

---

---

**Essential technical requirements for  
mechanical components and metallic  
structures foreseen for Generation IV  
nuclear reactors**

*Exigences techniques essentielles pour les composants mécaniques et  
les structures métalliques prévus pour les réacteurs nucléaires de la  
quatrième génération*

STANDARDSISO.COM : Click to view the full PDF of ISO 18229:2018



STANDARDSISO.COM : Click to view the full PDF of ISO 18229:2018



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2018

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva, Switzerland  
Tel. +41 22 749 01 11  
Fax +41 22 749 09 47  
copyright@iso.org  
www.iso.org

Published in Switzerland

# Contents

	Page
Foreword .....	v
Introduction .....	vi
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
<b>4 Units of measurements</b> .....	<b>4</b>
<b>5 Management system</b> .....	<b>4</b>
<b>6 Technical requirements</b> .....	<b>4</b>
6.1 General .....	4
6.2 Materials .....	4
6.2.1 General .....	4
6.2.2 Specification of materials .....	5
6.2.3 Material conformity declaration .....	7
6.3 Design .....	7
6.3.1 General .....	7
6.3.2 Damages .....	7
6.3.3 Considerations for operating conditions and load combinations .....	8
6.3.4 Criteria levels .....	9
6.3.5 Corrosion, erosion, erosion-corrosion, wear .....	11
6.3.6 Attachments .....	11
6.3.7 Sudden variation in the mechanical properties at junctions .....	11
6.3.8 Nuclear cleanliness requirements .....	11
6.3.9 Thermal ageing .....	12
6.3.10 Irradiation .....	12
6.3.11 Design methods .....	12
6.4 Fabrication .....	13
6.4.1 General .....	13
6.4.2 Identification of materials/parts .....	14
6.4.3 Preparation of parts .....	14
6.4.4 Welding .....	14
6.4.5 Forming and dimension tolerances .....	16
6.4.6 Cleaning .....	17
6.4.7 Heat treatment .....	17
6.5 Tests and examination methods .....	17
6.5.1 General .....	17
6.5.2 Methods .....	17
6.5.3 Procedures .....	17
6.5.4 Personnel qualification .....	18
6.6 Final inspection and testing .....	18
6.6.1 Final inspection .....	18
6.6.2 Final pressure test .....	18
6.7 Marking/labelling .....	18
<b>7 Documentation</b> .....	<b>19</b>
<b>8 Conformity assessment</b> .....	<b>19</b>
<b>Annex A (informative) Description of GEN IV reactors</b> .....	<b>20</b>
<b>Annex B (informative) Illustration of material selection for sodium fast reactor (SFR) components</b> .....	<b>21</b>
<b>Annex C (informative) Description of types of damage</b> .....	<b>22</b>
<b>Annex D (informative) Documentation</b> .....	<b>25</b>

STANDARDSISO.COM : Click to view the full PDF of ISO 18229:2018

## Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 6, *Reactor technology*.

## Introduction

GEN IV reactors' objectives are to meet reinforced requirements (compared to GEN II to III reactors) concerning safety and reliability and linked with design and fabrication of equipment:

- to excel in safety and reliability;
- to eliminate the need for offsite emergency response;
- to have a very low likelihood and degree of reactor core damage.

This is supported with the use of codes or standards with a proven history of supporting public safety.

The purpose of this document is not to replace these codes or standards but to identify the essential technical requirements which need to be addressed by the design and fabrication codes in order to allow to meet such safety requirements at the expected level for the GEN IV reactors.

It enables these standards to co-exist, providing an approach that can accommodate technical innovations, existing national frameworks and market needs.

STANDARDSISO.COM : Click to view the full PDF of ISO 18229:2018

# Essential technical requirements for mechanical components and metallic structures foreseen for Generation IV nuclear reactors

## 1 Scope

This document defines the essential technical requirements that are addressed in the process of design and construction of Generation IV (GEN IV) nuclear reactors. It does not address operation, maintenance and in-service inspection of reactors.

Six reactor concepts are considered for GEN IV: the sodium fast reactor, the lead fast reactor, the gas fast reactor, the very high temperature reactor, the supercritical water reactor and the molten salt reactor.

[Annex A](#) details the main characteristics for the different concepts.

The scope of application of this document is limited to mechanical components related to nuclear safety and to the prevention of the release of radioactive materials

- that are considered to be important in terms of nuclear safety and operability,
- that play a role in ensuring leaktightness, partitioning, guiding, securing and supporting, and
- that contain and/or are in contact with fluids (such as vessels, pumps, valves, pipes, bellows, box structures, heat exchangers, handling and driving mechanisms).

## 2 Normative references

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

ISO/IEC 17050-1, *Conformity assessment — Supplier's declaration of conformity — Part 1: General requirements*

## 3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

### 3.1 certification

third-party attestation related to products, processes, systems or persons

[SOURCE: ISO 17000:2004, 5.5 modified — notes deleted]

### 3.2 component

part of equipment which can be considered as an individual item

**3.3  
conformity**

fulfilment of specified requirements

**3.4  
contractor**

*supplier* (3.16) in a contractual situation

**3.5  
designer**

organization or individual that performs design of *components* (3.2) in compliance with a number of requirements, such as customer's needs, nuclear safety rules, national and international standards, good engineering practices

**3.6  
equipment specification**

document used to specify technical and quality assurance requirements of the equipment

Note 1 to entry: The equipment specification specifies in particular:

- scope;
- scope of supplies (such as description, safety classification, quality grade, seismicity);
- reference documents, together with details of their conditions of application, where necessary.

