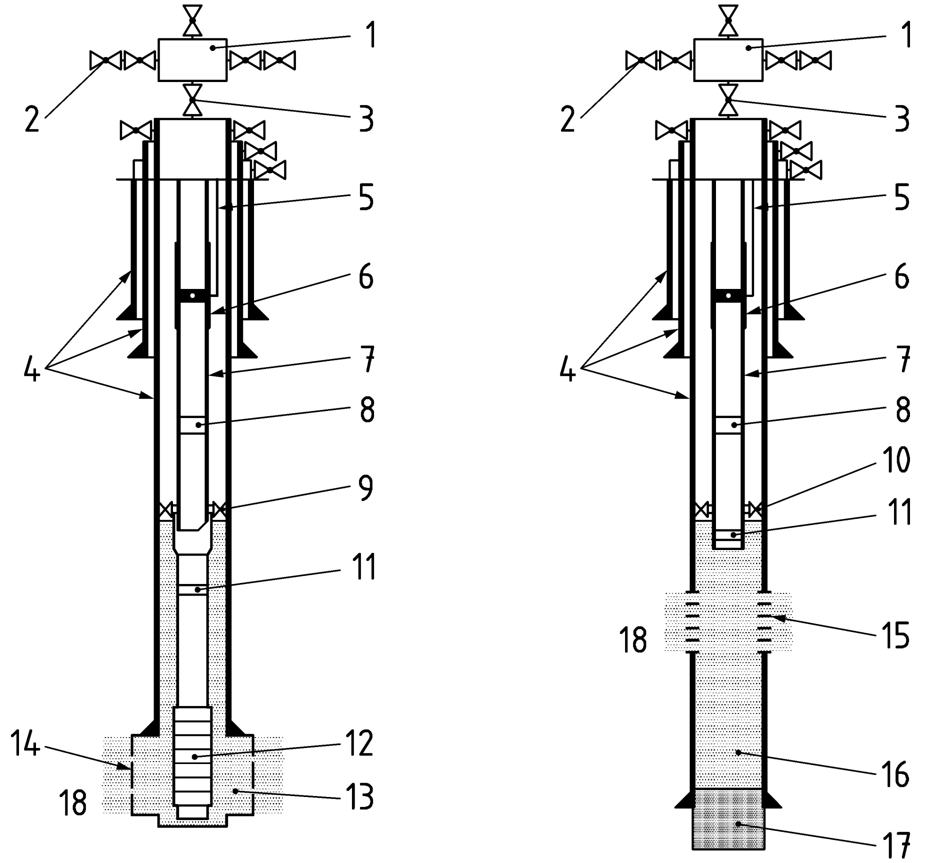
— applicable standards and recommendations (see list in informative Annex A).

To ensure the integrity of the system all information shall be used, which are necessary to evaluate the wellhead, casing, cement and the completion scheme for all operating conditions in all existing and abandoned wells penetrating the storage formation or the directly overlaying caprock. It shall be verified that the wellhead, tubing, liners and casing strings of the existing wells and abandoned wells meet these requirements. Wells shall be designed so that stimulations and perforating can be carried out without jeopardizing caprock, casing and cement integrity.

All equipment should conform to the product related standards in force. Most of the equipment necessary is related to the petroleum industry, e.g. valves, tubing strings, accessories or packers.

If the status of a well may jeopardize storage containment, remedial action shall be taken; if necessary such a well shall be plugged and abandoned.

Original design of the wells is recommended to include their plugging and abandonment process.



Key

1	wellhead	10	production packer with snap-latch seal assembly
2	wing valve	11	landing nipple
3	master valve	12	sand screen
4	casing	13	gravel pack
5	control line for subsurface safety valve	14	underreamed storage horizon
6	subsurface safety valve	15	perforation
7	tubing	16	sump
8	sliding side door	17	cement head
9	production gravel pack packer – safety joint	18	storage reservoir

Figure 3 — Examples for well completions – gravel pack completion (left) and perforated cased hole completion (right)

5.4.2 Location

The drilling platform, well site and wellhead area shall be selected so that any inadmissible impact on the environment is prevented. It shall be located in positions such that, if an emergency situation occurs, the risk of harm to people and neighbouring property will not exceed acceptable levels.

Wells should, if applicable, be concentrated on well platforms in well clusters.

Safety distances to housing zones or critical neighbouring points shall be based on normal operation and emergency according to applicable rules and regulations.

