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**Erdöl- und Erdgasindustrie –
Rohrleitungstransportsysteme –
Zuverlässigkeitsanalysen (ISO 16708:2006);
Englische Fassung EN ISO 16708:2006**

Petroleum and natural gas industries –
Pipeline transportation systems –
Reliability-based limit state methods (ISO 16708:2006);
English version EN ISO 16708:2006

Industries du pétrole et du gaz naturel –
Systèmes de transport par conduites –
Méthodes aux états-limites basées sur la fiabilité (ISO 16708:2006);
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Nationales Vorwort

Diese Europäische Norm wurde vom Technischen Komitee CEN/TC 12 „Materialien, Ausrüstungen und Offshore-Bauwerke für die Erdöl-, petrochemische- und Erdgasindustrie“, dessen Sekretariat vom AFNOR (Frankreich) gehalten wird, erstellt. Es handelt sich dabei um die im einstufigen Annahmeverfahren (UAP) unverändert zur Übernahme vorgesehene Fassung von ISO 16708:2006, erarbeitet von ISO/TC 67 „Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries“, Subkomitee SC 2 „Pipeline transportation systems“.

Für Deutschland war der Normenausschuss Erdöl- und Erdgasgewinnung (NÖG), Arbeitsausschuss NÖG 2 „Fernleitungssysteme“ an der Erarbeitung dieser Norm beteiligt.

Diese Europäische Norm enthält unter Berücksichtigung des DIN-Präsidialbeschlusses 13/1983 nur die englische Originalfassung der ISO-Norm.

English Version

Petroleum and natural gas industries - Pipeline transportation
systems - Reliability-based limit state methods
(ISO 16708:2006)

Industries du pétrole et du gaz naturel - Systèmes de
transport par conduites - Méthodes aux états-limites basées
sur la fiabilité (ISO 16708:2006)

Erdöl- und Erdgasindustrie - Rohrleitungstransportsysteme -
Zuverlässigkeitsanalysen (ISO 16708:2006)

This European Standard was approved by CEN on 3 March 2006.

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Foreword

This document (EN ISO 16708:2006) has been prepared by Technical Committee ISO/TC 67 “Materials, equipment and offshore structures for petroleum and natural gas industries” in collaboration with Technical Committee CEN/TC 12 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2006, and conflicting national standards shall be withdrawn at the latest by October 2006.

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

Endorsement notice

The text of ISO 16708:2006 has been approved by CEN as EN ISO 16708:2006 without any modifications.

Introduction

The International Standard ISO 13623 allows the use of innovative techniques and procedures such as reliability-based limit state methods providing the minimum requirements of ISO 13623 are satisfied.

This International Standard provides the supplement to ISO 13623 in giving recommendations and specifying the framework and principles for the application of the probabilistic approach, i.e. “reliability-based limit state methods”.

Pipeline integrity management during design and operation are performed by the following two limit state approaches:

- a deterministic approach, with the use of safety or usage factors applied to characteristic loads and resistances; and
- a probabilistic approach, based on structural reliability analysis applied to the relevant limit states, e.g. reliability-based limit state methods.

Both approaches satisfy the safety requirements; implicitly by the deterministic approach (via earlier-calibrated safety factors) and explicitly by the probabilistic approach (a direct check on the actual safety level) as illustrated in Figure 1.

Significant differences exist among member countries in the areas of public safety and protection of the environment. Within the safety framework of this International Standard, such differences are allowed for and individual member countries can apply their national requirements for public safety and the protection of the environment to the use of this International Standard.

1 Scope

This International Standard specifies the functional requirements and principles for design, operation and re-qualification of pipelines in the petroleum and natural gas industries using reliability-based limit state methods as permitted by ISO 13623. Reliability-based limit state methods provide a systematic way to predict pipeline safety in design and operation.

