INTERNATIONAL STANDARD

ISO 13623

Second edition
2009-06-15

Petroleum and natural gas industries — Pipeline transportation systems

Industries du pétrole et du gaz naturel — Systèmes de transport par conduites

Reference number
ISO 13623:2009(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 13623 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for the petroleum, petrochemical and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems*.

This second edition cancels and replaces the first edition, (ISO 13623:2000), which has been technically revised. Major revisions include replacement of various references to national standards with references to International Standards; replacement of sections on coatings and cathodic protection with ISO references; revision of design to accommodate line pipe above L555 in the new edition of ISO 3183; and the addition of a section on life extension.

Introduction

Significant differences exist between member countries in the areas of public safety and protection of the environment, which cannot be reconciled into a single preferred approach to pipeline transportation systems for the petroleum and natural gas industries. Reconciliation was further complicated by the existence in some member countries of legislation that establishes requirements for public safety and protection of the environment. Recognizing these differences, ISO/TC 67/SC 2 concluded that this International Standard, ISO 13623, should allow individual countries to apply their national requirements for public safety and the protection of the environment.

This International Standard is not a design manual; rather, it is intended for use in conjunction with sound engineering practice and judgment. This International Standard allows the use of innovative techniques and procedures, such as reliability-based limit state design methods, providing the minimum requirements of this International Standard are satisfied.

Petroleum and natural gas industries — Pipeline transportation systems

1 Scope

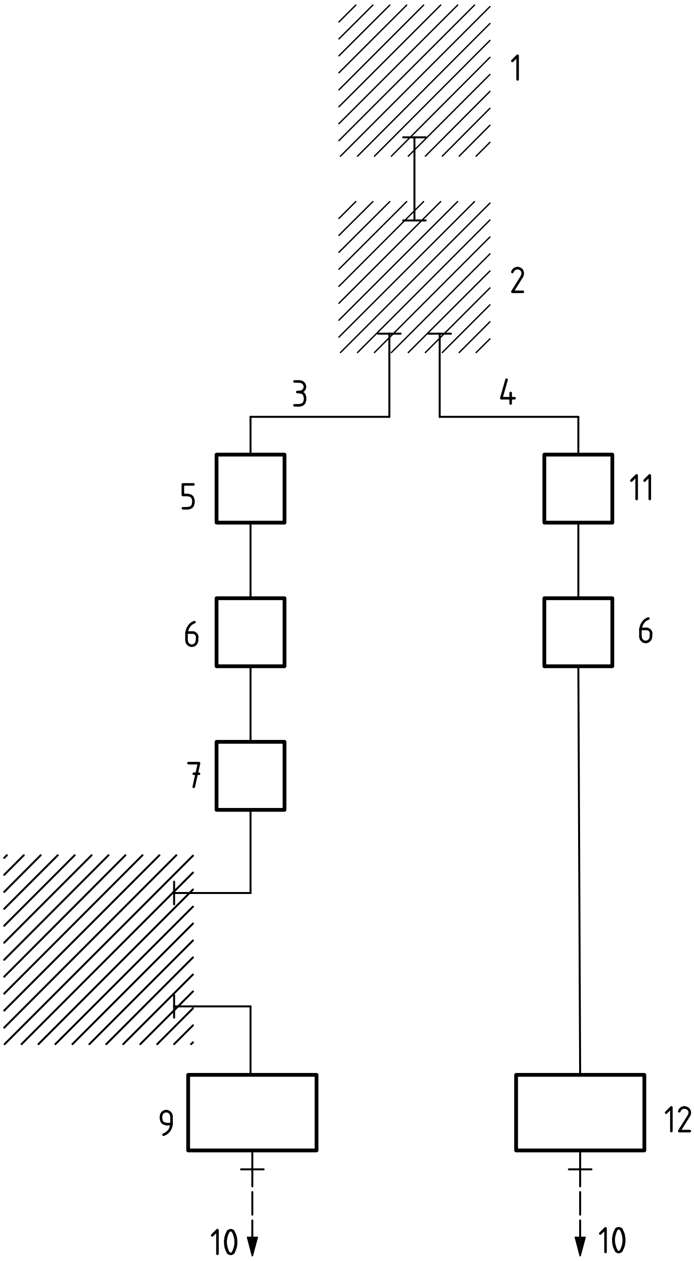
This International Standard specifies requirements and gives recommendations for the design, materials, construction, testing, operation, maintenance and abandonment of pipeline systems used for transportation in the petroleum and natural gas industries.

It applies to pipeline systems on land and offshore, connecting wells, production plants, process plants, refineries and storage facilities, including any section of a pipeline constructed within the boundaries of such facilities for the purpose of its connection. The extent of pipeline systems covered by this International Standard is illustrated in Figure 1.

This International Standard applies to rigid, metallic pipelines. It is not applicable for flexible pipelines or those constructed from other materials, such as glass-reinforced plastics.

This International Standard is applicable to all new pipeline systems and can be applied to modifications made to existing ones. It is not intended that it apply retroactively to existing pipeline systems.

It describes the functional requirements of pipeline systems and provides a basis for their safe design, construction, testing, operation, maintenance and abandonment.



Key

1	wellsite	5	pump station	9	depot
2	gathering station, treatment plant or process plant	6	valve station	10	distribution
3	liquid	7	tankage	11	compressor station
4	gas	8	refinery	12	pressure-reduction station

Pipeline elements covered by this International Standard

Connections with other facilities. The pipeline system should include an isolation valve at connections with other facilities and at branches.

Pipeline elements not covered by this International Standard.

Station/plant area, offshore installation not covered by this International Standard.

Station/plant area covered by this International Standard.

NOTE The pipeline system should include an isolation valve at connections with other facilities and at branches.

Figure 1 — Extent of pipeline systems covered by this International Standard

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) corrigendum, and maintenance agency output applies.

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 3183:2007, *Petroleum and natural gas industries — Steel pipe for pipeline transportation systems*

ISO 3977 (all parts), *Gas turbines — Procurement*

ISO 10439, *Petroleum, chemical and gas service industries — Centrifugal compressors*

ISO 10474:1991, *Steel and steel products — Inspection documents*

ISO 13707, *Petroleum and natural gas industries — Reciprocating compressors*

ISO 13709, *Centrifugal pumps for petroleum, petrochemical and natural gas industries*

ISO 13710, *Petroleum, petrochemical and natural gas industries — Reciprocating positive displacement pumps*

ISO 13847, *Petroleum and natural gas industries — Pipeline transportation systems — Welding of pipelines*

ISO 14313, *Petroleum and natural gas industries — Pipeline transportation systems — Pipeline valves*

ISO 14723, *Petroleum and natural gas industries — Pipeline transportation systems — Subsea pipeline valves*

ISO 15156-1, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156-2, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons*

ISO 15156-3, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

ISO 15589-1, *Petroleum and natural gas industries — Cathodic protection of pipeline transportation systems — Part 1: On-land pipelines*

ISO 15589-2, *Petroleum and natural gas industries — Cathodic protection of pipeline transportation systems — Part 2: Offshore pipelines*

ISO 15590-1, *Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems — Part 1: Induction bends*

ISO 15590-2, *Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems — Part 2: Fittings*

ISO 15590-3, *Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems — Part 3: Flanges*

ISO 15649, *Petroleum and natural gas industries — Piping*

ISO 16708, *Petroleum and natural gas industries — Pipeline transportation systems — Reliability-based limit state methods*

ISO 21809-1, *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 1: Polyolefin coatings (3-layer PE and 3-layer PP)*

ISO 21809-2, *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 2: Fusion-bonded epoxy coatings*

ISO 21809-3, *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 3: Field joint coatings*

ISO 21809-4, *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 4: Polyethylene coatings (2-layer PE)*

ISO 21809-5, *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 5: External concrete coatings*

IEC 60034-1, *Rotating electrical machines — Part 1: Rating and performance*

IEC 60079-10, *Electrical apparatus for explosive gas atmospheres — Part 10: Classification of hazardous areas*

IEC 60079-14, *Electrical apparatus for explosive gas atmospheres — Part 14: Electrical installations in hazardous areas (other than mines)*

API[1] 620, *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*

API 650, *Welded Steel Tanks for Oil Storage*

ASME B16.5, *Pipe Flanges and Flanged Fittings — NPS 1/2 Through NPS 24*

ASME Boiler and Pressure Vessel Code, Section VIII, Division I, *Rules for Construction of Pressure Vessels* (BPVC)

MSS[2] SP-25, *Standard Marking System for Valves, Fittings, Flanges and Unions*

MSS SP-44, *Steel Pipeline Flanges*

NFPA[3] 30, *Flammable and Combustible Liquids Code*

NFPA 220, *Standard on Types of Building Construction*

1) American Petroleum Institute, 1220 L Street, Northwest Washington, DC 20005-4070, USA.

2) Manufacturer's Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180, USA.

3) National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101, USA.

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

3.1.1
commissioning
activities associated with the initial filling of a pipeline system with the fluid being transported

3.1.2
design life
period for which the design basis is planned to remain valid

3.1.3
design pressure
maximum internal pressure of the pressure-containing components of the pipeline system designed in compliance with this International Standard

3.1.4
design strength
strength level to be used in design, based on material's specified minimum properties

3.1.5
fabricated assembly
grouping of pipe and components assembled as a unit and installed as a subunit of a pipeline system

3.1.6
fluid
medium being transported through the pipeline system

3.1.7
hot tapping
tapping, by mechanical cutting, of an in-service pipeline or piping

3.1.8
in-service pipeline
pipeline that has been commissioned for the transportation of fluid

3.1.9
lay corridor
corridor in which an offshore pipeline is being installed, usually determined prior to construction

3.1.10
location class
geographic area classified according to criteria based on population density and human activity

3.1.11
maintenance
all activities designed to retain the pipeline system in a state in which it can perform its required functions

NOTE These activities include inspections, surveys, testing, servicing, replacement, remedial works and repairs.

3.1.12
maximum allowable operating pressure
MAOP
maximum internal pressure at which a pipeline system, or parts thereof, is allowed to be operated in compliance with this International Standard

3.1.13
offshore pipeline
pipeline laid in maritime waters and estuaries seaward of the ordinary high water mark

3.1.14
pipeline
those components of a pipeline system connected together to convey fluids between stations and/or plants, including pipe, pig traps, components, appurtenances, isolating valves, and sectionalising valves

See Figure 1.

3.1.15
pipeline on land
pipeline laid on or in land, including lines laid under inland water courses

3.1.16
pipeline system
pipelines, stations, supervisory control and data acquisition system (SCADA), safety systems, corrosion protection systems, and any other equipment, facility or building used in the transportation of fluids

3.1.17
piping
pipe, fittings and components inside stations and terminals, but not part of the pipeline

3.1.18
primary piping
piping conveying or storing the fluid transported by the pipeline

3.1.19
right-of-way
corridor of land within which the pipeline operator has the right to conduct activities in accordance with the agreement with the land owner

3.1.20
riser
that part of an offshore pipeline, including subsea spool pieces, that extends from the sea bed to the pipeline termination point on an offshore installation

3.1.21
secondary piping
piping carrying fluids other than those of the primary piping and pipeline, such as fuel gas, water, or lube oil

3.1.22
specified minimum tensile strength
SMTS
minimum tensile strength required by the specification or standard under which the material is purchased

3.1.23
specified minimum yield strength
SMYS
minimum yield strength required by the specification or standard under which the material is purchased

3.1.24
station
facility for the purpose of increasing pressure, decreasing pressure, storage, metering, heating, cooling or isolating the transported fluid

3.2 Symbols

A_i internal cross-sectional area of the pipe

A_s cross-sectional area of pipewall

D specified diameter (outside or inside)

D_{max} maximum measured diameter (outside or inside)

D_{min} minimum measured diameter (outside or inside)

D_o nominal outside diameter

E modulus of elasticity

f_h hoop-stress design factor, obtained from Table 2 for pipelines on land and Table 3 for offshore pipelines;

F pipe wall axial force

p_{id} design pressure

p_{od} minimum external hydrostatic pressure

O ovality or out-of-roundness

t_{min} specified minimum wall thickness

T_1 installation temperature

T_2 maximum or minimum metal temperature during operation

ν Poisson ratio

α linear coefficient of thermal expansion

σ_{eq} equivalent stress

σ_h circumferential stress

σ_{hp} circumferential hoop stress due to fluid pressure

σ_l longitudinal stress

σ_y specified minimum yield strength (SMYS) at the maximum design temperature

σ_D design strength

τ shear stress

4 General

4.1 Health, safety and the environment

The objective of this International Standard is that the design, material selection and specification, construction, testing, operation, maintenance and abandonment of pipeline systems for the petroleum and natural gas industries be safe and conducted with due regard to public safety and the protection of the environment.

4.2 Competence assurance

All work associated with the design, construction, testing, operation, maintenance and abandonment of the pipeline system shall be carried out by suitably qualified and competent persons.

4.3 Compliance

A quality system should be applied to assist compliance with the requirements of this International Standard.

NOTE ISO/TS 29001 gives sector-specific guidance on quality management systems.

4.4 Records

Records of the pipeline system shall be kept and maintained throughout its lifetime to demonstrate compliance with the requirements of this International Standard. Annex F can be used for guidance or records which should be retained.

5 Pipeline system design

5.1 System definition

The extent of the pipeline system, its functional requirements and applicable legislation should be defined and documented.

The extent of the system should be defined by describing the system, including the facilities with their general locations and the demarcations and interfaces with other facilities.

The functional requirements should define the required design life and design conditions. Foreseeable normal, extreme and shut-in operating conditions with their possible ranges in flowrates, pressures, temperatures, fluid compositions and fluid qualities should be identified and considered when defining the design conditions.

5.2 Categorization of fluids

The fluids being transported shall be placed in one of the following five categories given in Table 1 according to the hazard potential with respect to public safety.

Table 1 — Classification of fluids with respect to potential hazard to public safety

Category A	Non-flammable, water-based fluids.
Category B	Flammable and/or toxic fluids that are liquids at ambient temperature and at atmospheric pressure conditions. Typical examples are oil and petroleum products. Methanol is an example of a flammable and toxic fluid.
Category C	Non-flammable fluids that are non-toxic gases at ambient temperature and atmospheric pressure conditions. Typical examples are nitrogen, carbon dioxide, argon and air.
Category D	Non-toxic, single-phase natural gas.
Category E	Flammable and/or toxic fluids that are gases at ambient temperature and atmospheric pressure conditions and are conveyed as gases and/or liquids. Typical examples are hydrogen, natural gas (not otherwise covered in category D), ethane, ethylene, liquefied petroleum gas (such as propane and butane), natural gas liquids, ammonia and chlorine.

Gases or liquids not specifically included by name should be classified in the category containing fluids most closely similar in hazard potential to those quoted. If the category is not clear, the more hazardous category shall be assumed.

5.3 Hydraulic analysis

The hydraulics of the pipeline system should be analysed to demonstrate that the system can safely transport the fluids for the design conditions specified in 5.1, and to identify and determine the constraints and requirements for its operation. This analysis should cover steady-state and transient operating conditions.

NOTE Examples of constraints and operational requirements are allowances for pressure surges, prevention of blockage such as caused by the formation of hydrates and wax deposition, measures to prevent unacceptable pressure losses from higher viscosities at lower operating temperatures, measures for the control of liquid slug volumes in multi-phase fluid transport, flow regime for internal corrosion control, erosional velocities and avoidance of slack line operations.

5.4 Pressure control and overpressure protection

Provisions such as pressure-control valves or automatic shutdown of pressurizing equipment shall be installed, or procedures implemented, if the operating pressure can exceed the maximum allowable operating pressure anywhere in the pipeline system. Such provisions or procedures shall prevent the operating pressure from exceeding MAOP under normal steady-state conditions.

Overpressure protection, such as relief or source-isolation valves, shall be provided if necessary to prevent incidental pressures exceeding the limits specified in 6.3.2.2 anywhere in the pipeline system.

5.5 Requirements for operation and maintenance

The requirements for the operation and maintenance of the pipeline system shall be established and documented for use in the design and the preparation of procedures for operations and maintenance. Aspects for which requirements should be specified include

- requirements for identification of pipelines, stations and fluids transported;
- principles for system control, including consideration of manning levels and instrumentation;
- location and hierarchy of control centres;
- voice and data communications;
- corrosion management;
- condition monitoring;
- leak detection;
- pigging philosophy;
- access, sectionalizing and isolation for operation, maintenance and replacement;
- interfaces with upstream and downstream facilities;
- emergency shut-in;
- depressurization with venting and/or drainage;
- shutdowns and restart;
- requirements identified from the hydraulic analysis.

5.6 Public safety and protection of the environment

National requirements that take precedence over the requirements in this International Standard shall be specified by the country in which the pipeline system is located. The requirements in this International Standard for public safety and protection of the environment shall apply where no specific national requirements exist.

On-land pipeline systems for category D and E fluids should meet the requirements for public safety of Annex B where specific requirements for public safety have not been defined by the country in which the pipeline is located.

6 Design of pipeline and primary piping

6.1 Design principles

The extent and detail of the design shall be sufficient to demonstrate that the integrity and serviceability required by this International Standard can be maintained during the design life.

Representative values for loads and load resistance shall be selected in accordance with good engineering practice. Methods of analysis may be based on analytical, numerical or empirical models, or a combination of these methods.

Principles of reliability-based limit state design methods may be applied, provided that all relevant ultimate and serviceability limit states are considered. All sources of uncertainty in loads and load resistance shall be considered and sufficient statistical data shall be available for adequate characterization of these uncertainties.

Reliability-based limit-state design methods shall not be used to replace the requirements in Tables 2 and 3 for the maximum permissible hoop stress due to fluid pressure.

NOTE 1 Ultimate limit states are normally associated with loss of structural integrity, e.g. rupture, fracture, fatigue or collapse, whereas exceeding serviceability limit states prevents the pipeline from operating as intended.

NOTE 2 ISO 16708 gives guidance on reliability-based limit state design.

6.2 Route selection

6.2.1 Considerations

6.2.1.1 General

Route selection shall take into account the design, construction, operation, maintenance and abandonment of the pipeline in accordance with this International Standard.

To minimize the possibility of future corrective work and limitations, anticipated urban and industry developments shall be considered.

Factors that shall be considered during route selection include

— safety of the public, and personnel working on or near the pipeline;

— protection of the environment;

— other property and facilities;

— third-party activities;

- geotechnical, corrosivity and hydrographical conditions;
- requirements for construction, operation and maintenance;
- national and/or local requirements;
- future exploration.

