Hungarian Atomic Energy Authority

Guideline 3.25

Strength analysis of operating pressure retaining components

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2.

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The legal hierarchy of nuclear safety regulations in Hungary is as follows:

1. The uppermost level is represented by the Act CXVI of 1996 on Atomic Energy (Atomic Act).

2. The next level basically consists of two government decrees issued as executive orders of the Atomic Act. The 114/2003. (VII.29.) Korm. government decree defines the legal status of the Hungarian Atomic Energy Authority (HAEA), while the 89/2005. (V.5.) Korm. government decree specifies the HAEA’s generic procedural rules in nuclear safety regulatory matters. The nuclear safety code consists of seven volumes, which are issued as the annexes of this latter decree. The first four volumes address the NPP, the fifth one the research and training reactors, whilst the sixth volume addresses the spent fuel interim storage facility. These six volumes determine the specific nuclear safety requirements, whilst the seventh volume contains the definitions applied in the code. The regulations are mandatory; failing to meet any of them is possible only in those specific cases that are identified by the decree.

3. The regulatory guidelines constituting the next level of the regulatory system are connected to one of the volumes of the code. The guidelines describe the method recommended by the proceeding authority for meeting the requirements of the nuclear safety code. The guidelines are issued by the director general of the HAEA, and they are regularly reviewed and reissued based on accumulated experience. So as to proceed smoothly and duly the authority encourages the licensees to take into account the recommendations of the guidelines to the extent possible.

4. In addition to the described regulations of general type, individual regulatory prescriptions and resolutions may also address specific components, activities and procedures.

5. The listed regulations are obviously supplemented by the regulating documents of other organizations participating in the use of nuclear energy (designers, manufacturers, etc.). Such documents are prepared and maintained in accordance with the internal quality assurance system of the user.

Before applying a given guideline, always make sure whether the newest, effective version is considered. The effective guidelines can be downloaded from the HAEA's website: http://www.haea.gov.hu.
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1. INTRODUCTION

1.1. Scope and objective

Current guideline provides recommendations on strength analysis aimed at design and design verification of nuclear power plant pressure retaining systems and components categorized into safety classes. It interprets the regulatory requirements on the methodology, and thus facilitates the compliance with the nuclear safety criteria prescribed in the laws.

Objective of strength analysis belonging under the effect of the Guideline is to justify that structural components, as the subject of analysis, are able to tolerate the loads specified in the design with a safety margin required for a nuclear power plant within the determined service life.

The Guideline contains the methods recommended by the proceeding authority in respect to the compliance with the requirements of regulations.

The Guideline determines the procedure that should be followed during strength design and verification of nuclear power plant pressure retaining systems. Every such structural element should be handled as part of the pressure retaining system, the failure of which could lead to loss of pressure retaining capability. Components and boundaries of systems belonging under the effect of the Guideline are designated by Figure 1. Definitions used in the Guideline are included in Chapter 2.

Fatigue analysis according to the Guideline covers the calculation of cumulative usage factor necessary for the evaluation of ageing. It has to be emphasized, however, that these calculations do not fully cover the ageing management related problems.

1.2. Corresponding laws and regulations

According to the requirements included in 3.053, 3.054 and 3.056 of Volume 3 of the Nuclear Safety Code issued as specified by Article 4, § (1) of the 89/2005. (V. 5.) Korm. government decree on the generic rules of procedures of the Hungarian Atomic Energy Authority in nuclear safety regulatory matters:

"The strength analysis shall verify that the lifetime of the loaded component is long enough, taking into account all mechanisms that occur during the
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whole lifecycle. These analyses shall be performed by proven methods and it shall be complemented by model examinations, as necessary.

The data applied during the strength analyses shall originate from conservative approach. The material characteristics resulting in the degradation of structural materials shall be taken into account.

Strength analyses shall be applied to demonstrate that

a) strength properties of structural materials, considering the safety margin prescribed for the operating state, meets the maximal load conditions calculated for normal operation and design basis accident conditions,

b) stress intensity in the structure shall nowhere exceed the fracture toughness at the given temperature, i.e. flaws in the structures shall not grow,

c) during design basis accidents the load of the examined components shall remain under the acceptable load level.”

Furthermore Chapter 4.8 and paragraph 4.083 of Volume 3 of Nuclear Safety Code corresponds to the Guideline:

“In the selection of structural materials based on the design requirements appropriate for the application objective the following factors shall be taken into account: physical and mechanical properties, applicability for technologies, reliable operability under operational incidents and design basis accidents, design lifetime, constructional characteristics, characteristics induced by technological processes and environmental conditions.

a) Within the physical-mechanical properties in line with the extent of the requirements emerged at the design stage, the structural, material strength and other material properties taken at the environmental and design temperature should be considered.

b) The requirements for applicability for technologies depending on the intended application shall comprise the deformation and welding properties.

c) The examination of reliable operability shall comprise the guaranteed tolerance of minimum and maximum operating design basis accident temperatures, and maximum operating pressure.
d) The consideration of design lifetime consists of verification of degradation mechanisms and material property changes induced by cyclic loads, thermal ageing, neutron radiation and durable strength.

e) The consideration of constructional characteristics comprises the compatibility of contacting structural materials, the possibilities of verification and regular periodic instrumental inspection as well as the conditions of reparability.

f) The characteristics of the technological process.

g) The environmental parameters.

The licensee should take into account, when applying the guideline, that in compliance with the requirements of Volume 3 of NSC associated with design, verification and general acceptability of the construction are also contributed by other guidelines. These guidelines describe the methodology and procedures of verification of the design of construction for special loads or processes, and thus they include special recommendations for the strength analysis performed in relation to the given issue.
1.3. Effect of the guideline

The rules and recommendations described in the guideline contribute the strength analysis of nuclear power plant pressure retaining systems already licensed (i.e. operating) and wished to use for the license application for the extension of service life. The application of the guideline for the strength design of new facilities is not recommended. The effect of the guideline is limited to Class 1 and Class 2 construction code systems.

1.3.1. Scope of construction requirements

The safety of a nuclear power plant pressure retaining component, in addition to meeting the criteria required by strength analysis, is also contributed by other considerations. Constructional prescriptions are as follows:

a) Material properties
b) Design (strength calculation is part of it)
c) Manufacturing
d) Inspections (pres-service)
e) Surveillance (in-service inspections presented be the operator)
f) Tests
g) Certificates
h) Overpressure protection

The strength analysis is integrated, inseparable part of the system of constructional safety prescriptions. The above listed technical requirement systems influencing the pressure retaining safety of the operating equipment should be in the background of determination of allowable stresses applied for the judgment of strength acceptability, by the presumption of which the allowable stresses in the wall of the pressure retaining component has been determined.

A Determination of code classes: see Guideline 3.3.
1.3.2. **Standard basis**

The relevant Sections\(^1\) of the 2001 issuance of the ASME Boiler and Pressure Vessel Code (ASME BPVC, or shortly ASME), which contain the constructional requirements for the integrity of pressure retaining components.

The ground for system of requirements covered by the Guideline is comprised of the ASME prescriptions referred to in section 1.3.2.1 and 6.2.

1.3.2.1. Justification of strength compliance and integrity of pressure retention

Figure 4 designate the design requirements related to the certain component types from the prescriptions of *ASME BPVC Sect. III. Division 1 – Rules for construction of nuclear facility components*.

The following connection points appeared in the figure does not fall under the scope of the guideline:

a) overpressure protection functional requirements

b) strength verification of building structures.

1.3.3. **Strength analysis of systems not constructed according to the ASME**

The guideline covers the strength verification of those pressure retaining systems that are already commissioned, but the design of which was not performed according to the ASME.

1.3.3.1. Evaluation of constructional deviation directly not affecting allowable stresses

Deviations from ASME requirements in the field of material properties, design, manufacturing, assembling and certification belong to this category. These are detailed in the respective chapter of the guideline.

1.3.3.2. Evaluation of constructional deviation directly not affecting the allowable stresses

To the Strength Analysis Report the licensee should attach the justification that in the fields listed in point 1.3.1 requirements equivalent to ASME constructional rules have been applied. The justification of compliance or equivalent compliance with the following two requirement systems should be addressed with emphasis:
a) Overpressure protection \((NB-, NC-, ND 7000 Articles)\)
b) Inservice Inspections \((ASME BPVC Sect. XI.)\)

The method of justification is not covered by the Guideline, but its existence and its regulatory approval are preconditions for the validity of Strength Analysis Report.
2. DEFINITIONS

2.1. Definitions

Acknowledging that the basis of this Guideline is ASME BPVC, thus the definitions and technical phrases used therein should be taken from that. In this chapter those definitions are identified, which also have other meaning in the Hungarian language and to which this guideline gives specific sense.