This International Standard supplements ISO 13623 and can be used in cases where ISO 13623 does not provide specific guidance and where limit states methods can be applied, such as, but not limited to,

- qualification of new concepts, e.g. when new technology is applied or for design scenarios where industry experience is limited,
- re-qualification of the pipeline due to a changed design basis, such as service-life extension, which can include reduced uncertainties due to improved integrity monitoring and operational experience,
- collapse under external pressure in deep water,
- extreme loads, such as seismic loads (e.g. at a fault crossing), ice loads (e.g. by impact from ice keels),
- situations where strain-based criteria can be appropriate.

This document applies to rigid metallic pipelines on-land and offshore used in the petroleum and natural gas industries.

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) applies.

ISO 13623:2000, *Petroleum and natural gas industries — Pipeline transportation systems*

3 Terms and definitions

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

3.1

basic variable

load or resistance variable entering the limit state function including the variable accounting for model uncertainty in the limit state function itself

3.2

characteristic load

nominal value of a load to be used in determination of load effects

NOTE Characteristic load is normally based upon a defined fractile in the upper end of the distribution function of the load.

3.3

characteristic resistance

nominal value of a strength parameter to be used in determination of capacities

NOTE Characteristic resistance is normally based on a defined fractile in the lower end of the distribution function of the resistance.

3.4

characteristic value

nominal value to characterize the magnitude of a stochastic variable

NOTE Characteristic value is normally defined as a fractile of the probability distribution of the variable.

3.5

commissioning

activities associated with the initial filling of a pipeline with the fluid to be transported

[ISO 13623]

3.6

construction

phase comprising installation, pressure testing and commissioning

3.7

design life

period of time selected for the purpose of verifying that a replaceable or permanent component is suitable for the anticipated period of service

[ISO 13623]

3.8

design point

most probable outcome of the basic variables when failure occurs

NOTE The design point is the point on the limit-state surface with the highest probability density.

3.9

design value

value to be used in the deterministic design procedure, i.e., characteristic value multiplied by the safety factor

3.10

failure

loss of ability of a component or a system to perform its required function

3.11

fluid category

categorization of the transported fluid according to hazard potential

3.12

importance factor

dimensionless number between zero and one describing the contribution of a random variable to the overall uncertainty

3.13

inspection

processes for determining the status of items of the pipeline system or installation and comparing it with the applicable requirements

EXAMPLE Inspection can be by measuring, examination, testing, gauging or other methods.

3.14

limit state

state beyond which the pipeline no longer satisfies the design requirements

NOTE Categories of limit states for pipelines include serviceability limit state (SLS) and ultimate limit state (ULS).

3.15

limit-state design

structural design where specific limit states relevant for the actual case are explicitly addressed

NOTE A limit-state design check can be made both using the deterministic approach or using the probabilistic approach where uncertainties are modelled.

3.16

limit state function

function of the basic variables, which has negative values when the structure fails and positive values when the structure is safe

3.17

load

any action causing deformation, displacement, motion, etc. of the pipeline

3.18

load combination

set of loads acting simultaneously

3.19

load effect

effect of a single load or load combination on the pipeline

EXAMPLE Load effects include stress, strain, deformation, displacement.

3.20

location class

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

[ISO 13623]

3.21

maintenance

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

[ISO 13623]

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

3.22

maximum allowable incidental pressure

MAIP

maximum allowable internal pressure due to incidental operation of the pipeline or pipeline section

3.23

maximum allowable operating pressure

MAOP

maximum allowable pressure at which a pipeline, or parts thereof, is allowed to be operated

[ISO 13623]

3.24

mean value

first order statistical moment of the probability distribution function of the considered variable

3.25

mill test pressure

test pressure applied to pipe joints and pipe components upon completion of manufacture and fabrication at the mill

3.26

model uncertainty

uncertainty in the predictions of a selected calculation model that remains when the exact values of all input parameters are known

EXAMPLES Load model, strength model, function model for the pipeline.

