

Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs

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Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs

1 Scope

This Recommended Practice (RP) applies to natural gas storage in depleted oil and gas reservoirs and aquifer reservoirs, and focuses on storage well, reservoir, and fluid management for functional integrity in design, construction, operation, monitoring, maintenance, and documentation practices. The scope does not include pipelines, gas conditioning and liquid handling, compressors, and ancillary facilities associated with storage. Storage design, construction, operation, and maintenance include activities in risk management, site security, safety, emergency preparedness, and procedural documentation and training to embed human and organizational competence in the management of storage facilities. This RP embodies historical knowledge and experience and emphasizes the need for case-by-case and site-specific conditional assessments.

This RP applies to both existing and newly constructed facilities. However, [Section 5](#) and [Section 7](#) apply to new facilities, and facilities undergoing significant expansion. [Section 6](#) applies to new well construction and remediation of a new or existing well. Specific portions of [Section 5](#) and [Section 6](#) may be applicable to existing reservoirs and wells as risk analysis, the availability of new data, or other information or conditions over the life of the facility warrants re-assessment. [Figure 1](#) provides a chart showing the flow of functional integrity assurance activities through the design, operation, and maintenance of storage facilities, with references to the sections within this RP containing guidance for those activities. Applicable distinctions for aquifer facilities are identified within each section as necessary. The term “Replacement,” as used in this document, refers to the complete replacement of a facility unit, as, for example, when an existing well is abandoned and replaced with a new well. This document recommends that operators manage integrity through monitoring, maintenance, and remediation practices and apply specific integrity assessments on a case-by-case basis.

The contents of this RP are not all inclusive or intended to replace the utilization of detailed information and procedures found in textbooks, manuals, technical papers, or other documents.

This document is intended to supplement, but not replace, applicable local, state, and federal regulations.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Recommended Practice 5A3, *Recommended Practice on Thread Compounds for Casing, Tubing, Line Pipe, and Drill Stem Elements*

API Recommended Practice 5C1, *Recommended Practice for Care and Use of Casing and Tubing*

API Technical Report 5C3, *Technical Report on Equations and Calculations for Casing, Tubing, and Line Pipe Used as Casing or Tubing; and Performance Properties Tables for Casing and Tubing*

API Specification 5CT, *Specification for Casing and Tubing*

API Recommended Practice 1170, *Design and Operation of Solution-mined Salt Caverns Used for Natural Gas Storage*

