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PRESENTATION OF RCC-MRX CODE 2010 FOR SODIUM REACTORS (SFR), RESEARCH REACTOR (RR) AND FUSION (ITER) : GENERAL OVERVIEW AND CEN-WORKSHOP

T. Lebarbé, D. Hyvert, S. Marie,
CEA Saclay DEN/DANS/DM2S/SEMT/LISN
91191 Gif sur Yvette, France

O. Gelineau, D. Bonne
Areva NP SAS
69456 Lyon, France

Frantz De La Burgade
Areva TA
13115 Saint Paul Lez Durance, France

ABSTRACT

A draft of the fifth edition of the RCC-MR code, named RCC-MRx 2010, has been issued in French and English versions on December 2010 by AFCEN (Association Française pour les règles de Conception et de Construction des Matériels des Chaudières Electro-nucléaires). This RCC-MRx Code is the result of the merger of the RCC-MX 2008 developed in the context of the research reactor Jules Horowitz Reactor project, in the RCC-MR 2007 which set up rules applicable to the design of components operating at high temperature and to the Vacuum Vessel of ITER. This is a non-public document established in order to prepare the fifth edition which will be published in French and English by AFCEN and will be named RCC-MRx 2012.

By this next edition, AFCEN try to bring together all the relevant stakeholders in a CEN-Workshop (CEN-WS-MRx) in order to develop, on the RCC-MRx basis, the European code for the design and fabrication of mechanical equipments for ESNII innovative nuclear installations. This CEN Workshop (whose duration is 18 months, from January 2011) will allow the Workshop members to consider the RCC-MRx 2010 and to propose modifications to be included in the RCC-MRx 2012 edition to meet the needs of MYRRHA and ASTRID projects and to prepare the design and construction of ALFRED and ALLEGRO.

This paper presents the code evolutions from the 2007 edition of the RCC-MR and describes the organization of the Workshop.

1. INTRODUCTION

The French AFCEN association proposed a complete collection for the design and construction codes for nuclear plants and related equipments, plants initiated by RCC-M for Pressurized Water Reactors (PWR).
The RCC-MRx design and construction code constitutes a single document that covers in a consistent manner the design and construction of components for high temperature reactors and research reactors and the associated auxiliaries, examination and handling mechanisms and irradiation devices.
The design rules were adapted to cover the mechanical resistance of structures close to neutron sources that can, depending on the situation, also operate in significant thermal creep conditions.
This RCC-MRx code was first issued in 2009 from the merging of the RCC-MR code, 2007 edition, devoted to high temperature reactors and ITER vaccum vessel and the RCC-MX code, edition 2008, dedicated to research reactors and related devices.

A new draft version has been prepared in 2010 and will be analysed in the frame of the CEN Workshop : the goal is to have a review of this code by all European stakeholder involved in various project (ASTRID, MYHRRA, ESS,...) to identify needed evolution of the code to be fully complete to answer their needs. A new version of the RCC-MRx code will then be officially edited by AFCEN in 2012.

This paper presents a general overview of this draft document, focuses on particularities of this AFCEN draft RCC-MRx 2010 Code and gives few words on the CEN Workshop MRx.

2. GENERAL OVERVIEW

The scope of application of the RCC-MRx design and construction rules is limited to mechanical component:

- considered to be important in terms of nuclear safety and operability,
- playing a role in ensuring leaktightness, partitioning, guiding, securing and supporting,
- containing fluids such as pumps, valves, pipes, bellows, compartmentalized structures, heat exchangers and their supports.

To enable the introduction of complementary design and construction rule sets such as those contained in new Standards NF/EN 13445 (unfired pressure vessels) and NF/EN 13480 (Metallic industrial piping), the usual RCC code format has been modified with the creation of three sections (**Fig. 1**):

- **Section I:** general provisions common to the entire code,
- **Section II:** additional requirements for the alternative use of other applicable rule sets (Standards NF EN 13445 and NF EN 13480 for instance) for Class 3 component, and special instructions for component subject to regulation such as pressure equipment or nuclear pressure equipment.
- **Section III:** set of applicable rules, adopting the format of RCC-M [1], RCC-MR [2] or RCC-MX [3] codes with five Tomes, Tome 1 being sub-divided into subsections:
  - **Tome 1** contains the design and construction rules and comprises subsections which are alphanumerically numbered.
  - **Tomes 2 to 5** contain the rules corresponding to various technical areas:
    - * Tome 2: part and product procurement specifications,
    - * Tome 3: destructive tests and non-destructive examination methods,
    - * Tome 4: qualifications for welding operations and welding procedures and their application,
    - * Tome 5: manufacturing operations other than welding.