3.27

nominal wall thickness

specified wall thickness of a pipe, which is equal to the minimum design wall thickness plus the negative manufacturing tolerance and the corrosion allowance

3.28

normal operation

conditions that arise from the intended use and application of the pipeline, including associated condition and integrity monitoring, maintenance and repair

NOTE Normal operations includes steady flow conditions over the full range of design flow rates, as well as possible packing and shut-in conditions.

3.29

ovality

deviation of the pipeline perimeter from a circle, having the form of an elliptical cross-section

3.30

pipeline

those facilities through which fluids are conveyed, including pipe, pig traps, components and appurtenances, up to and including the isolating valves

[ISO 13623]

3.31

offshore pipeline

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

[ISO 13623]

3.32

on-land pipeline

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

[ISO 13623]

3.33

reliability

ability of a component or a system to perform its required function without failure during a specified time interval

NOTE Reliability equals 1 minus the failure rate, P_f .

3.34**risk**

combination of the probability of an event and the consequences of the event

[ISO 17776]

NOTE Individual risk is related to the risk of a single person injury/death and societal risk is the risk of human safety in the entire society affected by the pipeline.

3.35**safety class**

concept to classify the criticality of pipelines

3.36**safety factor**

γ

factor by which the characteristic value of a variable is multiplied to give the design value

3.37**specified minimum tensile strength****SMTS**

minimum ultimate tensile strength required by the specification or standard under which the material is purchased

3.38**specified minimum yield strength****SMYS**

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

[ISO 13623]

3.39**system reliability**

reliability of a system of more than one element, or the reliability of an element which has more than one relevant failure mode

3.40**target safety level**

maximum acceptable failure probability level for a particular pipeline and limit state condition

4 Symbols and abbreviated terms

4.1 Symbols

C_f	consequences of a given failure
P_f	probability of a failure, i.e. the actual failure rate calculated
$P_{f, target}$	target safety level, equal to the target probability of failure
R	resistance or the capability of a structure or part of a structure to resist load effects
S	load effect on a structure or part of a structure
γ	safety factor
$g(x)$	limit state function

D	pipe diameter
L	gouge length of impacts
d	gouge depth of impacts
d_d	dent depth of impacts
f_{imp}	frequency of occurrence of impacts
f	ovality
σ_y	yield strength
σ_u	ultimate tensile strength
t	time
$f_x(x)$	joint distribution
$I(x)$	indicator function
$H(x)$	event margin
C	vector of serviceability constraints
ΔK	stress intensity factor range
p	random pressure variable
λ	scale parameter
S_C	characteristic load effect
$S_{C,E}$	environmental load effects
$S_{C,F}$	functional load effects
R_C	characteristic value of component resistance, based on characteristic values of material properties
f_C	characteristic values of material properties, for example yield strength
γ_i	partial load effect factors
η_R	resistance or strength usage factors
γ_m	partial material factors
$\Delta\alpha$	additive partial geometrical quantities

4.2 Abbreviated terms

ALS	accidental limit state
CTOD	crack tip opening displacement
FLS	fatigue limit state
LRFD	load and resistance factor design

MAIP	maximum allowable incidental pressure
MAOP	maximum allowable operating pressure
QRA	quantitative risk analysis
SLS	serviceability limit state
SMTS	specified minimum tensile strength
SMYS	specified minimum yield strength
SRA	structural reliability analysis
ULS	ultimate limit state

5 Principles for design and operation

Pipeline design and operational principles can be implemented using different methods with varying levels of detail as indicated in Figure 1. In order of decreasing level of detail, these methods are quantitative risk analysis (QRA) and structural-reliability analysis (SRA), both of which are probabilistic, and the deterministic limit-state design methods [partial safety-factor design and load and resistance-factor design (LRFD)], which are collectively termed LRFD in this document.

