Date: 14 April 2014
Validity: **until next update or archiving**
Version : Public 1

MDEP Technical Report TR-CSWG-03

Related to: Codes and Standards Working Group

Technical Report

FUNDAMENTAL ATTRIBUTES FOR THE DESIGN AND CONSTRUCTION OF REACTOR COOLANT PRESSURE-BOUNDARY COMPONENTS

Participation

Countries involved in the MDEP working group discussions:	Canada, Finland, France, India, Japan, Russian Federation, South Africa, the U.A.E., the U.K., and the U.S.
Countries which support the present common position	
Countries with no objection:	China and Sweden
Countries which disagree	
Compatible with existing IAEA related documents	Yes

Contents

I. INTRODUCTION

This CSWG document provides the fundamental attributes which have been developed for the codes and standards used in the design and construction[1] of reactor coolant pressure boundary components[2] in nuclear power plants. The fundamental attributes are the basic concepts to be considered in the design, materials, fabrication, installation, examination, testing and over-pressure protection requirements for pressure boundary components.

II. BACKGROUND

The primary, long-term goal of MDEP's CSWG is to achieve international harmonisation of codes and standards for pressure boundary components in nuclear power plants that are important to reactor safety. The key to achieving harmonisation is to understand the extent of similarities and differences amongst the pressure boundary codes and standards used in various countries. To assist the CSWG in its long-term goals, several standards development organisations (SDOs) from various countries performed a comparison of their pressure boundary codes and standards to identify the extent of similarities and differences in code requirements and the reasons for their differences. The results of the code-comparison project are documented in a separate report in the MDEP library [Ref. 1].

The results of the code-comparison project enabled the CSWG to take the next steps towards harmonisation of codes and standards. The results enabled the CSWG to understand from a global perspective how each country's pressure boundary code or standard evolved into its current form and content. The CSWG recognised the important fact that each country's pressure boundary code or standard is a comprehensive, living document that is continually being updated and improved to reflect changing

[1] According to ASME Code Section III NCA 9000 Glossary, the term "construction" (as used in Division 1) is defined as an all-inclusive term comprising material, design, fabrication etc. Meanwhile in some other codes, "construction" does not include "design". So, in this document, construction is defined as all activities listed in NCA 9000 except design. Therefore, "design and construction" is used in this document, meaning all-inclusive term.

[2] In this document, "reactor coolant pressure boundary components" is used instead of "class-1 components", as there are some differences in the definition of "class-1" among codes. Furthermore, the term "reactor coolant pressure boundary component" is hereafter shortened as "pressure boundary component".

technology and common industry practices unique to each country. The rules in the pressure boundary codes and standards include comprehensive requirements for the entire design and construction of nuclear power plant components including design, materials selection, fabrication, examination, testing and over-pressure protection. The rules also contain programmatic and administrative requirements such as quality assurance; conformity assessment (e.g., third-party inspection); qualification of welders, welding equipment and welding procedures; non-destructive examination (NDE) practices; and qualification of NDE personnel.

In the course of reviewing the results of the SDO's code-comparison project, the CSWG found that the similarities and differences between each county's code and standard varied considerably amongst different countries. Some country's code or standard was almost identical to another country's code or standard in key areas while another country's code or standard was vastly different. These differences are due to the historical, cultural, social, industrial and regulatory differences of each country.

In addressing these commonalities and differences, the CSWG found it possible and useful to establish a global framework of a hierarchy structure of the pressure boundary codes and standards, as a basis of harmonisation of the codes and standards. However, certain programmatic and administrative requirements, such as quality assurance and conformity assessment, were not addressed in detail in this document because these programs are unique to each country's national and cultural practices.

III. GLOBAL FRAMEWORK FOR THE PRESSURE BOUNDARY CODES AND STANDARDS

A hierarchy structure of three levels was considered for providing a global framework that would unite the regulatory requirements on the pressure boundary codes and standards in each country, with an ultimate goal of harmonisation of the codes and standards for nuclear components.

The concept of this framework would enable all member countries to share commonalities of their codes as is appropriate to their needs. However, based on this framework, the efforts towards harmonisation can be promoted.

At the top of the hierarchy, the Fundamental Attributes provide fundamental concepts governing the design and construction of pressure boundary components. At the middle level, the Essential Performance Guidelines provide performance based guidelines for nuclear pressure boundary codes. At the bottom level, the pressure boundary codes and standards of each country provide specific rules for the design, material, fabrication, installation, examination, testing and overpressure protection

The Fundamental Attributes describe the basic concepts underpinning the pressure boundary codes and standards used in the design and construction of nuclear power plant pressure boundary components. These concepts shall govern the design and construction of pressure boundary components, regardless of the detail differences of each code. Therefore, the fundamental attributes are described in "shall" statements. In the regulatory system of each country, these attributes can be used as requirements or recommendations.