Note 2 to entry: The equipment specification and a set of supplementary reports (operating conditions report, limiting conditions definition report, interface reports, loading definition reports) contain all data required to check the design rules according to the specified criteria level. All these data are designated by the general term equipment specification.

Note 3 to entry: The equipment specification also addresses the design activities.

**3.7  
examination**

activity carried out by qualified personnel using qualified procedures to assess that given products, processes or services fulfil *conformity* (3.3)

**3.8  
inspector**

person in charge of verifying the compliance of the documentation issued by a *supplier* (3.16) against the technical attachments to the order

Note 1 to entry: The inspector is also the person in charge of verifying the correctness of certain fabrication phases to which he or she is called to attend.

Note 2 to entry: The inspector can or cannot be a member of the supplier's staff.

**3.9  
manufacturer**

legal entity responsible for final design, manufacturing, engineering, and for the construction of any *component* (3.2) of the nuclear reactor

Note 1 to entry: Beyond the scope of mechanical components and metallic structures, different entities are usually responsible for the functions of manufacturing, engineering and design. Sometimes, one entity could be responsible for more than one of the mentioned functions (e.g. design and engineering).

**3.10****operating organization**

legal entity having been duly authorized to implement and execute the operation of the nuclear installation

Note 1 to entry: In the subject field, the concept is usually designated by the term “Operator” beginning with capital letter.

**3.11****prime contractor**

legal entity granted that receives a major contract from the owner for providing a full provision of either the nuclear island and/or the balance of plant

**3.12****qualification**

proof of suitability of an individual, product, process, procedure or service to fulfil specified requirements

**3.13****regulation**

rules promulgated by a regulatory body in accordance with legal statutes or directives

**3.14****standard  
code**

document established and approved by a standard issuing body that provides for common and repeated use, mandatory requirements, guidelines or characteristics for activities or their results

Note 1 to entry: A code or standard can be approved by a safety authority, depending on the *regulations* (3.13) in a given country.

**3.15****subcontractor**

any *contractor* (3.4), except for a *prime contractor* (3.11), providing supplies and/or services through a contract passed with other project contractor or eventually the project management for specific items

Note 1 to entry: Some of these subcontractors will be explicitly named as *tubes manufacturer* (3.9), *plates manufacturer* (rolling mill), *forgings manufacturer* (forging mill), *pumps manufacturer*, *valves manufacturer*.

**3.16****supplier**

individual and legal entity (steelmaker, forging mill, pipemaker, foundry, etc.) responsible for the fabrication of products or parts on behalf of the *manufacturer* (3.9) or one *subcontractor* (3.15)

**3.17****surveillance agent**

person not subordinated to the *supplier* (3.16) concerned, commissioned to ensure that the *component* (3.2) is constructed and inspected in compliance with the documents attached to the orders placed with the supplier, with the present code and with the documents drawn up in application of the latter

**3.18****testing**

activity carried out to determine, by specific procedures, that one or more characteristic of a product, process or service fulfil *conformity* (3.3)

**3.19****inspection body**

organization that performs inspections on any granted-by-contract service or supply as provided for by *standards* (3.14) and is independent of the *manufacturer* (3.9), contracting party, owner or *operating organization* (3.10)

## 4 Units of measurements

Measurements shall be in SI units. Product standards that are available only in other units may be used. Other cases are to be adopted with appropriate and consistent conversion factors to avoid assembly/interface-related issues.

## 5 Management system

A management system shall be established and implemented that meets the requirements defined by the IAEA.

## 6 Technical requirements

### 6.1 General

The use of a code or standard for the design of a component ensures structural integrity against loads and combination of them, though some level of geometrical and functional damage can be present.

The user of a code or standard shall select the code/standard in adequacy with the component to be designed.

The adequacy shall be evaluated on:

- the type of components (component function, component classification);
- relevant operating conditions such as pressure, temperature, flow rate, chemical environment, sort and level of radiation;
- material;
- failure modes (include identification of possible loads and their combinations).

As standards or codes ensure consistency between the different steps of a component manufacturing (material, design, fabrication), it is recommended to use consistent set of standards or codes for the different steps of a component design.

If the code or standard does not fully cover the needs for design of the component, the user shall define the complementary requirements to apply and shall verify the consistency between the different requirements and the code.

In a reactor, it is possible to use different standards or codes for different components; nevertheless, it will lead to define additional requirements to provide rules for consistency between equipment in the same system built according to different standards or codes.

### 6.2 Materials

#### 6.2.1 General

Materials of pressure-bearing parts, materials for non-pressure bearing parts (e.g. supports and attachments) and welding consumables used for the manufacture of mechanical components shall be suitable for intended application and to other foreseeable but unintended conditions.

Choosing a material referred to in a code or standard does not automatically assume its suitability for use, as this is specifically dependent on the radiation field, physical and chemical environment (e.g. incompatibility of aluminium with a sodium environment).

An identification system shall be established and maintained for materials used in fabrication so that all materials can be traced to their origin. This includes the use of welding consumable.