The wellhead area should be protected against unauthorized access.

The wellhead area shall be designed to avoid any flow of contaminating fluids to the environment during drilling and workover as well as during storage operation.

The cellar and the foundation for the drilling and workover rig shall be designed to bear the static and dynamic loads resulting from drilling or workover.

Ambulances and safety equipment shall have access to the well site at any time.

5.4.3 Equipment

5.4.3.1 Casings

A well (see Figure 3) is built up by a set of casing strings cemented in the annulus between the casing and the formation. The last cemented inner casing string of wells likely to be in contact with gas should be provided with gastight connections.

By the installation of cemented casings sensitive formations such as fresh water horizons and unstable layers are protected and tightness is provided between water bearing horizons, hydrocarbon formations and the storage horizon. A sufficient number of casing strings shall be set to avoid uncontrolled fluid movements into the well during the drilling operation. A casing shall be installed and cemented on either the storage caprock or a leak tight formation separating the storage horizon from overlaying aquifers and/or oil and gas fields. In certain cases, a liner installation may be installed in the lowermost interval of the well without a surface casing string.

The program for the casing scheme and the cementation shall be planned and carried out so that there is no impact on upper fresh water horizons.

The diameter of the casings shall be selected to meet withdrawal/injection requirements.

The grades of the casings shall be selected to ensure that pressure integrity is maintained under the permitted operating conditions. Design and safety factors for collapse, burst, tension and compression of casings should be applied according standards in force.

Casings should be manufactured, inspected and tested in accordance with the standards and recommendations in force.

Casing strings shall be cemented to prevent fluid movements behind them. Particular attention should be paid to cementing techniques which minimize voids, channelling and micro annuli. Cement bonding to both the casing string and the strata should be investigated.

The bottom part of the last cemented casing string should be pressure tested after installation in accordance with Clause 7.

Suitable technical measures for preventing corrosion of the last cemented casing should be considered.

5.4.3.2 Completion

A well completion (see Figure 3) consists of installations that are necessary for safe operating or inspection purposes inside the casing strings and/or bottom hole, e.g. tubing strings or sand screens.

A storage well completion typically consists of:

— if applicable, a sand screen in front of the storage horizon;

— a tubing string completed with gastight joints (under the permitted operating conditions) installed inside the casing;

— a packer anchored to the casing above the storage formation and connected to the tubing to isolate the cemented casing from the fluid and pressure inside the tubing;

— a packer/tubing anchor seal assembly or a sliding seal assembly at the packer or a telescopic joint in the tubing may be used to cover the cyclic stresses caused by temperature and pressure fluctuations. To face the effect of elongation or shrinkage due to storage operation the tubing shall be pre-stressed;

— one or more landing nipples at strategic positions in the tubing;

— a subsurface safety valve, which may if applicable be surface-controlled, located in the tubing string of operating wells and of wells, which penetrate gas-bearing intervals and are in pressure communication with the storage;

— a wellhead with at least one master valve and one wing valve.

Completion needs to be adapted for observation and auxiliary wells.

Gas storage wells are characterized by long-term use.

Unlike in gas or oil production the operation cycles in gas storages lead to large variations in pressure and temperature in the operation wells. This has to be taken into account for the design and installation of the completion.

The annulus between the last cemented casing and the tubing isolated at its bottom end by the packer and at its top end by the tubing hanger is filled with annulus fluid. This prevents the last cemented casing from coming into contact with flowing gas and so protects it against corrosion and undue pressure changes which might otherwise damage the surrounding cement. Above all, it provides a double containment for enhanced safety. Leaks may be detected and monitored by measuring pressure and volume at the wellhead. Consequently, all wells likely to be gas filled shall use this double containment concept, providing greater safety in terms of leak tightness.

Landing nipples for plugs should be added to the system to ensure that the well can be totally sealed at the packer level.

Measures shall be taken to minimize blow-out hazards. Therefore in gas bearing wells or in wells in pressure communication with the storage reservoir at least one master valve shall be installed at the wellhead and, except for exceptional cases justified by technical considerations, a subsurface safety valve shall be installed in the tubing.

This subsurface safety valve is set into the upper part of the tubing several meters below the surface. It can be activated via a control line from the surface and/or by the subsurface pressure and/or flow rate conditions. Subsurface velocity safety valves operated without control lines, e.g. "storm chokes", can be installed as well in certain cases.