This level corresponds to the Safety Requirements of the IAEA Safety Standards (Figure 1). The Fundamental Attributes could, in the future, be incorporated into the relevant IAEA Safety Requirements related to nuclear pressure boundary components.

At the middle level, the Essential Performance Guidelines provide qualitative performance descriptions of the rules and practices derived from the codes and standards, which can be considered as essential and are described in most of the codes and standards in the MDEP member countries. These Guidelines can govern most of the pressure boundary codes and standards but not necessarily all of them. They will therefore be regarded as guides or recommendations and will be described in "should" statements. In the regulatory system of each country, these Guidelines can be used as guides or recommendations. They can also be used as regulatory requirements, depending upon the regulatory decision of each country.

This level corresponds to the Safety Guides of the IAEA Safety Standards (Figure 1). It is envisaged that a new IAEA Safety Guide could be developed based on the information contained in the Essential Performance Guidelines.

Pressure-boundary codes and standards are inevitably large, complex and very detailed documents. As a consequence it is difficult for non-code specialists to appreciate the important requirements of the codes and standards. The Essential Performance Guidelines was therefore also written to provide the essence of codes and standards on nuclear pressure boundary components. The Essential Performance Guidelines can be used also as a tutorial material.

The bottom level contains the pressure boundary codes and standards from the individual countries. The intention is that stepwise efforts will commence to harmonise the different pressure codes and standards. This will be performed jointly by the SDOs and WNA/CORDEL[3]. Initially, a few code differences will be selected for trial convergence. If the efforts are a success, then code convergence will be further conducted on more code differences. This process will repeat and the scope of convergence will be expanded.

[3] World Nuclear Association's working group on Cooperation in Reactor Design Evaluation and Licensing

The relationship between the IAEA Safety Standard series and MDEP/CSWG documents is shown in Figure 1 below.