Annex C provides guidance on the planning of a route selection. Annex D provides examples of factors that should be addressed during the considerations required in 6.2.1.1 to 6.2.1.7.

6.2.1.2 Public safety

Pipelines conveying category B, C, D and E fluids should, where practicable, avoid built-up areas or areas with frequent human activity.

In the absence of public safety requirements in a country, a safety evaluation shall be performed in accordance with the general requirements of Annex A for

- pipelines conveying category D fluids in locations where multi-storey buildings are prevalent, where traffic is heavy or dense, and where there can be numerous other utilities underground;
- pipelines conveying category E fluids.

6.2.1.3 Environment

An assessment of environmental impact shall consider as a minimum:

- temporary works during construction, repair and modification;
- the long-term presence of the pipeline;
- potential loss of fluids.

6.2.1.4 Other facilities

Facilities along the pipeline route that can affect the pipeline should be identified and their impact evaluated in consultation with the operator of these facilities.

6.2.1.5 Third-party activities

Third-party activities along the route shall be identified and should be evaluated in consultation with these parties.

6.2.1.6 Geotechnical, hydrographical and meteorological conditions

Adverse geotechnical and hydrographic conditions shall be identified and mitigating measures defined. In some instances, such as under arctic conditions, it can be necessary also to review meteorological conditions.

6.2.1.7 Construction, testing, operation and maintenance

The route shall permit the required access and working width for the construction, testing, operation and maintenance, including any replacement, of the pipeline. The availability of utilities necessary for construction, operation and maintenance should also be reviewed.

6.2.2 Surveys — Pipelines on land

Route and soil surveys shall be carried out to identify and locate with sufficient accuracy the relevant geographical, geological, geotechnical, corrosivity, topographical and environmental features, and other facilities such as other pipelines, cables and obstructions, that can impact the pipeline route selection.

6.2.3 Surveys — Offshore pipelines

Route and soil surveys shall be carried out on the proposed route to identify and locate

— geological features and natural hazards;

— pipelines, cables and wellheads;

— obstructions such as wrecks, mines and debris;

— geotechnical properties.

Meteorological and oceanographic data required for the design and construction planning shall be collected. Such data may include

a) bathymetry;

b) winds;

c) tides;

d) waves;

e) currents;

f) atmospheric conditions;

g) hydrologic conditions (temperature, oxygen content, pH value, resistivity, biological activity, salinity);

h) marine growth;

i) soil accretion and erosion.

6.3 Loads

6.3.1 General

Loads that can cause or contribute to pipeline failure or loss of serviceability shall be identified and accounted for in the design.

For the strength design, loads shall be classified as

— functional; or

— environmental; or

— construction; or

— accidental.

6.3.2 Functional loads

6.3.2.1 Classification

Loads arising from the intended use and residual loads from other sources shall be classified as functional.

NOTE The weight of the pipeline, including components and fluid, and loads due to pressure and temperature are examples of functional loads arising from the intended use of the system. Pre-stressing, residual stresses from installation, soil cover, external hydrostatic pressure, marine growth, subsidence and differential settlement, frost heave and thaw settlement, and sustained loads from icing are examples of functional loads from other sources. Reaction forces at supports from functional loads and loads due to sustained displacements, rotations of supports or impact by changes in flow direction are also functional.

6.3.2.2 Design pressure

The design pressure at any point in the pipeline system shall be equal to or greater than the maximum allowable operating pressure (MAOP). Pressures due to static head of the fluid shall be included in the steady-state pressures.

Incidental pressures during transient conditions in excess of MAOP are permitted, provided they are of limited frequency and duration, and the MAOP is not exceeded by more than 10 %.

NOTE Pressure due to surges, failure of pressure control equipment, and cumulative pressures during activation of over-pressure protection devices are examples of incidental pressures. Pressures caused by heating of blocked-in static fluid are also incidental pressures, provided blocking-in is not a regular operating activity.

6.3.2.3 Temperature

The range of fluid temperatures during normal operations and anticipated blowdown conditions shall be considered when determining temperature-induced loads. Both a maximum design temperature and a minimum design temperature shall be established.

6.3.3 Environmental loads

6.3.3.1 Classification

Loads arising from the environment shall be classified as environmental, except where it is necessary that they be considered as functional (see 6.3.2) or when, due to a low probability of occurrence, as accidental (see 6.3.5).

EXAMPLE Loads from waves, currents, tides, wind, snow, ice, earthquake, traffic, fishing and mining are examples of environmental loads. Loads from vibrations of equipment and displacements caused by structures on the ground or seabed are also examples of environmental loads.

6.3.3.2 Hydrodynamic loads

Hydrodynamic loads shall be calculated for the design return periods corresponding to the construction phase and operational phase. The return period for the construction phase should be selected on the basis of the planned construction duration and season and the consequences of the loads associated with these return periods being exceeded. The design return period for the normal operation phase should be not less than three times the design life or 100 years, whichever is shorter.

The joint probability of occurrences in magnitude and direction of extreme winds, waves and currents should be considered when determining hydrodynamic loads.

The effect of increases in exposed area due to marine growth or icing shall be taken into account. Loads from vortex shedding shall be considered for aerial crossings and submerged spanning pipeline sections.

6.3.3.3 Earthquake loads

The following effects shall be considered when designing for earthquakes:

— direction, magnitude and acceleration of fault displacements;

— flexibility to accommodate displacements for the design case;

— mechanical properties under operating conditions;

— design for mitigation of stresses during displacement caused by soil properties for buried crossings and inertial effects for above-ground fault crossings;

— induced effects (liquefaction, landslides).

6.3.3.4 Soil and ice loads

The following effects shall be considered when designing for sand loads:

— sand-dune movement;

— sand encroachment.

The following effects shall be considered when designing for ice loads:

a) ice frozen on pipelines or supporting structures;

b) bottom scouring of ice;

c) drifting ice;

d) impact forces due to thaw of the ice;

e) forces due to expansion of the ice;

f) higher hydrodynamic loads due to increased exposed area;

g) effects added on possible vibration due to vortex shedding.

6.3.3.5 Road and rail traffic

Maximum traffic axle loads and frequency shall be established in consultation with the appropriate traffic authorities and with recognition of existing and forecast residential, commercial and industrial developments.

6.3.3.6 Fishing

Loads and frequency from fishing activities shall be established based on the applied fishing techniques.

6.3.3.7 Mining

Loads due to ground vibrations from the use of explosives shall be considered. Loads from subsidence arising from mining activities shall be classified as functional.

6.3.4 Construction loads

Loads necessary for installation and commissioning shall be classified as construction loads. The effect of dynamic behaviour of installation vessels and equipment shall be considered where appropriate.

NOTE Installation includes transportation, handling, storage, construction and testing. Increases in external pressure during pressure grouting or sub-atmospheric internal pressure by draining and vacuum drying also give rise to construction loads. Dynamic effects from the movements of lay vessels are also construction loads that it can be necessary to consider for offshore pipelines.

6.3.5 Accidental loads

Loads imposed on the pipeline under unplanned but plausible circumstances shall be considered as accidental. Both the probability of occurrence and the likely consequence of an accidental load should be considered when determining whether the pipeline should be designed for an accidental load.

EXAMPLE Loads arising from fire, explosion, sudden decompression, falling objects, transient conditions during landslides, third-party equipment (such as excavators or ships' anchors), loss of power of construction equipment and collisions.

6.3.6 Combination of loads

When calculating equivalent stresses (see 6.4.1.2), or strains, the most unfavourable combination of functional, environmental, construction and accidental loads that can be predicted to occur simultaneously shall be considered.

If the operating philosophy is such that operations are reduced or discontinued under extreme environmental conditions, then the following load combinations shall be considered for operations:

— design environmental loads plus appropriate reduced functional loads;

— design functional loads and coincidental maximum environmental loads.

Unless they can be reasonably expected to occur together, it is not necessary to consider a combination of accidental loads or accidental loads in combination with extreme environmental loads.

6.4 Strength requirements

6.4.1 Calculation of stresses

6.4.1.1 Hoop stress due to fluid pressure

The circumferential stress, σ_{hp}, due to fluid pressure only (hoop stress), shall be calculated as given in Equation (1):

$$\sigma_{hp} = \left(p_{id} - p_{od}\right) \times \frac{\left(D_o - t_{min}\right)}{2\,t_{min}} \tag{1}$$

where

p_{id} is the design pressure;

p_{od} is the minimum external hydrostatic pressure;

D_o is the nominal outside diameter;

t_{min} is the specified minimum wall thickness.

NOTE The specified minimum wall thickness is the nominal wall thickness less the allowance for manufacturing per the applicable pipe specification and corrosion. For clad or lined pipelines (see 8.2.3), the strength contribution of the cladding or lining is generally not included.

6.4.1.2 Other stresses

Circumferential, longitudinal, shear and equivalent stresses shall be calculated taking into account stresses from all relevant functional, environmental and construction loads. Accidental loads shall be considered as indicated in 6.3.5. The significance of all parts of the pipeline and all restraints, such as supports, guides and friction, shall be considered. When flexibility calculations are performed, linear and angular movements of equipment to which the pipeline is attached shall also be considered.

Calculations shall take into account flexibility and stress concentration factors of components other than plain straight pipe. Credit may be taken for the extra flexibility of such components.

Flexibility calculations shall be based on nominal dimensions and the modulus of elasticity at the appropriate temperature(s).

Equivalent stresses, σ_{eq}, shall be calculated using the von Mises equation as given in Equation (2):

$$\sigma_{eq} = (\sigma_h^2 + \sigma_l^2 - \sigma_h\sigma_l + 3\tau^2)^{1/2} \quad (2)$$

where

σ_h is the circumferential stress;

σ_l is the longitudinal stress;

τ is the shear stress.

Equivalent stresses may be based on nominal values of diameter and wall thickness. Radial stresses may be neglected when not significant.

6.4.2 Strength criteria

6.4.2.1 General

Pipelines shall be designed for the following mechanical failure modes and deformations:

— yielding;

— buckling;

— fatigue;

— ovality.

6.4.2.2 Yielding

The maximum hoop stress, σ_{hp}, due to fluid pressure shall be determined in accordance with Equation (3):

$$\sigma_{hp} \leqslant f_h \times \sigma_y \quad (3)$$

where

f_h is the hoop-stress design factor, obtained from Table 2 for pipelines on land and Table 3 for offshore pipelines;

σ_y is the specified minimum yield strength (SMYS) at the maximum design temperature.

Pipelines using steel grades above L555 should be designed using a reliability-based limit-state design approach in accordance with ISO 16708 or other recognized code or standard. If a limit-state design approach is not used, the maximum hoop stress due to fluid pressure shall be determined in accordance with Equation (4):

$$\sigma_{hp} \leqslant f_h \times \sigma_D \tag{4}$$

where σ_D is the design strength, which is the lesser of SMYS or the specified minimum tensile strength (SMTS) divided by 1,15 for grades above L555.

For temperatures above 50 °C, σ_y or σ_D shall be documented in accordance with 8.1.7.

σ_D characterizes the material strength at the maximum temperature for the analysed scenario. σ_D may be different in different phases; typically representing the ambient temperature during installation and pressure test and the design temperature during operation.

Table 2 — Hoop-stress design factors, f_h, for pipelines on land [a]

Location	f_h
General route [b]	0,77
Crossings and parallel encroachments: [c]	
— minor roads	0,77
— major roads, railways, canals, rivers, diked flood defences and lakes	0,67
Pig traps and multi-pipe slug catchers	0,67
Primary piping in stations and terminals	0,67
Special constructions such as fabricated assemblies and pipelines on bridges	0,67

[a] The hoop stress factors of Table B.2 shall apply for category D and E pipelines to be designed to meet the requirements of Annex B.

These factors apply to pipelines pressure-tested with water. Lower design factors may be necessary when tested with air.

[b] The hoop stress factor may be increased to 0,83 for pipelines conveying category C and D fluids at locations subject to infrequent human activity and without permanent human habitation (such as deserts and tundra regions).

[c] See 6.9 for the description of crossings and encroachments.

Table 3 — Hoop stress design factors, f_h, for offshore pipelines

Location	f_h
General route[a]	0,77
Shipping lanes, designated anchoring areas and harbour entrances	0,77
Landfalls	0,67
Pig traps and multi-pipe slug catchers	0,67
Risers and primary piping	0,67

[a] The hoop stress factor may be increased to 0,83 for pipelines conveying category C and D fluids.

The maximum equivalent stress, σ_{eq}, shall be determined in accordance with Equation (5):

$$\sigma_{eq} \leqslant f_{eq} \times \sigma_{y} \quad (5)$$

where f_{eq} is the equivalent stress design factor, obtained from Table 4.

If a pipeline is designed using steel grade above L555, σ_{y} shall be replaced by σ_{D} in Equation (5).

Table 4 — Equivalent stress design factors, f_{eq}

Load combination	f_{eq}
Construction and environmental	1,00
Functional and environmental	0,90
Functional, environmental and accidental	1,00

The criterion for equivalent stress may be replaced by a permissible strain criterion where

— the configuration of the pipeline is controlled by imposed deformations or displacements; or

— the possible pipeline displacements are limited by geometrical constraints before exceeding the permissible strain.

A permissible strain criterion may be applied for the construction of pipelines to determine the allowable bending and straightening associated with reeling, J-tube pull-ups, installation of a bending shoe riser and similar construction methods.

A permissible strain criterion may be used for pipelines in service for

a) pipeline deformations from predictable non-cyclic displacement of supports, ground or seabed, such as fault movement along the pipeline or differential settlement;

b) non-cyclic deformations, where the pipeline is supported before exceeding the permissible strain, such as in case of a pipeline offshore that is not continuously supported but with sagging limited by the seabed;

c) cyclic functional loads, provided that plastic deformation occurs only when the pipeline is first raised to its “worst-case” combination of functional loads and not during subsequent cycling of these loads.

The permissible strain shall be determined considering the fracture toughness of the material, weld imperfections and previously experienced strain. The possibility of strain localization, such as for concrete-coated pipelines in bending, shall be considered when determining strains.

NOTE BS 7910 provides guidance for determining the level of permissible strain.

6.4.2.3 Buckling

The following buckling modes shall be considered:

— local buckling due to external pressure, axial tension or compression, bending and torsion, or a combination of these loads;

— buckle propagation;

— restrained buckling due to axial compressive forces induced by high operating temperatures and pressures.

NOTE Buckling of restrained pipelines can take the form of lateral displacement for unburied pipelines or vertical upheaval of trenched or buried pipelines.

6.4.2.4 Fatigue

Fatigue analyses shall be performed on pipeline sections and components that can be subject to fatigue from cyclic loads in order to

— demonstrate that initiation of cracking does not occur; or

— define requirements for inspection for fatigue.

Fatigue analyses shall include a prediction of load cycles during construction and operation and a translation of load cycles into nominal stress or strain cycles.

The effect of mean stresses, internal service, external environment, plastic prestrain and rate of cyclic loading shall be accounted for when determining fatigue resistance.

Assessment of fatigue resistance may be based on either S-N data obtained on representative components or a fracture mechanics fatigue life assessment.

The selection of safety factors shall take into account the inherent inaccuracy of fatigue-resistance predictions and access for inspection for fatigue damage. It can be necessary to monitor the parameters causing fatigue and to control possible fatigue damage accordingly.

6.4.2.5 Ovality

Ovality, or out-of-roundness, O, expressed as a percentage, is defined as given in Equation (6):

$$O = \frac{D_{\text{max}} - D_{\text{min}}}{D} \times 100 \qquad (6)$$

where

D is the specified diameter (outside or inside);

D_{max} is the maximum measured diameter (outside or inside);

D_{min} is the minimum measured diameter (outside or inside).

Ovality or out-of-roundness arising from manufacture, construction and installation shall be considered in relation to buckling and operational requirements.

6.5 Stability

Pipelines shall be designed to prevent horizontal and vertical movement, or shall be designed with sufficient flexibility to allow predicted movements within the strength criteria of this International Standard.

Factors which should be considered in the stability design include

— hydrodynamic and wind loads;

— axial compressive forces at pipeline bends and lateral forces at branch connections;

— lateral deflection due to axial compression loads in the pipelines;

— exposure due to general erosion or local scour;

- geotechnical conditions including soil instability due to, for example, seismic activity, slope failures, frost heave, thaw settlement and groundwater level;
- construction method, including bundled or piggybacked lines;
- trenching and/or backfilling techniques.

NOTE Stability for pipelines on land can be enhanced by such means as pipe mass selection, anchoring, control of backfill material, soil cover, soil replacement, drainage and insulation to avoid frost heave. Possible stability improvement measures for subsea pipelines are pipe mass, mass coating, trenching, burial (including self-burial), gravel or rock dumping, anchoring and the installation of mattresses or saddles.

6.6 Pipeline spanning

Spans in pipelines shall be controlled to ensure compliance with the strength criteria in 6.4.2. Due consideration shall be given to

- support conditions;
- interaction with adjacent spans;
- possible vibrations induced by wind, current and waves;
- axial force in the pipeline;
- soil accretion and erosion;
- possible effects from third-party activities;
- soil properties.

6.7 Pressure test requirements

6.7.1 General

Pipelines and primary piping shall be pressure-tested in place after installation but before being put into operation to demonstrate their strength and leak-tightness. Prefabricated assemblies and tie-in sections may be pretested before installation provided their integrity is not impaired during subsequent construction or installation. The requirements for pressure testing can govern the necessary pipe wall thickness and/or steel grade in terrain with significant elevations.

6.7.2 Test medium

Pressure tests shall be conducted with water (including inhibited water), except if low ambient temperatures prevent testing with water, if sufficient water of adequate quality cannot be made available, if disposal of water is not possible, if testing is not expedient or if water contamination is unacceptable. Pneumatic tests (when necessary) may be made using air or a non-toxic gas.

NOTE Rerouting of short pipeline sections or short tie-in sections for pipelines in operation are examples of situations for which pressure tests with water might not be expedient.

6.7.3 Pressure levels and test durations

The duration of strength and/or leak testing shall be determined taking into consideration ambient temperature changes and leak detection methods.

Pipelines and primary piping shall be strength-tested, after stabilization of temperatures and surges from pressurizing operations, for a minimum period of 1 h with a pressure at any point in the system of at least 1,25 × MAOP.