[Annex B](#) gives some illustrations of material selections for the different projects.

### 6.2.2 Specification of materials

The material properties shall:

- a) be appropriate for all operating conditions that are reasonably foreseeable and for all test conditions:
  - in particular, they shall be sufficiently ductile and tough;
  - they shall be sufficiently chemically resistant to the fluid contained in the component;
  - they shall not be adversely affected at operating conditions (e.g. by ageing, creep, irradiation embrittlement);
- b) be suitable for the intended fabrication procedures;
- c) be compatible with NDT methods needed for fabrication and in service inspection issues (NDT and inspection feasibility are not only depending on the material selection, but material shall not be incompatible with the selected methods).

A way to select a material may be to use a material file. A material file might contain the following parts:

- a) Introduction
  - 1) Material specification (including chemical composition, grade)
  - 2) Codes and standards dealing with these parts or products
  - 3) Procurement specifications
  - 4) Industrial application and experience
- b) Physical properties
- c) Base metal and welded joints mechanical properties for design and analysis
  - 1) Justification of the applicability of the design rules for the specified usage conditions
  - 2) Basic mechanical properties
  - 3) Mechanical properties needed for the specified usage conditions
  - 4) Guaranty of the consistency between the properties of the final part laid-on the plant and the material properties used to design the component
- d) Manufacturing
  - 1) Industrial experience
  - 2) Metallurgy
- e) Fabrication
  - 1) Industrial experience
  - 2) Forming operation ability
- f) Welding
  - 1) Weldability
  - 2) Industrial experience for the welding procedure qualification

- 3) Industrial experience for the welding repair procedure qualification
- g) Capability to be inspected
- h) In service behaviour
- 1) Thermal ageing, corrosion, erosion-corrosion, irradiation

STANDARDSISO.COM : Click to view the full PDF of ISO 18229:2018

Once the material is selected, the way to procure it shall be described in a document (procurement specification). This specification shall include:

- a) Scope
- b) Melting process
- c) Chemical requirements
- d) Manufacture (including forming, surface treatments, heat treatments)
- e) Mechanical properties
- f) Surface examination — Surface defects
- g) Volumetric examination
- h) Removal of unacceptable areas
- i) Dimensional check
- j) Marking
- k) Cleanliness — Packaging — Transportation
- l) Test reports
- m) Acceptance criteria

### 6.2.3 Material conformity declaration

The component manufacturer shall take appropriate measures to ensure that materials used comply with the requirements of specifications permitted by the applicable standards. The manufacturer shall obtain material identification and linkability certification as required by the applicable material specification.

## 6.3 Design

### 6.3.1 General

The aim of design rules is to ensure that the components are mechanically resistant under the various mechanical loads and load combinations to which they could be exposed in specified operating conditions.

The damages shall be identified, taking into account the elements (e.g. safety classification, functionality of the components, operating conditions, component material) given by the equipment specification.

The adopted design standard might not cover other jeopardizing factors, such as erosion/corrosion, or radiation embrittlement. For this reason, the designer shall identify additional standards or measures to cope with these factors and apply their contents.

The design includes the identification of damages, the consideration of loads applied to the component, the definition of criteria to apply to the design, the design by itself, the fabrication of the component, the test and examinations needed to validate the fabrication and the establishment of the documentation.

### 6.3.2 Damages

The following is a list of the damages identified for the different types of reactors. A short definition of the damages is given in [Annex C](#). The design shall consider the following failure modes and specifically

address those listed in the table identifying the damages which are likely to occur for the different type of reactors:

- immediate excessive deformation;
- immediate plastic instability;
- time-dependent excessive deformation;
- time-dependent plastic instability;
- time-dependent fracture;
- elastic or elastoplastic instability;
- progressive deformation;
- fatigue (progressive cracking);
- creep fatigue;
- load controlled buckling;
- strain controlled buckling;
- time-dependent buckling;
- fast fracture.

### 6.3.3 Considerations for operating conditions and load combinations

During operation, a component may be subjected to a number of different operating conditions which are classified under four categories according to considerations on structural integrity and other relevant technical aspects associated with plant operation.

The operating conditions for each component are classified as follows:

- the first category operating conditions and the second category operating conditions are the conditions to which the component may be subjected in the course of normal operation, including normal operating incidents, basis events (including anticipated operational occurrences), start-up and shutdown;
- the third category operating conditions include design basis accident, emergency conditions, corresponding to very low probability of occurrence but which shall nonetheless be considered;
- the fourth category operating conditions, which are highly improbable but whose consequences on component are studied among others for safety reasons.

The testing conditions in which the component may be subjected in the course of post-fabrication test shall be classified under one of the three first categories defined above.

The list and classification of operating conditions shall be defined in the equipment specification and the credible combination of events shall be taken for structural integrity assessment.

There is a set of possible effects (pressures, forces, heat flux, irradiation, corrosion) corresponding to each operating condition. Some of these effects, which may produce mechanical work depending on the component deformation, are referred to as loads. Sets of simultaneous loads are referred to as loadings.

The loads constituting loadings include, but are not limited to, the following:

- internal and external pressures;

- the weight of the component and its contents, and the static and dynamic loads produced by liquids under each condition analysed;
- forces resulting from weight, thermal expansion, and pressure and dynamic loads which originate outside the zone studied and which are applied at its boundaries;
- loads resulting from earthquakes and vibrations, if any;
- reactions of supports;
- temperature effects, either constant or transient;
- wind;
- wind-borne missile;
- flood loads;
- forces resulting from non-free swelling in irradiation conditions.