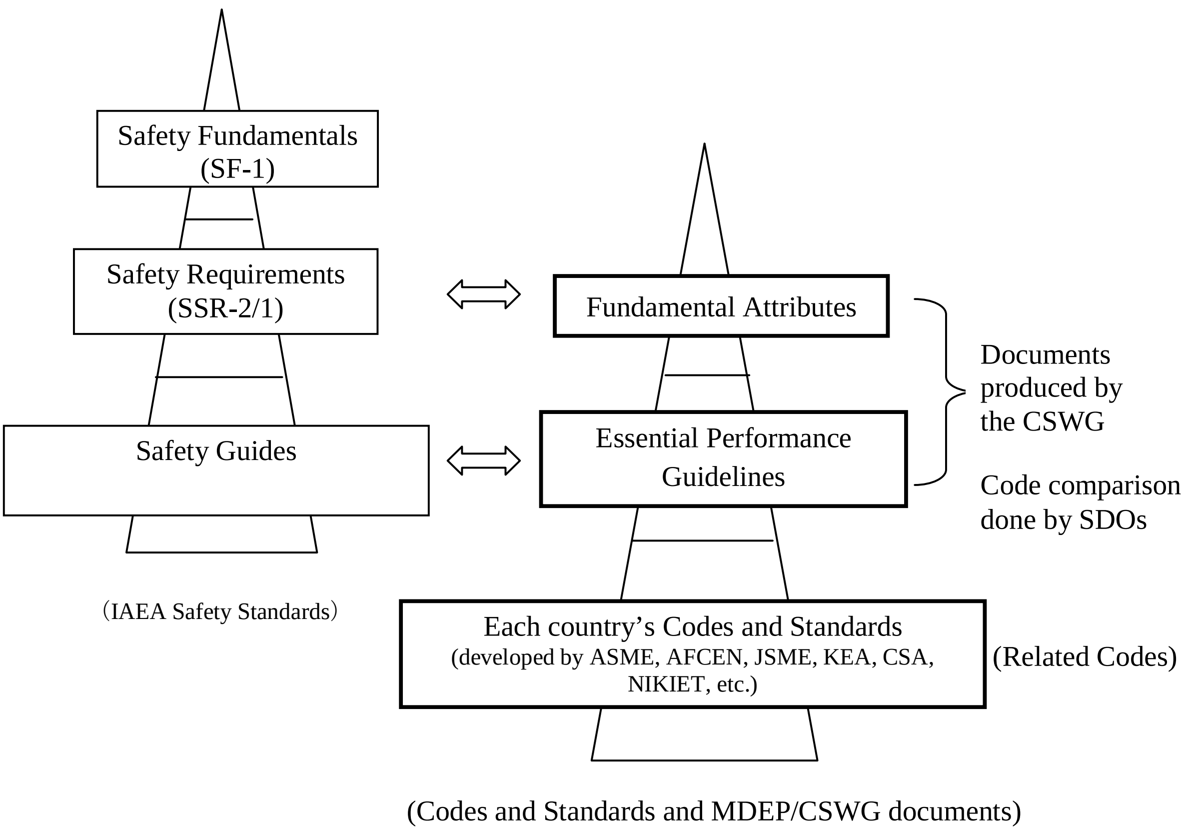

Fig.1 Relationship between the hierarchy structures of the IAEA Safety Standards series and MDEP/CSWG documents

IV. RELATIONSHIP WITH IAEA SAFETY STANDARDS

The Fundamental Attributes described in this document provide the basic concepts underpinning the codes and standards used in the design and construction of pressure boundary components in a nuclear power plant. Pressure boundary components include vessels, piping, pumps and valves.

The IAEA Specific Safety Requirements SSR-2/1 (Safety of Nuclear Power Plant: Design) [Ref. 2] includes some requirements in terms of design, and overpressure protection devices which can be regarded as fundamental attributes for the pressure boundary components. However, these are not sufficient in themselves and further aspects need to be considered. In particular it is necessary and important to develop new principles to cover areas such as fabrication, installation, examination and testing.

V. FUNDAMENTAL ATTRIBUTES

1. <u>General</u>

The pressure-boundary components in the nuclear power plant shall be designed, manufactured, examined, tested, and equipped with pressure protection devices, so that the pressure retaining functions can be maintained and necessary reliability can be ensured

1.1 Fundamental Attribute 1: Management/quality assurance system for the plant design and construction

The design organisation shall establish and implement a quality management/assurance system for ensuring that the safety requirements established for the pressure-boundary components of the plant are considered and implemented in all phases of the design and construction process and that they are met in the final products for the lifetime of the nuclear power plant.

1.2 Fundamental Attribute 2: Classification and Graded Approach

The pressure-boundary components; vessels, pumps, valves, piping etc., shall be classified on the basis of their safety significance. A graded approach consistent with the classification of components shall be applied for procurement of materials, design, fabrication, examination and testing for all the components so that the reliability of the items shall be commensurate with their safety significance.

1.3 Fundamental Attribute 3: Service Conditions corresponding to Plant States

Service conditions of the pressure-boundary components shall be grouped corresponding to plant states which shall be identified into a limited number of groups primarily on the basis of their frequency of occurrence at the nuclear power plant. These service conditions and plant states shall be taken into consideration for pressure-retaining components in establishing their design requirements.

2. <u>Design</u>

The design of pressure-boundary components shall be carried out so that structural integrity and pressure retaining capability can be maintained.

2.1 Fundamental Attribute 4: Design basis for items important to safety

The design basis for components important to safety shall specify the necessary capability, reliability and functionality for the relevant operational states, for accident conditions and for conditions arising from internal and external hazards, to meet the specific acceptance criteria over the lifetime of the nuclear power plant.

For pressure boundary components, design loadings and service conditions shall be defined with appropriate design margins. The loading conditions shall be defined by identifying the various kinds of internal and external loads, which include loads due to natural phenomena. Based on these loading conditions, design loadings such as design pressure, design temperature and design mechanical loads shall be established. Each service condition to which the components may be subjected shall be defined corresponding to the plant states. The above items are to be included in the design specification on which the design of the component is to be carried out.

2.2 Fundamental Attribute 5: Provision for inspectability

The pressure-boundary components in a nuclear power plant shall be designed so that components are accessible for inspections during manufacturing, pre- and in-service inspections.

2.3 Fundamental Attribute 6: Design by Analysis

2.3.1 For the components of highest level classification which are covered by this document, a stress analysis of a component shall be carried out in sufficient detail to show that each stress limit defined for each stress category and each service level is satisfied when the component is subjected to design basis loadings, except for the portions to which the approach of design by rules are admitted, such as openings and their reinforcements The theory of failure (e.g. maximum shear stress), on which the detail stress analysis is based, shall be identified.

2.3.2 Evaluations and protections on relevant failure modes such as fatigue, brittle fracture, buckling, etc. shall be carried out.

2.4 Fundamental Attribute 7: Design by Rule[4]

2.4.1 The design of components shall meet the design rules specific to each type of components, such as vessels, pumps, valves, piping and their appurtenances.

2.4.2 The design rules for specific types of configuration or specific parts of components shall include limitations on the type of configuration and usage of formulas for design.

[4] When the detail stress analysis is performed, the application of this rule may not be mandatory.