If applicable, the strength test pressure shall be multiplied by the following ratios:

— σ_y at test temperature divided by σ_y at the design temperature; and

— t_{min} plus corrosion allowance divided by t_{min} in case of corrosion allowance.

The strength test pressure for pipelines conveying category C and D fluids at locations subject to infrequent human activity and without permanent habitation may be reduced to a pressure of not less than 1,20 × MAOP, provided the maximum incidental pressure cannot exceed 1,05 × MAOP.

Following a successful strength test, the pipeline shall be leak-tested for a minimum period of 8 h with a pressure at any point in the system of at least 1,1 × MAOP.

The strength and leak test may be combined by testing for a minimum of 8 h at the pressure specified above for strength testing. The requirement for a minimum duration of a leak test is not applicable to pipelines or primary piping completely accessible for visual inspection, provided the complete pipeline is visually inspected for leaks following a hold-period of 2 h at the required leak-test pressure. The additional test requirements of Clause B.6 shall apply for category D and E pipelines to which Annex B applies.

6.7.4 Acceptance criteria

Pressure variations during strength testing shall be acceptable if it can be demonstrated that they are caused by factors other than a leak.

Pressure increases or decreases during leak testing shall be acceptable provided it can be demonstrated through calculations that they are caused by variations in ambient temperature or pressure, such as tidal variation for offshore pipelines.

Pipelines not meeting these requirements shall be repaired and retested in accordance with the requirements of this International Standard.

6.8 Other activities

6.8.1 Activities by others

The following factors shall be considered when determining the requirements for the protection of pipelines:

— possible effects of pipeline damage on public safety and the environment;

— possible effects of interference from other activities;

— national requirements for public safety and the protection of the environment.

EXAMPLES Activities that it is necessary to consider for pipelines on land include other land users, traffic, cultivation, installation of drainage, construction of buildings and work on roads, railways, waterways and military exercises. Examples for offshore pipelines include the setting of jack-up vessels, the movement of anchors and anchor chains, snagging cables and umbilicals, dropping of objects near installations, moving vessels close to risers, seabed fishing activity during their installation and military exercises.

Protection requirements shall be established as part of the safety evaluation in 6.2.1.2 where required.

EXAMPLES Protection of pipelines on land includes cover, increased wall thickness, markers and marker tape, mechanical protection, controlling access to the pipeline route, or a combination of these measures. Trenching or burial, rock dumping, cover with mattresses or protective structures and riser protection are possible protective measures for offshore pipelines.

For pipelines on land, markers should be erected at road, rail, river and canal crossings and elsewhere, to enable other users of the area to identify the location of pipelines. The use of marker tape should be considered for buried pipelines on land.

6.8.2 Pipeline cover

6.8.2.1 Pipelines on land

Buried pipelines on land should be installed with a cover depth not less than shown in Table 5. Cover depth shall be measured from the lowest possible ground surface level to the top of the pipe, including coatings and attachments.

Table 5 — Minimum cover depth for pipelines on land

Location	Cover depth [a] m
Areas of limited or no human activity	0,8
Agricultural or horticultural activity [b]	0,8
Canals, rivers [c]	1,2
Roads and railways [d]	1,2
Residential, industrial, and commercial areas	1,2
Rocky ground [e]	0,5

[a] Special consideration for cover may be required in areas with frost heave.

[b] Cover shall not be less than the depth of normal cultivation.

[c] To be measured from the lowest anticipated bed.

[d] To be measured from the bottom of the drain ditches.

[e] The top of pipe shall be at least 0,15 m below the surface of the rock.

Pipelines may be installed with less cover depth than indicated in Table 5, provided a similar level of protection is provided by alternative methods.

The design of alternative protection methods should take into account

— any hindrance caused to other users of the area;

— soil stability and settlement;

— pipeline stability;

— cathodic protection;

— pipeline expansion;

— access for maintenance.

6.8.2.2 Offshore pipelines

Offshore pipelines shall be trenched, buried or protected if external damage affecting the integrity is likely, and where necessary to prevent or reduce interference with other activities. Other users of the area shall be consulted when determining the requirements for reducing or preventing this interference.

Protective structures for use on offshore pipelines should present a smooth profile to minimize risks of snagging and damage from anchoring cables and fishing gear. They should also have sufficient clearance from the pipeline system to permit access where required, and to allow both pipeline expansion and settlement of the structure foundations. The design of protective structures should be compatible with the cathodic protection of the pipeline.

6.9 Crossings and encroachments

6.9.1 Consultations with authorities

The pipeline design loads, including frequency, construction methods and requirements for the protection of crossings, shall be established in consultation with the appropriate authorities.

6.9.2 Roads

Roads should be classified as major or minor for the application of the hoop-stress design factor.

Motorways and trunk roads should be classified as major and all other public roads as minor. Private roads or tracks should be classified as minor even if used by heavy vehicles.

The hoop stress design factors in Table 2 and the cover depth requirements in Table 5 should, as a minimum, apply to the road right-of-way boundary or, if this boundary has not been defined, to 10 m from the edge of the hard surface of major roads and 5 m for minor roads.

Pipelines running parallel to a road should be routed outside the road right-of-way boundary where practicable.

6.9.3 Railways

The hoop stress design factors in Table 2 and the cover depth requirements in Table 5 should, as a minimum, apply to 5 m beyond the railway boundary or, if the boundary has not been defined, to 10 m from the rail.

Pipelines running parallel to the railway should be routed outside the railway right-of-way where practicable.

The vertical separation between the top of the pipe and the top of the rail should be a minimum of 1,4 m for open-cut crossings and 1,8 m for bored or tunnelled crossings.

6.9.4 Waterways and landfalls

Protection requirements for pipeline crossings of canals, shipping channels, rivers, lakes and landfalls should be designed in consultation with the water and waterways authorities.

Crossings of flood defences can require additional design measures for the prevention of flooding and limiting the possible consequences.

The potential for pipeline damage by ships' anchors, scour and tidal effects, differential soil settlement or subsidence, and any future works such as dredging, deepening and widening of the river or canal, shall be considered when defining the protection requirements.

6.9.5 Pipeline/cable crossings

Physical contact between a new pipeline and existing pipelines and cables shall be avoided. Mattresses or other means of permanent separation should be installed if necessary to prevent contact during the design life of the pipeline.

Crossings should occur at as close as practicable to 90°.

6.9.6 Pipeline bridge crossings

Pipeline bridges may be considered when buried crossings are not practicable.

Pipeline bridges shall be designed in accordance with structural design standards, with sufficient clearance to avoid possible damage from the movement of traffic, and with access for maintenance. Interference between the cathodic protection of the pipeline and the supporting bridge structure shall be considered.

Provision shall be made to restrict public access to pipeline bridges.

6.9.7 Sleeved crossings

Sleeved crossings should be avoided where possible.

NOTE API RP 1102 provides guidance on the design of sleeved crossings.

6.10 Adverse ground and seabed conditions

Where necessary, protective measures, including requirements for surveillance, shall be established to minimize the occurrence of pipeline damage from adverse ground and seabed conditions.

EXAMPLE Adverse ground and seabed conditions include landslide, erosion, subsidence, differential settlement, areas subject to frost heave and thaw settlement, peat areas with a high groundwater table and swamps. Possible protective measures are increased pipe wall thickness, ground stabilization, erosion prevention, installation of anchors, provision of negative buoyancy, etc., as well as surveillance measures. Measurements of ground movement, pipeline displacement or change in pipeline stresses are possible surveillance methods.

Local authorities, local geological institutions and mining consultants should be consulted on general geological conditions, landslide and settlement areas, tunnelling and possible adverse ground conditions.

6.11 Section isolation valves

Section isolation valves should be installed at the beginning and end of a pipeline and where required for

- operation and maintenance;
- control of emergencies;
- limiting potential spill volumes.

Account should be taken of topography, ease of access for operation and maintenance, including requirements for pressure relief, security and proximity to occupied buildings when locating the valves.

The mode of operation of section isolation valves shall be established when determining their location.

6.12 Integrity monitoring

Requirements for pipeline integrity monitoring shall be established at the design stage.

NOTE Monitoring can include corrosion monitoring, inspection and leak detection.

6.13 Design for pigging

The requirements for pigging shall be identified and the pipeline designed accordingly. Pipelines should be designed to accommodate internal inspection tools.

The design for pigging should consider the following:

- provision and location of permanent pig traps or connections for temporary pig traps;
- access;
- lifting facilities;
- isolation requirements for pig launching and receiving;
- requirements for venting and draining (for pre-commissioning and during operation);
- pigging direction(s);
- permissible minimum bend radius;
- distance between bends and fittings;
- maximum permissible changes in diameter;
- tapering requirements at internal diameter changes;
- design of branch connections and compatibility of line pipe material;
- internal fittings;
- internal coatings;
- pig signallers.

The safety of access routes and adjacent facilities shall be considered when determining the orientation of pig traps.

6.14 Fabricated components

6.14.1 Welded branch connections

Welded branch connections on steel pipe shall be designed in accordance with the requirements of a recognized design standard. The hoop stress in the connection shall not exceed the hoop stress permitted in the adjacent pipe.

Mechanical fittings may be used for making hot taps on pipelines, provided they are designed to meet or exceed the design pressure of the pipeline.

6.14.2 Special components fabricated by welding

The design of special components shall be in accordance with sound engineering practice and this International Standard. Where the strength of such components cannot be computed or determined in accordance with the requirements of this International Standard, the maximum allowable operating pressure shall be established in accordance with the requirements of ASME BPVC, Section VIII, Division 1.

Prefabricated items, other than commonly manufactured butt-welded fittings, that employ plate and longitudinal seams shall be designed, constructed and tested in accordance with this International Standard. Orange-peel bull plugs, orange-peel swages and fish tails shall not be used.

Flat closures shall be designed in accordance with ASME BPVC, Section VIII, Division 1.

Special components shall be capable of withstanding a pressure equal to the pressure during the strength-testing of the pipeline. Components to be installed in existing pipelines shall be pressure-tested before installation in accordance with 6.7.

6.14.3 Extruded outlets

Extruded outlets shall be designed in accordance with ISO 15590-2.

6.14.4 Pig traps

All anticipated pigging operations, including possible internal inspection, shall be considered when determining the dimensions of the pig trap.

Pig traps, both permanent and temporary, shall be designed with a hoop-stress design factor in accordance with Tables 2 and 3, including such details as vent, drain and kicker branches, nozzle reinforcements, saddle supports. Closures shall comply with ASME BPVC, Section VIII, Division 1.

Closures shall be designed such that they cannot be opened while the pig trap is pressurized. This may include an interlock arrangement with the main pipeline valves.

Pig traps shall be pressure-tested in accordance with 6.7.

6.14.5 Slug catchers

6.14.5.1 Vessel-type slug catchers

All vessel-type slug catchers, wherever they are located, shall be designed and fabricated in accordance with ASME BPVC, Section VIII, Division 1.

6.14.5.2 Multi-pipe slug catchers

Multi-pipe slug catchers shall be designed with a hoop-stress design factor in accordance with Tables 2 and 3.

6.14.6 Fabricated assemblies

The hoop-stress design factors for fabricated assemblies shall apply to the entire assembly and shall extend, excluding transition ends of piping, bends or elbows, for a distance of the lesser of five pipe diameters or 3 m in each direction beyond the last component.

6.15 Attachment of supports or anchors

The pipeline and equipment shall be adequately supported, so as to prevent or to damp out excessive vibration, and shall be anchored sufficiently to prevent undue loads on connected equipment.

Branch connections for pipelines on land shall be supported by consolidated backfill or provided with adequate flexibility.

When openings are made in a consolidated backfill to connect new branches to an existing pipeline on land, a firm foundation shall be provided for both the header and the branch to prevent both vertical and lateral movements.

Braces and damping devices required to prevent vibration of piping shall be attached to the carrier pipe by full-encirclement members.

All attachments to the pipeline shall be designed to minimize the additional stresses in the pipeline. Proportioning and welding-strength requirements of attachments shall conform to standard structural practice.

Structural supports, braces or anchors shall not be welded directly to pipelines designed to operate at a hoop stress of 50 % or more of SMYS. Instead, such devices shall be supported by a full-encirclement member.

Where it is necessary to provide positive support, as at an anchor, the attachment should be welded to the encircling member and not to the pipe. The connection of the pipe to the encircling member shall be by continuous circumferential rather than intermittent welds.

Supports not welded to the pipeline should be designed to allow access for inspection of the pipeline underneath the supports.

Design of anchor blocks to prevent axial movement of a pipeline should take into account the pipeline expansion force and any pipe-to-soil friction preventing movement.

The design of the full-encirclement member shall include the combined stress in the carrier pipe of the functional, environmental, construction and accidental loads. Attachment of the full-encirclement member may be by clamping or continuous full encirclement welds.

The pipe wall axial force, F, to be resisted for fully restrained pipelines should be calculated as given in Equation (7):

$$F = -p_{id} \times A_i(1 - 2\nu) - A_s \times E \times \alpha(T_2 - T_1) \tag{7}$$

where

p_{id} is the design pressure;

A_i is the internal cross-sectional area of the pipe;

A_s is the cross-sectional area of pipewall;

E is the modulus of elasticity;

α is the linear coefficient of thermal expansion;

T_1 is the installation temperature;

T_2 is the maximum or minimum metal temperature during operation;

ν is the Poisson ratio.

Significant residual installation loads shall also be taken into account when determining axial pipeline forces.

6.16 Offshore risers

Offshore risers should be given careful design consideration because of their criticality to an offshore installation and its exposure to environmental loads and mechanical service connections. The following factors should be taken into consideration in their design:

— splash zone (loads and corrosion);

— reduced inspection capability during operation;

— induced movements;

— velocity amplification due to riser spacing;

— possibility of platform settlement;

— protection of risers by locating them within the supporting structure.

7 Design of stations and terminals

7.1 Selection of location

In selecting the locations for stations and terminals on land, consideration shall be given to

- topography;
- ground conditions;
- access;
- availability of services;
- requirements for inlet and outlet connections to and from the pipeline;
- hazards from other activities and adjacent property;
- public safety and the environment;
- anticipated developments.

Stations and terminals should be located such that the facilities constructed on the site can be protected from fires on adjacent properties that are not under the control of the pipeline operating company.

The location of parts of the pipeline system within other installations, both on land and offshore, should be determined as part of an overall installation layout review. The review should take into account the results of safety evaluations including consequences on personnel accommodation and evacuation in the case of explosion or fire.

7.2 Layout

Open space shall be provided around stations and terminals for the free movement of fire-fighting equipment. Sufficient access and clearance shall be provided at stations and terminals for movement of fire-fighting and other emergency equipment.

Layouts of stations and terminals shall be based on minimizing the spread and consequences of fire.

Areas within stations and terminals with possible explosive gas mixtures shall be classified in accordance with IEC 60079-10 and the requirements for plant and equipment defined accordingly.

Spacing of tankage shall be in accordance with NFPA 30.

Piping and pipelines shall be routed such that trip or overhead hazards to personnel are avoided and access to piping and equipment for inspection and maintenance is not hindered. Requirements for access for replacement of equipment shall also be considered.

Vent and drain lines to atmosphere shall be extended to a location where fluids can be discharged safely. Particular attention shall be paid to safety in locating vent and drain lines near living quarters on offshore installations.

7.3 Security

Access to stations and terminals shall be controlled. They should be fenced, with gates locked or attended.

Permanent notices shall be located at the perimeter indicating the reference details of the station or terminal and a telephone number at which the pipeline operating company can be contacted.

Security requirements for parts of the pipeline system within other installations shall be established in conjunction with the requirements for the installation.

7.4 Safety

Signs shall be placed to identify hazardous, classified and high-voltage areas. Access to such areas shall be controlled.

Fences shall not hinder the escape of personnel to a safe location. Escape gates shall open outward and be capable of being opened from the inside without a key when the enclosure is occupied.

Adequate exits and unobstructed passage to a safe location shall be provided for each operating floor of main pump and compressor buildings, basements, and any elevated walkway or platform. Exits shall provide a convenient possibility of escape.

Appropriate fire and gas detection and fire-fighting facilities shall be provided. For stations and terminals on land, the requirements for such facilities shall be established in consultation with the local fire authorities.

Tanks, dikes and firewalls shall meet the requirements of NFPA 30.

Ventilation shall be provided to prevent the exposure of personnel to hazardous concentrations of flammable or noxious liquids, vapours or gases in enclosed areas, sumps and pits during normal and abnormal conditions, such as a blown gasket or packing gland. Equipment for the detection of hazardous concentrations of fluids shall be provided.

Hot and cold piping that can cause injury to personnel shall be suitably insulated or protected.

7.5 Environment

The disposal of effluent and discharges shall comply with national and local environmental requirements.

7.6 Buildings

Pump and compressor buildings that house equipment or piping in sizes larger than 60 mm outside diameter or equipment for conveying, except for domestic purposes, category D and E fluids, shall be constructed of fire-resistant, non-combustible or limited combustibility materials defined in NFPA 220.

7.7 Equipment

Pumps and compressors, prime movers, their auxiliaries, accessories, control and support systems, shall be suitable for the services specified in the system definition in accordance with 5.1. Pumps, compressors and their prime movers shall be designed for a range of operating conditions within the constraints of the pipeline system as limited by the controls identified in 5.4.

Prime movers, except electrical induction or synchronous motors, shall be provided with an automatic device that is designed to shut down the unit before the speed of the prime mover or of the driven unit exceeds the maximum safe speed specified by the manufacturer.

Plant and equipment shall meet the requirements of the area classification in accordance with 7.2.

In addition to the functional requirements stated above, pumps, compressors, gas turbines and electric motors shall meet the requirements of ISO 3977, ISO 10439, ISO 13707, ISO 13709, ISO 13710 or IEC 60034-1, as applicable.

7.8 Piping

7.8.1 Primary piping

Primary piping shall be designed in accordance with the requirements of Clause 6.

Vibrations caused by vibrating equipment, fluid pulsations from reciprocating pumps or compressors and flow induced pulsations shall be considered during the piping design.

Piping shall be protected against damage from vacuum pressures and overpressures. Pressure control and over-pressure protection shall comply with the requirements of 5.4.

NOTE Piping can be subjected to overpressure or vacuum conditions as a result of surge following a sudden change in flow during valve closure or pump shutdown, excessive static pressure, fluid expansion, connection to high-pressure sources during a fault condition, or as a result of a vacuum created during shutdown or drain-down.