The subsurface safety valve shall shut down automatically in the event of unallowable operating conditions as excessive rates, abnormal low pressure or emergency or remote/local shut-down signal. Safety valves should only be re-opened after safe conditions have been re-established. Re-opening of the subsurface safety valve shall not be possible from the control room.

An access port shall be installed at the head of the annulus. As a minimum requirement, installations on the last cemented annulus for pressure measurement and on the casing-tubing annulus for pressure measurement and for injection of fluid shall be provided.

5.4.3.3 Wellhead

The wellhead shall control the flows into and out of the storage under normal and emergency operating conditions.

The wellhead shall have sufficient mechanical strength to withstand the maximum operating pressure of the storage facility.

The storage wellhead and the associated valves including actuators, flanges and ring type joints, should be compliant with the standards and recommendations in force.

Wellheads shall be designed to be installed with the workover/drilling rig on site.

Storage wells shall have at least one master valve. This valve shall isolate the well for operational reasons and in case of emergency or maintenance.

On the major intakes and offtakes the wellhead should have a manual and/or an actuated valve. Actuated valves are usually controlled by a local wellhead panel with an option for remote operation from a central control room.

Wellheads shall be equipped with standardized fittings so that, in the event of an accident, the flanges and fittings which compose them can be used for the direct connection of emergency equipment.

The design shall allow each connection to be pressure tested.

The wellhead/flowline system has to be equipped with devices to automatically shut down the well in case of unallowable operation or emergency. Remote controlled shut off of the flowline may be used as an alternative.

At least one surface safety device shall be installed and shall close in the event of:

— flowline rupture, e.g. extra low wellhead pressure;

— failure of utility supply (e.g. power, electricity, instrument air);

— site emergency shutdown system actuated either remotely or at the wellhead.

Safety devices shall not allow for re-opening from the control room.

A system for hydrate inhibitor injection may be provided at the wellhead to inhibit and control hydrate formation.

5.5 Monitoring systems

The monitoring system shall be designed to verify gas containment and storage reservoir integrity while the storage facility is operating. The design should require the collection of data such as representative storage pressures and annuli pressures, injected and withdrawn volumes and gas qualities and, if applicable, saturation logging results.

If required, observation wells and modelling techniques should be implemented in the monitoring system.

The storage behaviour, the extent of the gas phase and any losses should be identified and analysed, e.g. by material balance calculation or simulation studies.

The most appropriate monitoring system shall be individually established for each project.

5.6 Neighbouring subsurface activities

The design, construction and monitoring of any proposed storage facility shall take into account all neighbouring subsurface activities, past or present, such as oil or gas reservoirs, fresh water aquifers, mining activities and other underground gas storage facilities.

The operation of the planned storage facility and neighbouring subsurface activities shall be compatible with each other.

All available information necessary to evaluate the potential impact of a planned storage facility on neighbouring subsurface activities shall be used.

6 Construction

6.1 General

Construction of a storage facility begins after the design and exploration phase and should be carried out in accordance with the storage design.

This phase covers the construction of surface facilities (see EN 1918-5) and the drilling and completion of wells. It is based on proven experience from the oil and gas industry.

Drilling, cementing and completion, as well as inspection and testing of all subsurface equipment and the wellhead, shall conform to relevant standards and recommendations in force.

Employees and contractors shall be informed about the local safety and environmental circumstances and instructed to comply with the safety rules and environmental requirements.

A reporting system shall be set up. All equipment installed and materials used shall be documented. Discharge of all wastes, solids and fluids shall be controlled and documented in a reporting system.

6.2 Wells

Drilling mud shall be compatible with the formations drilled through in order to ensure good resistance of the open hole walls and to achieve a good open hole geometry, absence of damage to aquifers and from water contamination and to ensure quality of cementation.

The quality of the casing cement job, especially in the vicinity of the caprock/overburden shall be monitored. The last cemented casing shall be constructed that it is gas tight and any unintended release of gas does not occur under the pressure conditions likely during storage operation.

If fluids are expected during drilling, measures shall be taken to avoid any risk of unintended release of these fluids. Such measures include e.g. providing mud pumps with a large enough capacity, providing an adequate reserve of appropriate quality mud, providing emergency power supply, checking the anchorage and solidity of the casings and using blow-out preventers.

6.3 Completions

The length and diameter of casing, tubing and equipment should be measured and a complete tally should be made for the tubing string.