### 6.3.4 Criteria levels

#### 6.3.4.1 General

The level of criteria to be met shall be defined in the equipment specification for each loading associated with an operating condition or set of operating conditions for each equipment.

To simplify the text, the following minimum criteria to be applied for the different situation categories will be identified as level A, B, C and D criteria with the following correspondence (see 6.3.3):

- level A criteria correspond to the first category operating conditions,
- level B criteria correspond to the second category operating conditions,
- level C criteria correspond to the third category operating conditions,
- level D criteria correspond to the fourth category operating conditions.

#### 6.3.4.2 Levels A and B criteria

The aim of levels A and B criteria is to protect the component against the following types of damage:

- immediate or time-dependent excessive deformation;
- immediate or time-dependent plastic instability;
- time-dependent fracture;
- elastic or elastoplastic instability, immediate or time-dependent;
- progressive deformation;
- creep fatigue;
- fatigue.

The respect of levels A and B criteria guarantees the level of safety required with regard to these types of damage throughout the life of the component, for operation as specified. It shall be met for the first and second category operating conditions.

### 6.3.4.3 Level C criteria

The aim of level C criteria is to protect the component against the following types of damages:

- immediate or time-dependent excessive deformation;
- immediate or time-dependent plastic instability;
- time-dependent fracture;
- elastic or elastoplastic instability, immediate or time-dependent.

When a component has been subjected to loadings which, while satisfying level C criteria, exceed level A and B criteria, it is possible that small levels of overall deformation could occur. Consequently, it could be necessary to inspect a component subjected to these types of loading before reusing it to ensure that its condition is satisfactory.

It is recalled that level C criteria do not require fatigue analyses and consequently, the number of stress cycles, which are only limited by level C criteria, should not exceed 10.

The criteria to be met for third category operating conditions shall be at least as severe as those of level C.

### 6.3.4.4 Level D criteria

#### 6.3.4.4.1 General

The aim of level D criteria is to protect the component against the following types of damages but with lower safety margins than those with level C criteria:

- immediate or time-dependent plastic instability;
- time-dependent fracture;
- elastic or elastoplastic instability, immediate or time-dependent.

It will not always be possible to return to service a component having been subjected to a loading only limited by level D criteria.

The criteria to be met for fourth category operating conditions shall be at least as severe as those of level D.

**6.3.4.4.2** When allocating an event to a situation category, the operating conditions of the equipment shall not be mixed with the operating conditions of the plant. For example, operating under accidental conditions may be a normal operating situation for some specific equipment. Still, this does not mean that all A and B criteria shall apply to this equipment if, for example, the mission time for this equipment under these conditions is short and if these conditions do not induce certain phenomena such as fatigue.

**6.3.4.4.3** For all criteria levels, margins shall be defined. Design margins on material properties and types of design (including appropriate fabrication details) shall address foreseeable failure modes under specified loading conditions.

Material properties to be taken into account, where applicable, include:

- yield strength;
- tensile strength;
- time-dependent strength, i.e. creep strength;
- fatigue data;
- modulus of elasticity;

- strain;
- impact strength;
- fracture toughness.

**6.3.4.4.4** The method described in [6.3.3](#) and [6.3.4](#) is related to the design deterministic approach. Classification of events in category is an input for the design. It should be done in link with safety considerations such as included in IAEA requirement SSR-2/1<sup>[5]</sup>.

The following parts give some warning regarding failure modes not necessarily addressed by design and construction codes in general.

### **6.3.5 Corrosion, erosion, erosion-corrosion, wear**

If the component is subject to in-service thinning resulting from surface corrosion (erosion, erosion-corrosion, abrasion and wear) or under the effects of products handled or environmental conditions, a certain additional thickness shall be provided. This thickness, which shall compensate for thinning during the specified service life of the component, shall be added to the minimum thickness determined on the basis of design the rules set. This additional thickness need not be the same for all areas of the component if different rates of attack are expected for various areas.

### **6.3.6 Attachments**

Plugs, brackets, hooks, stiffeners pads and other attachments may be welded, bolted or screwed to the internal or external component walls. The effects of attachments on thermal stresses, on stress concentrations and their possible deformation limiting effects on pressure-retaining parts shall be taken into account when checking that the design requirements are met.

A fatigue analysis of the zones concerned by these attachments is essential and shall be carried out in accordance with the rules of the selected code or standard.

Insofar as possible, attachments intended for assembly shall be ground flush after installation of the component.

### **6.3.7 Sudden variation in the mechanical properties at junctions**

Special attention shall be paid to the design, analysis, manufacture and controllability of joints, where assembled by welding or compression, between materials which do not have the same mechanical properties. These properties comprise expansion, creep rate and ductility, and fatigue strength at high temperature.

Heterogeneous welded joints between an austenitic steel or a nickel-base-alloy and a ferritic steel should, wherever possible, be avoided in areas subject to significant creep. Unless it is technically impossible, these joints shall be ground flush using a suitable procedure that limits the induced residual surface stresses. They shall be located in areas where the cyclical thermal stresses are weak.