7.8.2 Secondary piping

7.8.2.1 Fuel gas piping

Fuel-gas piping within a station shall be in accordance with ISO 15649.

Fuel-gas lines shall be provided with master shut-off valves located outside any building or residential quarters.

The fuel gas system shall be provided with pressure-limiting devices to prevent fuel pressures from exceeding the normal operating pressure of the system by more than 25 %. The maximum fuel pressure shall not exceed the design pressure by more than 10 %.

Provision shall be made to vent and purge fuel headers to prevent fuel gas from entering combustion chambers when work is in progress on the drivers or connected equipment.

7.8.2.2 Air piping

Air piping within a station shall be in accordance with ISO 15649.

Air receivers or air-storage bottles shall be constructed and equipped in accordance with ASME BPVC, Section VIII, Division 1.

7.8.2.3 Lubricating oil and hydraulic oil piping

All lubricating oil and hydraulic oil piping within stations shall be in accordance with ISO 15649.

7.8.2.4 Vent and drain lines

Vent and drain lines shall be sized to match the capacity of relief valves.

7.9 Emergency shutdown system

Each pump or compressor station shall be provided with an emergency shutdown system that is readily accessible, locally and/or remotely operated, and which shuts down all prime movers. Consideration should also be given to isolating the station from the pipeline and to relieving or venting when required.

Operation of the emergency shutdown system shall also permit the shutdown of any gas-fired equipment that can jeopardize the safety of the site, provided it is not required for emergency purposes.

Uninterrupted power supply shall be provided for personnel protection and those functions that are necessary for protection of equipment.

7.10 Electrical

Electrical equipment and wiring installed in stations shall conform to the requirements of IEC 60079-14. Electrical installations that are required to remain in operation during an emergency shall be based on the zone applicable during the emergency.

7.11 Storage and working tankage

Tanks for storage or handling of fluids shall be designed and constructed in accordance with the following standards:

— API 650 for fluids with a vapour pressure less than 3,5 kPa [0,035 bar(g)];

— API 620 for fluids with a vapour pressure higher than 3,5 kPa [0,035 bar(g) but not more than 100 kPa [1 bar(g)];

— this International Standard for pipe-type holders used for fluids with a vapour pressure of more than 100 kPa [1 bar(g)];

— applicable standards for holders other than pipe-type holders for fluids with a vapour pressure of more than 100 kPa [1 bar(g)].

Foundations shall be designed and constructed in accordance with plans and specifications which shall take into account local soil conditions, type of tank, usage and general location.

7.12 Heating and cooling stations

Temperature indication and controls should be provided where heating or cooling of the fluids is required for operation of the pipeline system.

For heating stations, trace heating can be required on pipework, pump bodies, drains and instrument lines to ensure satisfactory flow conditions following shutdown.

7.13 Metering and pressure control stations

Meters, strainers and filters shall be designed for the same internal pressure and shall meet the pressure-test requirements of this International Standard.

Components shall be supported in such a manner as to prevent undue loading to the connecting piping system.

Design and installation shall provide for access and ease of maintenance and servicing while minimizing interference with the station operations. Consideration shall be given to backflow, vibration or pulsation of the flowing stream.

The retention size of any filtering medium shall be selected to protect the facilities against the intrusion of harmful foreign substances and to prevent electrostatic charge accumulation.

7.14 Monitoring and communication systems

The requirements for monitoring pressure, temperature, flowrate, physical characteristics of the fluid being conveyed, information on pumps, compressors, valve positions, meters and tank levels, together with alarm conditions such as power supply failure, high temperature of electric motor windings and rotating machinery bearings, excessive vibration levels, low suction pressures, high delivery pressures, seal leakage, abnormal temperatures, and the detection of fire and hazardous atmosphere shall be defined and included in the system design in accordance with Clause 5.

Supervisory control and data acquisition (SCADA) systems may be used for controlling equipment.

Operating requirements of the pipeline system, as well as safety and environmental requirements, shall be the basis for determining the requirement for redundant monitoring and communication components, and back-up power supply.

7.15 Compressor stations for on-land gas supply systems

Additional specific functional requirements for compressor stations are given in EN 12583.

8 Materials and coatings

8.1 General material requirements for pipelines and primary piping

8.1.1 Selection

Materials for use in the pipeline and primary piping shall

- have the mechanical properties, such as strength and toughness, necessary to comply with the design requirements of 6.4;
- have the properties necessary to comply with the requirements for corrosion control of Clause 9;
- be suitable for the intended fabrication and/or construction methods.

NOTE Material requirements for secondary piping are addressed in ISO 15649.

8.1.2 Materials for sour service

Specifications for materials in sour service shall meet the requirements in ISO 15156-1, ISO 15156-2 and ISO 15156-3 as applicable.

8.1.3 Consistency of requirements

Requirements shall be specified consistently for all pressure-containing components.

EXAMPLE Such requirements include chemical composition to ensure weldability and toughness to prevent brittle fracture.

8.1.4 Chemical composition

Ferritic steel materials intended for welding and for which a product standard is not available should have a maximum carbon equivalent, CE, of

- 0,45 for grades with a specified minimum yield strength not exceeding 360 MPa;
- 0,48 for grades with a specified minimum yield strength above 360 MPa.

Ferritic steel materials intended for welding and for which a product standard is available shall have a CE not exceeding the above values or the values quoted in the product standard, whichever is the lowest.

The purchaser of materials may consider applications for which higher CEs are acceptable or the acceptable maximum CE requires further limitation.

The CE shall be calculated as given in Equation (8):

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 \qquad (8)$$

where the symbols of the elements represent the percent mass fraction of the corresponding element.

NOTE The formatting for Equation (8) does not conform to the standard ISO formatting but it has been accepted, exceptionally, on the basis of its long-standing and well established history in the industry.

For pipelines and primary piping transporting category A fluids, where the full chemical composition is not reported, an alternative CE formula may be used.

$$CE = C + Mn/6 + 0{,}04 \qquad (9)$$

8.1.5 Brittle fracture toughness

Materials shall be selected and applied in such a way that brittle fracture is prevented.

Materials used in pipelines and primary piping transporting category C, D and E fluids, with a nominal diameter above DN 150 and of ferritic, ferritic/austenitic or martensitic stainless or carbon steel, shall meet the following minimum Charpy impact energy values for full-size Charpy V-notch test specimens:

— 27 J average/20 J individual for grades with specified minimum yield strength not exceeding 360 MPa;

— 40 J average/30 J individual for grades with specified minimum yield strength above 360 MPa.

The requirements for preventing brittle fracture of materials in pipelines and primary piping transporting category A and B fluids and of components with a nominal diameter not exceeding DN 150 in pipelines transporting category C, D and E fluids shall be determined based on the design conditions.

NOTE Higher impact values can be required to arrest running ductile fractures; see 8.1.6.

Full-size Charpy V-notch tests shall be carried out in accordance with ISO 148-1. The alternative, tapered test pieces specified by ISO 3183 may also be used. Reduced-size specimens may be tested and the minimum required impact energy values reduced in proportion to the thickness of the specimen when the thickness of the components being tested does not permit a full-size Charpy V-notch test.

The test temperature shall not be higher than the minimum temperature the material can experience while under pressure. Lower test temperatures shall be considered for gas or gas/liquid pipelines and primary piping, for offshore risers and for large-thickness components.

The requirements for preventing brittle fracture shall be met in the parent metal and, for welded components, the weld metal and heat-affected zones by the use of a welding procedure qualified to provide the specified brittle fracture resistance.

8.1.6 Shear-fracture toughness

The parent metal of line pipe for pipelines conveying category C, D, and E fluids shall be capable of arresting running shear fractures. The phase behaviour of fluids during sudden decompression shall be determined and the required shear-fracture arrest properties verified for all phases.

NOTE ISO 3183:2007, Annex G, provides guidance on determining the fracture-toughness requirements for the arrest of running shear fractures.

Charpy V-notch tests shall be carried out, in accordance with the requirements of 8.1.5, at the minimum temperature the pipeline can experience during service under the effect of lowest air, seawater or ground temperature.

Mechanical crack arrestors consisting of sleeves or heavy-wall pipe may be applied where it is not practical to achieve the toughness required for fracture arrest. The consequences of fracture propagation shall determine the locations and minimum spacing of arrestors along the pipeline.

8.1.7 Higher-temperature service

The mechanical properties at the maximum operating temperature of materials for operations above 50 °C should be documented unless specified in the referenced product standard or complementary justification.

8.1.8 Properties after forming and heat treatment

For materials subjected to heat treatment, hot or cold forming, or other processes that can affect the material properties, compliance with the specified requirements in the final condition shall be documented. Documentation shall be provided for the parent metal and, in the case of welded components, for the weld metal and heat-affected zones.

8.1.9 Production qualification programmes

Requirements for production qualification programmes and pre-production testing for material should be considered on the basis of available experience with previous fabrication of that material.

8.1.10 Marking

Materials and components shall be marked in accordance with the requirements of the applicable product standard or, if not specified, the requirements of MSS SP-25.

Marking by die stamping shall be done in a manner resulting in minimum stress concentrations and at locations where the marking will not be harmful.

8.1.11 Inspection documents

All materials shall be supplied with an inspection document in accordance with ISO 10474, which can be traced to the pipeline component. For materials for pressure-retaining components, an inspection certificate type 3.1.B in accordance with ISO 10474:1991 shall be supplied as a minimum.

8.1.12 Specifications

All materials for line pipe, piping components and coatings shall be manufactured and used in accordance with the requirements of the relevant product standard and of this International Standard.

Requirements of this International Standard not included in the relevant product standard shall be specified and supplemented to the product standard.

Detailed specifications, which shall include the required properties, dimensional requirements and requirements for fabrication, testing, inspection, certification and documentation, shall be prepared for materials if a relevant product standard is not available.

8.1.13 Reuse of components

The reuse of components is permitted provided

- the specification for the original fabrication is known and meets the requirements of this International Standard;
- inspection documentation complies with the requirements of 8.1.11;
- it is demonstrated by inspection, following cleaning, and repair where permitted by this International Standard, that they are sound and free from defects.

Line pipe for which the specification of the original fabrication is not known may be used as grade L245 only provided it is demonstrated by adequate inspection and testing that the line pipe meets the requirements of the appropriate part of ISO 3183. The use of such materials shall be limited to pipe operating at stress levels below 30 % of the specified minimum yield strength.

NOTE The pipeline operator can clarify in project specifications his acceptance of the reuse of materials.

8.1.14 Records

Specifications with agreed deviations, design dossier such as calculations and drawings, test and inspection results, and certification shall be collected for retention during operations, in accordance with the requirements of 13.1.7.

8.2 Line pipe

8.2.1 Carbon steel pipe

Line pipe made of C-Mn steel shall conform to ISO 3183.

8.2.2 Stainless steel and non-ferrous metallic pipe

Stainless steel and non-ferrous metallic line pipe may be welded or seamless pipe.

8.2.3 Carbon steel pipe with stainless steel or non-ferrous metallic layer

Carbon steel line pipe shall conform to ISO 3183.

The design and internal corrosion evaluation shall address whether the internal stainless steel or non-ferrous metallic layer should be metallurgically bonded (clad) or may be mechanically bonded (lined) to the outer carbon steel pipe. The minimum thickness of the internal layer should not be less than 3 mm in the pipe and at the weld.

The requirement of pipe-end tolerances closer than specified in ISO 3183 for welding shall be reviewed and specified if deemed necessary.

8.3 Components other than pipe

8.3.1 Flanged connections

Flanged connections shall meet the requirements of ISO 15590-3, ASME B16.5 or MSS SP-44 or other recognized codes. Proprietary flange designs are permissible. They should conform to relevant sections of ASME BPVC, Section VIII, Division 1.

Compliance with the design requirements of ISO 15590-3 shall be demonstrated when deviating from the flange dimensions and drillings specified in ISO 15590-3.

Consideration shall be given to matching the flange bore with the bore of the adjoining pipe wall to facilitate alignment for welding.

Gaskets shall be made of materials that are not damaged by the fluid and shall be capable of withstanding the pressures and temperatures to which they are subjected in service. Gaskets for services with operating temperatures above 120 °C shall be of non-combustible materials.

Bolt material shall be compatible with the operating and environmental conditions and with the pipeline material. Bolts or studbolts shall completely extend through the nuts.

8.3.2 Bends made from pipe

Bends may be made from pipe by hot, cold or induction bending. Mitred bends shall not be used.

The requirements for hot or cold bends are

- pipe shall be of fully killed steels;
- the ovality of the bend body shall not exceed 2,5 %;
- bend-end tolerances shall meet the pipe end tolerances of the matching pipe;
- wrinkling shall not be permitted;
- all areas of the bend shall comply with the requirements for specified minimum wall thickness of the adjacent piping;
- bends shall comply with the mechanical properties specified for the pipe in 8.2.

Induction bends shall meet the requirements of ISO 15590-1.

Testing and inspection of bends shall be done in the delivery condition.

8.3.3 Fittings

Fittings shall comply with the requirements specified in ISO 15590-2.

Fittings shall be made from fully killed steel and made using recognized practices to provide the intended heat treat response and notch toughness properties.

8.3.4 Valves

Ball, check, gate and plug valves shall meet the requirements of ISO 14313. Valves for subsea application shall meet the requirements of ISO 14723.

8.3.5 Prefabricated isolating couplings

Prefabricated isolating couplings shall be pressure-tested to 1,5 × MAOP and tested electrically to confirm the electrical discontinuity, prior to installation in the pipeline.

8.3.6 Other components

The design of components for which there is no product standard shall meet the requirements of ASME BPVC, Section VIII, Division 1. Fabrication welding and welding attachment to the pipeline, of all other components, shall be in accordance with ISO 13847.

8.4 Coatings

8.4.1 External coatings

8.4.1.1 Concrete weight coatings

Concrete weight coating shall comply with ISO 21809-5.

8.4.1.2 Coating for corrosion prevention and thermal insulation

Plant-applied coating shall comply with the requirements of 9.5 and the applicable part of ISO 21809 as follows:

- three layer polyolefin coating: ISO 21809-1;
- fusion bonded epoxy (FBE) coating: ISO 21809-2;
- two-layer polyolefin: ISO 21809-4.

8.4.1.3 Thermal insulation coatings

Thermal insulation coating shall comply with a recognized standard or specification, covering the following requirements:

- type of coating and reinforcement, where relevant;
- thickness of individual layers and total thickness;
- composition and/or base material;
- mechanical properties;
- temperature limitations;
- surface preparation requirements;
- adhesion requirements;
- requirements for materials, application and curing, including possible requirements for health, safety and environmental aspects;
- requirements for qualification testing of coating system and personnel, where relevant;
- requirements for testing and inspection;
- repair procedures where relevant.

8.4.2 Internal coatings/linings

Internal coating should, in general, comply with a recognized standard or specification covering the following requirements:

- type of coating and reinforcement, where relevant;
- thickness of individual layers and total thickness;
- composition and/or base material;
- mechanical properties;
- temperature limitations;
- surface preparation requirements;
- adhesion requirements;

- requirements for materials, application and curing, including possible requirements for health, safety and environmental aspects;
- requirements for qualification testing of coating system and personnel where relevant;
- requirements for testing and inspection;
- repair procedures where relevant.

Anti-friction coatings should have a minimum thickness of 40 µm.

9 Corrosion management

9.1 General

Internal and external corrosion of pipeline systems shall be managed to prevent unacceptable risk of failure or loss of operability from corrosion within the specified design life. The corrosion management should include

- identification and evaluation of the potential sources of corrosion;
- selection of materials, taking into account the results of the internal and external corrosivity evaluations;
- identification of the necessary corrosion mitigation;
- definition of the requirements for corrosion monitoring and inspection;
- review of the findings from corrosion monitoring and inspection;
- periodic modification of the requirements of corrosion management, as dictated by experience and changes in the design conditions and environment.

Internal and external corrosivity evaluations shall be carried out to document that, for the selected material(s), corrosion can be controlled within the design intent over the design life.

The evaluations should be based on relevant operating and maintenance experience and/or the results of laboratory testing.

Any corrosion allowance should take into account the type and rate of corrosion predicted for the design life.

Possible internal and external corrosion of materials during transport, storage, construction, testing, preservation, commissioning and operational upset conditions shall be included in the evaluations.

9.2 Internal corrosivity evaluation

Possible loss or degradation of materials shall be determined for all design conditions; see 5.1.

The possible formation of free liquid water shall be evaluated for the fluid velocities, pressures and temperatures anticipated during operations.

Components of the fluid(s) that can cause or affect internal corrosion shall be identified and their potential for corrosion determined for the predicted ranges of concentrations, pressures and temperatures.

EXAMPLES Fluid components that may cause or affect internal corrosion include carbon dioxide, hydrogen sulfide, elemental sulfur, mercury, oxygen, water, dissolved salts (chlorides, bicarbonates, carboxylates, etc.), solid deposits (in relation to line cleanliness), bacterial contamination, chemical additives injected during upstream activities, contamination from upstream process upsets.

The types of potential corrosion to be addressed shall include

- general material loss and degradation;
- localized corrosion, such as pitting under deposits and mesa- or crevice-type attack;
- microbiologically induced corrosion;
- stress cracking;
- hydrogen-induced cracking or stepwise cracking;
- stress-oriented hydrogen-induced cracking;
- erosion and erosion-corrosion;
- corrosion fatigue;
- bimetallic/galvanic couples, including preferential weld corrosion.

9.3 Internal corrosion mitigation

9.3.1 Methods

Methods for the mitigation of internal corrosion may include

- a modification of design/operating conditions;
- the use of corrosion-resistant materials;
- the use of chemical additives;
- the application of internal coatings or linings;
- the use of regular mechanical cleaning;
- the elimination of bimetallic couples.

The compatibility of the selected mitigation with downstream operations should be considered.

9.3.2 Revision of design conditions

Fluid-processing facilities upstream of the pipeline system and procedures for operating the pipeline system may be reviewed to identify opportunities for the removal of corrosive components or conditions identified during the corrosivity evaluation.

9.3.3 Chemical additives

Factors for consideration during the selection of chemical additives should include

- effectiveness at water-wetted areas over the full pipeline system;
- velocity variation of fluids;
- partitioning behaviour in multiphase systems;
- influence of sediments and scales;

- compatibility with the fluid specification;
- compatibility with other additives;
- compatibility with the component materials, in particular non-metallic materials;
- personnel safety in chemicals handling;
- environmental effects in the event of discharge;
- compatibility with operations downstream of the pipeline system.