This chapter does not include the definitions listed in the Annex 7 of 89/2005. (V. 5.) Korm. government decree.

**Construction**

Technical activity aimed at material selection, design, manufacturing, inspection, examination, testing, certification and overpressure protection of pressure retaining systems, to which the ASME rules relate (ASME BPVC III, Foreword).

**Strength reduction effect**

All those effects, which modify the strength properties of the material in unfavorable direction, but which have not been taken into account during the measurements grounding the consideration of material properties. Factors affecting the reduction of resistance against permanent and cyclic loads causing fatigue belong to here.

**Pressure retaining component (shortly: component)**

A component of the pressure retaining system manufactured as separate unit, which is joined to the other components of the system by circumferential weld or threaded joint. The components may be pressure retaining and not pressure retaining structural elements. ASME definitions: NB-, NC-1000

**Pressure retaining system (Symbol: S)**

All those components belong to the pressure retaining system, in which the flow of medium between the components is unhindered. If necessary, the pressure of the S may be limited by one or more overpressure protection instrument. The end points of the system may connect to other pressure boundary systems by closing valves. ASME Definition: NB-, NC-7111.
Pressure retaining structural element (Symbol: SE)

All those elements of the component, which have considerable role in pressure proportion tolerance of the load, their failure entail loss of pressure retaining ability. Definition: NB-, NC-, ND-1000. The SE is the smallest unit, for which the prescriptions of a given code class should be applied. According to NCA-2000:

a) SEs constructed according to NB Subsection belong to Class 1  
b) SEs constructed according to NC Subsection belong to Class 2  
c) SEs constructed according to ND Subsection belong to Class 3  

Originating from the above definition a component may consist of SEs categorized to different classes. These components are referred to as more classed component. ASME definition of more classed component: according to NCA-2133.

Supports

Those structural elements that do not have pressure retaining function but take part in transmitting loads between the component and the building structure necessary for the clamping and support of the component.  

ASME definition: according to Subsection NF.

Strength Analysis Report

Document justifying the strength acceptance of the concerned SE, the content of which complies with the requirements of sectin 8.3.

Design specification

Document containing the technical background for the construction of nuclear equipment, which is based on the analyses and evaluations included into the FSAR (see in the US prescriptions: 10 CFR50_36). The general content requirements are included in NCA-3250. Content requirements related to components are detailed in Appendix B, Division 1, Section III, while to supports in Appendix J.
3. ITEMS UNDER SCOPE OF THE GUIDELINE AND THE RELATED VERIFICATION CRITERIA

Figure 1 summarizes ASME classification and designation of conceptual boundaries separating the elements of the pressure retaining system. The guideline addresses only the Class 1 and Class 2 code class system components and attachments of these.

In selection and application of the criteria justifying the acceptance of structural elements the licensee should, beyond this chapter, consider the whole content of the guideline.

3.1. Components

Definition: according to Chapter 2.

Designation of the boundary between two components: according to: NB-, NC-1131.

Designation of the boundary between components and attachments: according to NB-, NC-1132.

3.1.1. General design (NB-, NC-3100)

3.1.1.1. Loading conditions

Load conditions listed in NB-, NC-3110 should be taken into account based on the design specification of the component or in case of already commissioned components the load catalogue compiled by the licensee. Acceptance condition of the Strength Analysis Report is that the loads considered for the component should not be less than the upper limit specified in the licensee’s effective Technical Specifications (TechSpec, or in its newer name: Operational limits and conditions, OLC, see Guideline 4.2). The licensee should detail the loads and service conditions in the Strength Analysis Report in the below grouping of service load levels:

a) Design parameters: design temperature, pressure, mechanical loads

\^ When determining design parameters the conditions of NCA-2142.1 should be fulfilled.
b) Parameters of loads and service limits classified in A, B, C, D Service Levels according to NB-, NC-3133.

Test conditions: Temperature and pressure parameters of pressure test executed according to NB-, NC-6000.

Loads during startup leak-test should be evaluated according to requirements related to Service Level A.

3.1.1.2. Calculation of thermal stresses

Thermal stresses should be taken into account in the strength analysis as specified by the component-specific requirements of the ASME: as general requirements the prescription of Article A-7000 of ASME Division 1 are authoritative. Thermal material properties listed in paragraph A-7120 (3) may primarily be taken by considering the data specified in the design and manufacturer documents. Thermal properties of most common VVER440/213 type nuclear power plant materials are included in Annex 1.

If the given material may be classified into one of the material groups of ASME Section II: Part D, then the values of table TCD may also be used.

3.1.1.3. Special loads

3.1.1.3.1. Earthquake

Loads should be taken as determined in Guideline 3.2, as function of seismic safety classification of the given component.

Load combinations constituted with SL-1 level earthquake according to Guideline 3.2 (OBE, Operational Basis Earthquake) should be evaluated as classified into Service Level B.

Load combinations constituted with the SL-2 earthquake (SSE, Safe Shutdown Earthquake) should be evaluated as classified into Service Level D. Higher (A, B, C) classification is allowed.

3.1.1.3.2. Vibrations

The construction of the pressure retaining component ensures that the contribution of cyclic loads on cumulative usage factor from service vibrations and oscillation is negligible. The related constructional and monitoring methods, criteria are not included into this guideline, but it is an acceptance condition for the Strength Analysis Report that the licensee should describe the method of management of vibration.
3.1.1.3.3. Water hammer

The construction of the pressure retaining systems ensures that the pressure wave (water hammer) induced by sudden closing or opening of pipelines or instable condensation of steam space from stratified state is negligible from the aspect of loading of system components. The related constructional and monitoring methods, criteria are not included into this guideline.

3.1.1.4. Erosion-corrosion effects

Wall thickness of system components in service may decrease depending on the chemical and flow conditions of the coolant contacting the wall. So as to take account of this effect allowance should be added to the wall thickness considered in the acceptance criteria referred here, differentiating by components or structural elements, if necessary. The following should be considered for allowancing the wall thickness:

a) Chapter 4 of PNAE G-7-002-88\textsuperscript{2} strength standards

b) Considering upper limit of location specific, actual service wall thickness reduction data.

Considering that the corrosion allowance necessary till the end of design lifetime may be assessed in design only with preliminary not known error, the licensee should manage the actual erosion-corrosion induced wall thickness reduction in the frame of the inservice inspection program. The method of management is not covered by the Guideline, but it is an acceptance condition for the Strength Analysis Report that the licensee should describe the related inservice inspection program\textsuperscript{A}.

3.1.1.5. Standard products

Strength calculation are not necessary to be performed for products complying with the standards referred to in NB-, NC-3132, if it is not so required by the component-specific ASME requisites. In respect to standard products the licensee should justify the safety for those loads listed in 3.1.1.1, which have not been considered by the product standard.

\textsuperscript{A} The Inspection Manual 49001 NRC procedure can be used for specification of content requirements for the program
3.1.2. **Strength analysis criteria for Class 1 code class**

3.1.2.1. Design verification by analysis. Requirements for acceptability

Requirements listed in NB-3211 should be met with the following supplementary conditions, deviations:

a) NB-3211 a) Stress intensity limitations

Recommendations of Chapter 5 should be applied for calculation of design stress intensity (NB-3112.4) necessary to evaluate the criteria.

b) NB-3211 d) Justification of protection against non-ductile fracture

In case of operating components the protection against non-ductile fracture should be justified according to Chapter 7.

The justification should be performed for those cases, for which the paragraph NB-2311 a) provides exemption from impact energy examinations.

3.1.2.2. Vessels NB-3300

Beyond the requirements of NB-3100 and NB-3200 also the requirements of NB-3300 should be justified. NB-3300 should be applied if contradiction arises.

3.1.2.2.1. Openings and reinforcements

Verification should be performed according to NB-3331 (c) for the vessels not designed according to the ASME.

3.1.2.2.2. Welds

For welds not complying with the weld design requirements specified in NB-3350 and NB-3360, based on individual judgment, strength reduction factors should be applied according to Chapter 5.

For operating vessels not designed according to ASME the licensee should justify that its manufacturing and inspection requirements for the welds are equivalent to those referred to in NB-3350.