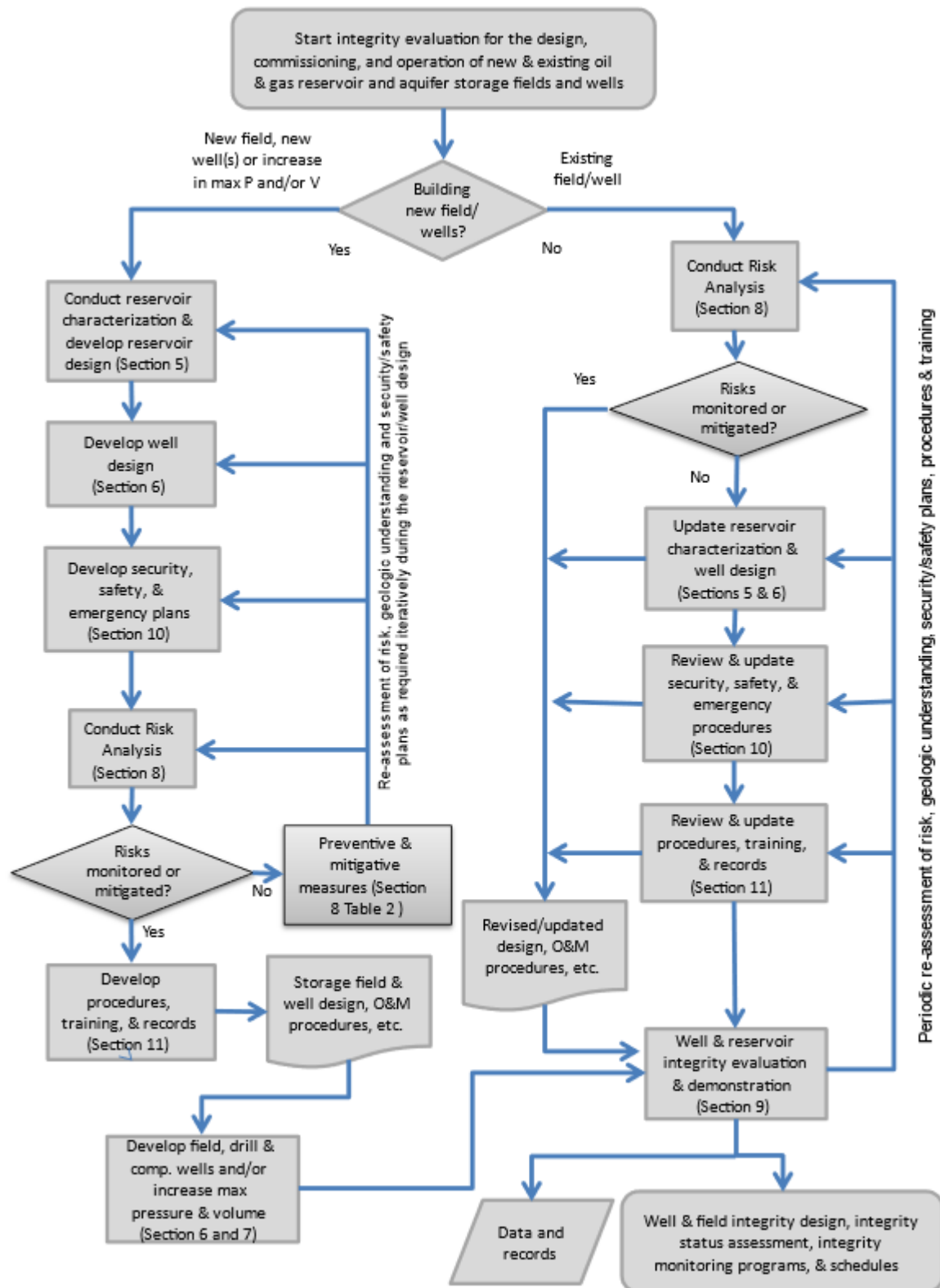


Figure 1—Flowchart of Document Sections

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply. The definitions emphasize the use of the terms in the context of functional integrity.

3.1.1

abnormal operating condition

Condition identified by the operator that may indicate a malfunction of a component or deviation from normal operations that may:

- indicate a condition exceeding design limits; or
- result in a hazard(s) to persons, property, or the environment; or
- indicate a potential downhole problem not related to design or hazard(s) but that may risk the integrity of the well or the reservoir.

3.1.2

aquifer pressure

Current pressure in the infinite-acting aquifer attached to an aquifer storage reservoir at a distance not influenced by the storage operation and to which a gas storage reservoir would eventually return if given a long enough shut-in period.

3.1.3

aquifer reservoir storage

Porous and permeable rock media originally filled with water and converted to gas storage.

3.1.4

area of review

The underground gas storage reservoir and all wells associated with it, as well as all non-associated subsurface or surface structures, formations, or activities proximal enough that could impact or be impacted by the underground gas storage facilities and operation process.

NOTE Area of review includes the buffer zone.

3.1.5

as low as reasonably practicable

ALARP

Reducing risk to a level which is ALARP involves objectively determining the balance where the effort and cost of further reduction measures becomes disproportionate to the additional amount of risk reduction obtained.

3.1.6

average (shut-in) reservoir pressure

Pressure of the reservoir based on an average of well pressures in a shut-in condition of no active injection or withdrawal of storage gas.

NOTE Due to the dynamic pressure conditions in a typical gas storage reservoir or operational limitations on field shut-in periods, the average reservoir pressure can be extrapolated or assumed based on well pressures from a key indicator well(s) (see key indicator well).

3.1.7

basal rock

Horizontal rock layer(s) that forms a seal (barrier) to fluid flow in the vertical direction at the lower boundary of a storage reservoir.

3.1.8**base gas**

Volume of gas needed in a storage reservoir to maintain reservoir pressure to cycle the working storage volume and meet required deliverability rates.

NOTE Also commonly referred to as 'cushion gas' or "cushion gas" or "pad gas".

3.1.9**buffer zone**

Area or interval outside the defined gas storage reservoir, horizontally and vertically, to provide protection of the storage reservoir from encroachments and losses.