9.3.4 Internal coatings or linings

Coatings or linings may be applied to reduce internal corrosion provided that it is demonstrated that incomplete protection, at areas such as holidays and other defects, does not lead to unacceptable corrosion.

Factors for consideration during coating or lining selection should include

- internal coating of field joints;
- application methods;
- availability of repair methods;
- operating conditions;
- long-term effects of the fluid(s) on the coating/lining;
- resistance to pressure change;
- influence of temperature gradients over the coating;
- compatibility with pigging operations.

9.3.5 Cleaning

Requirements for the periodic internal mechanical cleaning should be determined. Factors for consideration should include

a) the removal of accumulated solids and/or pockets of corrosive liquid to assist in the reduction of corrosion in these areas;

b) enhancement of the effectiveness of chemical additives.

In choosing a mechanical cleaning device, consideration should be given to

- the possible consequences of removing protective layers of corrosion products or chemical additives, or damage to internal coatings or linings, by mechanical cleaning;
- the possible adverse effects of contacts between pipeline system materials, such as stainless steels, and the materials of mechanical cleaning devices.

9.4 External corrosion evaluation

The possibility of external corrosion occurring shall be determined on the basis of operating temperatures (see 5.1) and the external conditions (see 6.2).

Table 6 lists typical environments that shall be considered when evaluating the possibility of external corrosion.

Table 6 — Environments to be considered for external corrosion

Offshore pipelines	Pipelines on land
Atmosphere (marine)	Atmosphere (marine/industrial/rural)
Air/water interface (splash zone)	Sea water (tidal zone/shore approach)
Sea water	Fresh or brackish water
Seabed or buried in seabed	Marshes and swamps
Inside bundles or sleeves	River crossings
Rock dump/concrete mattresses	Dry or wet soil
Inside J-tubes/caissons	Inside tunnels, sleeves or caissons

Environmental parameters that should be considered include

a) ambient temperatures;

b) resistivity, salinity and oxygen content of the environment;

c) bacterial activity;

d) water current;

e) degree of burial;

f) potential in-growth of tree roots;

g) potential soil pollution by hydrocarbons and other pollutants.

The evaluation of corrosion measures should take into account the probable long-term corrosivity of the environment rather than be solely confined to the as-installed corrosivity. For pipelines on land, due consideration should be given to any known planned changes in the use of the land traversed by the pipeline route that can alter the environmental conditions and, thus, soil corrosivity, e.g. irrigation of land previously arid or of low corrosivity.

The possible effect of the pH of the environment and possible sources of stray and alternating currents shall be evaluated for pipelines on land.

The types of external corrosion damage for consideration shall include

— general metal loss and degradation;

— localized corrosion, e.g. pitting under deposit or crevice attack;

— microbiologically induced corrosion;

— stress-corrosion cracking, e.g. carbonate/bicarbonate attack.

9.5 External corrosion mitigation

9.5.1 Protection requirements

All metallic pipelines and primary piping should be provided with an external coating and, for buried or submerged sections, cathodic protection. The use of corrosion allowance and a durable coating or the use of a corrosion-resistant alloy cladding should also be considered for areas with a high probability of severe corrosion.

EXAMPLE The splash zone is an area with a high probability of severe external corrosion of risers in offshore pipelines.

9.5.2 External coatings

The effectiveness in providing the required protection and the possible hazards during application and service shall be considered when selecting external coatings.

Parameters for consideration when evaluating the effectiveness of external coatings shall include

— electrical resistivity of the coating;

— moisture permeation and its relation to temperature;

— required adhesion between the coating and the base material;

— required resistance to shear forces between the coating and additional coating, insulation or environment;

— susceptibility to cathodic disbondment;

— resistance to ageing, brittleness and cracking;

— requirements for coating repair;

— possible detrimental effects on the pipe material;

— possible thermal cycling;

— resistance to damage during handling, shipping, storage, installation and service.

External coatings of line pipe should be factory-applied, except for field joints and other special points, which shall be coated on site.

Field joints should be protected with a coating system that is compatible with the line-pipe coating. The coating should meet or exceed the line-pipe coating specification and allow satisfactory application under the predicted field conditions.

Thermally insulated pipelines should have an anti-corrosion coating between the pipeline and the insulation.

Pipelines in J-tubes should be externally coated. Possible coating damage during installation inside J-tubes should be considered when selecting a coating.

9.5.3 Cathodic protection

Cathodic protection systems shall be designed, manufactured, installed and operated in accordance with ISO 15589-1 for on-land pipelines and ISO 15589-2 for offshore pipelines.

9.6 Monitoring programmes and methods

9.6.1 Requirement for monitoring

The requirements for corrosion monitoring programmes shall be established on the basis of the predicted corrosion mechanisms and corrosion rates (see 9.2 and 9.4), the selected corrosion mitigation methods (see 9.3 and 9.5) and safety and environmental factors.

The use of internal inspection tools should be considered if monitoring of internal or external corrosion or other defects is required over the full length of the pipeline. Approximate rates or trends of corrosion degradation may be determined by analysis of results of consecutive metal loss inspections.

An inspection of the pipeline soon after commissioning should be considered to provide a baseline for the interpretation of future surveys.

9.6.2 Monitoring internal corrosion

9.6.2.1 Selection of techniques

The selection of techniques for the monitoring of internal corrosion shall consider

— anticipated type of corrosion;

— potential for water separation, erosion, etc. (flow characteristics);

— anticipated corrosion rate; see 9.2;

— required accuracy;

— available internal and external access;

— hindrance of the passage of pigs or inspection vehicles by internal obstructions.

NOTE Possible techniques include the installation of devices such as coupons or probes to give an indication of the corrosion in the pipeline system, or periodic analyses of the fluid to monitor its corrosivity.

9.6.2.2 Location of test points for local corrosion monitoring

Test points for corrosion monitoring should be located along the pipeline or associated facilities, where it is most likely to obtain representative indications of corrosion in the pipeline.

9.6.3 Monitoring external condition

Accessible sections should be visually surveyed periodically to assess the conditions of the pipeline system and, where applied, the external coating. Buried or submerged pipelines shall also be inspected when exposed.

A more detailed, close visual examination of the coating shall be carried out periodically at locations with a high probability of severe corrosion.

The requirements for periodic surveys of the coating of pipelines on land shall be determined, taking into account the selected coating and predicted degradation, the soil type, the observed cathodic protection potentials and current demands and known metal loss.

NOTE Applicable survey techniques are described in ISO 15589-1.

9.6.4 Monitoring cathodic protection

Periodic surveys shall be carried out to monitor the cathodic protection in accordance with ISO 15589-1 and ISO 15589-2.

9.7 Evaluation of monitoring and inspection results

All findings of the monitoring and inspection activities shall be analysed to

- review the adequacy of the corrosion management;
- identify possible improvements;
- indicate a requirement for further detailed assessment of the pipeline system condition;
- indicate the requirement to modify the corrosion-management requirements.

9.8 Corrosion-management documentation

Documentation that describes the following shall be prepared in accordance with the requirements for corrosion management given in 9.1 to 9.6:

- assessment of the corrosion threats and associated potentials for failure;
- choice of materials and corrosion mitigation methods;
- selection of inspection and corrosion-monitoring techniques and inspection frequencies;
- any specific decommissioning and abandonment requirements associated with the selected corrosion-management approach.

10 Construction

10.1 General

10.1.1 Construction plan

A construction plan shall be prepared before the commencement of construction to assist in the control of the work. This plan shall be commensurate with the complexity and the hazards of the work and should contain, as a minimum,

- a description of the construction;
- a health, safety and environment plan;
- a quality plan.

The description of the construction should include methods, personnel and equipment required for the construction and working procedures.

NOTE Special construction, such as tunnels, landfalls for offshore pipelines, pipeline bridges and horizontal directional drilling, can require supplemental pipeline installation procedures.

The health, safety and environment plan should describe requirements and measures for the protection of the health and safety of the public, personnel involved in the construction and the environment. It should contain the requirements of the relevant legislation and applicable standards, identification of hazards and measures required for their control and emergency procedures.

10.1.2 Construction near other facilities

All facilities that can be affected by the construction of the pipeline system shall be identified prior to beginning the work.

Temporary provisions and safety measures necessary to protect the identified facilities during construction should be established. Owners and/or operators of the facilities should be consulted when defining these temporary provisions and safety measures and shall be given timely notification of the commencement of construction.

EXAMPLES Other facilities can include existing roads and railways, watercourses, footpaths, pipelines, cables and buildings.

10.1.3 Plant, equipment and marine vessels

All major plant, equipment and marine vessels used for construction shall be inspected before and during construction to determine their suitability for the intended work in accordance with good engineering practice.

10.1.4 Transport and handling of materials

Handling, storing, transport and installation of materials shall be performed in a manner that prevents or minimizes damage to pipes, fittings, components and coating. Transport and handling procedures may be required. These procedures should identify the equipment being used and the stacking requirements.

NOTE API RP 5LW and API RP 5L1 provide guidance for the transport of line pipe.

Materials shall be inspected for damage and defects that do not conform to the specifications. These materials shall not be installed unless the damage and/or defect has been removed or corrected.

10.2 Preparation of the route on land

10.2.1 Site inspections

Site inspections of existing conditions along the working width of the pipeline route shall be undertaken after access to the route has been granted and before commencement of construction. Reports of these inspections shall state the condition of the items potentially affected by construction and record the mutual approval of all parties concerned.

10.2.2 Survey and marking

The pipeline route, working width, buried structures and overhead structures shall be surveyed and marked prior to construction. Marking shall be maintained in good condition during the construction period.

10.2.3 Preparation of the working width

Appropriate fencing shall be provided along the working width where required for public safety and to prevent livestock from encroaching on the working width. Constraints or precautions that it is necessary to observe within the working width shall be defined in the construction specifications.

EXAMPLES Such constraints or precautions include preservation of specific trees, disposition of trees and stumps, separation of topsoil, drainage and scour and erosion prevention.

10.2.4 Blasting

Blasting shall be in accordance with relevant legislation and environmental constraints and shall be performed by competent and qualified personnel.

10.3 Preparation of the route offshore

10.3.1 Surveys

In addition to the survey requirements of 6.2.3, a pre-construction seabed survey should be performed along the proposed pipeline route to identify potential hazards for the pipeline or construction operations.

10.3.2 Seabed preparation

Seabed survey data shall be analysed and seabed preparation undertaken, if necessary, to meet the strength criteria in 6.4.2.

10.4 Welding and joining

10.4.1 Welding standard

Welding of the pipeline and primary piping shall be carried out in accordance with ISO 13847. Welding of the secondary piping shall be carried out in accordance with ISO 15649.

10.4.2 Weld examination

Examination of welds in the pipeline and primary piping shall be performed in accordance with ISO 13847 and, except as allowed for tie-in welds in 11.5, the weld examination shall be carried out before pressure-testing.

The extent of the non-destructive examination for girth welds shall be as follows.

a) All welds shall be visually examined.

b) A minimum of 10 % of the welds completed each day shall be randomly selected by the owner or owner's designated representative for examination by radiography or ultrasonics. The 10 % level should be used for pipelines in remote areas, pipelines operating at 20 % or less of SMYS or pipelines transporting fluids that are low hazards to the environment or personnel in the event of a leak. The percentage of weld examination for other fluids and locations shall be selected appropriate to the local conditions. The examination shall be increased to 100 % of the welds if lack of weld quality is indicated, but may subsequently be reduced progressively to the prescribed minimum percentage if a consistent weld quality is demonstrated.

c) 100 % of the welds shall be examined by radiography or ultrasonics for the following circumstances:

   — pipelines designed to transport category C fluids at hoop stresses above 77 % of SMYS;

   — pipelines designed to transport category D fluids at hoop stresses at or above 50 % of SMYS;

   — pipelines designed to transport category E fluids;

   — pipelines not pressure-tested with water;

   — primary piping and sections of pipelines in stations and terminals;

   — pipelines within populated areas, such as residential areas, shopping centres and designated commercial and industrial areas;

   — pipelines in environmentally sensitive areas;

   — pipelines with river, lake, and stream crossings, including overhead crossings or crossings on bridges;

   — pipelines on railway or public highway rights-of-way, including tunnels, bridges and overhead crossings;

— pipelines in offshore and coastal waters;

— pipelines with tie-in welds not pressure-tested after installation.

Radiography or ultrasonic examination shall cover the weld over its full circumference. The examination shall be appropriate to the joint configuration, wall thickness and pipe diameter.

Welds in secondary piping shall be examined in accordance with the applicable standard.

Welds shall meet the acceptance criteria specified in the applicable welding standard. Welds not meeting these criteria shall be either removed or, if permitted, repaired and re-inspected.

10.4.3 Joining other than welding

Joining by other techniques shall be performed in accordance with approved procedures.

10.5 Coating

10.5.1 Field joint coating

Field joint coatings shall satisfy the requirements of ISO 21809-3.

10.5.2 Coating inspection

Coatings shall be visually inspected at the time of pipe installation to ensure compliance with the specified standard and application procedure.

Immediately before the pipe is lowered into the trench, or before the pipe leaves the installation vessel, the entire coating surface shall be inspected, where accessible, using a holiday detector set to the correct voltage applicable to the coating. Defects shall be marked and repaired before the pipe is placed in its final position. Where coating damage or disbondment has occurred, the coating shall be removed, replaced and retested.

Coating on tie-ins, special assemblies and pipe sections for crossings shall be inspected with a holiday detector prior to installation.

10.6 Installation of pipelines on land

10.6.1 Pipe stringing

Stringing shall be performed in accordance with written procedures that define access limitations and provisions for minimizing interference with local and public land use and include provisions for access across the working width.

10.6.2 Field pipe bends

Pipes may be bent cold in the field to fit pipeline alignment and topographical conditions. Field bends shall be made on bending machines that provide sufficient support to the pipe cross-section to prevent buckling or wrinkling of the pipe wall and to maintain coating integrity.

The minimum bending radii should not be less than

— 20 D for pipe OD of less than 200 mm;

— 30 D for pipe OD of 200 mm to 400 mm;

— 40 D for pipe OD of over 400 mm.

Field bends may be made to a shorter radius than shown above provided that, after bending, the ovality is not greater and the wall thickness is not less than permitted by the design and that the material properties meet the toughness requirements specified for the line pipe.

Bends shall be free from buckling, cracks or other evidence of mechanical damage.

When bending pipe with diameters above 300 mm and with a diameter-to-wall-thickness ratio of greater than 70:1, consideration should be given to the use of an internal mandrel.

A test bend should be made to verify that the requirements of this subclause can be met.

Bends should not be made from pipe lengths containing girth welds that are within 1 m of the bend. Longitudinal weld seams should be placed near the neutral axis of field bends.

10.6.3 Excavation

Trench depth shall be sufficient to provide the cover specified in accordance with 6.8.2.1.

Trench side slopes shall be analysed to determine whether shoring or sloping is required to provide safe working conditions. Erosion-mitigation measures should be established to prevent trench instability and damage to the environment.

The trench bottom shall be flat and free from sharp edges or objects that can damage the pipe or its coating. If this is not possible, the pipe shall be protected by installing bedding material or mechanical protection. Any bedding material or mechanical protection shall not act as a shield to the passage of the cathodic-protection current to the pipe surface.

When work is performed in the trench, it shall be widened and deepened to allow safe working conditions. Precautions shall be taken prior to personnel entering the trench to ensure that a safe, non-flammable atmosphere is present. When trenching occurs adjacent to existing underground structures, precautions shall be taken to avoid damage to such structures. A minimum separation of 0,3 m shall be provided between the outside of any buried pipe and the extremity of any other underground structure, unless special provisions are made to protect the pipeline and the underground structure.

10.6.4 Lowering pipe

Prior to lowering, the trench bottom shall be clean and free of objects likely to cause coating damage and shall be graded to provide uniform support to the pipeline.

Equipment or methods used for lowering the pipe into the trench shall not damage the pipe or its coating. Lifting and lowering procedures shall such that the strength criteria specified in 6.4.2 are not exceeded.

10.6.5 Backfill

To avoid coating damage, backfill should be carried out as soon as possible after lowering.

Flooded trenches should be pumped dry or drained prior to backfilling. When this is not possible and it is necessary to backfill a flooded trench, care shall be exercised to ensure that liquefied backfill does not displace the pipe.

Backfill materials or protective measures shall be selected to prevent damage to the pipe or its coating.

Field drains, ditches and other drainage systems interrupted during the work should be reinstated.

Backfill materials and installation methods under roads, footpaths, shoulders, banks and similar areas shall be selected to ensure the stability and integrity of these facilities. When terrain, soil and water conditions are present that can cause erosion, consideration shall be given to the installation of barriers to prevent land slippage or washout.

10.6.6 Tie-in

Tie-in procedures shall include provisions for controlling the pipe stress to the allowable strength criteria in 6.4.2. Procedures shall include consideration of the pipeline configuration, planned movement after tie-in and temperature differences between tie-in and future operations.

10.6.7 Reinstatement

Reinstatement of the working width and other areas affected by construction shall be carried out in accordance with procedures that meet the requirements of relevant legislation and agreements with landowners and occupants.

10.6.8 Crossings

All crossings shall be carried out in a manner that meets the requirements of 6.2.1 and 10.1.2.

Where watercourses are crossed by the open-cut method, consideration shall be given to the composition of the bottom, variation in banks, velocity of water, scouring and special seasonal problems. Work shall be executed in such a way that flooding of adjacent land does not occur.

Precautions shall be taken during installation to avoid impact, distortion of the pipeline or other conditions that can cause pipe stress or strain to exceed the levels established in the design.

Installation procedures for horizontal directionally drilled crossings shall address the requirements unique to such crossings, for example,

- containment and disposal of drilling fluid;
- selection of abrasion-resistant corrosion coating;
- instrumentation for monitoring drilling profile, alignment and pulling forces.

10.6.9 Markings

Pipeline location markers shall be placed as specified in 6.8.1.

10.7 Installation of offshore pipelines

10.7.1 Marine operations

10.7.1.1 Anchors and station-keeping

The station-keeping system should have adequate redundancy or back-up systems to ensure that other marine vessels or installations are not endangered by its partial failure.