Joints shall be carefully cleaned, inspected and gauged before running into the well.

Joints shall be torqued up in accordance with the manufacturer’s instructions.

Provision shall be made for pressure testing the casing/tubing during the installation.

If the setting depth of a special item of equipment is of relevance, it may be necessary to run a casing collar locator log or any other appropriate measure to identify and locate the equipment within the cased hole.

6.4 Wellheads

All flanged joints shall be pressure tested.

All the major casing/tubing seals shall be energized and tested to the supplier's recommended pressures and durations.

7 Testing and commissioning

Testing and commissioning shall be based on written procedures and shall be performed by skilled personnel. The safety of the first operational steps should be ensured by fully observing the recommendations on design and construction described in Clauses 5 and 6.

A complete knowledge of the storage behaviour and performance is only possible once the storage facility has been fully developed. Thus, for this type of storage facility, it may be impossible to carry out all testing and commissioning for the whole facility directly after construction. Some elements of the facility such as wells can be tested and commissioned both individually and combined in all relevant modes.

For every well, logging and testing shall be performed to verify wellhead, casing and cement integrity. It shall be verified that the wellhead, tubing, liners and casing strings of the wells conform to the recommendations in Clauses 5 and 6.

After drilling the last cemented casing including the casing shoe, may be pressure tested.

All parts of the wellhead shall be pressure tested before the well is commissioned.

Test pressures, test fluids and test duration may vary according to the specific requirements. They shall be chosen to check the operability of the tested installation.

Safety devices shall be functionally tested prior to operation.

8 Operation, monitoring and maintenance

8.1 Operating principles

The operation of any gas storage facility consists of several activities. The main part is the control of the injection and of the withdrawal of gas.

Operation of these facilities shall conform to written operating instructions and safety procedures. These shall cover start-up, normal operations, emergency conditions, shut-down and maintenance operations.

The management should employ operating staff of suitable number, ability and experience. The management shall ensure that staff is trained to carry out their duties in a safe manner. Safety training shall be given and updated as necessary.

All safety devices shall be periodically checked to ensure that they function properly.

Monitoring results may require remedial action and/or limitation of gas inventory in case of unacceptable deviation from the planned gas spreading. Workover jobs shall be carried out as soon as possible, if there is evidence that operation of a well is no longer safe or that the well integrity is jeopardized.

8.2 Monitoring

The main activity is the monitoring of the injected and withdrawn gas volumes, the storage pressures and determination of the extent of the gas phase.

The operator shall regularly control the storage behaviour and ensure the confinement of the storage facility by the installed monitoring system (see 5.5).

Stabilized shut-in wellhead pressures should be measured regularly for the operating and observation wells to monitor the storage facility.

These pressures can be converted to subsurface pressures for the control of the storage behaviour. Furthermore, downhole pressure tests should be carried out to verify the storage pressures and to verify the conversion of the wellhead pressures to downhole pressures.

Based on the monitored data the reservoir inventory shall be verified and the designed storage concept should be checked. If required, the storage model should be revised and predictions of the storage behaviour should be updated.

For the monitoring of all wells, an integrated analysis is required.

Wells are spread out over a large area and it is important that they are closely monitored. To this effect, periodic inspection runs shall be carried out on all the wells so as to detect any anomaly and to carry out any necessary measurement. Inspections to check that the annulus fluid is maintained in the annulus should be carried out at suitable intervals. The pressure on the casing/tubing annulus shall be monitored.

For monitoring the completion integrity, the annuli pressures shall be regularly measured. The completion or wellhead should be designed so that any build-up of pressure in the annuli can be vented safely.

An annular casing pressure management concept should also be established defining in particular the Maximum Allowable Annular Surface Pressure (MAASP).

Any deviations should be recorded and assessed as to whether remedial action needs to be taken.

8.3 Injection and withdrawal operations

During the injection phase the operation design limits, especially the maximum operating pressure (see 5.3), shall be adhered to.

The operator shall ensure that corrosion and erosion of casing and tubing are minimized and that they do not affect the safe operation of the storage facilities.

8.4 Maintenance of wells

It is recommended to develop a preventive well integrity plan. This can be defined as the application of technical, operational and organizational solutions to reduce risk of uncontrolled release of fluids throughout the life cycle of a well.

As part of the well integrity plan all equipment, such as wellhead, valves, plugs and especially safety equipment, such as subsurface safety valve, surface master valve and pressure control equipment, shall be regularly tested in situ (functional test) or in workshop when applicable.