The LRFD formats apply partial safety factors to the characteristic load and resistance properties, representing more traditional design for pipelines. This is the format applied in ISO 13623 by the use of the hoop stress design factor and the equivalent stress design factor, i.e. one partial factor only. This approach is classified as deterministic, as no quantitative information about the safety margin is given. The partial safety factors in the LRFD format have to be calibrated by the use of reliability-based methods prior to the publication to satisfy its design requirements and provide a satisfactory safety margin. The routine use of the LRFD formats do not, therefore, require the partial safety factors to be determined. In LRFD approaches (see left side of Figure 1), the load and resistance are defined by their characteristic values and partial safety factors are applied separately (as required) to the characteristic values of load, resistance and material properties.

Application of the probabilistic approach (SRA and QRA) involves the steps on the right hand side of Figure 1. The limit-state definition is generally the same as for the LRFD. In this approach, load effects and resistance are represented by probability functions, given in terms of distribution type, mean value and standard deviation. This approach is classified as probabilistic, as quantitative information about the safety margin in terms of reliability or the complementary failure probability is given. The most comprehensive probabilistic method is QRA, as it takes into consideration the consequences of failure.

The format and requirements for the reliability-based limit state method are described in Clause 6.

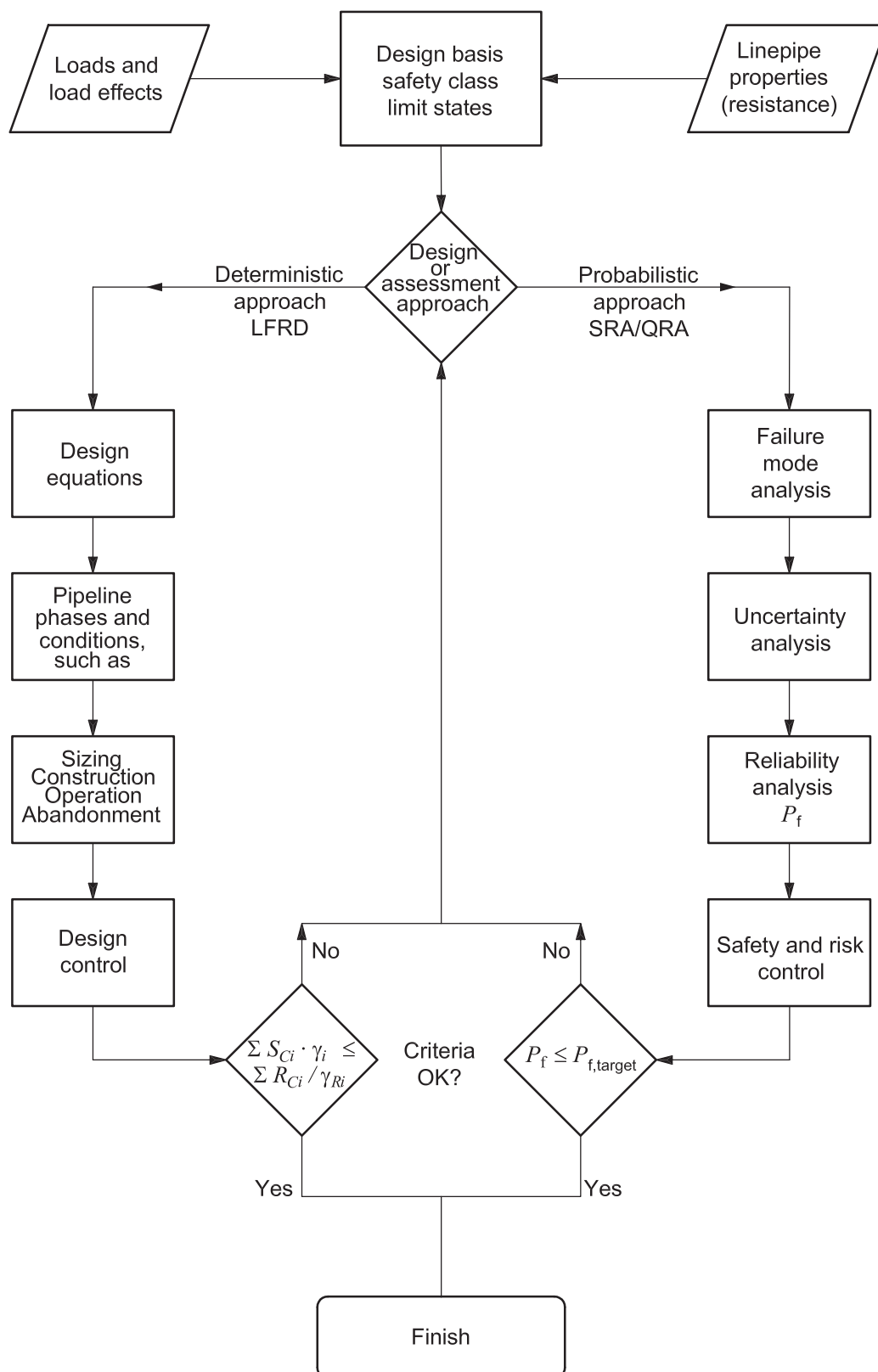


Figure 1 — Pipeline design and assessment approaches

6 Reliability-based limit state methods

6.1 General

Use of the reliability-based limit state approach shall include

- determining the design and operational data basis: data gathering, see 6.2,
- determining the safety requirements: targets, see 6.3,
- failure mode analysis; see 6.4,
- uncertainty analysis including estimation of probability functions; see 6.5,
- reliability analysis, see 6.6, and
- safety and risk assessment, see 6.7.

6.2 Design and operational data basis — Data gathering

Data gathering is collecting and defining all relevant information related to the pipeline to be considered and shall include the following information:

- a) design basis and operational information including
 - pipe system characteristics, e.g. pipe diameter, pipeline length, product composition, operating conditions (pressure, temperature), design life and interface facilities,
 - definition of loads and load effects and associated hazards,