### **6.3.8 Nuclear cleanliness requirements**

Components shall be designed so that each part or subassembly can be thoroughly cleaned during manufacture and after installation, and that the state of cleanliness thus obtained can be verified over the entire part or subassembly.

Components shall be designed and installed so that they comply with the following:

- The manufacturer shall not adopt a geometry which favours the local accumulation of corrosion residues or products liable to cause corrosion.
- Provision shall be made for the necessary inlet and outlet openings for fluids, vents and drains, as well as for access openings required for visual examination.

### 6.3.9 Thermal ageing

Many materials are subject to thermal ageing at temperatures which depend on their analysis and their metallurgical condition. The degradation of mechanical properties of the material which are taken into account in the design is a possible result of thermal ageing. Temperature and time conditions likely to produce a significant deterioration in monotonic tensile properties shall be determined. When these conditions are reached, the negative effect of thermal ageing on design analyses shall be taken into account.

### 6.3.10 Irradiation

Irradiation generally has an effect of increasing tensile stress properties (conventional yield strength at 0,2 % offset,  $R_{p0,2}$  %, conventional yield strength at 1 % offset,  $R_{p1}$  % and tensile strength  $R_m$ ), called hardening; in return, ductility and toughness are diminished. When irradiation is sufficiently significant to have a notable negative effect on design rules, it shall be taken into account.

### 6.3.11 Design methods

The purpose of mechanical analyses is to demonstrate that a component does not undergo certain types of damage when subjected to the loadings associated with the conditions specified in the equipment specification.

To fulfil, in each condition category, the criteria applicable to a level defined in the equipment specification satisfies this requirement.

Analyses consist in verifying criteria selected on the basis of the method of analysis and the level of criteria and the type of damage. In the course of this verification, practical methods of analysis are used to determine significant quantities and to compare these quantities with maximum acceptable values.

Three methods of analysis are acceptable in defining the significant quantities used in the criteria:

- elastic analysis;
- inelastic analysis (elastoplastic, plastic, visco-plastic, elasto-visco-plastic);
- experimental analysis.

The term elastic analysis designates analyses carried out on the assumption that the behaviour of the material is elastic and linear, that the displacements are small (geometrical linearity) and that there is no initial stress (or residual stress).

The term inelastic analysis designates all the other methods except for experimental analysis.

Experimental analysis consists in subjecting models representing the component or some of its elements to loadings in order to determine the deformation and stresses or margins with regard to the damage under study.

Elastic analysis should be the most commonly used method, the other methods of analysis only being used when it has not been possible to check certain criteria associated with elastic analysis.

It may be necessary for technical reason to break a component up into several zones of calculation in order to analyse a single type of damage.

In this case, an overall analysis of the component shall be made to determine the connections and loads or displacements to be applied to the zone boundaries for each load case considered.

As a general rule, the same analysis method shall be used for all parts of the component. A method other than that used for the entire component may be used locally provided that the coherence between the two analysis methods is checked at the boundaries of the parts examined.

The rules to be respected differ according to:

- the level of criteria;
- the method of analysis: elastic, inelastic or experimental;
- the damage envisaged.

These rules also depend on three factors: temperature, time and irradiation:

- temperature because the properties of the material (allowable stresses, fatigue curves, creep properties) often depend upon it and it shall therefore be taken into account;
- time because its influence on the behaviour of the materials shows up in phenomena which can often be neglected at moderate temperatures but which, on the other hand, shall be taken into account at high temperatures. These phenomena due to the effect of time are generally designated by the term creep;
- irradiation because neutrons could, at moderate temperature, generate movement of atoms and transmutation that could lead to changes in the material's properties. At high temperature, irradiation could influence the behaviour of materials over time and thus contribute to creep ("irradiation" creep combined with "thermal" creep). At high temperature, neutrons could also cause gas swelling, coming from the formation and growth of cavities due to the vacancies created by irradiation.

Design rules shall be associated with their applicability domain based on:

- the conditions for the absence of significant creep (negligible creep). Under these conditions (if they are met), it is possible to neglect creep; that is, the effect of time;
- the conditions for the absence of significant irradiation (negligible irradiation). Under these conditions (if they are met), it is possible to neglect the effect of irradiation;
- the conditions for the absence of significant ageing (negligible ageing) for materials displaying reduced mechanical strength under tension. Under these conditions (if they are met), it is possible to neglect the effect of ageing.

## 6.4 Fabrication

### 6.4.1 General

Manufacturing methods and techniques shall be appropriate for all aspects of the fabrication process, considering degradation of materials from fabrication, heat treatment or forming.

They shall be described in documents containing the minimum requirements to be met, as far as possible, following the chronological order of fabrication.

The documents give generally the minimum requirements that apply to manufacture apart from welding of components, the manufacturer being required to add any additional arrangements it considers necessary to ensure quality of manufacture. This is because no manufacture and implementation rule can be expressed in sufficient detail to ensure a proper fabrication. This essentially depends on the resources and the know-how of each manufacturer. Furthermore, the latter shall make allowance for any additional rules and tolerance limits that may be specified in the equipment specification.

The manufacture includes:

- identification of materials;
- preparation of parts;
- welding;

- forming and dimension tolerances (taking into account interface requirements);
- cleaning;
- heat treatment.