If a requirement for inspection of weld given in the subarticles referred to therein is not met, then this fact should be included in the Strength Analysis Report.
3.1.2.3. Pumps NB-3400

The criteria according to NB-3400 are relevant for pump parts listed in NB-3411.

3.1.2.3.1. Non-ductile fracture

For operating pumps the protection against non-ductile fracture should be justified according to Chapter 7 instead of NB-3412.

The justification should not be performed for those cases, for which the paragraph NB-2311 a) provide exemption from impact energy examinations.

3.1.2.3.2. Pumps with inlet connection greater than NA 100

Strength requirements

Requirements of NB-3412.1 should be justified.

3.1.2.3.3. Pumps with inlet connection of NA 100 or smaller

Requirements of NB-3412.2 should be justified.

3.1.2.4. Valves NB-3500

The word “valves” also relates to gate type valves.

3.1.2.4.1. Valves with inlet piping connection greater than NA 100

Requirements of NB-3512 should be justified.

3.1.2.4.2. Valves with inlet piping connection of NA 100 or smaller

Requirements of NB-3513 should be justified.

3.1.2.4.3. Interpretation of Appendix II referred to in NB-3512.2 (d) (3)

In case of valves not designed according to ASME, operating longer than 8 years, the experimental justification according to II-1100–1400 may be omitted. Spatial finite element model may be applied for stress analysis. The licensee should demonstrate the reliability of finite element modeling. Methods that can be used for the justification of reliability are detailed in Chapter 8.2.

3.1.2.4.4. Spring-loaded pressure relief valves

The acceptability of spring-loaded pressure relief and safety valves should
be justified according to NB-3590.

3.1.2.4.5. Non-ductile fracture

In case of operating valves the protection against non-ductile fracture should be justified according to Chapter 7 instead of the requirements of NB-3512.

The justification should not be performed for those cases, for which the paragraph NB-2311 a) provides exemption from impact energy examinations.

3.1.2.5. Piping NB-3600

Acceptance criteria according to NB-3611 should be verified.

3.1.2.5.1. Non-ductile fracture

In case of operating piping the protection against non-ductile fracture should be justified according to Chapter 7 instead of the requirements of NB-3611.5.

The justification should not be performed for those cases, for which the paragraph NB-2311 a) provides exemption from impact energy examinations.

3.1.2.5.2. Stress analysis according to NB-3650, for piping not designed according to ASME

When applying the stress and flexibility indices given in NB-3683, used in the stress intensity criteria appearing in NB-3650 the licensee should examine in detail and justify the validity conditions according to NB-3680. If they are not met then it should proceed as specified in NB-3681 and NB-3683.

3.1.3. Strength analysis criteria for Class 2 code class

3.1.3.1. General recommendations

When justifying the fulfillment of requirements according to Subsection NC the allowable stress should be determined according to Chapter 5.

NC-3124 Justification of protection against non-ductile fracture

In case of operating components belonging under the effect of Subsection NC the protection against non-ductile fracture should be determined
3.1.3.2. Vessels
When verifying vessels the full compliance with one of the following requirement systems should be justified:

a) NC-3200 (alternate design rules), and the requirements listed in NC-3211.1 (d)

b) Full stress analysis according to NC-3211.1 (c), and the requirements listed in NC-3211.1 (d)

c) NC-3300 (vessel design)

3.1.3.2.1. Welds
In case of welds that do not meet the weld design requirements of NC-3250 or NC-3350 – based on individual judgment – the licensee should apply strength reduction factors according to the guidance of Chapter 5.

In case of operating vessels not designed according to ASME the licensee should justify that the manufacturer and inspection requirements of the welds are equivalent to the requirements referred to in NC-3250 or NC-3350. If any of the requirements of the subarticle referred to therein, related to the inspection of the weld is not met, then it should be described in the Strength Analysis Report.

3.1.3.3. Pumps NC-3400
Criteria according to NC-3400 should be justified.

3.1.3.4. Valves NC-3500
The word valves also relates to gate type valves.
Criteria according to NC-3500 should be justified.

3.1.3.5. Piping NC-3600
Criteria according to NC-3600 should be justified.

3.1.3.5.1. Stress analysis according to NC-3650, for piping not designed according to ASME
When applying the stress and flexibility indices given in NC-3673, used in the stress intensity criteria appearing in NC-3650 the licensee should
examine in detail and justify the validity conditions according to NB-3673. If they are not met then it should proceed as specified in NB-3673.2(e).

3.1.3.6. Electrical and mechanical penetration assemblies NC-3700

Requirements according to NC-3700 should be justified.

3.1.3.7. Atmospheric storage tanks NC-3800

Requirements according to NC-3800 should be justified.

3.1.3.8. Low pressure storage tanks (0-103 kPa)

Requirements according to NC-3900 should be justified.

3.2. **Attachments**

Definition: according to NB-,NC-1132.1.

Those attachments should be included into this group that belong to the scope of the guideline, have pressure retaining function, and take part in clamping or support of a component, or serves as support for the core.

3.2.1. *Attachment with pressure retaining*

Pressure retaining attachment should be regarded as part of that component to which it connects.

Definition: according to NB-,NC-1132.2.

For pressure retaining attachments the requirements of NB-,NC-3135 should be justified.

3.2.2. *Supports*

Definition: according to Chapter 2.

General requirements: according to Subsection NF.

3.2.3. *Core support structures of reactor pressure vessels*

Definition: according to NG-1100.

Specification of boundaries: between the core support structure and
a) reactor pressure vessel: NG-1131
b) other internal structures: NG-1132

c) and temporary attachments: NG-1133

General requirements: according to Subsection NG.

3.3. Other special items

3.3.1. Gaskets

Definition: structural unit ensuring pressure retention and detachable joint between components.

Its parts:

a) Flanges: pressure retaining structural elements

b) Bolted joint: specific pressure retaining structural elements

c) Gaskets: special elements not taking part in pressure retention, ensuring the leak-tight closing of contacted surfaces through the force exerted by the bolted joint that pushes the surfaces together.

For strength analysis of operating gasket units the licensee should consider the dimensions and material properties related to the gasket according to own system of requirements, agreed with the authority such a way that the dimension and material property combinations within the allowable limits should include the following two cases, as minimum:

d) The most unfavorable case from leak-tightness aspect

e) The case causing the most load of flanges and bolted joints.

The description of requirement system containing the dimension tolerances and material properties related to the gaskets is precondition of acceptance of the Strength Analysis Report.

3.3.1.1. Requirements for Class 1 code class

Flange connections not conforming to the conditions of NB-3362 and acceptance of access openings according to NB-3363 should be justified by stress analysis according to NB-3200.

3.3.1.2. Requirements for Class 2 code class

Requirements according to NC-3362 should be justified.
For the access or inspection openings of operating components the requirements of NC-3363 should be taken. The following are exceptions:

a) requirements in NC-3363.1 – 3363.5 related to minimum dimension of access or inspection opening,

b) requirement in NC-3363.7 related to gasket bearing surface.
4. **DIMENSIONS**

The licensee should justify that drawings used for the strength analysis (including the dimension data appeared on them and used for the calculations) are in agreement with the realized and actual condition of the SE concerned. The following may be regarded as justified data source:

a) Drawings prepared by the manufacturer, being the part of supplied documentation.

b) As-built drawings prepared for the original design documentation, piping system assembly plans,

c) Plans of approved and implemented modifications,

d) Service manual of applied valves,

e) Data from measurement records of in-service inspections.

4.1. **Handling of data deficiency**

In case of missing, contradicting dimension data or of unjustified origin the below procedure should be followed:

a) Suspension of analysis until the doubtful dimension is measured on-scene by the accredited organization.

b) If it is practical then the analysis may be performed by assumed dimension data. In this case the strength analysis will only become valid, if the assumed data are justified. If assumed data is applied then this fact should be highlighted in the Strength Analysis Report, and the assumed data should be classified into separate chapter. The document containing the justification of assumed data should be attached to the Strength Analysis Report.

4.2. **Dimension and shape faults**

The dimension and shape tolerances appeared in the applied drawings may be taken into account in the strength analysis with due conservatism in respect to the acceptance criteria. When the dimension and shape tolerances are taken the licensee should consider the dimension deviations revealed during in-service inspection.
In case of missing dimension and shape tolerances the requirements of standards applied for the design, manufacturing and assembling may be used. If the standards considered cannot be identified based on the available documents supplied, then the standards mandatory for the manufacturing at the time of fabrication should be taken into account.
5. ALLOWABLE STRESSES

Current chapter provides guidance on the determination of allowable stresses of those materials, which are not included in the material specification of ASME BPVC Section II: Part D. Allowable stresses of materials approved by the ASME should be determined according to the component-specific ASME requirements.