The three classes of design and construction proposed ($N1_{Rx}$, $N2_{Rx}$ and $N3_{Rx}$) correspond to decreasing levels of construction quality assurance.

New materials, different from the steels used in Pressurized Water Reactors (PWR) and Sodium Fast breeder Reactors (SFR), such as alloys of aluminium and zirconium can meet requirements for neutron transparent materials of research or irradiation reactors (RR). For instance, for reflectors, the substitution of 10 mm of steel tube for 10 mm of zirconium or aluminium alloy tubes makes it possible to potentially obtain 50% more thermal flux. It is therefore necessary to make sure that suitable compromises are made between mechanical strength, thermal control (gamma heating of 10 to 20W/g in core) and activation effect control (e.g. cobalt content).

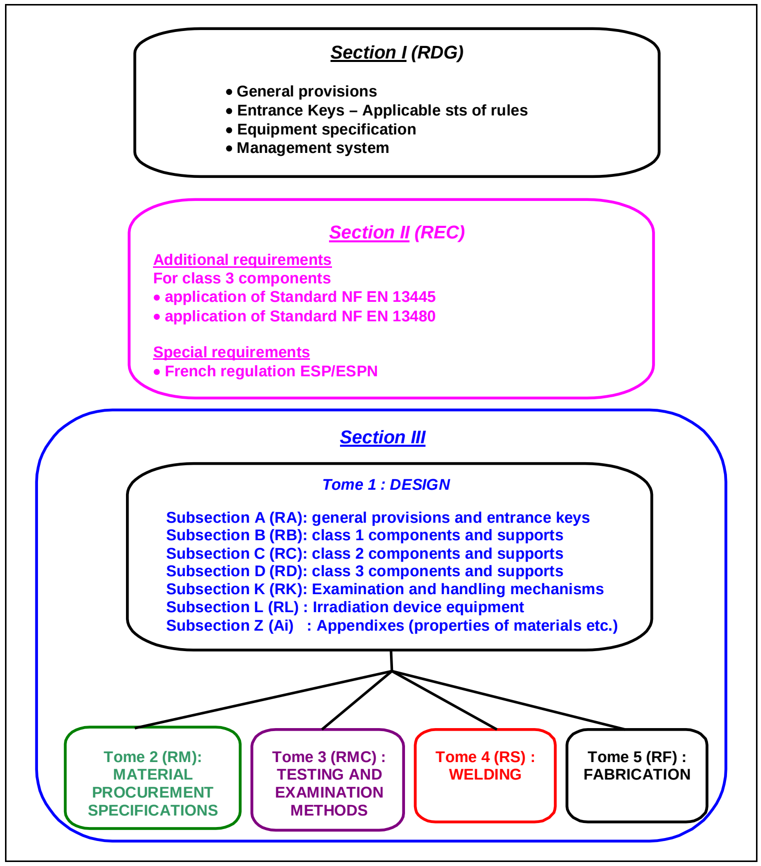

Figure 1: general plan of the RCC-MRx code

An update of subsection K for examination and handling mechanisms has been integrated.

Although the initial editions of the RCC-M and RCC-MR rely greatly on the French NF series standards at the time, the rapid development of European standards (EN and EN ISO) covering all subjects such as procurement, destructive and non-destructive testing, welding and now even design, leaded to carry out a considerable amount of work to integrate these new standards into the RCC-MR 2007 and RCC-MX 2008. This update of the standards is naturally found in the RCC-MRx code.

3. PARTICULARITIES OF RCC-MRx

Materials

According to the practice in RCC-M for Pressurized Water Reactors (PWR), material selection for the various components should be listed in Tome 1 chapter 2000 in table format showing item by item the Reference Procurement Specification or standard which have to be used. Such solution is not possible for a Design and Construction Code devoted to several types of reactors (high temperature reactors, research reactors, ITER,…). The "presentation of the RCC-MRx", included in the code, summarizes the selections for Sodium Fast Reactors (SFR) based on the most recent projects, and for Research Reactor (RR) « Jules Horowitz » (RJH).