#### 6.4.2 Identification of materials/parts

The identification system is a means of unequivocally associating a part or welded joint with a given set of documents.

An identification system shall be established and maintained for all materials used in fabrication so that all materials including those welded thereto in the completed component can be traced to their origin. This includes the use of welding consumable.

Procedures to ensure material traceability, including transfer of markings, shall be performed throughout fabrication and records maintained to document the method used.

Final records shall include all material certification required by quality control procedures appropriate.

#### 6.4.3 Preparation of parts

Appropriate methods for preparation of parts (e.g. cutting and forming) shall be selected to ensure that defects, such as cracks or detrimental changes in the mechanical and chemical characteristics, are avoided.

These include:

- the checks before fit-up (checking of dimensions, visual examination and surface finished checking);
- checking after fit-up (dimensional checking, visual examination of the joint ready for welding for instance);
- the associated criteria as a function of the class of the component.

#### 6.4.4 Welding

##### 6.4.4.1 General

As welding results in changes in the mechanical and chemical properties of the parent metal, it is essential that the process be well-controlled.

##### 6.4.4.2 Production welds

A welding operation is defined as:

- preparation of the surfaces to be welded;
- utilization of filler metals;
- utilization of welding processes for production welds, repair of component;
- the completion of weld production and repair welds;
- associated heat treatment (pre-heating, post-heating and stress relief);
- checks at the different stages of the welding operations;
- the conditions of producing production coupon parts;
- other operations associated with welding such as choice of joint type, cutting, fit-up and associated checking.

The main links for the qualifications are summarized below.

- The acceptance of a lot of filler metals may only take place after drawing up the qualification for the product. This is because the qualification specification makes it possible to specify the content of a lot and to limit the scope of utilization of the product.
- The lot of filler metals used during qualification of the welding procedure shall have been the subject of acceptance.
- Welders and operators who have successfully completed the qualification test of a procedure are qualified for use of the procedure.
- Qualification of a procedure includes the completion of a test on a conventional joint with the filler metal used. The procedure qualification report is to be quoted in the qualification certificate.
- Changing the brand or the conditions of production of a filler metal does not necessarily invalidate qualification of the procedure when the conditions in the sections relating to the scope of validity of the qualification, as concerns the filler metals, are satisfied. However, this necessitates resumption of qualification of the filler metal.
- A procedure shall have been pronounced qualified in the workshop where it is utilized. Transfer from one workshop to another, or on the site and storage conditions, is however, acceptable if conditions of such a transfer are defined.
- The tests on conventional joints provided for qualification of filler metals are to be carried out by a production workshop qualified and with filler metals which have passed acceptance tests.

#### 6.4.4.3 Acceptance of filler materials

These tests are intended for checking that lots of filler metals used in fabrication are of unvaried quality corresponding to that of the lots that have been the subject of prior testing. Therefore, acceptance tests shall be carried out under conditions that can be replicated and ensure that the filler metal qualification test results apply. The acceptance tests to be performed on products are a function of the type of weld to be performed. They include product tests and tests on metal after dilution.

#### 6.4.4.4 Welding procedure qualification

The requirements concerning the qualification of welding processes depend on the grade of the parent metal, the type of weld to be made and, possibly, the operating procedure.

For each type of qualification, the qualification document specifies:

- the qualification test piece (e.g. parent and filler metals, geometry, heat treatment after welding);
- the welding conditions;
- the non-destructive examinations to be carried out and the associated criteria;
- the destructive tests to be carried out and the associated criteria;
- the scope of validity.

As a general rule, the manner in which the qualification terms and conditions are written is based on the standard plan of ISO 15614 (all parts).

#### 6.4.4.5 Qualification of welders and operators

Qualification shall be ensured before any fabrication begins, in order to ascertain the ability of welders and operators to make satisfactory welds in accordance with qualified welding procedures.

#### 6.4.4.6 Qualification of filler materials

Filler metal qualification shall be defined when actions for which qualification of the designation in the brand is required. These products are:

- powder fluxes (associated with a wire or strip of a given chemical composition);
- cored wires;
- coated electrodes.

#### 6.4.4.7 Technical qualification of production workshops

Technical qualification of the fabrication workshop is intended to evaluate its capacity and technical resources for performing the welding operations. The workshop shall possess appropriate facilities for carrying out satisfactory welding work. Such installations include:

- welding equipment suited to the procedure applied and in good operating condition, well-equipped work areas (including handling equipment) of the desired standard for the materials handled and the class of the components, and storage areas and systems adequate for proper conservation and stocking of filler metals;
- heat treatment facilities in good condition and of adequate capacity for the work to be performed;
- destructive and non-destructive examination facilities suited to the inspections to be performed.

#### 6.4.4.8 Storage of the welding materials

The conditions of storage shall be such that products conserve their properties. Accordingly, products shall be stored in a closed dry place with heating provided if necessary. The organization responsible for the qualification of the filler material (e.g. manufacturer or filler material supplier) shall be responsible for specifying the storage requirements (e.g. acceptable temperature and humidity).

#### 6.4.4.9 Visual and dimensional checks

Production welds are always, whatever their class, to be the subject of a visual check and a dimensional check as per the terms and conditions specified by the manufacturer. These checks are to be carried out before any other non-destructive testing required herein.