5.1. Scope of necessary material properties

For the determination of allowable stresses the following mechanical material properties should be identified.

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>$S_T$</td>
<td>MPa</td>
</tr>
<tr>
<td>Yield point</td>
<td>$S_Y$</td>
<td>MPa</td>
</tr>
<tr>
<td>Contraction percent</td>
<td>$Z$</td>
<td>%</td>
</tr>
<tr>
<td>Breaking strain</td>
<td>$A$</td>
<td>%</td>
</tr>
</tbody>
</table>

The mechanical material properties should be specified as function of temperature, in 50 °C intervals, for the whole temperature application range. The minimum and maximum values of temperature application range should be designated according to ASME BPVC Section II: Part D. Appendix 5.

For the determination of mechanical properties the following standards are accepted: ASTM, AWS, CEN, GOSZT, MSZ, DIN.

Beyond these the material specification should contain the chemical composition and the conditions of

a) manufacturing,
b) quality assurance,
c) supply,
d) thermal treatment,
e) inspection,
f) applicable operating temperature.

5.2. Material applied in operating pressure retaining systems

5.2.1. Definition
Materials of nuclear power plant pressure boundary components and attachments (see Chapter 3) performing pressure retaining function operating with license belong to the scope of current (5.2) Subchapter.

5.2.2. Certificate requirements form material properties
As justified source of material properties of the given SEs according to 5.1 the following documents may be accepted.

Mechanical properties of raw materials used for the fabrication of pressure retaining elements should be taken from quality certificate according to standard MSZ EN 10204 or according to standards or prescriptions referred to in expert quality certificate. A quality acceptance record is not prescription.

Mechanical properties of weld materials should be justified by quality certificate (provided by the manufacturer) as minimum.

5.2.3. Design temperature (T)
The licensee should determine the design temperature of the SE according to NCA-2142.1(b), by taking account of the limiting conditions approved in the Technical Specifications.

During service the temperature of SE should not exceed the upper limit of applicability temperature given in the material specification according to 5.1 in any operating state.

5.2.4. Calculation of allowable stresses
The material properties established according to 5.2.2 should be applied for calculation of the below listed allowable stresses.

^ Earlier: MSZ 14900-73
5.2.4.1. Design Stress Intensity Values (DSIV)
For Class 1 construction it should be interpreted as per NB-3112.4.
ASME symbol: Sm
Its calculation may take place as per the following points of PNAE G-7-002-88:
   a) For non-bolt materials: point 3.4 of PNAE
   b) Bolt materials: point 3.5 of PNAE

5.2.4.2. Design Allowable Stress Values (DASV)
For Class 2 construction it should be interpreted as per NB-3112.4.
ASME symbol: S
Its calculation may take place as per the following points of PNAE G-7-002-88:
   a) For non-bolt materials: point 3.4 of PNAE
   b) Bolt materials: point 3.5 of PNAE

5.3. Non pressure retaining material applied in operating systems

5.3.1. Definition
Materials used for supports, beams (shortly for supports) belong to here.

5.3.2. Certificate requirements of material properties
Mechanical properties of non-pressure retaining elements should be justified by quality equivalent certificate\(^\text{A}\), at least.

5.3.3. Calculation of allowable stresses
The material properties established according to 5.3.2 should be applied for calculation of the below listed allowable stresses.

\(^\text{A}\) Determination: MSZ EN 10204, earlier: MSZ 14900-73.
5.3.3.1. Design Stress Intensity Values (DSIV)

ASME symbol: Sm

In relation to plate and shell type supports of Class 1 components the DSIV should be determined according to Article ASME BPVC Section. II: Part D. Appendix 2-110.

5.3.3.2. Design Allowable Stress Values (DASV)

ASME symbol: S

a) In relation to plate and shell type supports of Class 2 components the DASV should be determined according to Article ASME BPVC Section. II: Part D. Appendix 1-110.

b) In relation to linear type Class 2 components and standard support of any other class components (except for the case in 5.3.3.1) the DASV should be determined based on certified yield point according to 5.3.2.

5.4. Strength reduction factors

This Subchapter interprets those permanent type (not cyclic) strength reduction factors, which result in reduction of stresses allowable according to 5.3.3.

The following formula should be used for considering the strength reduction effect:

\[ S^* = S_s \varphi \]  

Where

- \( S_s \) is the allowable stress determined as per 5.3.3.1 or 5.3.3.2.
- \( S^* \) reduced allowable stress
- \( \varphi \) strength reduction factor \( \leq 1 \)

Each such effect should be corrected by strength reduction factor, which changes the strength properties of the material in unfavorable direction, and which has not been considered during the measurements grounding the consideration of material properties. The following effects should be regarded as such:

a) Heat introduction entailed by repair welding,
b) Damages, working and other mechanical effects.

In the above cases the \( \phi \) factor should be determined by individual technical justification by considering the service manual and material testing documents.

5.4.1. **Welded joints**

Strength reduction factor calculation of welded joints should be performed with the following formula:

\[
\phi = \phi_A \phi_w
\]

Where the factors of the product should be calculated according to 5.4.1.1 and 5.4.1.2.

5.4.1.1. **Contraction**

In case of those local contractions, which are caused by, for example the excessive taking off of not through wall welds or weld surface:

\[
\phi_A = A^*/A
\]

Where:

- \( A^* \) Actual least cross-section
- \( A \) Nominal cross-section

If the stress analysis of the weld and its environment is carried out by finite element model accurately following the geometry and material properties, then \( \phi = 1 \).

For welded joints in the calculation of the value of Ss from the strength properties of the weld and the base metal the one resulting in the least allowable stress should be selected.

5.4.1.2. **Butt, inclined and T welds**

Depending on the scope of weld inspections performed during manufacturing or the inservice, non-destructive examinations the value of \( \phi_w \) should be determined according to table 4.5 of PNAE\(^1\) (see Table 4).
Table 1 Values of strength reduction factors of welded joints

<table>
<thead>
<tr>
<th>Scope of X-ray or ultrasonic testing, %</th>
<th>Maximum value of $\phi_w$ strength reduction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1.0</td>
</tr>
<tr>
<td>50</td>
<td>0.9</td>
</tr>
<tr>
<td>25</td>
<td>0.85</td>
</tr>
<tr>
<td>At least 10</td>
<td>0.8</td>
</tr>
</tbody>
</table>

5.4.2. Repair requirements of welds

In case of structural elements repaired after commissioning due to the fact of repair the application of strength reduction factors is not necessary for the determination of allowable stresses, if the requirements of Subsection IWA-4000 are met, or it may be justified that the repair has taken place according to requirements equivalent to the prescriptions of IWA-4000.

If the above justification is not possible then the strength reduction effect of the repair should be considered. The considerations on the effect of repair should be justified in the Strength Analysis Report. If technical estimation has been made then the potential consequences of estimation error should be analyzed.
6. **FATIGUE ANALYSIS**

6.1. **Definitions**

6.1.1. *Fatigue stress amplitude*

Symbol according to ASME: $S_{alt}$

6.1.1.1. Class 1 components

The fatigue stress amplitude should be determined from reciprocating operating loads by considering NB-3216, NB-3222.4 and the respective component-specific prescriptions.

6.1.1.2. Class 2 components

The fatigue stress amplitude should be determined from reciprocating operating loads by considering ASME BPVC Section III Appendix XIV-1220 and the respective component-specific prescriptions.

6.1.1.3. FSRF factors

For the determination of FSRF factors as defined in the ASME the point 6.5 should also be considered.

6.1.2. *Cumulative usage factor*

Symbol according to ASME: CUF

Its calculation formula:

$$CUF = \Sigma U_i F_{ei}$$  \(2\)

Where:

$U_i$ usage factor calculated for the load pair $i^\wedge$ according to the ASME.

The fatigue curve to be taken during the calculation is addressed in 6.4.

[^] Load pairs should be taken according the below subarticles:
Class 1: NB-3222.4(e)(5) or component specific prescriptions
Class 2: XIV-1221.3(e) or component specific prescriptions
F_{eni} \quad \text{environmental effect factor for load pair i as per point 6.6.}

6.2. **Designation of locations to be analyzed**

The basis for the scope of fatigue verification should be taken from the Annex of Guideline 1.26 or the locations indicated in the ageing management program of the licensee as approved by the authority. Beyond that those locations should also be examined, where the highest peak stress has been calculated for the given structural element during the strength analysis\(^A\).