3. Materials

The materials appropriate for the component's function and operating environment shall be selected to ensure the integrity of the component for its design life with sufficient margins for degradation in service.

3.1 Fundamental Attribute 8: Provision for material

The material, of pressure boundary components and their attachments, shall be selected and used so as to minimise any significant degradation during the lifetime of the component taking into account the operating environment. In addition, brittle behaviour shall be avoided by ensuring adequate toughness considering embrittlement.

3.2 Fundamental Attribute 9: Specification of materials

The material specification shall be defined on the materials used for nuclear component, taking into consideration the experiences in other industries and/or incorporating the nuclear unique requirements to be added for usage in a nuclear power plant. The items to be specified include, as applicable, chemical composition, microstructure, mechanical/thermal properties, heat treatment, and fabrication requirements of materials, etc.

3.3 Fundamental Attribute 10: The additional requirements for material

The following additional requirements shall be established on materials on the basis of a graded approach so that the requirements on materials can be commensurate with their safety significance. (1) The impact test requirements shall be established to ensure toughness of materials against fracture in environmental conditions. (2) The requirements for welding materials used for fabrication or repair of components shall be established so that the welds have sufficient strength and toughness, and are free from harmful defects. (3) The non-destructive examination requirements shall be established for verifying the acceptability of materials and welds, and for ensuring acceptable repair of materials. (4) The material specifications shall ensure minimum activation in neutron flux environment.

3.4 Fundamental Attribute 11: Quality management requirements for materials

The quality management system shall be established, including material certification, identification, and traceability during manufacturing.

4. Fabrication and Installation

The pressure boundary components shall be constructed so that the high level of quality can be achieved.

4.1 Fundamental Attribute 12: Provision for fabrication and installation

The pressure boundary components in a nuclear power plant shall be manufactured, assembled and installed in accordance with established processes that ensure the achievement of the design specifications and the required level of safety.

4.2 Fundamental Attribute 13: Quality management requirements during fabrication

The quality management system shall be established for fabrication process including identification and traceability of materials, welding, handling, and storage of fabricated components.

4.3 Fundamental Attribute 14: Requirements on fabrication

(1) The permitted type of weld joint designs shall be defined for each group of weld joints which are categorised according to the configuration and location of the weld.

(2) The welding qualification is required for both the welding procedures and the welders before the welding is performed to ensure reliability of the welding.

(3) Dimensional tolerances on forming, machining and aligning shall be defined.

4.4 Fundamental Attribute 15: Requirements on heat treatment

The need for material pre-heat treatment and post weld heat treatment shall be defined.

5. Examination

The pressure boundary components shall be examined with non-destructive examination methods so that the integrity of the components can be assured

5.1 Fundamental Attribute 16: Provision for examination

The pressure boundary components in a nuclear power plant shall be examined as required to ensure their capability for performing their functions and to maintain their integrity in all conditions specified in their design requirements.

5.2 Fundamental Attribute 17: Requirements on nondestructive examination

Non-destructive examination shall be conducted on welds and weld claddings to ensure their acceptability, on the basis of pre-defined acceptance criteria for each type of non-destructive method. The method and acceptance criteria of the required non-destructive examination shall be determined for each type of weld joint category.

The weld portion shall be accessible for inspection during manufacturing, and inspection during pre-service stage to obtain base-data for in-service inspection.

5.3 Fundamental Attribute 18: Qualification of non-destructive examination personnel, equipment and procedures

The personnel, equipment and procedures shall be qualified prior to performing the non-destructive examination.

6. Testing

The components shall be pressure tested and qualified to verify their integrity, leak-tightness, and functionality

6.1 Fundamental Attribute 19: Provision for testing

A qualification programme for pressure boundary components shall be implemented to verify that the pressure boundary components at a nuclear power plant are capable of performing their intended functions when necessary, and in the prevailing environmental conditions, by applying a predetermined testing pressure on the pressure boundary components.

7. Over-pressure Protection

Protective devices shall be designed and installed to prevent failures in pressure boundary components caused by system pressure exceeding the component's design pressure

7.1 Fundamental Attribute 20: Provision for over-pressure protection

Provision shall be made to ensure that the operation of pressure relief devices will protect the pressure boundary of the reactor coolant systems against overpressure and will prevent the release of radioactive material from the nuclear power plant directly to the environment.

VI. REFERENCES

1. CODE COMPARISON REPORT for Class 1 Nuclear Power Plant Components, STP-NU-051-1, ASME (December 2012)

2. International Atomic Energy Agency, "Safety of Nuclear Power Plants: Design" Specific Safety Requirements No. SSR 2/1, IAEA, Vienna, Austria (2012).