NOTE Buffer zones accommodate geologic uncertainties in the exact location of the storage reservoir boundaries.

3.1.10**caprock**

Rock layer(s) acting as the vertical seal (barrier) preventing migration of fluids at the upper boundary of the storage reservoir.

3.1.11**caprock threshold displacement pressure**

Minimum pressure difference between the gas pressure at the face of the caprock and the water phase pressure immediately above the gas-water interface within the caprock, at which the gas starts to move continuously through the caprock.

3.1.12**cement plug**

Cement that is placed in the wellbore with a defined bottom and top to achieve zonal isolation within the wellbore and to prevent communication of fluids between zones by providing a mechanical seal.

3.1.13**collector formation**

A formation, usually vertically above the gas storage reservoir, capable of trapping and accumulating gas.

3.1.14**communication**

Fluid movement influence, which may be detected by pressure observation, fluid physical and chemical composition analysis techniques, or other means.

3.1.15**consequence**

Outcome of an event affecting objectives.

3.1.16**containment**

Ability of a reservoir to confine stored gas and prevent migration either laterally or vertically out of the reservoir.

3.1.17**contractor personnel**

Person or entity used by the operator but not directly employed by the operator.

3.1.18**encroachment**

Intrusion of a non-storage well or operations into the defined surface or subsurface storage area threatening the integrity of the storage operations.

3.1.19**functional integrity**

Total reliability of the storage system, including the physical integrity of the reservoir and well components and the performance reliability assurance established by management systems employed by the storage operator.

3.1.20**groundwater**

Subsurface fresh water, potable water, or water that is or can be potentially used as a drinking water supply.

3.1.21**hazard**

A situation or condition that has the potential to cause loss, damage, or harm to a storage well, well site, or reservoir and thus affect the functional integrity of the storage operation.

3.1.22**inventory verification**

Procedure for confirmation or accounting of total gas present within the storage reservoir at a given time to reconcile with measured volumes and total inventory.

3.1.23**inventory, total**

Total gas volume within the storage reservoir.

NOTE The total inventory at any given time can be determined by an initial determination of gas in place and adjusting that volume for production, fuel, and field use or other losses during production operations; cumulative storage injection and withdrawal activity; and storage operations fuel, field use, or other losses and adjustments.

3.1.24**key indicator well**

Shut-in storage well that is representative of the average reservoir pressure of the active gas storage area.

NOTE Key indicator well pressure can be used to develop the pressure-inventory relationship of the gas storage reservoir.

3.1.25**maximum cycling capacity**

Maximum amount of working gas volume able to be withdrawn and injected over the time of a complete design cycle from maximum to minimum pressures within the reservoir.

3.1.26**maximum reservoir pressure**

Average stabilized shut-in reservoir pressure at maximum design capacity of gas in storage.

3.1.27**mechanical integrity**

Quality or condition of a well in being structurally sound with competent pressure seals by application of technical, operational, and organizational solutions that reduce the risk of uncontrolled release of formation fluids throughout the well life cycle.

3.1.28**mechanical integrity test**

Pressure test that obtains data that demonstrates if a well is mechanically fit for service and capable of storing natural gas within design limitations.

3.1.29**minimum reservoir pressure**

Average stabilized shut-in reservoir pressure at minimum design capacity of gas in storage.

3.1.30**native gas**

Unproduced gas indigenous to the reservoir that remains in the reservoir at the time of conversion to storage.

3.1.31**observation well**

Well that functions as a pressure and fluid monitoring point, located within, above or below, or laterally adjacent to the active storage reservoir, and generally not used to inject or withdraw storage gas.

3.1.32**plan**

Documented explanation of the mechanisms or procedures used to implement a program and to achieve compliance with standards.

NOTE A specific well work plan for drilling, completion, servicing, or workover operations can be written step-by-step instructions and associated information (cautions, notes, warnings) that describe how to safely perform a task.

3.1.33**pound-days**

Empirical method of estimating the aquifer response to gas injection and withdrawal cycling.

NOTE 1 Net pound-days are calculated by summing the differences in daily reservoir pressure, in pounds per square inch, above (plus) or below (negative) the aquifer pressure over the period of an injection and withdrawal cycle.