#### 6.4.4.10 Weld-related heat treatment

The heat treatment associated with a weld is to be carried out according to written procedure. The terms and conditions of the application shall be specified, for example:

- when it is required;
- stage;
- temperature;
- soak time;
- rate of heating and cooling.

#### 6.4.5 Forming and dimension tolerances

Before starting forming and surface treatment, the manufacturer shall perform the required qualification operations. The manufacturer shall ensure that the mechanical properties verified during acceptance of the materials have not been deteriorated by forming.

The alignment tolerance limits for weld assembly parts shall be defined. These depend on the type of welded joint and the type of component involved (chamber or pipe).

Tolerances or ranges of welding grooves, weld reinforcement, dimensions and heat treatment shall be maintained at the appropriate stages of fabrication and on the finished component (reference temperature for dimensions should be mentioned for ease of assembly interface).

#### 6.4.6 Cleaning

These are intended to limit the risks associated with the presence of impurities in the systems:

- activation of deposits in the reactor core;
- disturbance of operation of moving parts by deposits;
- localized corrosion of stainless steels, alloys of nickel, aluminium and zirconium;
- reduction of heat transfer due to deposits.

The degree of cleanliness is the state to be obtained for a given surface, before the tests and commissioning of the facility.

There are a number of degrees of cleanliness. These are characterized by tests and different associated criteria levels. The degree of cleanliness is, furthermore, necessary for preservation of component in storage.

#### 6.4.7 Heat treatment

When there is a risk that the fabrication process can cause unacceptable changes in the properties of the material or weld, suitable heat treatment shall be applied at appropriate stage(s) of manufacture, such as cutting, forming and welding.

### 6.5 Tests and examination methods

#### 6.5.1 General

Components shall be examined for dimensional conformance and indications of imperfections by appropriate visual and non-destructive examinations.

#### 6.5.2 Methods

Inspection and examination methods and any limitations shall consider material types, fabrication process, thickness, configuration, intended application.

#### 6.5.3 Procedures

Any activities for testing, and examination, their acceptance criteria and the responsibilities for carrying out such activities shall be specified. It shall be specified when and at what stages independent inspection, testing, and verification and validation are required to be conducted. The procedures to be applied for testing and examination shall be defined at different stages of constructions of component: procurement of products, qualification of fabrication processes, non-destructive examination of parts of component and the use of production specimens.

It covers:

- the mechanical, physical and chemical tests;
- the various non-destructive examination techniques:
  - ultrasonic;

- radiographic;
- penetrant;
- magnetic particle;
- eddy current;
- other methods of inspection (visual, video, determination of surface finish, detection of leaks);
- non-destructive examination individual competences (qualification or certification for instance).

Criteria for evaluation of indications and acceptance criteria shall be included and be consistent with material types, component thickness and manufacturing class.

#### 6.5.4 Personnel qualification

Any activities for testing, and examination, their acceptance criteria and the responsibilities for carrying out such activities shall be specified. It shall be specified when and at what stages independent inspection, testing, and verification and validation are required to be conducted.

### 6.6 Final inspection and testing

#### 6.6.1 Final inspection

Components shall undergo a final inspection to assess compliance with the requirements of the applicable specification and any included standards. Tests carried out during manufacture may be taken into account. When practical, the final inspection shall be carried out internally and externally on every part of the component; when access for a final inspection is not possible, appropriate inspections shall be made during the course of manufacture and justification should be provided that the subsequent stages of manufacturing do not compromise the conclusions of the previous inspection.

#### 6.6.2 Final pressure test

Final assessment of pressure equipment and boundaries shall include a test for pressure.

The equipment specification shall stipulate the test pressure, holding time at pressure and the characteristics of the test medium. These provisions shall take account of the applicable statutory requirements.

When possible, a hydrostatic test is recommended. When a hydrostatic pressure test is harmful or impractical, other tests of a recognized value may be employed.

If it is not possible either, perform tests such as non-destructive tests in addition to a pressure test (which is not equivalent to a hydrostatic one).

The equipment specification defines the test acceptance criteria.

### 6.7 Marking/labelling

Required information shall be physically marked on the equipment in accordance with the applicable standard. As a minimum, the information shall include:

- a unique identification number or type series identification;
- an indication of conformity;
- the manufacturer's identification;
- for pressure vessels, the maximum allowable pressure(s) at coincident design temperature(s).

When physical marking is not practical, alternative means are allowed such as traceable records or a suitable label attached to the equipment.

## 7 Documentation

The manufacturer shall compile all the technical documentation of the reactor components. This documentation shall make it possible to evaluate its compliance with the applicable requirements; the documentation shall be as complete as necessary for the evaluation, design, manufacturing and operating of the equipment (assembly) and shall contain at least the following:

- a general description of the equipment (assembly);
- conceptual design and manufacturing drawings and diagrams of components, sub-assemblies, circuits;
- descriptions and explanations necessary for an understanding of the said drawings and diagrams and the operation of the equipment (assembly);
- a list of the standards, applied in full or in part;
- results of design calculations made, examinations carried out;
- the test reports;
- appropriate details relating to the choice of materials, the approval of the manufacturing and test procedures, and the qualifications or approvals of the personnel concerned;
- non-compliance reports (NCRs), design concession requests/notices (DCRs/DCNs) and other deviation regularization notes issued/accepted in the course of the manufacture of components.