 - definition of linepipe properties (resistance) and relevant pipeline capacities, and
 - inspection and monitoring philosophy for operation, e.g. integrity management plan;
- b) Hazard identification and classification of failure conditions including
 - determination of limit state conditions which constitute structural non-compliance for the pipeline as judged against the safety requirements and constraints, e.g. partial or total loss of supply, any loss of fluid, loss of operability or serviceability without loss of fluid, and
 - determination how the pipeline can become structurally non-compliant, in terms of loadings, resistance, and degradation; i.e. hazard identification.

Determination of operational requirements and classification of failure conditions shall be performed in accordance with Clauses 7 and 8.

6.3 Safety requirements — target

The objective of this step is to define the relevant safety requirements for the hazards/failure modes.

- a) The target safety level shall be defined for all pipeline sections according to the location and consequence categorization in Clause 8;
- b) Target safety levels shall be determined for all phases of the pipeline design life; e.g. construction, normal operation, and any temporary conditions.

Target safety levels shall be based upon public safety, environmental and business issues, taking account of safety and serviceability principles dictated by society, the local regulator, the specific company involved, and the performance requirements for the pipeline under consideration.

These targets should be clearly communicated to all relevant stakeholders.

Target safety levels shall be defined in accordance with Clauses 8 and 9. If no risk and/or safety levels are predefined, equivalent target probabilities of failure, $P_{f,target}$, may be taken from Annex C based on the current state of technology and design practice.

6.4 Failure mode analysis

The objective of this step is to identify all relevant failure modes (i.e. significant hazards with a probability of occurrence larger than the target safety level for the appropriate condition). The steps involved are

- a) the gathering of data to assess the severity of all hazards identified,
- b) the assessment of each hazard against the target safety requirement to determine whether each hazard is possible but incredible (e.g. a plane crash on a particular pipeline), or both possible and credible (e.g. corrosion),

This analysis may be undertaken in a semi-qualitative manner, e.g. a return period of a particular hazard estimated as being below 10^{-5} /km/year, being smaller than the target performance requirement, implies that the hazard is insignificant, and therefore a probabilistic assessment is not necessary and the hazard can be excluded from the further analysis.

