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RCC-MR 07 CODE : SPECIFICITIES AND RECENT DEVELOPMENTS

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1 ABSTRACT

The fourth edition of RCC-MR code has been issued on October 2007 by AFCEN (Association Française pour les règles de Conception et de Construction des Matériels des Chaudières Electro-nucléaires) and results of an important work by AREVA NP and CEA to develop and improve design and construction rules of the previous edition.

The improvements and new developments added in the new version of the RCC-MR differ from the last 2002 edition by an enlargement of the scope of the code not only applicable to mechanical equipments in fast breeder reactors working at high temperatures but also to the ITER vacuum vessel, and other nuclear components.

The last evolutions of the code are summed up as follow:

1. In the field of design rules, improvement of defect assessment rules and the creep-fatigue rules for shells and pipes, and extension of the scope of the code concerning bolts,
2. In relation with the development program of the ITER vacuum vessel, introduction of a new quality class for the box type structures and a specific appendix dealing with fabrication requirements of the ITER vacuum vessel,
3. Modification or addition of requirements in accordance with the European Pressure Equipment Directive with in particular the replacement of French standards by European ones and as far as possible by harmonized European standards.

2 INTRODUCTION

RCC-MR 2007 edition (10) is the fourth edition of the code. The initial decision to draw up a complete set of design and construction rules for Sodium Fast Reactor's components was taken in 1978 following the construction of Superphenix (SPX) and to take advantages of the large R&D program performed at this time. Thanks to successive projects, as the European Fast Reactor (EFR) project for which European countries have adopted RCC-MR, it has been continuously improved, gathered all the European experience in design and construction and supported by the large R&D program.

The feedback of Phenix Reactor operation is collected in the code. The RCC-MR has been used as a basis for the safety reassessment of this plant, and in this frame was used for the procurement of several spare components. More recently RCC-MR has been chosen by Indian for the design and construction of the PFBR.

The decision of updating the RCC-MR has been motivated by the international renewal of Sodium Fast Reactors (SFR) combined with the interest of ITER project to use this code for the Vacuum Vessel (VV) construction.

This new edition has been issued in October 2007; the main improvements and new developments introduced in the codes rely on three motivations:

- First, improvements of design rules, regarding the R&D work results launched since the last edition of the code, as:
    - Improvement of the creep-fatigue rules for shells and pipes.

- Improvement of the leak-Before-Break procedure and related defect assessment tools.
- Extension of the scope of subsections devoted to bolt

- Second, addition of a new appendix (A19) to deal with the specificities of ITER and development of the “class 2 box” to cope with the ITER VV design needs.
- Third, change from AFNOR standards to European standards and introduction of requirements in line with the new European regulations (“European Pressure Equipment Directive”). An appendix, devoted to pressure retaining equipments set up on a French site was added to the code. The objective of this appendix is to provide prescriptions in order to help the Manufacturer to fulfill the requirements of the French regulation “arrêté des Equipements Sous Pression Nucléaires”;

This paper sets out those improvements and then gives an overview of the future works.

3 RCC-MR 2007 : MAIN IMPROVEMENTS

3.1 Design

3.1.1 Creep-fatigue damage

The creep-fatigue rule in RCC-MR is based on the determination of fatigue and creep rupture usage fractions. For all loading cycles, the summation of these usage fractions allow to check that the structure complies with the creep-fatigue damages criteria, by using the creep-fatigue interaction diagram of the material. Up to 2002, the code considers that the dwell time is located at one extremes of the cycle.

In 2007 edition, the elastic approach has been adjusted mainly to improve the performance of the existing rule when primary loading is high and when maintain in temperature does not occur at one extremum of the loading cycle. The new rule proposed is the result of non linear calculations on simple and realistic cases (1, 2). The frame of mind of the previous rule is kept but now the designer can choose between 2 alternatives according to the relative position of the dwell time with the maximum of the loading cycle. The gain brought on damage evaluation using this new approach has been demonstrated on realistic cases as THERMINA tests (CEA) and on a bend pipe of Phenix reactor secondary circuit.

3.1.2 Leak-Before-Break procedure and defect assessment tools

The Leak-Before-Break procedure and related defect assessment methods is given in the Appendix A16 and has to be considered as a possible tool for the safety demonstration of a nuclear power plant. The ultimate objective of this approach is to check that a given defect (dimension, orientation, shape) present or postulate in the structure will not lead to component failure.