Documents are archived by the prime contractor or the operator for a time determined based on document types, in order to keep the knowledge in a way to improve the design or the operation of the installation.

[Annex D](#) provides an illustration of a possible documentation system.

## 8 Conformity assessment

Reactor components shall be constructed under a conformity assessment system agreed to by the parties concerned. A statement of conformity to the standard shall be supplied by the appropriate conformity assessment body or manufacturer.

## Annex A (informative)

### Description of GEN IV reactors

The Generation IV goals, as stated originally, are as follows:

- Sustainability
  - Generate energy sustainably and promote long-term availability.
  - Minimize nuclear waste and reduce the long-term stewardship burden.
- Safety and reliability
  - Excel in safety and reliability.
  - Have a very low likelihood and degree of reactor core damage.
  - Eliminate the need for offsite emergency response.
- Economics
  - Have a life cycle cost advantage over other energy sources.
  - Have a level of financial risk comparable to other energy projects.
- Proliferation resistance and physical protection
  - Be a very unattractive route for diversion or theft of weapon-usable materials.
  - Provide increased physical protection against acts of terrorism.

In 2002, the Generation IV International Forum (GIF) selected as Generation IV technologies six systems from several tens of candidates:

- gas-cooled fast reactor (GFR);
- lead-cooled fast reactor (LFR);
- molten salt reactor (MSR);
- sodium-cooled fast reactor (SFR);
- supercritical-water-cooled reactor (SCWR);
- very-high-temperature reactor (VHTR).

Detailed information is provided in the Gen IV International Forum Annual Report 2013.

## Annex B (informative)

### Illustration of material selection for sodium fast reactor (SFR) components

- a) The compatibility of reactor grade sodium with structural materials in general is better than water or lead from the viewpoint of corrosion. In addition, it has good heat transfer characteristics.
- b) Therefore, sodium is used as a coolant in many fast reactors. Most of them use austenitic stainless steels for their main structural components. This enables taking advantage of good heat resistance, elevated temperature strength and corrosion resistance that sodium has.
- c) Other materials such as 2 1/4Cr-1Mo steel, whose thermal expansion rate is meaningfully lower than that of austenitic stainless steels, have also been used for secondary coolant loops, and in some cases, high nickel steels have been utilized focusing on the resistance and behaviours under accidental conditions.
- d) As described above, sodium exhibits good compatibility not only with austenitic stainless steels, which is the primary choice for main components, but also with other steels and alloys that may be used to meet various design needs.

The selection of a material shall take into account that:

- different product forms (e.g. plate, pipe, forging) may show different strength and behaviours. Allowable stresses shall be determined accordingly;
- some materials may exhibit cyclic softening during service. In this case, appropriate considerations would be necessary in design and structural integrity evaluation;
- the purity of sodium shall be controlled in appropriate ranges, or effects that may take place on materials during service due to the impurity shall be accounted for;
- mass transfer should be considered in design particularly when materials whose chromium, nitrogen or carbon content has been optimized to achieve certain strength are used.

## Annex C (informative)

### Description of types of damage

#### C.1 Overview

Damage may be classified in different category, for instance, into short-term, long-term and cyclic-type failures, or into cyclic, non-cyclic failures.

This annex gives a brief description of the damage identified in [6.3.2](#) classified in two groups, general damage and damage linked to elevated temperature regimes.

#### C.2 General damage

##### C.2.1 Immediate excessive deformation

For a structure made of elastic, ductile material to which a loading multiplied by a gradually increasing coefficient is applied, the following behaviour can be observed: with lower coefficient values, the structure behaves elastically and deformation is reversible. At higher values, irreversible plastic deformations occur such that if the loading were to be cancelled, the structure would not return to its original dimensions or shape. These plastic deformations are firstly contained by elastic zones which limit them and then, the plastic zones being sufficiently extended, yielding takes place easily. The overall permanent deformation of the structure thus increases faster the higher the loading coefficient. It is when the overall permanent deformation begins to increase rapidly that it is said to be excessive. The following convention is recommended: excessive deformation is attained when the overall permanent deformation exceeds the deformation which would occur with purely elastic behaviour.

##### C.2.2 Immediate plastic instability

When, in the previous case, the loading continues to increase, the behaviour of the structure depends on any variations in its shape and the strain hardening increase of the yield strength of the material. These two effects rapidly become counteracting: any change in shape tends to weaken the structure, whereas an increase in the yield strength of the material tends, on the contrary, to reinforce it. As long as the first effect is dominated by the second, the structure is deformed in a stable manner; when the first becomes dominant, deformation is unstable and fracture is not far behind if the loading is maintained.

Plastic instability considered here is an overall phenomenon. It shall be distinguished from ductile tearing which is a form of fast fracture and shall be examined separately.

##### C.2.3 Elastic or elastoplastic instability

Apart from the instabilities described above, other elastic or elastoplastic instabilities may occur, in which elastic deformation, by the changes in shape it induces, considerably weakens the strength of a structure and its ability to withstand the applied loading.

##### C.2.4 Progressive deformation

When we consider a structure subjected to cyclic loading, at the end of the first cycle, the structure may show signs of permanent deformation.

During the following cycles, two cases may arise:

- either, after a few cycles, the overall permanent deformation is stable, or