6.3. **Allowed lifetime usage criteria**

It is acceptable from the aspect of location designated for fatigue analysis, if the cumulative usage factor (CUF) calculated as per 6.1 is less than or equal to 1 for each location of the structure. If the value is exceeded than one of the following opportunities should be implemented so as to achieve acceptance:

a) Justification of acceptability as per ASME BPVC Section XI Appendix L (see point 6.3.1)

b) Elaboration and implementation of fatigue-monitoring program for the given location

c) Implementation of such operational measure or modification that ensures the meeting of condition CUF \leq 1

6.3.1. **Justification of acceptability as per ASME BPVC Section XI IWB-3740, Appendix L**

If the permissibility of the design lifetime cannot be justified as per the conditions of Article L-2000, then it is acceptable for the service life extension application to apply the Article L-3000 of the mentioned Appendix. In the application of the referred article, however, the following supplementary analyses are necessary:

\(^A\) Definitions: Class 1: NB-3222.4 (b), Class 2: Appendix XIII-1123-(k)
a) Justification of that the size ratio 6 applied at the crack means conservative assumption in respect to the given location.

b) Also the environmental effect of the contacting medium should be considered when taking the crack propagation rate.

The Article L-3000 should not be used for modification license application.

6.3.2. Fatigue monitoring program

In the fatigue monitoring program related to the given location the licensee should describe the in-service inspections wished to be applied, which ensure the timely detection of the potentially occurring cracks. The safety risks of crack initiation should also be analyzed if the inspection period is such long that the occurrence of a crack exceeding ¾ of wall thickness could not be excluded.

If the inspection of the given location is not prescribed by the licensee’s in-service material testing program, then the fatigue monitoring program is enough to be launched from that time, from which the condition CUF ≤ 1 is not met.

6.4. Allowable stress amplitudes in the function of cycle number

The allowable fatigue stress amplitude should be determined as the function of cycle number (hereinafter referred to as fatigue curves) as specified in this chapter.

6.4.1. Steps of determination

6.4.1.1. Design fatigue curve according to ASME

The material specified according to its certificate should be classified into one of the categories specified for design fatigue curves in ASME BPVC Section III Appendix I. The fatigue curve to be used should be identified according to the given category also considering the validity conditions given for the curve. If more curves are possible to be applied for the material, then the following subarticles should be considered:

Class 1: NB-3222.4 (e)(3)

Class 2: XIV-1221.3 (c)

Instead of ASME fatigue curves for carbon, low alloyed and austenite steels
also the fatigue curves of the US NRC RG 1.207\(^3\) can be taken, after classification into the appropriate steel types. The curves shown in Figures 2, 3 and 4 can be applied accordingly.

6.4.1.2. Design fatigue curve according to PNAE

Taking the material property specification into account according to the certified material specification the licensee should determine the allowable fatigue curve for the material according to PNAE. When applying the formulas specified in the PNAE the safety factors should be taken as \(n_\sigma = 2\) and \(n_N = 10\). By considering the specified validity limits the curves given in Figures 5.5 – 5.10 may also be used.

6.4.1.3. Fatigue curve of welded joints

In the analysis of welded joints the common lower bound of the curves specified for the base metal and the weld metal should be used both at 6.4.1.1 and 6.4.1.2.

6.4.1.4. Lower bound curves

The stress amplitude allowed for the given cycle number should not exceed the value as per the lower bound curve determined according to 6.4.1.1, 6.4.1.2 and 6.4.1.3.

6.4.2. Certification requirements

Identical to the requisites described in Chapter 5.

6.5. Fatigue strength reduction factor (FSRF)

6.5.1. Definition

ASME Class 1: NB-3213.17
ASME Class 2: XIII-1123(q)

“Local structural discontinuity” appearing in the above ASME definitions relates to the changes in geometry and material properties, if it is also extended to welded joints (see WRCB 432\(^4\) Appendix 3).

In general the fatigue strength reduction effect consists of the production of the below factors:
FSRF = SCF * FSRFM * FSRFNDE  \hspace{1cm} (3)

Where:

SCF \hspace{1cm} \text{theoretical stress concentration factor taking account of geometry and material discontinuity (see WRCB 432 Appendix 3).}

FSRFM \hspace{1cm} \text{factor expressing the local change of material quality in the weld and heat affected zone, which depends on the weld technology and heat treatment applied}

FSRFNDE \hspace{1cm} \text{factor depending on the method applied for pre-service and inservice non-destructive inspection of the weld}

The FSRF factor, originating from its interpretation, should not be considered in the calculation of “Ke” factor applied in the simplified elastic-plastic analysis performed according to the component-specific subarticles of ASME (see in details in WRCB-432).

The fatigue strength reduction factor can be calculated by the methods specified therein. Other calculation methods documented in details may also be applied, if they are not in contradiction with ASME limitations for the given component.

6.5.1.1. Determination of FSRF if stress concentration factor is known

In case of application of the results of a finite element model precisely describing the local change of geometry and material properties in a given environment of the SE the SCF factor appearing in formula (3) have been taken into account, thus SCF = 1 may be taken.

The SCF may also be specified by analytic formulas of design ids (for example:1,5,6), within the validity domain of the given formula. Correctness of the applied formulas should be justified in the strength calculation.

Other members of formula (3) can be calculated as follows:

FSRFM = 1 / ϕs  \hspace{1cm} (4)

Where ϕs is the material quality factor of welded joints according to PNAE:

ϕs = 1 without weld, in homogeneous material, or

ϕs = value given in Table 5.8. or 5.9 of the PNAE.
Factor depending on the scope of non-destructive testing:

\[ \text{FSRF}_{\text{NDE}} = \frac{1}{\varphi_w} \quad (5) \]

Where \( \varphi_w \) is the examination quality factor of welded joints according to PNAE:

\( \varphi_w = 1 \) without weld, in homogeneous material, or
\( \varphi_w = \) value given in Table 4.5 of the PNAE.

6.5.1.2. Determination of FSRF based on weld quality

The FSRF factor may be determined for welds without calculating the SCF according to the WRCB-432 method referred to in 6.5.1. Exceptions are the piping analyses as per NB-, NC-3650.

6.5.1.2.1. FSRF factors of Class 1 piping welds

For welds of piping components, the analysis of which should take place as per NB-3650, the stress concentration is taken into account by the stress indices applied in the formulas. Thus the FSRF can be calculated according to 6.5.1.1 by taking SCF=1.

6.5.1.2.2. FSRF factors of Class 2 piping welds

For welds of piping components, the analysis of which should take place as per NC-3650, the “i” stress intensification factor interpreted as per NC-3673.2 takes account of stress concentration. Thus the FSRF can be calculated according to 6.5.1.1 by taking SCF=1.

6.6. Consideration of environmental effects \( (F_{\text{EN}}) \)

The \( F_{\text{EN}} \) environmental effect factor appeared in 6.1.2 takes account of the cyclic stress corrosion effect of the medium contacting the pressure retaining wall and increasing damage (reducing the lifetime).

Its definition:

\[ F_{\text{EN}} = \frac{N_{\text{air},RT}}{N_{\text{water}}} \]

where:

\( N_{\text{air},RT} \) Fatigue cycle number in air, at room temperature
\( N_{\text{water}} \) Fatigue cycle number in water, at operating temperature
Its determination should be performed by considering the NRC RG 1.207\textsuperscript{7}, as specified below.

The stress corrosion effect may be classified into 3 main groups:

a) The damage is governed by the fatigue damage mechanism induced by the cyclic stress changes. Locations contacting only dry (non-condensing) air are in this group.

b) The damage, besides the cyclic stress change, is also accelerated by the corrosive effect of the medium contacting the surface. Pressure retaining surfaces contacting the primary or secondary circuit water are in this group, where significant concentration increase of corrosive agents is not expected.

c) The damage is governed by the corrosion effect, compared to which the cyclic stress change is not significant or negligible. Such locations are for example the corrosion occurring on steam generator heat exchanger tubes or on external surfaces affected by leakage.

The Fen factor formulas given herein relate to group b).

For group a): Fen = 1

For the group 3 the lifetime prediction is so unreliable that they should not be taken into account for decisions safety measures. Reliable information may be obtained from inservice inspection.

6.6.1. Interpretation of the factors considered

The factors considered for the calculation and listed in 6.6.1.1 - 6.6.1.4 may be interpreted in two approaches:

a) The exact change of the factors during the service life is not known, only the extreme values are available. The simplified calculation procedure describe herein relates to this case.

b) Time dependence of the factors is known. In this case the less conservative calculation methods given in document EPRI MRP-47\textsuperscript{8} can be applied.