NOTE 2 The pound-days calculation can be used in hydrocarbon reservoir storage applications as well as aquifer reservoir storage applications.

3.1.34**pressure cycling**

Cyclic variations in reservoir pressure due to the injection and withdrawal of gas.

NOTE In reservoir gas storage operations, pressure cycling often occurs over a one-year period with injections in the summer and withdrawals in the winter; however, storage operations may involve any number, timing, and amplitude of pressure cycles.

3.1.35**pressure-inventory relationship**

Correlation between reservoir pressure and total gas inventory over time.

NOTE The data to trend the relationship can be derived from well pressure observations and total inventory.

3.1.36**procedure**

Documented explanation of action taken to achieve the steps of a process.

NOTE Procedures can be a description of the execution of tasks in a method or linked set of methods that will enable the activity to be accomplished according to a set of guidelines and standards.

3.1.37**process**

Systematic, ordered series of events directed to some end that comprise an approach or methodology to achieve an objective.

NOTE A process can describe workflow activity and quality standards for a wide range of procedures.

3.1.38**program**

Overall approach to manage a functional activity or physical part of an asset.

NOTE A program can be a defined outline of work activities that are designed to address specific objectives. Programs identify what to do and why it needs to be done. The program can define important aspects such as purpose and scope, roles and responsibilities, tasks and procedures, and anticipated results and work products.

3.1.39

risk

The consequence's severity of a realized threat multiplied by the likelihood of its occurrence.

3.1.40

risk analysis

Process to comprehend the nature of risk and to determine the level of risk.

3.1.41

risk assessment

Overall process of risk identification, risk analysis and risk evaluation.

3.1.42

risk evaluation

Process of comparing the results of risk analysis with risk criteria to determine whether the risk and its magnitude is acceptable or tolerable.

3.1.43

risk identification

Process of finding, recognizing, and describing risks.

3.1.44

risk management program

Coordinated activities to direct and control an organization with regard to risk.

3.1.45

safe work practices

Written methods outlining how to perform a task with minimum risk to people, equipment, materials, environment, and processes.

3.1.46

spill point

Point or area in a hydrocarbon trap at which the trap can be breached.

NOTE The spill point may be related to geologic structure, permeability, fluid density, pressure, and viscosity, or any combination of those features.

3.1.47

threat

created by an encounter with or an activation of a hazard during the storage operation.

3.1.48

wellhead

Assemblage of surface equipment used to maintain control of the well and to permit access into the wellbore.

3.1.49

working gas

Volume of gas in the reservoir above the designed level of base gas.

NOTE Also commonly referred to as "top gas" or "current gas".

3.1.50**zonal isolation**

Condition of no communication between the gas storage formation and other formations in a wellbore or between the wellbore and any formation intended to be isolated.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

ALARP	as low as reasonably practicable
API	American Petroleum Institute
BPV	back pressure valve
CFR	Code of Federal Regulations
ERP	emergency response plan
H ₂ S	hydrogen sulfide
ID	inner diameter
MOC	management of change
MWD	measurement-while-drilling
O&M	operations and maintenance
pH	hydrogen ion potential
P&M	preventive and mitigative
PSL	product standard level
SSSV	subsurface safety valve
Tcf	trillion cubic feet
TD	total depth
VR	valve removal
WCP	well control plan

4 General Principles of Underground Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs

4.1 General

This section provides general background into the functions, history, and geotechnical aspects of underground natural gas storage.

4.2 Functions of Underground Natural Gas Storage

Natural gas storage utilizes depleted hydrocarbon and aquifer reservoirs selectively located where geology is suitable. The natural gas storage reservoirs are connected into the natural gas infrastructure via pipelines. Residential and commercial heating and cooling, value arbitrage, swing service between pipelines, and load-following service to electric generation create fluctuations in gas demand. The fluctuations in natural gas demand versus the relative consistency of natural gas supply are managed by underground natural gas storage. Underground natural gas storage facilities function to smooth out the disparity between supply and demand during these peak demand periods. Without storage, serving demand fluctuations would require wide swings in the sources of gas supply, which could negatively impact ultimate gas recovery. Furthermore, without the integration of storage facilities into the pipeline system, the capacity of the pipeline network would need to be

much greater to accommodate the highest flow rates to the markets during peak demand periods. Gas supply and transportation can be more efficient with storage available to the pipeline system.