In RCC-MR 2007 edition, important improvements of this appendix are proposed :

- Defect size determination at penetration and after penetration in the LBB procedure has been modified (3) ; the defect straightening after penetration has been completed including an extension for all loading conditions (in 2002 edition, nearly pure bending loading is not handled)
- Compendia for K_I and reference stress have been improved and extended for cracked plates, pipes (4). For other geometries such as elbows, the code advise the use of pipe shape coefficients (up to a limited maximum defect sizes) and analytical solutions for the elastic opening stress distribution (5,6,7,8)
- Combined mechanical and thermal loading interaction in the Fracture Mechanics parameters (J and C*) calculation has been revised (6, 9). The crack propagation analyses under creep conditions are notably provided.
- For cyclic thermal loading conditions, new methodology is introduced for the analysis of creep crack growth.

3.1.3 Bolting

An extension of the available rules for the design of bolts has been provided in the 2007 issue. Now, the RCC-MR puts forward three sets of rules related:

- preloaded bolts joining parts of pressure retaining boundaries, usable in case high values of preload plays a role in the design process as if there are risks of unscrewing due to vibrations, dynamic loadings, etc… ; rules in significant creep conditions are provided for this case.
- Rules for preloaded bolts which do not join parts of pressure retaining boundaries.
- Rules for non preloaded bolts which can be used for supports of pipes or components.

Appendix A6 dedicated to design of bolt assemblies and subsection of section 1, dealing with Support, include these modifications.

3.2 Specificities of RCC-MR for the ITER Vacuum Vessel

3.2.1 Box type structure

The Vacuum Vessel of the experimental reactor is a torus shape double-wall structure composed mainly by an inner and an outer shell strengthened by internal stiffening ribs. Thus, the design of this structure leads to the application of box structure rules.

RCC-MR contains this sort of rules which have been developed for two components of the Sodium Fast Reactor: the carbon steel reactor roof operating in air or gas and the stainless steel core support structure immersed in sodium. The safety classification of these two components set the use of Level 1 quality.

The ITER interest occurred of using RCC-MR rules for the Vacuum Vessel leads to develop a level 2 quality rules for box type structure. The advantages of such rules permit to sort out the welded joints in four categories. For these different categories, there are different authorized types of welded joints and different requirements for non destructive testing. The importance of the welded joints for the mechanical resistance and tightness of the box structures decreases from category 1 to category 4 according to their decreasing importance regarding safety:

- In category 1, assemblies shall be inspected in their whole volume (surface and volumetric examinations shall be performed); it concerns butt welds with two sides accessible (or with removal backing strip) or with one side accessible but gaseous protection on the back side, and also full penetration fillet welds with two sides accessible.
- In category 2, the authorized welded joints are the same than the category 1 completed by full penetration one side fillet welds with gaseous back protection. These welded assemblies category is dedicated to the assemblies of the external shell welds or the stiffeners on this weld,
- In category 3, the welds of category 2 are included with in addition butt and fillet welds on permanent backing strip.
- In category 4, any type of welds is authorized as only visual inspection has to be performed for these assemblies

3.2.2 Examination of welds

According to the pressure equipments regulation, the permanent assemblies which contribute to the pressure resistance shall be inspected in their whole volume (100%). RCC-MR gives a possibility to substitute the volumetric examination by periodic examination during welding for non pressure retaining parts for the assembly with no accessibility of the back side.

The inspection of pressure resistance welds not accessible on the back side is considered by the code: the use of ultrasonic inspection as an alternative method to the radiographic inspection can be selected if a demonstration of performance is provided by the Manufacturer to the Contractor.

For the ITER application and especially for the shell welds not accessible on the back side, RCC-MR open the possibility of using alternative ultrasonic techniques to the conventional single probe reflection method, such as phased-array, creeping wave, or tandem.

For the surface examination, the use of Photo Thermal Camera (PTC) instead of Liquid Penetrant Testing method is permitted for ITER components. Nevertheless, this substitution is subjected to Contractor agreement, after production of a specification with relevant method and criteria by the Manufacturer.

3.2.3 *ITER specificities new appendix*

Complementary requirements to the current rules specific for the design of the ITER Vacuum Vessel are gathered in Appendix A19. The specific non-destructive examination methods for welds describe above are handled in this appendix with the list of the different welded assemblies classified in the four categories defined in the box structure rules.

3.3 Laser welding

In section 4 of the code, laser welding is introduced and the methodology to comply with to perform welding procedure qualification is given. As for the electron beam welding, the specifications, tests and validity of the qualification (RS 3570) for laser welding are based on European harmonized standards specifications.