Construction vessels using anchors to maintain position should do so in accordance with a predetermined anchor pattern. The anchor pattern should be shown on a bathymetric chart to a suitable scale, containing the following information, as appropriate:

- position of each anchor and each cable touchdown point;
- location of existing pipelines and installations;
- vertical clearance between anchor cables and pipelines;
- proposed pipeline route and lay corridor;

- temporary works present during the construction period;
- anchor patterns of other vessels in the vicinity;
- construction-vessel position;
- prohibited anchoring zones;
- wrecks and other potential obstructions.

To prevent damage to existing facilities, minimum clearances shall be established between anchor and anchor cables and fixed structures, subsea installations or other pipelines.

All anchors transported over subsea installations or pipelines should be secured on the deck of the anchor-handling vessel. Construction-vessel anchor winches should be equipped with a cable length and load indicator.

10.7.1.2 Contingency procedures

Prior to beginning the work, contingency procedures shall be prepared. These should include

a) worksite abandonment;

b) pipe buckles (wet and dry);

c) loss of coating;

d) abandonment and recovery of the pipeline.

10.7.1.3 Notifications

Prior to construction of offshore pipelines, notification shall be given to operators of existing pipelines and cables that will be crossed during pipeline construction or pipeline tow. Notification shall also be given to the appropriate entities, such as coastguard, fishermen and other users of the sea.

10.7.2 Survey and positioning systems

Horizontal surface positioning, either satellite- or land-based, should form the basis for locating construction vessels, pipeline position and points of reference for local positioning systems. The positioning system shall have sufficient accuracy to allow placement of the pipeline within the tolerances specified in the design documents. Operations in congested areas and work requiring precise location can require a positioning system of greater accuracy than that required for pipeline placement.

The survey system used offshore shall be correlated with the onshore survey system when the pipeline includes a shoreline crossing.

10.7.3 Pipe laying

Pipe should be specified and ordered in lengths to suit the spacing of lay-barge work stations, such that variations in length do not disrupt operations.

The pipe-laying and tensioning systems shall be capable of laying the pipeline without exceeding the strength criteria in 6.4.2 and shall be designed to prevent damage to the coating and anodes.

The critical support points of the pipeline on the stinger should be monitored by video.

Buckle detectors should be used during pipe laying to detect reductions in diameter of the pipe. Detectors shall be capable of determining diameter changes of 5 % or greater.

Instrumentation should be provided to monitor and record the parameters required to demonstrate that the allowable strength criteria in 6.4.2 are not exceeded.

Pipelines installed by towing into position, either on the bottom, off-bottom or on the surface, can require a monitoring and/or guard vessel to prevent interference with the towed pipeline by other vessels.

Construction plans for the J-lay and reel barge methods shall address the unique stress levels and tensioning requirements associated with such methods.

10.7.4 Landfalls

Landfalls by bottom pull, directional drilling or other methods shall not cause the pipeline design stresses or strains to exceed the strength criteria in 6.4.2 or damage to coating and anodes.

10.7.5 Trenching

Trenching depth and profile should be selected to ensure that the pipeline stresses during trenching operations do not exceed the strength criteria in 6.4.2. Loads imposed on the pipeline during trenching should be monitored. Consideration shall be given to the extra loads imposed if the pipeline is flooded. Monitoring for boulders, debris and excessive spanning should be carried out. Trenching methods and equipment shall be selected to prevent damage to the pipe, coating and anodes and should be suitable for the soil conditions.

Post-lay and simultaneous-lay trenching equipment shall be provided with instrumentation that monitors and records the parameters required to demonstrate that the strength criteria are not exceeded.

EXAMPLES Acceptable trenching methods include jetting, ploughing, mechanical cutting for rock or hard soils and dredging.

10.7.6 Backfilling

Backfill material shall be placed in a controlled manner to prevent pipe and pipe-coating damage and to ensure the specified grading, cover and profile requirements are met. Backfill profiles shall be selected to minimize interference with fishing and other third-party activities.

10.7.7 Crossings of other pipelines and cables

The location, position and condition of a pipeline or cable being crossed shall be determined before construction of the crossing.

If preset supports are specified, the position of the existing pipeline or cable and the crossing point shall be accurately established prior to installing supports. The installation of supports should produce a smooth crossing profile that minimizes the risk of damage to either structure from external forces such as from anchors and fishing equipment.

Horizontal-surface positioning systems shall be supplemented by an on-bottom positioning system. Because of the close tolerances required, the crossing installation should be monitored to confirm that the structures are in their correct position.

10.7.8 Spans

The pipeline shall be surveyed for the presence of spans, and span rectification shall be performed, where required, to satisfy the strength-criteria limitations of 6.4.2. The potential for scour and the stability of supports or imported material shall be established.

10.7.9 Tie-ins

Construction procedures for tie-ins shall include provisions for controlling the pipe stress to the allowable strength criteria in 6.4.2.

10.8 Cleaning and gauging

Following construction, the pipeline sections should be cleaned by the passage of cleaning pigs or similar devices to remove dirt, construction debris and other matter.

Gauging pigs or devices that check for ovality and internal obstructions should be passed through each section before testing. The gauging-plate diameter shall be no less than 95 % of the smallest nominal internal pipe diameter of the pipeline, except that in no case should the clearance between the gauging plate and the pipe wall be less than 7 mm.

10.9 As-built surveys

Upon completion of construction, an as-built survey shall be performed to record the accurate location of the pipeline, crossings, adjacent features, spans and associated appurtenances.

10.10 Construction records

Permanent records in reproducible and retrievable form that identify the location and description of the pipeline system shall be compiled upon completion of the work and shall include the following:

— as-built surveys;

— welding documentation;

— as-built drawings and technical specifications;

— construction procedures.

11 Testing

11.1 General

Pressure-testing shall be in accordance with 6.7.

The number of test sections should be minimized. Selection of test sections shall take into account

— safety of personnel and the public, and the protection of the environment and other facilities;

— construction sequence;

— terrain and access;

— availability and disposal of test water.

If the test medium is subject to thermal expansion during the test, provisions shall be made for relieving excess pressure.

Equipment that should not be subjected to the test pressures shall be isolated from the pipeline during testing.

Valves should not be used as end closures during pressure-testing, unless rated for the differential pressure across the valve during testing. All devices used as end closures shall have sufficient strength to withstand the test pressure.

Temporary testing manifolds, temporary pig traps and other testing components connected to the test section shall be designed and fabricated to withstand the design pressure of the pipeline.

Individual components and fabricated items, such as pig traps, manifolds, metering skids, block valve assemblies, pipe for crossings (stream, road or railway), risers and tie-in assemblies, may be pretested in accordance with the provisions of this International Standard. Pre-tested assemblies shall be tested to at least the strength test pressure of the pipeline.

11.2 Safety

Work on, or near, any part of a pipeline system under test shall not be permitted for the period from the start of the increase in pressure to the reduction in pressure at the end of the test, except where necessary for the testing.

Warning signs shall be placed and the pipeline route, patrolled as appropriate to prevent access to the pipeline during the test.

In the case of pneumatic testing, the hazards from energy stored in the pipeline shall be taken into account when designing the safety requirements.

The safety of the public, construction personnel, adjacent facilities and the protection of the environment shall be ensured when depressurizing the test medium. If air or gas is used as a test medium, it shall be relieved by reducing pressure in a controlled manner.

11.3 Procedures

11.3.1 Written procedures

Written procedures for strength and leak tests shall be prepared prior to the beginning of testing and shall include the requirements of 6.7 and the following:

- profile, which should indicate the pipe grade and wall thickness, and length of each test section with the test pressure specified for each end of pipe section being tested;
- safety provisions;
- requirements for continuous monitoring; see 11.6 and 11.7;
- source and composition of test water and its disposal;
- equipment requirements;
- pressures and durations;
- evaluation of test results;
- leak-finding.

11.3.2 Communications

Communications should be provided between all points manned during the test.

11.3.3 Water quality

Water for testing and flushing should be clean and free from any suspended or dissolved substance that can be harmful to the pipe material or internal coating (where applied) or that can form deposits within the pipeline. Water samples should be analysed and suitable precautions taken to remove or inhibit any harmful substances. Consideration shall be given to the control of internal corrosion in accordance with 9.2, and the monitoring of internal corrosion in accordance with 9.6.2.

11.3.4 Inhibitors and additives

If hydrostatic test water analysis or procedures indicate that inhibitors and additives, such as corrosion inhibitors, oxygen scavengers, biocide and dyes, are necessary, then consideration shall be given to their interaction and the effect on the environment during test-water disposal. Consideration shall also be given to the effect of any such additives on the materials throughout the pipeline system.

11.3.5 Filling rate

Filling shall be performed at a controlled rate. Pigs or spheres may be used to provide a positive air-to-water interface and to minimize air entrainment. All locations in which air can be trapped, such as valve bodies and bypass piping, should be vented during the filling and sealed prior to beginning the hydrostatic test.

When the pipeline traverses steep terrain, provisions should be taken to prevent the pigs or spheres from running ahead of the linefill and creating a safety concern at the end of the fill section. Consideration should be given to the use of a pig-tracking system and to the use of backpressure to control the pig speed.

11.3.6 Air content

Where the air content can affect the accuracy of the hydrostatic test, the air content shall be determined and accounted for during the evaluation of the test results.

NOTE The assessment of air content can be carried out by constructing a plot of pressure against volume during the initial filling and pressurization until a definite linear relationship is apparent.

11.3.7 Temperature stabilization

Prior to beginning the hydrostatic pressure test, time should be allowed after filling for the temperature of the water to stabilize with the ambient temperature.

11.3.8 Temperature effects and correlations

Correlations that show the effect of temperature changes on the test pressures shall be developed to assess the possible differences between the initial and final test pressures and temperatures.

11.3.9 Leak-finding

Leak detection and location procedures shall be developed as part of the hydrostatic test procedure.

11.4 Acceptance criteria

The pressure test shall meet the requirements of 6.7.

11.5 Tie-ins following testing

Tie-in welds not subjected to a strength test after tie-in shall be examined in accordance with 10.4.2 c).

Non-welded tie-in connections not pressure-tested after construction should be leak-tested at the commencement of operation at the maximum available pressure but not exceeding MAOP.

11.6 Testing equipment

Hydrostatic testing equipment should include the following:

- deadweight tester or other device with equivalent accuracy;
- pressure gauges;

- volume-measuring equipment;
- temperature-measuring equipment; and
- pressure- and temperature-recording equipment.

Current certificates of calibration that identify the instrument with the calibration certification shall be provided.

11.7 Test documentation and records

Test records shall be retained for the life of the pipeline system and shall include the following:

- test procedure;
- pressure and volume change at half-hour intervals over the test period;
- seawater, underground and air temperature, where appropriate, and weather conditions at hourly intervals;
- pressure-recording charts;
- test instrument calibration data;
- name of the operator;
- name of the person responsible for making the test;
- name of the test company, if used;
- date and time of the test;
- minimum and maximum test pressures at the test site;
- test medium;
- test duration;
- test acceptance signature;
- description of the facility tested and the test apparatus;
- explanation and disposition of any pressure discontinuities, including test failures, that appear on the pressure-recording charts;
- where elevation differences in the section under test exceed 30 m, a profile of the pipeline showing elevations and test sites over the entire length of the test section.

11.8 Disposal of test fluids

Test fluids shall be disposed of in such a manner as to minimize damage to the public and the environment.

11.9 Protection following test

Test fluids shall not be left in the pipeline or piping following testing, unless provisions identified in accordance with 9.2 have been incorporated.

If water is used as a test medium in cold regions, provisions shall be made to prevent freezing of the test water.

12 Pre-commissioning and commissioning

12.1 General

Written procedures shall be established for pre-commissioning and commissioning. Procedures shall consider the characteristics of the fluids, the requirement to isolate any part of the pipeline system from other connected facilities and the transfer of the constructed pipeline system to those responsible for its operation.

Pre-commissioning and commissioning procedures, devices and fluids shall be selected to ensure that nothing is introduced into the pipeline system that is incompatible with the fluids, or with the materials in the pipeline system components.

12.2 Cleaning and gauging procedures

Consideration shall be given to the requirement for cleaning and gauging the pipeline system beyond that required in 10.8.

Additional cleaning can be required to remove the following:

— particles, including residue from testing and mill scale;

— metallic particles that can affect intelligent-pig result interpretation;

— chemical residue from test water inhibitor;

— organisms resulting from test water;

— construction devices, such as isolation spheres used for tie-ins.

Additional gauging can be required to prove the suitability of the pipeline for intelligent pigging.

Cleaning and gauging procedures shall consider the following:

a) protection of components from damage by cleaning fluids or devices;

b) removal of particles that can contaminate the fluid;

c) removal of metallic particles that can affect intelligent pigging devices.

12.3 Drying procedures

Drying methods should be selected on the basis of the requirement for dryness to meet the quality specifications of the transported fluids.

Dryness criteria shall be established as a water dew-point temperature. Drying procedures shall consider the following:

— compatibility with the transported-fluid quality specifications;

— effect of drying fluids and devices on valve seal materials, pipeline internal coating and other components;

— corrosion potential caused by a combination of free water and the drying fluids, especially for H_2S and CO_2 corrosion potential;

— removal of water and drying fluids from valve cavities, branch piping and other cavities in the system where such fluids can be retained;

— effect of hydrate formation during commissioning.

EXAMPLES Drying methods include swabbing with drying fluids or gels, air or nitrogen purging, vacuum drying or using the transported fluid itself.

12.4 Functional testing of equipment and systems

As a part of commissioning, all pipeline-system monitoring and control equipment and systems shall be fully function-tested, especially safety systems such as pig-trap interlocks, pressure- and flow-monitoring systems, and emergency pipeline-shutdown systems. Consideration should also be given to performing a final test of valves prior to the introduction of the transported fluid to ensure that they operate correctly.

12.5 Documentation and records

Pre-commissioning and commissioning records that shall be retained should include

— cleaning and drying procedures;

— cleaning and drying results;

— function-testing records of pipeline system monitoring and control equipment.

12.6 Start-up procedures and introduction of transported fluid

Written start-up procedures shall be prepared before introducing the transported fluid into the pipeline system and shall require the following:

— that the pipeline system should be mechanically complete and operational;

— that all functional tests should be performed and accepted;

— that all necessary safety systems shall be operational;

— that operating procedures shall be available;

— that a communication system shall be established;

— that the completed pipeline system be formally transferred to those responsible for its operation.

During filling with the fluid, the rate of fill shall be controlled and the fluid pressure shall not be allowed to exceed permitted limits.

NOTE Filling rates can be critical for certain fluids to prevent detonation, layering of gases, unstable dusty atmospheres, etc.

Provisions shall be taken to prevent hydraulic lock during filling of pipelines with liquid.

Consideration shall be given to carrying out leak checks during the filling process.

13 Operation, maintenance and abandonment

13.1 Management

13.1.1 Objectives and basic requirements

A management system shall be established and implemented to ensure safe and reliable operation of the pipeline system.

NOTE API STD 1160, ASME B31.8S, CEN/TS 15173 and CEN/TS 15174 give guidance on integrity management.

The management system shall include the following:

- identification of personnel responsible for the management of the operation and maintenance of the pipeline system, and for key activities;
- appropriate organization;
- written plan covering operating and maintenance procedures;
- written emergency response plan, covering failure of pipeline systems and other incidents;
- written permit-to-work system;
- written plan for the control of change of design conditions.

In addition, the management system shall specify the requirements for training, liaison with third parties and retention of records.

The operation, maintenance, modifications and abandonment of the pipeline system shall be carried out in accordance with the plans.

The management systems shall be reviewed from time to time as experience dictates, and as changes in the operating conditions and the environment require.

13.1.2 Operating and maintenance plan

The operating and maintenance plan shall include

- procedures for normal operations and maintenance;
- requirements for personnel communications;
- plan for the issue of procedures to cover non-routine operations and maintenance.

13.1.3 Operating and maintenance procedures

Operating and maintenance procedures shall define

- individual and functional responsibilities and tasks;
- necessary safety precautions;
- interfaces with other pipeline systems and installations;
- relevant information and references to applicable rules and guidelines.

Procedures for dealing with interfaces with other pipeline systems and installations should be developed in consultation with their operators.

NOTE Annex E provides guidance on the possible content of the operating and maintenance procedures.

13.1.4 Incident and emergency-response plan

The incident and emergency-response plan shall define the requirements for personnel and equipment for responding to incidents and emergencies, and for training.

The effectiveness of the plan shall be tested periodically through desk and field simulations of incidents and emergencies. Simulations may be carried out in cooperation with operators of other pipeline systems or facilities, organizations and individuals who are directly affected by an incident or emergency or who contribute to the response.

Causes of incidents and emergencies should be identified and analysed, and actions necessary to minimize recurrence implemented.

NOTE Annex E provides guidance on the content of the emergency procedures.

13.1.5 Permit-to-work system

The permit-to-work system shall define the activities to which it applies, the personnel authorized to issue a permit-to-work and the personnel responsible for specifying the necessary safety measures.

The permit-to-work system should specify requirements for

— training and instruction in the issue and use of permits;

— reviewing the effectiveness of the permit-to-work system;

— informing personnel controlling the pipeline system of the work activity and all related safety requirements;

— display of permits;

— control of pipeline system operation in the event of suspension of the work;

— handover between shifts.

The permit-to-work should

a) define the scope, nature, location and timing of the work;

b) indicate the hazards and define necessary safety measures;

c) reference other relevant work permits;

d) state the requirements for returning the pipeline system to service;

e) state the authorization for execution of the work.

13.1.6 Training

Training of personnel should include, where relevant,

— familiarization with the pipeline system, potential hazards associated with the fluid, and procedures for operations and maintenance;

— the use of permits-to-work;

— the use of protective equipment and fire-fighting equipment;

— provision of first aid;

— response to incidents and emergencies.

13.1.7 Liaison

Contacts should be established and maintained with appropriate organizations and individuals, such as

- fire, police, coast guard and other emergency services;
- regulatory and statutory authorities;
- operators of public utilities;
- operators of other pipelines that connect to, cross, or run in close proximity to the pipeline;
- members of the public living in close proximity to the pipeline system;
- owners and occupiers of land crossed by the pipeline;
- third parties involved in any activity that can affect, or be affected by, the pipeline system.

Pipeline route maps should be deposited with statutory authorities or “one-call” organizations, as appropriate.