Failure conditions shall be considered according to the classification given in 8.2. Justification shall be given for the classification of any hazard determined to be as “possible but incredible”, such documentation can, for example, be frequencies of occurrence. The significant (possible and credible) failure conditions shall be included in the uncertainty and reliability analysis.

6.5 Uncertainty analysis

In the uncertainty analysis, the significant failure conditions shall be considered, including

- a) establishment of all measures that are (or can be) implemented to mitigate against the hazard,
- b) determination of the appropriate method of assessment and identification of the most relevant limit state function, e.g. rupture, leak, etc.,
- c) collection of data that is required to quantify the variables in the limit state function,
- d) assessment of the uncertainty associated with the data and limit state function (model uncertainty), and
- e) selection of appropriate values for all variable parameters.

Uncertainty analysis and probabilistic modelling can be performed according to procedures given in Annex A and, if no other case-specific information is available, uncertainty measures can be found in Annex B. The uncertainty modelling should include all variables entering the limit state equation. The most relevant statistical properties are the mean value and the standard deviation in addition to information about the distribution function. Any correlation between parameters is important and shall be evaluated.

EXAMPLE For external corrosion of the pipeline, the mitigation measures can be a combination of any of the following: corrosion allowance, anti-corrosion coating, cathodic protection system, inspection and repair policy. It is noted that there are several ways of implementing an inspection, monitoring and repair policy.

6.6 Reliability analysis

The reliability analysis is to calculate the failure probability (P_f) for each significant limit state identified. The steps to be included are as follows.

- a) Probabilistic modelling of the limit state function, i.e. analytical formulation of the failure criteria. For a given limit state, a probabilistic design models the load, S , and resistance, R . The corresponding limit state function may be expressed in the form:

$$g(x) = R - S \quad (1)$$

- b) Selection of the most appropriate probabilistic calculation method for the problem and level of accuracy, possible methods include first order second moment (FOSM), "reliability" methods (FORM/SORM), Monte Carlo, or direct integration.
- c) Perform probabilistic calculations, i.e. calculate the failure probability for each relevant limit state. The reliability analysis may then be performed when the statistical properties of the limit state functions are defined (load effect and resistance properties). When the distribution functions for R and S are established through uncertainty analysis, the failure probability is calculated by

$$P_f = \int_{g(x) \leq 0} f_{R,S}(R,S) dR dS \quad (2)$$

The reliability analysis can be performed in accordance with the guidance given in Annex A or other relevant calculation procedures.

A calculated probability of failure is not a physical property of the pipeline itself, but gives a notional value. The calculated probability of failure depends on the method and procedure applied, including uncertainties in data and methods. It is, however, the intent of this document to standardize the methods and procedures used for the reliability-based approach and thus to bring this into a comparable level within the industry.

6.7 Safety and risk assessment

This step is to check that the pipeline meets the safety requirements (criteria). The reliability shall be compared with the requirements by ensuring that:

$$P_f \leq P_{f,target} \quad (3)$$

where

P_f is the calculated probability of failure from the reliability analysis;

$P_{f,target}$ is the target safety level that should not be exceeded for a design and/or operation to be accepted.

If the requirements are not met, the pipeline details should be modified and the assessment repeated (new iteration in Figure 1).

When applying Equation (3), the correct comparisons shall be undertaken; i.e. individual or system failure modes; for the correct time and spatial units; for the correct phase in the design life, e.g. operational or temporary.

The physical design parameters (e.g. wall thickness) selected to mitigate against failure shall satisfy all performance requirements.

The safety check shall be performed in accordance with Clauses 8 and 9.