4.3 History of Underground Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs

Natural gas has been stored underground in depleted hydrocarbon reservoirs in the United States since 1916 when the Zoar Field in western New York was first used for storage. As of 2015, there were more than 350 active gas storage reservoirs in the United States and Canada using depleted hydrocarbon reservoirs. These facilities represent over 16,000 reservoir-years of operation (i.e. sum of operating years of each of the 350 reservoirs), store over 7.8 Tcf of natural gas at maximum capacity and are accessed and monitored by more than 14,200 wells.

Aquifer reservoir storage dates to 1946. As of 2015, there were 51 operating aquifer storage reservoirs in the United States and Canada representing over 2,300 reservoir-years of operation, with a maximum inventory capacity of 1.3 Tcf, accessed and monitored by more than 2,600 wells.

4.4 Geotechnical Aspects of Underground Natural Gas Storage

Natural gas is stored underground in areas where porous and permeable rock is available and can contain the injected natural gas. Underground porous zones are typically fluid-filled in their native state and the fluid can be hydrocarbons (oil, gas) and/or water. Once the hydrocarbons are depleted, the porous zone can be used for natural gas storage. Alternatively, the porous zone may be filled with only water, which does not necessarily require any depletion before it can be converted for use as a natural gas storage reservoir. It is also possible to excavate or solution-mine caverns into otherwise impermeable rock for the storage of gases and liquids. API Recommended Practice 1170 ^[1] applies to natural gas storage in solution-mined salt caverns.

Depleted hydrocarbon reservoirs are candidates for natural gas storage because the reservoir integrity has been demonstrated over geologic time by hydrocarbon containment at initial pressure conditions. Depleted hydrocarbon reservoirs generally have available rock data, reservoir engineering data, and fluid compositional data from their production history. The storage suitability of a hydrocarbon reservoir requires investigation on an individual basis, using several means to evaluate reservoir integrity, well integrity and fluid chemistry.

In regions where depleted hydrocarbon reservoirs are not present, aquifers exhibiting the qualities of a hydrocarbon reservoir may be available. Aquifer reservoirs are similar to depleted hydrocarbon reservoirs in terms of the nature of the porous rock media used to contain the gas and the methodology for assessing the reservoir. The storage suitability of an aquifer reservoir requires investigation on an individual basis, using several means to evaluate reservoir integrity, well integrity, and fluid chemistry.

In practice, there is no ideal depth, rock type, or trapping mechanism; each reservoir requires site-specific evaluation. The gas trapping mechanism depends on rock porosity and permeability controls, hydrodynamics, and geologic structural controls. The top of the reservoir is sealed by impervious rock referred to as its “caprock.” The bottom of the reservoir and lateral boundaries are sealed by structural closure, decrease or loss of porosity and permeability, or hydrodynamic forces. The containment of stored gas can be managed by means of facility and operational controls when geologic boundaries are less than ideal.

Gas storage reservoirs are monitored over their operating lifetime to evaluate functional integrity and management of gas containment. Monitoring includes protecting the reservoir from potential integrity threats brought on by third-party drilling, hydrocarbon production, and mining operations.

The reservoir is accessed via wells drilled either vertically or directionally from the surface. The wells are connected to a surface pipeline network that transports the gas to and from a central station, where gas separation, dehydration, metering, and compression facilities are commonly located. New gas storage wells are constructed for a long useful life to withstand cyclic pressure and temperature conditions. Existing wells used in storage operations undergo mechanical integrity evaluations prior to conversion to ensure safety under storage operating conditions. Gas storage wells are monitored and maintained over their operating lifetime to evaluate the containment capability of the fluids at the pressures and flow rates expected.

5 Functional Integrity in the Design of Natural Gas Storage Reservoirs

5.1 General

This section addresses the requirements for the assessment and design of natural gas storage capacity development in hydrocarbon production reservoirs and aquifer reservoirs and increased maximum pressure or total capacity in existing natural gas storage reservoirs. The assessment steps are arranged generally in order of increasing effort and resources, beginning with use of available data, and progressing to data gathering and testing.

5.2 Geological Reservoir Characterization

5.2.1 General

The goal of the baseline geological reservoir characterization is to develop a practical understanding of the suitability of the reservoir and the adjacent geologic stratigraphic environment prior to storage development or expansion.