NOTE A "one-call" organization collects information on underground facilities and, following notification of construction in the area, advises the presence of these facilities. Local legislation can stipulate the requirement for soliciting information on the presence of underground utilities before commencement of work.

13.1.8 Records

Records of operating and maintenance activities shall be prepared and retained to

- demonstrate that the pipeline system is operated and maintained in accordance with the operating and maintenance plans;
- provide the information necessary for reviewing the effectiveness of the operations and maintenance plans;
- provide the information necessary for assessing the integrity of the pipeline system.

NOTE Annex F provides guidance on the retention of records.

13.2 Operations

13.2.1 Fluid parameter monitoring

Procedures for the operation of the pipeline system should define the envelope of operating conditions permitted by the design, and the operating requirements and constraints for the control of corrosion. Fluid parameters should be monitored to establish that the pipeline system is operated accordingly.

Procedures for the operation of multi-product pipeline systems should include requirements for the detection, separation and prediction of arrival of batches.

Procedures for the operation of multi-phase pipeline systems should include requirements for control of liquid hold-up in the pipeline and free volume in the slug catcher.

Deviations from the operating plan shall be investigated and reported, and measures to minimize recurrence implemented.

13.2.2 Stations and terminals

Procedures for the operation of stations and terminals should include requirements for start-up and shutdown of equipment, and for the periodic testing of equipment, control, alarm and protection devices.

13.2.3 Pigging

Procedures for pigging operations should include requirements for

- confirming that the pipeline is free of restraints or obstructions for the passage of pigs;
- control of pig travelling speed;
- safe isolation of pig traps;
- contingencies in the event of a stuck pig.

13.2.4 Decommissioning

Consideration should be given to decommissioning pipeline systems planned to be out of service for an extended period. The removal of fluids shall be in accordance with 13.3.7.

Decommissioned pipeline systems, except when abandoned, shall be maintained. Buried or submerged, decommissioned pipelines shall be cathodically protected unless abandoned.

13.2.5 Recommissioning

The condition of a decommissioned pipeline system shall be established and its integrity confirmed before re-commissioning.

Pipeline filling shall meet the requirements of 12.6.

13.3 Maintenance

13.3.1 Maintenance programme

Maintenance programmes shall be prepared and executed to monitor the condition of the pipeline system and to provide the information necessary to assess its integrity. Factors that shall be considered when defining the requirements for condition monitoring include

- pipeline system design;
- as-built condition;
- results of earlier inspections;
- predicted deterioration in the condition of the pipeline system;
- adverse site conditions;
- inspection time intervals;
- requirements of relevant legislation and statutory authorities.

EXAMPLE Possible deteriorations in pipeline condition include general and pitting corrosion, changes in the pipewall geometry (such as ovality, wrinkles, dents, gouges), cracking (such as stress corrosion and fatigue cracking), changes in the pipeline position, support or cover, and loss of weight coating.

Unfavourable results, such as defects, damage and equipment malfunctioning, shall be assessed and corrective action taken where necessary to maintain the intended integrity.

The maintenance programmes shall cover the complete pipeline system, including fire-fighting and other safety equipment, access roads, buildings, security provisions such as fences, barriers and gates, means of identifying the pipeline, its components and the fluids it carries, and notices. Particular attention should be paid to pipeline system protection and safety equipment.

13.3.2 Route inspection

13.3.2.1 General

The pipeline route, including the right-of-way for pipelines on land, shall be periodically patrolled/surveyed to detect factors that can affect the safety and the operation of the pipeline system. The results of surveys shall be recorded and monitored.

13.3.2.2 Pipelines on land

The right-of-way should be maintained to provide the necessary access to the pipeline and associated facilities. Pipeline markers shall be maintained to ensure that the route of the pipeline is clearly indicated. If necessary, additional markers should be installed in areas where new developments take place.

Surveys should identify

- encroachments;
- mechanical damage to above-ground and exposed pipeline sections and leakages;
- third-party activities;
- change of land use;
- fire;
- mineral extraction/mining operations;
- ground movement;
- soil erosion;
- condition of water crossings, such as sufficiency of cover, accumulation of debris, flood or storm damage.

The requirements for the route inspection of offshore pipelines in 13.3.2.3 shall also apply to sections of pipelines on land crossing large rivers and estuaries.

13.3.2.3 Offshore pipelines

Surveys of the pipeline and adjacent seabed should identify

- mechanical damage to the pipeline, including leakage;
- evidence of pipeline movement;
- extent of marine growth;
- condition of the adjacent seabed, including the presence of foreign objects;

- extent of any free spans;
- extent of any loss of cover along the buried or protected sections;
- extent of any loss of weight coating;
- extent of bank erosion or deposition of material;
- security of pipeline attachments, including anodes and clamps on piggy-back pipelines.

13.3.3 Mechanical condition monitoring

13.3.3.1 Corrosion

The maintenance programmes shall include the requirements for corrosion monitoring established for corrosion management in accordance with Clause 9.

The quality and performance of corrosion inhibitors should be verified periodically to ensure that they remain effective.

13.3.3.2 Adverse ground conditions and vibration

Surveillance in areas with adverse ground conditions, as identified in accordance with 6.10, shall be implemented.

Procedures shall be established to cover the protection of all pipelines and associated facilities in the vicinity of blasting or any other activity resulting in ground vibrations that can affect the integrity of the pipeline system. Such procedures should state the maximum allowable effect on the pipeline system.

13.3.4 Leak detection and surveys

The performance of the leak-detection system should be reviewed and tested periodically to confirm compliance with the requirements of 5.5. Records should be kept of alarms and leaks to assist the performance review. Where appropriate, leakage surveys should be carried out. The type of survey selected shall be effective for determining if potentially hazardous leakage exists.

13.3.5 Facilities, equipment and component monitoring

13.3.5.1 Above-ground pipelines, piping and overhead crossings

Above-ground pipelines, piping and pipe supports should be inspected for corrosion, mechanical integrity, stability and concrete degradation.

Barriers designed to restrict access or to resist third-party impact to above-ground pipelines and piping should be maintained.

13.3.5.2 Valves

Valves should be inspected periodically, moved and/or tested for proper operation. Where it is required to fully operate a valve, due account should be taken of the permissible pressure drop across the valve.

Remotely operable valves and actuators should be tested remotely to ensure the correct functioning of the whole system.

Pressure vessels associated with valve actuators shall be inspected and tested periodically.

13.3.5.3 Protection devices

Protection devices, including actuators, associated instrumentation and control systems, shall be inspected and tested periodically. The inspection and testing shall cover

- condition;
- verification of proper installation and protection;
- correct setting and activation;
- inspection for leakages.

EXAMPLE Protection devices include pressure control and overpressure protection, emergency shutdown isolations, quick-connect/disconnect connectors, storage tank level controls, etc.

Emergency shutdown valves, including actuators and associated control systems, should be inspected and tested periodically to demonstrate that the whole system functions correctly and that valve-seal leakage rates are acceptable.

Particular attention shall be paid to storage tank level controls and to relief valves on pressure storage vessels.

13.3.5.4 Pig traps and filters

Pig traps and filters with “quick-release” closures, together with associated equipment, shall be maintained, with special attention given to the locking closure mechanism, which shall be periodically tested.

Temporary or transportable pig traps should be inspected before use for signs of mechanical damage caused during transit or installation.

13.3.5.5 Instrumentation

Instrumentation, telemetry systems and the data acquisition, display and storage systems essential for the safe operation of the pipeline system shall be examined, tested, maintained and calibrated.

Maintenance procedures should cover the control of temporary disarming or overriding of instrumentation, for maintenance or other purposes.

13.3.5.6 Risers

Risers on offshore installations shall be inspected periodically with particular attention paid to sections in the “splash zone”. These inspections should cover

- the condition of the riser pipe, including any loss of wall thickness, particularly under riser clamps and guides;
- the condition of impact protection, fire protection, protective coatings, cladding and fitted anodes;
- the condition of riser flanges or couplings;
- the condition of attachment or clamping arrangements, and associated supporting structure;
- changes in position of the riser;
- the extent of marine growth;
- the corrosion protection in enclosed J-tubes or caissons.

13.3.5.7 Pipelines in sleeves or casings

The inspection of pipeline sections in sleeves or casings shall cover

- the condition of pipeline and sleeve or casing;
- the electrical isolation between the pipeline and sleeve or casing;
- leakage into, or from, pressurized sleeve or casing systems.

13.3.5.8 Storage vessels and tanks

Storage vessels and tanks, atmospheric and pressurized, shall be inspected to cover

- the stability of foundations;
- the condition of tank bottom, shell, stairs, roof and seals;
- venting and safety valve equipment;
- the condition of firewalls and tank bunds/dikes;
- condition and blockage of drain lines.

13.3.5.9 Pipeline systems in arctic conditions

Inspection of pipeline systems in arctic conditions shall include

- requirements for surveillance defined in accordance with 6.10;
- inspections and surveillance during and after spring ice break-up to monitor frost heave and erosion from floods;
- periodic inspection and surveillance of pipeline and piping exposed to wind-induced vibration, with particular attention to circumferential welds and threaded joints.

Procedures shall address requirements for snow removal from structures that are exposed to heavy snowfall.

13.3.6 Pipeline and piping defects and damage

13.3.6.1 Initial actions

If a defect or damage is reported, the pipeline pressure shall be maintained at or below the pressure at the time the defect or damage was first reported.

A preliminary assessment shall be carried out by a competent person and, if any unsafe condition is found, appropriate action shall be taken immediately.

13.3.6.2 Examination, inspection and assessment of defects

Care shall be exercised during preparation and examination of damaged and pressurized pipelines because of the possibility of sudden failure. Consideration should be given to reducing the pipeline operating pressure to ambient conditions, e.g. when divers are to conduct an examination of an underwater pipeline, or to a stress level that does not lead to pipeline rupture.

Procedures shall be established for assessment of pipeline defects and damages.

Defects and damage permitted under the original fabrication and construction specifications may remain in the pipeline without further action.

For other defects, further assessment should be made to determine their acceptability or the requirement for pressure-derating, repair or other corrective action. These assessments may include the review of

- inspection and measurement data, including orientation of the defect and proximity to other features such as welds or heat-affected zones;
- details of the original design and fabrication specifications;
- actual pipe-material mechanical and chemical properties;
- possible modes of failure;
- possible growth of the defect;
- operating and environmental parameters, including effect on pigging operations;
- consequences of failure;
- monitoring of the defect where possible.

13.3.7 Pipeline and piping repairs and modifications

13.3.7.1 General

Repair procedures shall cover the selection of repair techniques and the execution of repairs. Repairs shall reinstate the intended integrity at the location of the defect or damage.

NOTE Defects and damage can be grouped under a number of headings, including: pipewall defects (such as cracks including cracking caused by stress corrosion and fatigue, gouges, dents, corrosion, weld defects, laminations); pipe coating defects (such as loss of wrap or concrete coating); loss of support (such as spanning of pipelines); and pipe movement (such as upheaval buckling, frost heave and landslip, which can also result in buckling, denting or cracking).

13.3.7.2 Isolation

The selection of an isolation method should take into account

- hazards associated with the fluid;
- required availability of the pipeline system;
- the duration of the work activity;
- the need for redundancy in the isolation system;
- possible effect on materials;
- isolation of interconnected vents, drains, instrumentation piping and “dead legs”.

EXAMPLES Possible isolation techniques include removable spools, spectacle blinds, valves, pipe freezing or freeze blocking, line plugging, high friction pigs, inert fluid slugs.

13.3.7.3 Venting and flaring

Hazards and constraints that should be considered when planning to vent or flare are

- asphyxiating effects of vented gases;
- ignition of gases by stray currents, static electricity or other potential ignition sources;
- noise-level limits;
- hazard to aircraft movements, particularly helicopters in the vicinity of offshore installations and terminals;
- hydrate formation;
- valve freezing;
- embrittlement effects on steel pipework.

13.3.7.4 Draining

Liquids may be pumped, or pigged, out of a pipeline system using water or an inert gas. Hazards and constraints that should be considered when planning to drain include:

- asphyxiating effects of inert gases;
- protection of reception facilities from overpressurization;
- drainage of valve cavities, “dead legs”, etc.;
- disposal of fluids and contaminated water;
- buoyancy effects if gas is used to displace liquids;
- compression effects leading to ignition of fluid vapour;
- combustibility of fluids at increased pressures;
- accidental launch of stuck pigs by stored energy when driven by inert gas.

13.3.7.5 Purging

Hazards and constraints that should be considered when preparing for purging include

- asphyxiating effects of purge gases;
- minimizing the volume of flammable or toxic fluids released to the environment;
- combustion, product contamination or corrosive conditions when reintroducing fluids.

13.3.7.6 Cold cutting or drilling

Procedures for cold cutting and drilling shall specify the requirements for preventing the accidental release or ignition of the fluid, and other unsafe conditions.

Where appropriate, the section of pipeline or piping being worked on shall be isolated, depressurized by venting, flaring or draining and purged.

A temporary electrical continuity bond should be fitted across any intended break in an electrically conductive pipeline before making such breaks.

13.3.7.7 Hot work

The following should be considered prior to carrying out hot work on pipelines or piping in service:

- possible physical and chemical reactions, including combustion of the fluids or their residues;
- the type, properties and condition of the pipe material, and the wall thickness at the location of the hot work;
- possible corrosion of pipe and welds.

Welding procedures shall be approved and the validity of the welder qualification checked before commencement of welding.

The pressure, temperature and flowrate of the fluid through the pipeline should be monitored and maintained within the limits specified in the approved welding procedure.

All welds shall be adequately inspected during and after welding.

Consideration should be given to leak testing of welds of sleeves, saddles, reinforcing pads or any associated fitting before introducing fluids.

13.4 Changes to the design condition

13.4.1 Change control

The change-control plan shall define the requirements for following documented procedures to handle changes in the design condition.

It shall be demonstrated that the revised pipeline system meets the requirements of this International Standard before implementing changes to the design condition, such as an increase in MAOP or change of fluid. The documentation required by this International Standard shall be updated to reflect the revised design condition.

13.4.2 Operating pressure

An increase in MAOP can require additional hydrostatic testing, inspection, additional cathodic protection surveys and other measures to comply with this International Standard. When increasing operating pressures, pressures should be raised in a controlled manner to allow sufficient time for monitoring the pipeline system.

Where pipelines are permanently derated from pressures that cannot subsequently be reapplied, stringent data and supporting calculations shall be maintained to document the new operating conditions.

13.4.3 Service conversion

Prior to a change in service, including change of fluid, it shall be demonstrated that the design and integrity of the pipeline system is appropriate for the proposed new duty. A detailed review of as-built, operational and maintenance data of the pipeline system shall be made before implementing a change in service. Data for review should include

- original design, construction, inspection and testing; particular attention should be paid to the welding procedures used, other jointing methods, internal and external coatings and pipe, valve and other materials;
- all available operating and maintenance records, including corrosion-control practice, inspections, modifications, incidents and repairs.

13.4.4 New crossings and developments

Compliance with the strength requirements in 6.4 shall be demonstrated when crossing the pipeline with a new road, railway or other pipeline. The effect of a new crossing on the existing cathodic protection system shall be investigated.

The possible effects of new developments in the vicinity of the pipeline system shall be evaluated.

13.4.5 Moving in-service pipelines and piping

The following analyses and preparation should be carried out when planning the movement of pipelines in service:

— analysis of loads on the pipeline to demonstrate that the pipeline can be moved without adversely affecting its integrity;

— confirmation of the assumed pipeline data and its condition;

— preparation of procedures that should define the pipeline operating condition during movement, contingencies and safety measures for the protection of personnel, the public and the environment.

13.4.6 Testing of modified pipelines and piping

All prefabricated assemblies, including spool pieces, should be pressure-tested in accordance with 6.7, or before installation.

Mechanical joints in pressure-containing parts of the pipeline system that have been disconnected or disturbed shall, as a minimum, be leak-tested. Joints shall not show sign of leakage during the test.

The medium for the *in situ* pressure-testing should, in order of preference to minimize risks, be

a) water;

b) the fluid (if liquid);

c) an inert gas such as nitrogen (with a tracer element, if possible);

d) the fluid (if gas).

Modifications involving the use of welded tie-ins shall be inspected in accordance with 11.5 if not pressure-tested.

13.5 Life extension

Where it is intended to operate a pipeline beyond its original design life then, prior to the expiry of the original design life, an engineering investigation should be made of the design, operating conditions and history of the pipeline, to determine its condition and any limits for continued safe operation.

The engineering investigation should include verification of the following issues:

a) proof of structural integrity to confirm that the pipeline can continue to contain the fluid at the maximum allowable operating conditions;

b) if the pipeline has been subject to corrosion and/or erosion, the configuration of the imperfections, the rate of metal loss and the minimum remaining wall thickness;

c) if the pipeline has been subject to fatigue, the amplitude and frequency of fatigue cycling;

d) the completion of a safety evaluation in accordance with Annex A, and the identification of the proposed mitigation methods;

e) review of the adequacy of the safety and operating plan, operating and maintenance, emergency response, and safety and environmental procedures.

Upon completion of the review, and prior to the expiry of the design life, all issues identified in the engineering investigation should be addressed, and the pipeline records amended accordingly.

The pipeline should be operated only under the conditions and the limits so established and approved.

13.6 Abandonment

Parts of pipeline systems to be abandoned shall be decommissioned in accordance with 13.2.4 and disconnected from other parts of the pipeline system remaining in service.

Abandoned pipeline sections shall be left in a condition that is safe for the public and the environment.

Annex A
(normative)

Safety evaluation of pipelines

A.1 Introduction

This annex provides guidelines for the planning, execution and documentation of safety evaluations of pipelines required in 6.2.1.2.

This annex refers mainly to the evaluation of the effect of loss of fluids on public safety. The principles in this annex can, however, also be used for other safety evaluations.

A.2 General requirements

Safety evaluations should be performed according to a defined sequence of steps; Figure A.1 shows a sequence of steps that may be followed.

Safety evaluations should demonstrate that the pipeline is designed, constructed and operated in accordance with the safety requirements of this International Standard.

The level of detail of the evaluation and the techniques to be applied shall be appropriate to the objectives of the evaluation.

Further safety evaluations should be carried out during the operational life of the pipeline in case of relevant changes to the definition of the pipeline and the pipeline environment or other circumstances that can render the conclusions of the evaluation invalid.

Safety evaluations should be performed by personnel having the necessary specialist technical and safety expertise.