6.6.1.1. Sulfur content

Sulfur content of steel in %. Symbol: S

The highest value allowed for the steel according to standard can be
applied.

6.6.1.2. Temperature

The temperature of the steel during the service cycle in °C. Symbol: T.

Maximum value during the service cycle is the basis for simplified calculation.

6.6.1.3. Oxygen content

Oxygen content solved in the medium. Symbol: DO

The below extreme value during the service cycle is the basis for simplified calculation.

a) Maximum value for carbon steels and low alloyed steels

b) Minimum value for austenite steel

6.6.1.4. Load change rate

Strain change rate caused by load change is %/s. Symbol: ε’

Basis strain can be calculated by the below formula for the simplified calculation:

$$\varepsilon' = 100 \frac{\Delta \sigma}{(\Delta t \ E)}$$

where:

$\Delta \sigma$ the entire stress change domain under the cycle [MPa]

$\Delta t$ time spent between the occurrence of stress extreme values [s]. If one of the stress extreme values is in the steady state, then 90% settling time for the stress should be considered.

E reference modulus of elasticity pertaining to the fatigue curve [MPa]

As conservative estimate the following value can be used every time $\varepsilon' = 10^{-5} \%$/s.

6.6.2. Carbon and low alloyed steels

The fatigue accelerator environmental effect factor can be calculated by the below formula of NUREG/CR-6909, referred to in the US NRC RG 1.207.
6.6.2.1. Carbon steels

\[ F_{en} = \exp(0.632 - 0.101S^* T^* O^* \varepsilon^*) \]

\[ F_{en} = 1 \quad \text{if } (\varepsilon_a \leq 0.07\%) \]

where:

\( \varepsilon_a \) strain amplitude of the given cycle (half of the variation domain)

6.6.2.2. Low alloyed steels

\[ F_{en} = \exp(0.702 - 0.101 S^* T^* O^* \varepsilon^*) \]

\[ F_{en} = 1 \quad \text{if } (\varepsilon_a \leq 0.07\%) \]

where:

\( \varepsilon_a \) strain amplitude of the given cycle (half of the variation domain)

6.6.2.3. Interpretation of formulas related to carbon and low alloyed steels

**Sulfur content factor:**

\( S^* = 0.001 \quad (S \leq 0.001\%) \)

\( S^* = S \quad (0.001\% < S \leq 0.015\%) \)

\( S^* = 0.015 \quad (S > 0.015\%) \)

**Temperature factor:**

\( T^* = 0 \quad (T < 150^\circ C) \)

\( T^* = T - 150 \quad (150 \leq T \leq 350^\circ C) \)

**Oxygen content factor:**

\( O^* = 0 \quad (DO < 0.04 \text{ ppm}) \)

\( O^* = \ln(DO/0.04) \quad (0.04 \text{ ppm} \leq DO \leq 0.5 \text{ ppm}) \)

\( O^* = \ln(12.5) \quad (DO > 0.5 \text{ ppm}) \)
Strain rate factor:
\[ \varepsilon^* = 0 \quad (\varepsilon' > 1\%/s) \]
\[ \varepsilon^* = \ln(\varepsilon') \quad (0.001 \leq \varepsilon' \leq 1\%/s) \]
\[ \varepsilon^* = \ln(0.001) \quad (\varepsilon' < 0.001 \%/s) \]

6.6.3. **Austenite steels**

The fatigue accelerator environmental effect factors can be calculated by the below formula of NUREG/CR-6909, referred to in the US NRC RG 1.207:

\[ F_{en} = \exp(0.734 - T^* O^* \varepsilon^*) \]

\[ F_{en} = 1 \quad \text{if} \quad (\varepsilon_a \leq 0.10 \%) \]

where:
\[ \varepsilon_a \] strain amplitude of the given cycle (half of the variation domain)

6.6.3.1. **Interpretation of formula related to austenite steels**

Temperature factor:
\[ T^* = 0 \quad (T < 150^\circ\text{C}) \]
\[ T^* = (T-150)/175 \quad (150 \leq T < 325^\circ\text{C}) \]
\[ T^* = 1 \quad (T \geq 325^\circ\text{C}) \]

Oxygen content factor:
\[ O^* = 0.281 \]

Strain rate factor:
\[ \varepsilon^* = 0 \quad (\varepsilon' > 0.4\%/\text{sec}) \]
\[ \varepsilon^* = \ln(\varepsilon'/0.4) \quad (0.0004 \leq \varepsilon' \leq 0.4\%/\text{sec}) \]
\[ \varepsilon^* = \ln(0.0004/0.4) \quad (\varepsilon' < 0.0004\%/\text{sec}) \]
7. **JUSTIFICATION OF PROTECTION AGAINST NON-DUCTILE FRACTURE**

Justification of protection against non-ductile fracture is recommended to be performed for Class 1 and Class 2 operating equipment in scope and by methods as specified in this chapter.

The reactor pressure vessel is exception from the effect of this chapter, the evaluation of which is dealt with in Guidelines 3.17 and 3.18.

Evaluation as per Guidelines 3.17 and 3.18 is also recommended for other Class 1 and Class 2 components, with the supplementation of the chapter.

7.1. **Exceptions**

Justification of protection against non-ductile fracture can be omitted in the below cases.

7.1.1. **Class 1 components**

(1) Such material, the nominal cross-section thickness is 16 mm or less, where the thicknesses should be taken as specified in the below (a)-(e) points:

(a) for pumps and valves the largest nominal wall thickness of connected piping should be used;

(b) for vessels and tanks the nominal thickness of the shell or head should be used, as appropriate;

(c) for nozzles welded to vessels or for extensions the lower vessel shell thickness should be used to which the item is welded, or the maximum radial thickness of the item should be used but the internal shell butt weld should be excluded;

(d) for flat heads, pipe plates or flanges the connected maximum shell thickness of the butt welded part used be used.

(e) for those joined valves, at which the piping is fixed to the vessel or to one of its nozzles, the largest nominal thickness of pipe connections should be used.

(2) Bolted joints including bolts, nuts and stud bolts with 25 mm or less
Strength analysis of operating pressure retaining components

nominal dimension.

(3) Rods for which the nominal cross-sectional area is 645 mm$^2$ or less.

(4) Pipes, pipelines, valves and pumps of all material thickness where the nominal pipe diameter is 152 mm or less.

(5) Material of pumps and valves, where the nominal wall diameter of all pipe connection is 16 mm or less.

(6) Austenite stainless steels.

(7) Color metals.

7.1.2.  Class 2 components

(1) Such material, the nominal cross-section thickness is 16 mm or less, where the thicknesses should be taken as specified in the below (a)-(e) points:

(a) for pumps and valves the largest nominal wall thickness of connected piping should be used;

(b) for vessels and tanks the nominal thickness of the shell or head should be used, as appropriate;

(c) for nozzles welded to vessels or for extensions the lower vessel shell thickness should be used to which the item is welded, or the maximum radial thickness of the item should be used but the internal shell butt weld should be excluded;

(d) for flat heads, pipe plates or flanges the connected maximum shell thickness of the butt welded part used be used.

(e) for those joined valves, at which the piping is fixed to the vessel or to one of its nozzles, the largest nominal thickness of pipe connections should be used.

(2) Bolted joints including bolts, nuts and stud bolts with 25 mm or less nominal dimension.

(3) Rods for which the nominal cross-sectional area is 645 mm$^2$ or less.

(4) Pipes, pipelines, valves and pumps of entire material thickness where the nominal pipe diameter is 152.4 mm or less.

(5) Material of pumps and valves, where the nominal wall diameter of all
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pipe connection is 16 mm or less.

(6) Austenite stainless steels.

(7) Color metals.

(8) Material of those welded parts where the Lowest Service Temperature reaches 66°C.

7.2. Ferrite steel pressure retaining components

7.2.1. Requirements for justification of brittle-fracture

Protection against non-ductile fracture is ensured by the following two conditions:

1. Certified impact energy test performed for the component, which justify the value of $T_{ko}$ transition temperature according to Annex 5 of PNAE 2.

2. Brittle fracture analysis with postulated crack sizes according to Guidelines 3.17, 3.18 and to the recommendations of this chapter. For class 2 components the analysis should be performed only if the impact energy requirements are not met at the lowest service metal temperature or below.