Integrity of other well barrier elements such as tubing, production packer, last cemented casing and cementation should be regularly evaluated. In case the completion is removed, wall thickness measurements of the last cemented casing may be considered.

8.5 HSE

8.5.1 HSE management

The operator shall implement, within a reasonable time prior to start-up of the facility, a Health, Safety and Environmental (HSE) management system in accordance with applicable directives in force. It shall demonstrate that the operator takes all possible measures necessary to limit risks.

The HSE management system shall include operator’s Health, Safety, Security and Environmental (HSSE) requirements, rules, and regulations. It will provide a manual and procedures with the objective to accomplish operator’s HSSE performance standards. Subject manuals and procedures shall be auditable.

The HSE manual shall provide a structured collection of guidelines on HSE matters in all areas of underground gas storage by the storage facility operator. It covers but is not limited to the following topics: HSE management systems, HSE management in business and hazards and effects management tools & techniques.

8.5.2 Emergency procedures

The operator of the storage facility shall include emergency procedures in its HSE management system, which shall include but not be limited to:

— established emergency procedures, including procedures for the safe operation or the shut-down of the storage facility or parts thereof in the event of a failure or other emergency, and safety procedures for personnel at emergency site;

— documented emergency procedures to deal with fluid releases including mitigation of the release, notification and protection of operating personnel, documentation for notification and protection of the public in accordance with national regulation, and communications with community and regulatory bodies;

— audit and test procedures for operating personnel at frequencies determined by factors such as condition of the system and/or population density;

— a documentation system for audit and test results and recommendations.

9 Abandonment

9.1 General

The definitive closure and abandonment including restoration of the surface area of a storage facility shall be considered for each location, with special attention paid to long-term integrity and gas containment. In the case of the abandonment of one or few wells during operation, similar procedures for plugging and abandoning of wells as described in 9.3 shall be applied.

In individual cases, part of the infrastructure may be reused for another purpose but in this European Standard only definitive abandonment will be considered.

The studies and measurements shall prove the safety of the condition left after abandonment. A specific abandonment plan shall be prepared.

Plugging of wells is done to durably ensure the conservation of tightness between the storage reservoir and the major aquifers from bottom to surface.

The abandonment of a storage facility comprises:

— withdrawal of recoverable gas from the storage;

— plugging and abandonment of wells;

— dismantling surface facilities;

— monitoring.

The total abandonment program has to be confirmed by relevant authorities.

All operations comprised in the abandonment process shall be properly documented.

9.2 Withdrawal of the gas

Simulation shall be carried out to assess the recoverable gas and to analyse long-term impact on the integrity of the reservoir. The withdrawal of gas is subject to the technical and economic criteria of oil and gas production.

A long-term impact assessment of the remaining gas shall be conducted to determine the acceptable amount of gas which can be left in place, including status of the reservoir after blow down and pressure recovery.

9.3 Plugging and abandonment of wells

For the abandonment of wells usually the completion and finally the wellhead is removed.

Integrity of casing and tightness against the reservoir are investigated and repaired if needed to protect relevant horizons.

Plugging the well above the storage reservoir and if applicable below is usually done by packers, cement jobs or other plugging materials, equipment and procedures, which can demonstrate their long-term tightness.

Plugs shall be designed and positioned properly at specific intervals to seal off formations to be protected. Special attention is to be paid on the plug in contact with the gas, taking into account in particular the final situation after build-up of the reservoir pressure.

The abandonment of the well is concluded by cutting remaining casings below the surface. Subsequently casings are sealed by a solid patch welded on their top. The reference of the well is branded on the patch mentioning well name and date. If necessary, soil remediation is carried out, and the platform area may be restored.

9.4 Surface facilities

The abandonment of the surface facilities shall comply with EN 1918-5.

9.5 Monitoring

Monitoring and testing necessary for a safe abandonment should be put in place.