A.3 Definition of the scope of the evaluation

The scope of the evaluation should be defined and formulated to provide the basis for the safety evaluation plan. The scope should include, as a minimum,

- reason(s) for performing the evaluation and case-specific objective(s);
- definition of the pipeline to be evaluated;
- definition of the environment, e.g. human habitation and activities near the pipeline;
- identification of measures that can be practical and effective in removing or mitigating adverse effects on public safety;
- description of assumptions and constraints governing the evaluation;
- identification of the required output.

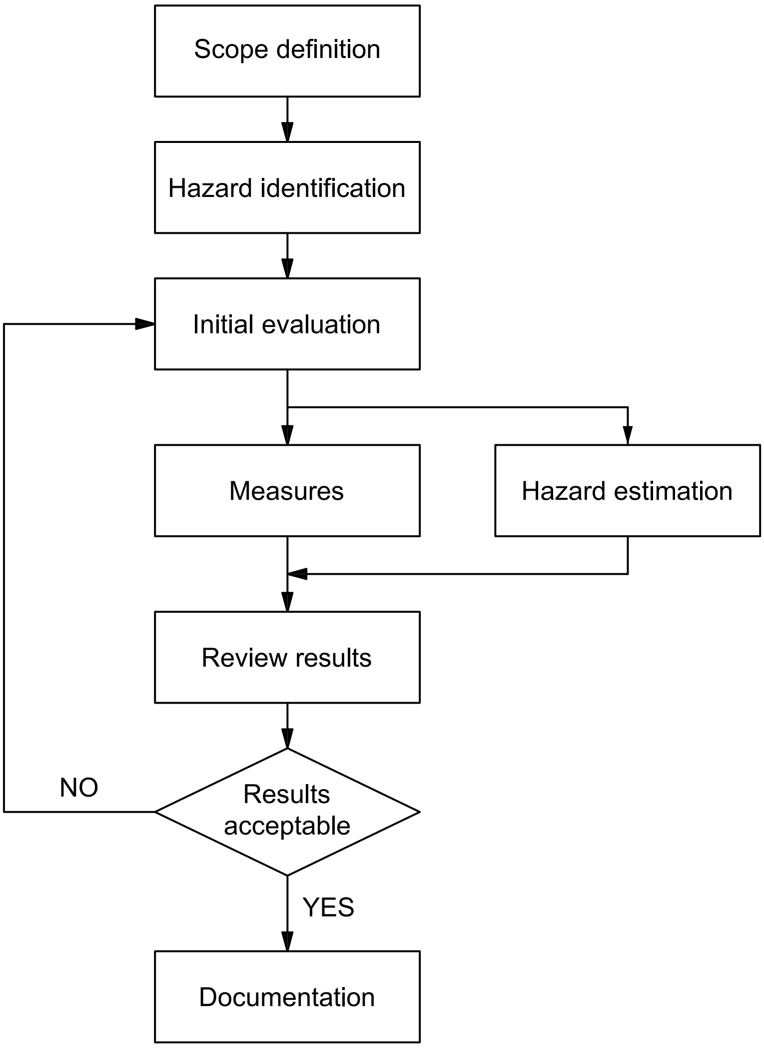


Figure A.1 — Safety evaluation

A.4 Hazard identification and initial evaluation

The hazard scenarios with the potential to result in a loss of fluid should be identified, together with their root causes. These may include

- design, construction or operator error;
- material or component failure;
- degradation due to corrosion or erosion, leading to loss of wall thickness;
- third-party activity;
- natural hazards.

Methods applied for identifying hazards may include review of checklists and historical incident data, brainstorming, and hazard and operability studies.

An initial evaluation of the significance of the identified hazards should be carried out based on the likelihood of their occurrence and estimation of possible consequences.

This step of the evaluation should result in one of the following courses of action for each of the identified hazards:

— curtailment of the evaluation because the likelihood of occurrences or consequences of the hazard is insignificant;

— recommended measure(s) to eliminate the hazard or reduce it to a tolerable level;

— estimation of risk.

A.5 Hazard estimation

A.5.1 General

Hazard estimation should produce a measure of the level of effect on public safety from a particular hazard. Estimates may be expressed quantitatively or qualitatively and determined in frequency of occurrence, consequence, risk or a combination as appropriate for accomplishing the objectives of the safety analysis.

There should be a clear explanation of all the terms employed when expressing exposure. Estimated exposure should not be attributed to a level of precision inconsistent with the accuracy of the information and analytical methods employed.

The effect on public safety from the hazards identified as relevant in the hazard-identification stage should be examined and the benefits of the identified mitigating measures in reducing this effect determined.

A.5.2 Frequency analysis

The likelihood of loss of fluid for each of the hazards identified should be estimated by such approaches as

— use of relevant historical data;

— synthesis of event frequencies using techniques such as failure mode and effect analysis;

— judgement.

A.5.3 Consequence analysis

Estimating the likely impact of the loss of fluid should take into account:

— nature of fluid, e.g. flammable, toxic, reactive, etc.;

— pipeline design;

— buried- or above-ground topography;

— environmental conditions;

— size of hole or rupture;

— mitigating measures to restrict loss of containment, such as leak detection and use of isolation valves;

— mode of escape of fluids;

— dispersion of fluid and probability of ignition;

— possible accident scenarios following a fluid loss, which may include:

  1) pressure waves following fluid release,

  2) combustion/explosion following ignition,

  3) toxic effects or asphyxiations;

— level of exposure and estimated effect.

A.5.4 Risk calculation

Risk is the exposure determined from the frequencies of occurrence and consequences of the hazards identified.

Risk should be determined in the most suitable terms for either individuals or populations and may be expressed qualitatively or quantitatively as appropriate. The completeness and accuracy of the calculated risk should be stated and effects of uncertainties or assumptions tested.

A.6 Review of results

The results of the hazard identification, initial evaluation and risk estimation shall be compared with the safety requirements to demonstrate compliance.

A.7 Documentation

The documentation on pipeline safety evaluations should include, as a minimum,

— table of contents;

— summary;

— objectives and scope;

— safety requirements;

— limitations, assumptions and justification of hypotheses;

— description of system;

— analysis methodology;

— hazard-identification results;

— model description with assumptions and validation;

— data and their sources;

— effect on public safety;

— sensitivity and uncertainties;

— discussion of results;

— conclusions;

— references.

Annex B
(normative)

Supplementary requirements for public safety of pipelines for category D and E fluids on land

B.1 Objective

This annex provides specific supplementary requirements for maximum hoop stresses and pressure testing for category D and E fluid pipelines on land. This annex is applicable to pipelines at locations where specific requirements for protection of public safety are not available.

B.2 Location classification

Pipeline locations shall be classified in relation to population density and concentration of people in accordance with Table B.1.

A significant factor contributing to the failure of pipelines is line damage caused by third-party activities along the line. Determining location classes based on human activity provides a method of assessing the degree of exposure of the line to damage and consequent effect on public safety.

Table B.1 — Location classes

Location class	Description
1	Locations subject to infrequent human activity with no permanent human habitation. Location class 1 is intended to reflect inaccessible areas such as deserts and tundra regions.
2	Locations with a population density of less than 50 persons per square kilometre. Location class 2 is intended to reflect such areas as wasteland, grazing land, farmland and other sparsely populated areas.
3	Locations with a population density of 50 persons or more but fewer than 250 persons per square kilometre, with multiple dwelling units, with hotels or office buildings where no more than 50 persons can gather regularly and with occasional industrial buildings. Location class 3 is intended to reflect areas where the population density is intermediate between location class 2 and location class 4, such as fringe areas around cities and towns, and ranches and country estates.
4	Locations with a population density of 250 persons or more per square kilometre, except where a location class 5 prevails. A location class 4 is intended to reflect areas such as suburban housing developments, residential areas, industrial areas and other populated areas not meeting location class 5.
5	Location with areas where multi-storey buildings (four or more floors above ground level) are prevalent and where traffic is heavy or dense and where there can be numerous other utilities underground.

B.3 Population density

Population density, expressed as the number of persons per square kilometre, shall be determined by laying out zones along the pipeline route, with the pipeline at the centreline of this zone having a width of

— 400 m for pipelines conveying category D fluids;

— to be determined for category E fluid pipelines, taking into account the possible extent of consequence of fluid release on the public, but not less than 400 m.

Other values may be used for the zone width, provided that representative values are obtained for the population density and half the width of the zone is not less than the “effect” distance of a fluid release.

This zone shall then be divided in random sections of 1,5 km in length such that individual lengths include the maximum number of buildings intended for human occupancy. For this purpose, each separate dwelling unit in a multiple-dwelling-unit building shall be counted as a separate building intended for human occupancy.

The length of random sections may be reduced where it is justified that physical barriers or other factors exist that limit the extension of the more densely populated area to a total distance of less than 1,5 km.

Measurement of population density shall be based on a direct count of the number of inhabitants or a survey of normally occupied dwellings, and should include premises where people congregate for significant periods of time, such as schools, public halls, hospitals and industrial areas.

The location and number of dwellings and premises shall be determined from available large-scale plans and/or aerial photographic surveys and, if necessary, field surveys. The occupancy of dwellings may be determined from census statistics where these are available.

The possible increase in population density and level of human activity from planned future developments shall be determined and accounted for when determining population density.

B.4 Concentration of people

Additional consideration shall be given to the possible consequences of a failure near a concentration of people, such as found in a church, school, multiple-dwelling unit, hospital or recreational area of an organized character in location classes 2 and 3.

Unless the facility is used infrequently, the supplementary requirements of location class 4 shall also apply to pipelines in location classes 2 and 3 when near places of public assembly or concentrations of people, such as churches, schools, multiple-dwelling-unit buildings, hospitals or recreational areas of an organized nature.

NOTE Concentrations of people referred to in Clause B.4 are intended to apply to groups of 20 or more people in an outside area as well as in a building.

B.5 Maximum hoop stress

The hoop-stress design factors of Table 1 shall be replaced by the factors in Table B.2 for determining maximum permissible hoop stresses in accordance with 6.4.2.2.

Table B.2 — Hoop-stress design factors, f_h

Fluid category	D	E	D and E			
Location class	1	1	2	3	4	5
General route	0,83	0,77	0,77	0,67	0,55	0,45
Crossings and parallel encroachments [a]						
— minor roads	0,77	0,77	0,77	0,67	0,55	0,45
— major roads, railways, canals, rivers, diked flood defences and lakes	0,67	0,67	0,67	0,67	0,55	0,45
Pig traps and multi-pipe slug catchers	0,67	0,67	0,67	0,67	0,55	0,45
Primary piping in stations and terminals	0,67	0,67	0,67	0,67	0,55	0,45
Special constructions, such as fabricated assemblies and pipelines on bridges	0,67	0,67	0,67	0,67	0,55	0,45

[a] See 6.9 for the description of crossings and encroachments.

B.6 Pressure test requirements

The minimum pressure in the pipeline during strength testing shall be increased from 1,25 × MAOP to 1,40 × MAOP for pipelines in location classes 4 and 5.

Annex C
(informative)

Pipeline route selection process

C.1 Limits

The geographic limits within which pipeline route selection takes place should be defined by identification of the starting point of the pipeline, the end point of the pipeline and any intermediate fixed points. These points should be marked on suitably scaled plans covering the area, for further consideration during the routing procedure.

C.2 Constraints

Existing and planned constraints to route selection (see 6.2.1) occurring within the area of interest should be identified to assist the selection of route options. The constraints identified should be plotted on suitably scaled maps, considering the complexity of terrain and information gathered. Potential corridors of interest should then be selected for route development.

C.3 Preferred corridors of interest

A preferred route corridor should be selected, taking into account all the technical, environmental and safety-related factors that can be significant during installation and operation of the pipeline system. It should be noted that the shortest corridor might not be the most suitable.

C.4 Detailed routing

The adoption of a provisional route within the selected route corridor should be preceded by a desk study, consultation and visual appraisal making use of all information available within the public domain.

Prior to the selection of the final route, land and environmental surveys should be made. These should cover sufficient width and depth around the provisional route and have sufficient accuracy to identify all features that can adversely influence installation and operation of the pipeline system. This should be accompanied by further detailed consultation with all affected third parties and route-walking where appropriate.

Third-party activities along the pipeline route and related safety aspects should be investigated.

A complete set of data relevant to design, construction and the safe and reliable operation of the pipeline system should be compiled from records, maps and physical surveys. The selected route should be recorded on alignment sheets of an appropriate scale. The coordinates of all significant points, such as target points, crossing points, bend starting- and end-points, should be indicated. Contour lines should be recorded at intervals sufficient for design purposes, particularly with regard to the installation and operational phases, and consideration should be given to the requirement for a vertical profile of the route.

Annex D
(informative)

Examples of factors for routing considerations

Consideration	Pipelines on land	Offshore pipelines
Safety	See Annex A	See Annex A Personnel accommodation
Environment	Environmentally sensitive areas: — areas of outstanding beauty — areas of archaeological importance — areas of designated landscape — areas of conservation interest — natural resources, such as water catchment areas, reservoirs and forestry — aquifers and potable water supplies	Environmentally sensitive areas: — areas of special scientific interest — areas of natural conservation importance — areas of marine archaeological importance — marine parks
Facilities	Pipelines Underground and above-ground services Tunnels	Pipelines Cables Subsea structures and wellheads Coastal protection works
Third-party activities	Land use Mineral workings Mining Military zones	Shipping lanes Anchoring Recreation Fishing Exploration and production Dredging and dumping Military exercises Offloading at platforms Boat landing

Consideration	Pipelines on land	Offshore pipelines
Environmental conditions	Geotechnical conditions: — uneven topography, outcrops and depressions — instability such as faults and fissuring — soft and waterlogged ground — soil corrosivity — rock and hard ground — flood plains — earthquake areas — muskeg and permafrost areas — areas of land slippage, subsidence and differential settlement — infill land and waste disposal sites including those contaminated by disease or radioactivity Hydrographic conditions	Geotechnical conditions: — uneven topography, outcrops and depressions — earthquake zones — high-slope gradients — seabed instability — soft sediment and sediment transport — presence of near-surface gas — coastal erosion — beach movement — high near-bottom currents Hydrographic conditions
Construction and operation	Access Working width Utilities Availability and disposal of test water Crossings Logistics	Maximum approachable water depth Minimum feasible laying radius Station-keeping vessels Platforms and subsea wellhead approach Tie-ins Shore approach and landfall installation technique Crossings Logistics

Annex E
(informative)

Scope of procedures for operation, maintenance and emergencies

E.1 Operating procedures

Operating procedures may include details of the following:

— the organization showing the responsible persons;

— the pipeline system, including pumping stations, terminals, tank farms, platforms and other installations;

— the fluids that may be transported;

— the pipeline system operating conditions, including limitations and permitted deviations from such limitations;

— the control functions and communications;

— the pipeline monitoring system and the means by which leaks can be detected;

— marine operations procedures, where applicable;

— scheduling and dispatching procedures;

— pigging procedures and their purpose;

— references to related documentation, e.g. permits to work, manufacturer's literature, drawings, maps, etc.;

— coordination with third parties;

— drawings showing demarcation of the pipeline system and limits of ownership and operatorship within the whole pipeline system;

— venting and flaring procedures;

— requirements of relevant legislation or statutory authorities.

E.2 Maintenance procedures

Maintenance procedures may include details of the following:

— the organization, showing the responsible persons;

— the pipeline system, including pumping stations, terminals, tank farms, platforms and other installations;

— schedules, inspection and maintenance specifications and instructions for each element of the pipeline system;

— references to related manuals and documentation, e.g. manufacturer's literature and permit-to-work systems;

— relevant drawings and route maps;

- stores and spares organization;
- specific procedures can be required for certain repairs or modifications.

E.3 Emergency procedures

Emergency procedures may include details of the following:

- duties of all personnel involved in the event of an incident or emergency; reference should be made to the organization chart;
- the pipeline system, including pumping stations, terminals, tank farms, platforms and other installations;
- the fluids (including details of any hazards associated with the release of the fluids) and normal operating conditions;
- the location and details of communications with control centres;
- the company and/or contract personnel, third parties and statutory bodies whom it is necessary to notify in the event of an incident or emergency;
- location of emergency equipment and specialist services;
- arrangements for the evacuation of personnel or third parties, particular attention being given to divers who can be undergoing decompression and are, therefore, confined to a chamber;
- arrangements to make safe the pipeline system in the event of an emergency and for limiting the effects of any loss of containment or to reduce the risk of loss of containment;
- for pipeline systems that link installations, procedures for shutting down the pipeline system in the event of an emergency at another installation;
- venting and flaring procedures.

Annex F
(informative)

Records and documentation

Records and documentation should include

a) design and construction details:

- design basis and calculations,
- material specifications and certification,
- inspection and test certification and reports,
- documents relating to authorizations and permits to operate,
- land ownership details,
- surveys and route documentation, including location of other services,
- as-built route alignment maps, special crossing details, detailed pipework and instrumentation diagrams,
- pipeline system operating parameters, such as pressure and temperature;

b) operational records:

- operations and maintenance details,
- inspection survey reports, including for example, acoustic/video records and cathodic protection surveys,
- incident records,
- repairs and modifications,
- service conversions,
- personnel training and qualification records;

c) records of abandoned pipelines:

- details of abandoned pipelines on land, including route maps, the size of the pipeline, depth of burial and its location relative to surface features,
- details of abandoned offshore pipelines, including navigation charts showing the route of the pipeline.

Bibliography

[1] ISO/TS 29001, *Petroleum, petrochemical and natural gas industries — Sector-specific quality management systems — Requirements for product and service supply organizations*

[2] API STD 1160, *Managing System Integrity for Hazardous Liquid Pipelines*

[3] API RP 5L1, *Recommended Practice for Railroad Transportation of Line Pipe*

[4] API RP 5LW, *Recommended Practice for Transportation of Line Pipe on Barges and Marine Vessels*

[5] API RP 1102, *Steel Pipelines Crossing Railroads and Highways*

[6] ASME B31.8S, *Managing System Integrity of Gas Pipelines*

[7] BS 7910, *Guide on methods for assessing acceptability of flaws in structures*

[8] CEN/TS 15173, *Gas supply systems — Frame of reference regarding Pipeline Integrity Management System (PIMS)*

[9] CEN/TS 15174, *Gas supply systems — Guideline for safety management systems for natural gas transmission pipelines*

[10] EN 12583, *Gas supply systems — Compressor stations — Functional requirements*

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