5.2.2 Geological Characterization

A preliminary evaluation of the extent and properties of the porous rock interval, or reservoir, intended for storing natural gas, and the confinement mechanisms to contain the hydrocarbon accumulation in the reservoir, shall be conducted, characterized, and presented in the form of geologic mapping and analysis. The geologic characterization uses available data, which can be obtained from various sources, including published literature, regulatory agencies, production operators, academic institutions, and commercial data providers, to provide a basis that can be refined by engineering reservoir characterization and supplemental data gathering.

The geologic characterization shall be used to establish the initial vertical and areal buffer zone to protect the integrity of the natural gas storage operation. Once a reservoir is in operation, the findings of ongoing reservoir performance monitoring programs may require that the buffer zone be reviewed and revised as necessary to protect and maintain the integrity of the storage reservoir.

The scope of the geologic characterization shall encompass the intended reservoir and sealing mechanisms, the vertical interval above and below the intended reservoir, areas where gas could potentially migrate, and the areas adjacent to the intended reservoir where potential entrapment of migrated gas could occur. The depths of groundwater and locations of surface waters should be delineated. Locations of abandoned wells, underground disposal horizons, mining, and other industrial activities should be mapped. Surface topography and land use should be included in the evaluation where topography and land use may impact storage surface facilities and/or subsurface integrity.

The reservoir rock itself should be characterized including its lithology, geo-mechanical competency, porosity, permeability, homogeneity, isotropy, and residual pore fluid saturations. Reservoirs that have proven suitable for natural gas storage include structural and stratigraphic entrapments within porous and permeable rock, which could have a connection to a regional aquifer, or a hydrodynamic entrapment in a structural feature within a regional aquifer. A competent and impermeable caprock, located above the intended gas-filled reservoir, should be identified, and evaluated for controlling the upward movement of the stored natural gas. The basal and lateral sealing mechanisms should be identified and evaluated for controlling movement of the stored gas.

Available data such as drilling data, logs, fluid samples, cuttings and core data from existing hydrocarbon and water wells, or other geophysical data such as seismic, gravity, and magnetic surveys should be used for the geological characterization. The quantity and quality of data used in the geologic characterization should be evaluated throughout the design phase to determine the need for supplemental data gathering, either prior to or during construction. The design should address alternative geological characterizations that are consistent with the data and plans for mitigating integrity issues associated with potential alternative interpretations.

Anomalous geologic features should be evaluated in terms of their potential for compromising reservoir integrity with respect to the containment of stored gas. Such features may include faulting, natural fracturing, folding, and unconformities.

NOTE The preventative and mitigative measures presented in [8.5](#) can help to address anomalous geologic features.

5.3 Reservoir Engineering Characterization

5.3.1 General

The engineering characterization expands upon the geological characterization. The goal is to understand, prior to storage development or expansion, the probable response of the reservoir and adjacent areas to the proposed pressure cycling and flow rates.

5.3.2 Engineering Characterization

The engineering reservoir characterization should incorporate the vertical and areal bounds of the geological characterization, and include examination of any anomalous geological features, if possible. The engineering characterization may suggest that the scope of the geologic characterization should be modified or expanded.

The engineering characterization should include a review of records for all existing and abandoned wells that penetrate the formations being characterized. Existing wellbore and wellhead records should be reviewed to evaluate their current mechanical integrity to verify suitability for the intended design and protection of reservoir integrity. At a minimum, casing materials, casing configuration, casing set depths, cement materials, and placement depths shall be evaluated for effective mechanical integrity. Plugged and abandoned wells should be evaluated to determine if the plugging practices, and plugging materials used and the placement of the plugs, effectively prevent fluid migration. Six provides guidance regarding recommended well characteristics.

Reservoir pore fluid chemistry and physical properties should be characterized, particularly in gas-liquid and oil production reservoirs and in reservoirs containing impurities exceeding pipeline gas quality specifications. The chemical and physical properties of pore water should be characterized, particularly for aquifer reservoirs intended for natural gas storage. Corrosive potential of the pore fluids shall be determined, and corrosion management shall be incorporated into design and operation strategies. Potential mineralogical and fluid compatibility issues with anticipated drilling or treating chemicals and liquid mixtures shall be identified and mitigated.