7.2.2. Exceptions from the analysis

Beyond the list of point 7.1 brittle-fracture analysis should not be performed in the below cases:

1. if the yield point of the material of the structural element (including welded joints) at 20°C is less than 300 MPa, and the thickness of the structural element is less than 25 mm.

2. if the wall thickness of the analyzed structural elements (s, mm) meets the following conditions:

   \[ s < 8000 \left( \frac{K_{ic1}}{R_{p_{0.2}}} \right)^2 \]

   where:

   $K_{ic1}$ is the material specific fracture toughness as per PNAE 5.8.3, calculated according to formulas given for 1-NUE normal service conditions at the lowest service temperature calculated at $T_k$ temperature taken at the end of the lifetime [MPa m$^{1/2}$]
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\[ R_{p_{0.2}}^T \] yield point taken at the lowest service temperature [MPa]

Cladding should not be taken into account in the wall thickness.

7.2.3. Impact energy requirements for Class 2 components

The impact energy test results of three specimens made of the structural element should comply with the requirements of Table 2 altogether or one-by-one.

**Table 2: Impact energy requirements for Class-2 pressure retaining components**

<table>
<thead>
<tr>
<th>Nominal wall thickness (largest connected pipe wall thickness), mm</th>
<th>Average impact energy (from 3 tests), J</th>
<th>Minimum value of impact energy (from 3 test), J</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 16 )</td>
<td>No examination necessary</td>
<td>No examination necessary</td>
</tr>
<tr>
<td>( &gt;16 ) \ and ( \leq 25 )</td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td>( &gt;25 ) \ and ( \leq 38 )</td>
<td>34</td>
<td>27</td>
</tr>
<tr>
<td>( &gt;38 ) \ and ( \leq 64 )</td>
<td>48</td>
<td>41</td>
</tr>
<tr>
<td>( &gt;64 )</td>
<td>61</td>
<td>54</td>
</tr>
</tbody>
</table>

The table is valid: yield point \( \leq 380 \) MPa

In case of materials of higher yield point the NF-2330 prescriptions can be used.

7.2.4. Fracture toughness as function of temperature

Temperature dependence of fracture toughness should be determined for material-specific curves according to 5.8.3 of PNAE, based on formulas specified for 3-ASZ accident states. The \( T_k \) transition temperature values should be calculated with the below formula

\[ T_k = T_{ko} + \Delta T_T + \Delta T_N \]

Where:
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\[ T_{ko} \text{ Initial, pre-service transition temperature value, which is certified according to 7.2.1 for the examined component.} \]

\[ \Delta T_T \text{ Transition temperature shift due to ageing effect} \]

\[ \Delta T_N = 20 \text{ CUF Transition temperature shift due to cycle loads induced ageing} \]

The \( T_{ko} \) and \( \Delta T_T \) values can be taken from table 5.11 of PNAE.

7.2.5.  Safety factors

The following safety factors should be applied when evaluating the criteria as per formula (1) of section 3.1.5 of Guideline 3.18.

7.2.5.1. A and B service load levels

According to ASME the following safety factors should be applied for Level A and B loads:

\[ n_{k1} = 2 \quad n_{k2} = 1 \]

7.2.5.2. Pressure test

For hydrostatic test the following safety factors should be applied:

\[ n_{k1} = 1.5 \quad n_{k2} = 1 \]

7.2.5.3. C and D service load levels and unanticipated operating occurrences

The following safety factors should be applied for loads classified as Level C and D according to ASME:

\[ n_{k1} = 1 \quad n_{k2} = 1 \]

7.2.6.  Residual stresses

7.2.6.1. Cladding

In the calculation of stress occurring due to the difference if thermal expansion of the cladding and the base metal the temperature expressing the balanced state should be taken as equal to the service temperature.

7.2.6.2. Welds

Residual stress of the welds should be considered only for unanticipated operating occurrences and loads classified as Level C and D. The residual
stress distribution along the wall thickness, if there is no other justified data for post-welding thermal treatment state, should be calculated by the formula of Guideline 3.18 for $\sigma_R$.

7.3. **Bolts**

In case of bolts the justification of protection against non-ductile fracture makes the verification of impact energy requirements necessary.

7.3.1. **Exceptions**

No impact energy test should be made for bolt diameters of less than 25 mm.

7.3.2. **Impact test requirements**

The protection against brittle fracture for bolts of nominal diameters exceeding 25 mm can be justified by Charpy V-notch impact energy tests as per NB-2332, NC-2332 according to Table 3. The measurements should be performed at or under the lowest temperature, where the pre-service tightening of the bolt is done.

<table>
<thead>
<tr>
<th>Nominal bolt diameter mm</th>
<th>Lowest allowable impact energy $C_v$ (J)</th>
<th>Lowest allowable specific impact energy* measured on U-notch specimen $K_{CU}$ (J/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 25 and 102</td>
<td>54</td>
<td>80</td>
</tr>
<tr>
<td>Above 102</td>
<td>61</td>
<td>100</td>
</tr>
</tbody>
</table>

* The criteria can be applied if the specific impact energy value $K_{CU}$ (J/cm²) related to U-notch specimen according to GOSZT standard effective at the licensing of the component is given for the material of the bolt.
7.4. Supports

In case of Class 1 and 2 components support the justification of protection against brittle fracture makes the verification of impact energy requirements necessary.

7.4.1. Exceptions

Justification of protection against brittle-fracture can be omitted in the below cases:

(1) Such material, the nominal cross-section thickness is 16 mm or less.

(2) Bolted joints including bolts, nuts and stud bolts with 25 mm or less nominal dimension.

(3) Rods for which the nominal cross-sectional area is 645 mm² or less.

(4) Supports of such pipes, where the nominal wall diameter of all pipe connection is 16 mm or less.

(5) Austenite stainless steels.

(6) Color metals.

(7) Those pipe support elements, where the maximum stress does not reach 41 tensile stress, or is below that.

(8) Those rolled structural elements, where the thickness of the flange is 16 mm or less.

(9) Class 1,2 supports listed in the Table NF-2311(b)-1, where the wall thickness is 64 mm or less, and the Lowest Service Temperature is 17°C higher than the values of the table.

(10) Material of those Class 2 and MC support structures, where the lowest Service Temperature reaches 66°.

(11) Material of those Class 2 support structures, where the lowest Service Temperature is above the allowable Minimum Design Temperature appeared in Figure NF-2311(b)-1.

7.4.2. Impact test requirements

For non bolt material of yield point less than 380 MPa the impact energy according to Tables 4 should be ensured at the minimum design
temperature of the support structure or below.

Table 4: Charpy Cv impact energy requirements for non bolt materials of support structures

<table>
<thead>
<tr>
<th>Nominal wall thickness, mm</th>
<th>Average impact energy (from 3 tests), J</th>
<th>Minimum value of impact energy (from 3 test), J</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>No examination necessary</td>
<td>No examination necessary</td>
</tr>
<tr>
<td>&gt;16 and ≤ 25</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>&gt;25</td>
<td>34</td>
<td>24</td>
</tr>
</tbody>
</table>

In case of material of higher yield point the prescriptions of NF-2330 should be applied.

For bolt materials the values of table Table 3 should be the basis.
8. IMPLEMENTATION OF ANALYSIS

8.1. Designer responsibility

Strength analysis may be performed by organization or contractor as per Guideline 3.3.

The designer responsibility is outlined in the below sections.

8.1.1. Verification criteria

8.1.1.1. Selection

The selection of all those criteria, which are relevant for the safety of the pressure retaining component being the subject of the analysis is the responsibility of the designer, within the designated nuclear standard system.

8.1.1.2. Constructional requirement system

The licensee should designate the constructional requirement system pertaining to the allowable limit appearing in the selected safety criteria. For operating pressure retaining system those elements of the requirement system should be selected and documented, the fulfillment of which, according to designer’s judgment, needs actions falling outside the effect of this guideline.

8.1.2. Composition of design specification

The licensee should collect and, in methodized form, document all such data related to the system being the subject of the analysis, which are necessary for the justification of the verification criteria and the acceptance according to the corresponding constructional requirement system, also considering Guideline 3.3.

1 Most important items of constructional requirement system are detailed by section 1.1.1.
8.1.2.1. Stipulations for operating equipment
In respect to operating equipment the licensee should verify the structural element specific validity of the used data, considering the changes documented during maintenance, repair and replacement implemented for the given structural element. The licensee is responsible for the actual and real content of the used data.

8.1.3. Evaluation of results
In the course of justification of acceptance according to safety criteria the potential errors if the used data, calculation methods and models should be taken into account.