Annex A
(informative)

Non-exhaustive list of relevant standards

Reference	ICS	Title
EN 1127-1	13.230	*Explosive atmospheres — Explosion prevention and protection — Part 1: Basic concepts and methodology*
EN 12954	77.060	*Cathodic protection of buried or immersed metallic structures — General principles and application for pipelines*
EN 13509	77.060	*Cathodic protection measurement techniques*
EN 14505	77.060	*Cathodic protection of complex structures*
EN 15112	77.060 23.040.99	*External cathodic protection of well casings*
CEN/TR 13737-1	91.140.40	*Gas infrastructure — Implementation Guide for Functional Standards prepared by CEN/TC 234 — Part 1: General*
CEN/TR 13737-2	91.140.40	*Gas infrastructure — Implementation Guide for Functional Standards prepared by CEN/TC 234 — Part 2: National Pages related to CEN/TC 234 standards*
EN ISO 10405	23.040.01 75.180.10	*Petroleum and natural gas industries — Care and use of casing and tubing*
EN ISO 10417	75.180.10	*Petroleum and natural gas industries — Subsurface safety valve systems —Design, installation, operation and redress*
EN ISO 10423	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Wellhead and Christmas tree equipment*
EN ISO 10424-1	75.180.10	*Petroleum and natural gas industries — Rotary drilling equipment — Part 1: Rotary drill stem elements*
EN ISO 10424-2	75.180.10	*Petroleum and natural gas industries — Rotary drilling equipment — Part 2: Threading and gauging of rotary shouldered thread connections*
EN ISO 10427-1	75.180.10	*Petroleum and natural gas industries — Equipment for well cementing — Part 1: Casing bow-spring centralizers*
EN ISO 10427-2	75.180.10	*Petroleum and natural gas industries — Equipment for well cementing — Part 2: Centralizer placement and stop-collar testing*
EN ISO 10427-3	75.180.10	*Petroleum and natural gas industries — Equipment for well cementing — Part 3: Performance testing of cementing float equipment*
EN ISO 10432	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Subsurface safety valve equipment*
EN ISO 10870	13.060.70	*Water quality — Guidelines for the selection of sampling methods and devices for benthic macroinvertebrates in fresh waters (*ISO 10870*)*
EN ISO 11960	77.140.75 75.180.10	*Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells*

Reference	ICS	Title
EN ISO 11961	77.140.75 75.180.10	*Petroleum and natural gas industries — Steel drill pipe*
EN ISO 13500	75.180.10	*Petroleum and natural gas industries — Drilling fluid materials —- Specifications and tests*
EN ISO 13533	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Drill-through equipment*
EN ISO 13534	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Inspection, maintenance, repair and remanufacture of hoisting equipment*
EN ISO 14310	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Packers and bridge plugs*
EN ISO 15463	75.180.10	*Petroleum and natural gas industries — Field inspection of new casing, tubing and plain-end drill pipe*
EN ISO 16070	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Lock mandrels and landing nipples*
EN ISO 17078	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment*
ISO 5596	23.100.99	*Hydraulic fluid power — Gas-loaded accumulators with separator — Ranges of pressures and volumes and characteristic quantities*
ISO 10414-1	75.180.10	*Petroleum and natural gas industries — Field testing of drilling fluids — Part 1: Water-based fluids*
ISO 10416	75.100 75.180.10	*Petroleum and natural gas industries — Drilling fluids Laboratory testing*
ISO 10945	23.100.99	*Hydraulic fluid power — Gas-loaded accumulators — Dimensions of gas ports*
ISO 10946	23.100.99	*Hydraulic fluid power — Gas-loaded accumulators with separator — Selection of preferred hydraulic ports*
ISO 13501	75.180.10	*Petroleum and natural gas industries — Drilling fluids — Processing equipment evaluation*
ISO 13535	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Hoisting equipment*
ISO 17824	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Sand screens*
ISO 28781	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Subsurface barrier valves and related equipment*
ISO/TR 10400	75.180.10	*Petroleum and natural gas industries — Equations and calculations for the properties of casing, tubing, drill pipe and line pipe used as casing or tubing*

Annex B
(informative)

Significant technical changes between this European Standard and the previous version EN 1918-2:1998

Clause	Title/Paragraph/Table/Figure	Change
	Introduction	More details on function and technology of underground storage, including figures
2	Normative references	Addition of this section
3	Terms and definitions	Addition of definitions
5.1	Design principles	Addition of activities and reviews related to safety
5.4.1	General	Additional elements to take into account in well design
8.5	HSE operation monitoring and maintenance	Addition of this new chapter
9	Abandonment	Addition of this new chapter
NOTE 1 The technical changes referred to include the significant changes from the European Standard revised but it is not an exhaustive list of all modifications from the previous version. NOTE 2 The previous standard was reviewed concerning environmental compatibility.		

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