Engineering data for the characterization of hydrocarbon reservoirs should include completion and production records for the target reservoir. Records from vertically and laterally offset well completion, stimulation, and production operations within the geological characterization zone described in [5.2](#) should be reviewed. Initial and current reservoir pressure shall be identified. For existing storage fields being considered for expansion, prior gas storage operational records should be analyzed to evaluate the interaction of the gas storage operation with the rock-fluid system of the reservoir. For aquifer reservoirs, available water well test data should be analyzed. The quantity and quality of available data used in the engineering characterization should be evaluated to determine the need for supplemental data gathering, either prior to or during construction. The design should address alternative engineering characterizations that are consistent with the data and plans for mitigating integrity issues associated with potential alternatives.

Anomalous locations of hydrocarbons or pressure found in the historic data review can indicate mechanical integrity issues related to existing wells, or that the reservoir characterization is inaccurate. Potential mechanical integrity issues should be identified for further investigation as appropriate.

NOTE The preventive and mitigative measures presented in [8.5](#) can help to address potential mechanical integrity issues.

5.4 Containment Assurance of Storage Design

5.4.1 General

Data shall be acquired to and interpreted to develop a facility design and operating plan that eliminates or manages uncertainties identified by the geologic and engineering reservoir characterization. The operator shall assess containment capability of the reservoir and the wells for the design storage operation volumes, pressure, and rates of withdrawal and injection. The quantity and quality of data used in the containment assurance analysis should be evaluated to determine the need for supplemental data gathering, either prior to or during construction. The design should address alternative characterizations that are consistent with the data and plans for mitigating integrity issues associated with potential alternatives.

5.4.2 Reservoir Connectivity

In cases where connectivity with another porous zone is indicated but can be accommodated without loss of functional integrity, the design shall address the gas migration control and containment risk mitigation methodology, such as gas recovery, pressure limitations, zonal control, and expansion of the vertical and lateral dimensions of the buffer zone.

5.4.3 Maximum and Minimum Pressure

The operator shall document the design basis for maximum reservoir pressure.

NOTE 1 The design basis can employ analysis of fracture gradient, water gradient, initial pressure, caprock permeability, caprock threshold displacement pressure, geo-mechanical testing, or other means.

The pressure required to inject intended gas volumes, particularly at total inventory, shall not cause the design pressure limits of the reservoir, wells, wellheads, piping, or associated facilities to be exceeded.

NOTE 2 Certain activities, such as storage injection operations or wellbore stimulations, can require a pressure at a level higher than the maximum reservoir pressure.

The minimum reservoir pressure should not be designed less than historic minimum operated pressure unless reservoir geo-mechanical competency can be demonstrated. The impacts of intended minimum reservoir pressure should be accounted for in a regional review of the geologic horizon as it relates to geo-mechanical stress, reservoir liquid influx, surface facility gas cleaning and liquid handling, and liquid disposal, all of which affect the maximum cycling capacity of the storage field and can impact mechanical integrity of the facilities. The minimum reservoir pressure determination can include supplemental well drilling, coring, and laboratory analyses to provide data for the evaluation.

5.4.4 Well Penetrations

Wells completed in or penetrating through the intended storage reservoir, caprock, and basal rock shall be evaluated for containment assurance for the design storage operation volumes, pressure, and flow rates. The operator should identify wells that may require integrity testing or well logging to meet the integrity demonstration requirements of [7.2](#). Selected plugged wells may be re-entered, examined, and replugged or monitored to manage identified containment assurance issues.

5.4.5 Supplemental Evaluation

Supplemental reservoir geological and engineering evaluation shall be required for the delineation of potential reservoirs to be developed within aquifers. Characterization of the potential extent of the aquifer and its potential or probable influence on the storage reservoir operation shall be evaluated. Well drilling, logging, and coring shall be performed to gather data and analyze characteristics of the reservoir, caprock, basal rock, and lateral seals. Site-specific geophysical delineation shall be performed, including drilling of test wells and observation wells, and identification of reservoir closure, spill points, and vertical containment. Water pump testing and water

level observation shall be performed to characterize reservoir dimensions, gas capacity, flow performance, and caprock integrity.