3.4 New European and French Regulations

In the 2007 edition, a hard work has been done to fulfill two objectives:

- The first one, is to change from AFNOR standards to European standards, referring as much as possible to European Harmonized standards,
- The second one is to propose rules and specifications in an appendix which can facilitate the designer and manufacturer to be consistent with the requirements of the Pressure Equipment Directive (PED) 97/23/CE and of its derived rule to nuclear equipment issued in France on December 12, 2005 “arrêté du 12 décembre 2005 relatif aux equipements sous pression nucléaires” (ESPN).

For the adaptation of the code to the new European standardization, almost all sections have been concerned:

- The material specifications listed in section 2, have been updated regarding the location and direction of sampling, the substitution for stainless steel of U-Notch by V-Notch impact test requirements, or the adjustment of the specified chemical requirements for a majority of grades to be consistent with European standards.
- The material data section for which the new definition of the mean and minimum values of characteristics and allowable stresses have been introduced. Consistency with European standards has also been established for physical, elastic and thermal properties as well as for minimum values of tensile properties of a majority of materials grades.
- The testing and examination methods section has been modified to introduce European Standards instead of French ones. Some of criteria and threshold of acceptable defects for surface and volumetric examination have been fitted by reference of the new system; Regarding mechanical testing, the measurement of Rp0,2% is done according to the European Standard, the 5 minutes holding time requirement is then no more maintained in the last edition.
- Concerning welding and fabrication, for qualification procedure, only supplementary requirements to European relevant standards are included in applicable sections. This is motivated by the well-known and large practice of these standards in the European engineering industry.

For the second objective, compliance with PED/ESPN, a new appendix (Appendix A18) has been developed in the 2007 edition of the code. In this appendix, the first input is a table which gives the sets of applicable sections of the code according to the PED/ESPN category and to the RCC-MR quality level of the component. Then, for each PED/ESPN category, additional requirements are given; It mainly concerns the documentation required by the regulation, minimum acceptance values for mechanical properties of materials (elongation and impact strength rupture energy), requirements for the non destructive examination (extend and qualification), and the way to determine of the hydrostatic pressure test value (considering material properties at temperature).

4 FUTURE WORKS

The original purpose of the RCC-MR was to collect Superphenix feedback and then was used by European countries in the frame of EFR project.

The RCC-MR has been selected by the innovative Sodium Fast Reactor project (Generation IV) and the ITER project as reference code for the design and construction. As a consequence, the RCC-MR code has to follow the progress in components design, in R&D, in manufacturing process and has to take into account the regulation evolution.

Number of challenges to meet can already be underlined:

- Introduction of new materials (alloy 800H, optimized ferritic/martensitic steels….) or improvements of existing database of materials. As a result, supply procurement specifications and material data for designer need to be updated taking into account technology of fabrication and welding for the grades retained.
- Update material data for a 60 years lifetime by capitalizing all results of R&D ongoing,
- Taking into account the will to have special supplies (heavy forged parts...). Hence, new manufacturing processes or welding methods will need to be incorporated,
- Introduction of new method for non destructive examinations. As an example, the possibility of using photo thermal Camera or innovated ultrasonic method for the ITER Project has been introduced in the code and is a first step to an evolution of the Examination Section,
- Capitalization of the experience feedback gathered in current projects.

A new edition is planned in 2011 to support the design and construction of future prototypes developed in the frame of Gen IV program.

5 CONCLUSIONS

RCC-MR code provides tools for design and construction of Nuclear Installations including High Temperature applications such as Sodium Fast Reactors and now the ITER Vacuum Vessel. Since the previous edition, the 2007 edition has included a lot of improvements:

- Improvement of the creep-fatigue rules,
- Improvement of the Leak-Before-Break procedure and related defect assessment tools,
- Extension of the available rules for bolts design,
- Introduction of a new chapter dedicated to laser welding,
- Adaptation of the code to the European standardization,
- Introduction of requirements in line with the European Pressure Equipment decree and its French declination to nuclear equipment. For this reason, a new specific appendix dedicated to French installations has been included in the code.

The RCC-MR will continue to evolve regarding industrial developments, supplier experience, project needs, operation experience, and evolution of regulation and standards. A new edition is planned in 2011.

Symbols

EFR European Fast Reactor

ESPN Arrêté du 12 décembre 2005 relative aux Equipements Sous Pression Nucléaires

ITER International Thermonuclear Experimental Reactor

LBB Leak Before Break

LPT Liquid Penetrant Testing

PED Pressure Equipment Directive

PFBR Prototype Fast Breeder Reactor

PTC Photothermal Camera

SFR Sodium Fast Reactor

SPX Superphenix

VV Vacuum Vessel

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