Similar safety principles apply to both offshore and on-land pipelines, but differences in failure consequences and safety regimes result in different required target safety levels, $P_{f,target}$.

For both offshore and on-land pipeline applications, it is appropriate to control the failure probability (P_f) as a function of the consequences, as established by the safety class designation (see Clause 8) to obtain a uniform risk level. For on-land pipelines, the acceptable probability of failure is also a function of the pipeline pressure and diameter to account for the impact of these parameters on the failure consequences. A uniform risk level is generally the objective for any application.

Equation (3) is equivalent to Equation (4) when risk is calculated as the product of probability of failure and consequences of that failure:

$$\text{calculated risk} \leq \text{allowable risk} \quad (4)$$

The target safety levels, $P_{f,\text{target}}$, given in Annex C have been derived from risk assessments and these values may be applied if no additional explicit risk assessment is performed.

Further technical details and requirements of the various items to be considered in the reliability-based approach are described in Clauses 7 to 10 and in Annex A.

7 Design and operational requirements

7.1 General

The safety against potential failure modes shall be checked for all conditions during construction and operation (including re-qualification) throughout the lifetime of the pipeline.

7.2 Design and construction

The pipeline shall be designed and constructed to satisfy the following performance requirements:

- a) to perform adequately under all anticipated load effects (serviceability limit state requirement);
- b) to withstand anticipated load effects during its construction and operation (ultimate limit state requirements);
- c) to avoid failure under repeated load effects during construction and operation (ultimate limit state — fatigue requirements);
- d) to avoid failure due to accidents during construction and operation (ultimate limit state — accidental requirements).

7.3 Operation and maintenance

The pipeline shall be operated and maintained such that the safety and the integrity is kept within the target safety level.

An integrity management programme shall be implemented by the operator to satisfy the safety requirements given in this document. Maintenance includes the requirements of inspections, inspections on special occasions (e.g., after an accident or severe environmental events), the upgrading of protection systems and repair of components.

The integrity of the pipeline may be achieved by either a maintenance programme and/or designing to avoid deterioration that can affect the integrity of the pipeline in those areas where the pipeline cannot or is not maintained.

The rate of deterioration may be estimated based on numerical calculations, experimental investigations, experiences from other pipelines or a combination of these.

7.4 Re-qualification

Re-qualification of the pipeline integrity shall be performed when

- the design life is to be extended,
- the pipeline has been found to have deteriorated or have been seriously damaged,
- the pipeline needs to be up-rated,
- the operational conditions change,
- the original design criteria or design basis are no longer valid.

A revised safety assessment in accordance with this document shall be conducted for those aspects of the design not in compliance with the original design requirements.

The re-qualification can require a deviation from the design basis or modifications to the pipeline or the operational conditions to achieve compliance with this document.

7.5 Hazards

Hazards that alone or in combination with loads in normal operation could violate the pipeline integrity shall be considered as part of the ultimate limit state — accidental condition ALS.

a) Possible hazards to the pipeline include

- effects due to extreme environmental loads,
- impact from third-party activities, and
- operational malfunction.

b) Measures taken to mitigate such hazards include

- avoiding the structural effects of the hazards by either eliminating the source or by bypassing and overcoming them,
- minimizing the consequences, and
- designing for hazards.

8 Acceptance criteria and safety classes

8.1 Safety requirements

A target safety level, $P_{f,target}$ shall be defined as the maximum acceptable failure probability level for a particular pipeline. Target safety levels are required for developing design criteria for the application of reliability methods. These criteria shall be satisfied during operation and maintained through the integrity management programme.

The evaluation of the target safety levels for pipelines should primarily be based on the inherent safety level achieved by using a currently accepted design practice (e.g. code of practice or standard), using uncertainty measures representative of the time when the relevant design practice was prepared. The nature of a failure and the consequence potential in terms of effect on human health and safety, damage to the environment, economic losses, and the cost and effort required to reduce such hazard potential should be taken into account.