Supplemental geological characterization may be performed for hydrocarbon reservoirs having a minimal amount of existing and available geologic data or if undrilled potential entrapments are indicated nearby from the initial evaluations. Additional targeted geophysical surveying or geologic data may be obtained and used for this characterization.

5.4.6 Other Design Factors

Design factors to protect the mechanical integrity of the storage facilities should include:

- analysis of facility flow erosion, hydrate potential, individual facility component capacity and fluid disposal capability at intended gas and liquid rates and pressures; and
- analysis of the specific impacts that the intended operating pressure range could have on the corrosive potential of fluids in the system.

5.4.7 Facility Integrity Plan

The operator should develop a facility integrity plan that covers the storage facility. The facility integrity plan documents work performed during a containment assurance analysis detailed in this subsection, identifies required integrity work and implementation schedule during and after construction, identifies integrity monitoring required during commissioning as detailed in [Section 7](#), and identifies operations monitoring requirements detailed in [Section 9](#) and [Section 10](#).

NOTE The facility integrity plan can be in the form of a standard plan used by the operator for multiple natural gas storage facilities or a site-specific plan.

5.5 Environmental, Safety, and Health Considerations in Design

5.5.1 Design and Construction Safeguards

Safeguards to the environment, safety, and health of workers and the public shall be incorporated into natural gas storage design.

NOTE Publications such as API Recommended Practice 51R ^[2] and API Recommended Practice 76 ^[3] can be referenced to identify safeguards for application in natural gas storage design.

The operator shall incorporate protection of surface water and groundwater resources in the design of storage facilities. The operator should conduct an environmental impact review prior to well drilling and facility construction.

The design of natural gas storage facilities shall incorporate plans for monitoring worksite conditions related to storage development and well drilling to protect the environment and the safety and health of workers and the public.

5.5.2 Operation and Maintenance Safeguards

The operator should design for long-term viability and functional integrity of the storage facility to promote the ability to maintain and operate the storage facility consistent with environmental regulations and to maintain worker and public safety throughout the life of the storage facility.

5.6 Recordkeeping

Accurate and comprehensive records of natural gas storage design activities shall be maintained for the life of the facility. The records shall include, as applicable and available:

- geologic records such as well logs, cuttings reports, core reports, geophysical records, and maps;
- engineering records such as historic hydrocarbon production data, data gathered during aquifer and hydrocarbon reservoir characterization, reservoir design data, and gas storage reservoir operational data;
- documents related to storage land and mineral ownership, rights, and control;
- facility integrity plan;
- well drilling, completion, workover, and plugging records for wells analyzed for the design and for proposed well actions during project construction; and
- regulatory records including permit applications, permits, reports, and correspondence.

NOTE Operators may find it beneficial to retain geological, well drilling, completion, and abandonment records beyond abandonment of storage operations.

6 Functional Integrity in the Design and Construction of Natural Gas Storage Wells

6.1 General

This section addresses the requirements for functional integrity in the design, construction, and completion of new natural gas storage wells, the remediation and reconditioning of existing wells, and abandonment of wells within a natural gas storage facility.

6.2 Wellhead Equipment and Valves

6.2.1 General

New or replacement wellhead equipment, including associated fittings, flanges, and valves, should conform to API Specification 6A ^[4], API Specification 6D ^[37], or an equivalent standard.

6.2.2 Wellhead Equipment Design

New and replacement wellheads shall allow for full-diameter entry to the wellbore. As part of the planning for well maintenance, the operator shall determine if limited or less-than-full-bore access situations are sufficient to allow for the planned activities.

A well shall be equipped with valves to provide isolation of the well from the pipeline system and to allow for entry into the well.

NOTE 1 The pipeline isolation valve, as defined by the operator, can be a pipeline jurisdictional or regulated valve.

NOTE 2 In the United States, the requirements for the pipeline isolation valve are defined in 49 *CFR* 192.145 ^[5].

All ports on the wellhead assembly above the casing bowl should be equipped with valves, blind flanges, or similar equipment.

NOTE 3 New and replacement wellhead and tree components may be equipped with back pressure valves (BPV) and valve removal (VR) plug profiles to assist with component replacement.

6.2.3 Pressure Rating

Wellhead equipment shall have operating pressure ratings sufficient to exceed the maximum anticipated operating pressure. In addition, the wellhead design should include evaluation of the following:

- treating, testing, and stimulation pressures;