8.2. Justification of analysis reliability

8.2.1. Selection of calculation formulas, methods and models
The major aspect of selection is that the error of the result obtained by calculation for the quantity in the acceptance criteria should be within an allowable limit. Thus in this sense the selection of the correct calculation method depends on that criteria, for the justification of which it should be applied. Thus for example a finite element shell model (in some cases) may be applicable to evaluate limitations related to membrane and bending stresses, but for the peak stress calculation necessary for fatigue calculation is not (alone).

8.2.2. Allowable error of calculation
The upper limit of allowable calculation error should be set such a way that it should not have influencing role concerning the decision on justification of safety criteria. Thus for example a calculation error estimated to be 10% can be regarded as too much, if the upper limit of the safety criteria is approached to 95%.

8.2.3. Calculation error categories
Basically two types of error category are differentiated based on the source of the error. Errors belonging to the not allowable category should be excluded by the procedures of the quality assurance system of the designer, allowable value cannot be interpreted.
The other category is of the calculation errors that can intentionally be undertaken and that can be taken into account by (over)estimation with good approximation during the evaluation of the safety criteria.

Uncertainties in the mechanical and thermal material properties applied for the calculation are classified as calculation errors, if they have been taken as specified by this guideline.

8.2.4. Non-allowable errors

8.2.4.1. Faulty or misinterpretation of safety criterion

There are safety criteria, mainly among the criteria related to Class 1 components, the evaluation of which, due to the complex nature of the concepts, the ASME does not provide unambiguous calculation instruction. Such is for example the classification of stress intensities (NB-3217).

Avoidance of this kind of error required design skills in understanding and application of ASME safety philosophy.

8.2.4.2. Faulty calculation results caused by error of the applied computer program or data transfer

Errors that have not been detected during the calculation process belong to this category, and which have taken place due to the errors of the computer program, data input or display. A proven method for the elimination of these errors is the parallel evaluation, which means the comparison of results of two analyses performed in parallel to but independently of each other. It is not requirement to perform the parallel analyses by different persons, but the tools used including those applied for data input and result display are different. The designer should ensure the method of data input verifications in the quality assurance system.

8.2.4.3. Faulty values among analysis input data

These are the analysis errors caused by the incorrectness of data collected from the documents used for compilation of analysis input deck. In several cases it could take place that illegible or even wrongly recorded data appear in the documents of operating components. The designer should ensure the method of elimination of this type of errors in the quality assurance system.
8.2.4.4. Using incorrect calculation methods

Detailed definition of errors of this category exceeds the opportunities of this guideline. The following errors belong to this category:

a) use of formulas inapplicable for the given case,

b) faulty treatment of singularities by finite element method,

c) generation of numeric oscillation in the calculation of time dependent temperature\(^9\) or displacement\(^10\) fields,

d) methodological errors that could be made in the elastic-plastic analyses.

Some portion of strength analysis documents submitted to the authority may be cited as good examples of the listed errors.

Exclusion of this type of errors requires high designer competence. The designer should take care of its exclusion in the quality assurance system.

8.2.5. Permissible errors

8.2.6. Application of approximate formulas

In several cases the analysis task may be resolved by analytic calculation formulas, by accepting that the formulas applied for the given case may not provide the theoretically correct solution (satisfying the respective differential equations).

Such is for example the Appendix A-3000 of the ASME XI, which provides formulas for the calculation of K\(_I\) stress intensity factor. The calculation method specified provides theoretically correct solution for SE of plane walls, but the article A-3100 permits to apply it for cylindrical shells irrespective of the diameter/wall thickness ratio.

When approximate formulas are applied in the evaluation of the safety criteria, the calculation errors should not be taken into account in the following cases:

a) If the calculation method is accepted by the ASME for the given case (as the above example).

b) It can be justified that the result of the formulas applied is conservative for the given case regarding the evaluation of the criteria.

In cases that cannot be placed in the above categories the licensee should
provide estimation for the upper limit of the error made by the application of the approximate formulas. The error determined this way should be taken into account in the justification of meeting the safety criteria.

8.2.7. **Finite element model approximation error**

In the application of variation methods using approximate functions the approximation error is a naturally involved attendant of the calculation results. The licensee should take into account this error in the evaluation of the safety criterion. The method applied for the estimation of the error should be described in the Strength Analysis Report.

Some examples of error estimation procedures:

a) Within the validity scope of convergence rules related to the given class of tasks, for the quantity appearing in the safety criterion to be evaluated, the approximation error may be estimated by using series of results obtained by gradual densification of the finite element mesh.

b) Justification of reliability of the finite element method may be performed by comparison to benchmark task of known results\(^2\). The reliability may be regarded as justified if the type of the element, the material model and the density of the finite element mesh in the finite element model used for the solution of the benchmark task is identical to the one wished to be applied in the model of the SE to be analyzed.

The approximation error should be taken into account in the evaluation of the safety criterion, if its estimated order is such that it may influence the acceptability in case of given criterion.

8.3. **Documentation**

The role of the Strength Analysis Report (SAR) is to justify the acceptability of the pressure retaining system, component or structural element being subject of the analysis, including the justification for fatigue and non-ductile fracture.

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\(^2\) Known solution of a benchmark task may be a result obtained by other calculation method or measurement.
8.3.1. **Reproducibility**

Guideline 3.3 specifies the requirements for the content of the SAR.

8.3.2. **Justification of validity**

In the SAR the licensee should describe the method of identification of all parameter (material properties and safety, stress concentration, strength reduction factors etc) applied in the calculation formulas of each safety criterion related to the examined location, by also justifying the validity conditions of applicability of the parameters. In case of analysis operating components, if the validity conditions of applicability of any parameter are violated, then it is possible to perform the justification by modifying the parameter in conservative direction, but for doing this detailed technical justification is necessary.

Justification of reliability of the analysis should be described according to the guidance of section 8.2.

8.3.3. **Specification of strength conditions limiting operation**

In the chapter “Limiting conditions of acceptability” of the SAR all those data and analysis results used for the justification of acceptability should be listed separately, which are taken into account during the operation\(^3\) of the structural element. At least but not exclusively the following should be detailed:

a) Design parameters

b) Limiting conditions of operation modes, in resolution to A, B, C, D service loads

c) Maintenance limiting conditions

d) Necessary inservice inspections

e) Necessary monitoring activities, strength analysis results necessary for elaboration of monitoring programs

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\(^3\) All such activity and event should be included under operation, which may affect the state of the SE.
f) Assigned identification of those structural elements, loads and safety
criteria, for which compliance with at least one of the safety criteria
could not have been justified.

8.3.4. Consideration of ASME content requirements

It is pre-condition of SAR acceptance that the design specification made by
considering of ASME Section III Division 1 Appendix B is available. Formal
requirements for the design specifications are detailed in Guideline 3.3. In preparation of the SAR also the requirements of Appendix C should
be considered.
9. FIGURES

Figure 1: Differentiation of pressure retaining system components, designation of component boundaries and overview of the respective requirement system as per ASME code base

Figure 1: Fatigue curve of carbon steels according to US NRC RG 1.207, in air

Figure 2: Fatigue curve of low alloyed steels according to US NRC RG 1.207, in air

Figure 3: Fatigue curve of austenite steels according to US NRC RG 1.207, in air
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**Figure 4:** Differentiation of pressure retaining system components, designation of component boundaries and overview of the respective requirement system as per ASME code base.
Fatigue curve with $E=207$ GPa modulus of elasticity

Figure 5: Fatigue curve of carbon steels according to US NRC RG 1.207, in air
Fatigue curve with $E=207$ GPa modulus of elasticity

Figure 6: Fatigue curve of low alloyed steels according to US NRC RG 1.207, in air
Fatigue curve with $E=195$ GPa modulus of elasticity $t$

Figure 7: Fatigue curve of austenite steels according to US NRC RG 1.207, in air
10. REFERENCES

1. 2001 ASME Boiler and Pressure Vessel Code, Section II Part D, Section III. Division 1, Section XI.

2. PNAE G-7-002-86: Нормы расчета на прочность оборудования и трубопроводов атомных энергетических установок, 1990

3. US NRC RG 1.207 GUIDELINES FOR EVALUATING FATIGUE ANALYSES INCORPORATING THE LIFE REDUCTION OF METAL COMPONENTS DUE TO THE EFFECTS OF THE LIGHT-WATER REACTOR ENVIRONMENT FOR NEW REACTORS. March 2007