Procurement requirements for products for components covered by the Section III are given in Subsections B, C, D, K and L 2000 with reference to Tome 2.
For each component or part of a component, the Equipment Specification shall define the document that the Manufacturer shall refer to for his procurement activity:

- either one of the Reference Procurement Specifications in Tome 2,
- or one of the Referenced Standards listed in RM 030-0 or in RB, C, D, K, L 2000,
- or Particular Procurement Specification (RM 011-5)

Parts/products representing a process innovation or material selection and particular parts made by reference to a special reference procurement specification are subject to Technical Qualification according to RM 014-3. These parts/products are listed in the Equipment Specification*;* they are identified during contract negotiations, by the Prime Contractor, Contractor and Manufacturers, from the lists of mechanical components to be designed and constructed in compliance with this Code (RDG 2330). Along with this Technical Qualification, a Product or Part Qualification Technical Report shall be prepared by the manufacturer, detailing the state of the art on this type of part/product.

The general design analysis rules are applicable to structures made of material whose properties are listed in one of the Properties Groups in Appendices A3 and A9 for the specified operating conditions. Then, in the case of a new product or new grade purchased under, for example, a Particular Procurement Specification, it must be:

- accompanied by a new Properties Group as shown in Appendices A3 and A9,
- validated by a Material Report as well as a report justifying the applicability of the general design analysis rules for the specified usage conditions.

Design

Design rules are contained in chapters 3000 of subsections B, C, D, K, L. They cover sizing and material behavior analysis and they aim to ensure that components are sufficiently safe under the various mechanical damages to which they could be exposed under loads in specified operating conditions.

These were drafted with due regard for the corresponding chapter of the RCC-MR code in order to introduce additional rules into it to cover conditions where irradiation is significant.

In addition to the negligible creep test in the RCC-MR which allows the effects of creep to be disregarded, a negligible irradiation test, based on a ductility criteria, has been added in RB 3216.2. This test makes it possible to disregard the effects of irradiation if the fluence received by the component in question remains below a value specified in Appendix A3 (Properties Group) at the service temperature in question. If the test is meet, the fluence is considered to be negligible and the rules "without irradiation" apply unrestrictedly. The same layout as RB 3200 of the RCC-MR code is used with allowance, in additional sections, for the effects of irradiation. The structure of RB 3200 is as follows:

	Negligible creep	**Significant creep**
Negligible irradiation	RB 3251.1 (Type P damages) RB 3261.1 (type S damages) identical to RCC-MR	RB 3252.1 (Type P damages) RB 3262.1 (Type S damages) Identical to RCC-MR
Siignificant irradiation	RB 3251.2 (Type P damages) RB 3261.2 (Type S damages) New rules	RB 3252.2 (Type P damages) RB 3262.2 (Type S damages) New rules

Table 1: Design rules for each domain

RCC-MRx proposes criteria to ensure sufficient safety and thus justify their design and sizing when these structures are made with materials with reduced ductility, either from the outset or as a result of irradiation.
To this end, to cover the area of negligible thermal creep and negligible irradiation, Appendix A3 provides, for the various materials and products, the allowable stress S_m (class 1 and 2) and S (class 3) used to limit the primary stress at criteria A level, as well as the permissible stress S_{mb} (class 1 and 2) and S_B (class 3) used for bolting. RCC-MRx 2010 lists the values of coefficients applied to $R_{p0.2}$ and R_m to determine them based on the different types of material, these coefficients are consistent with the European regulation for pressure vessel dispositions. For steel, the coefficients are taken from normal practice defined in RCC-M and RCC-MR. RCC-MRx shows the permissible stress in design rules for vessels (RB, RC, RD, RK, RL 3300) for criteria C and D levels. Proposed as an alternative for Level 3, the harmonized European standard NF EN 13445 uses the allowable stress f under conditions similar to S. For exceptional operating conditions, NF EN 13445 limits the stress with a allowable stress $f_{exceptional}$.

To cover the area of significant irradiation (under negligible thermal creep), in the case of elastic analysis, the primary stress is limited as shown previously by S_m, but all of the stresses (membrane stress and total stress) are also limited. The allowable stresses called S_{em} and S_{et} (listed in A3.57) are based on standard tension tests, with margins applied, which results in specific values: R_m(standard tensile strength at maximum force), A_{gt} (associated percentage total elongation at maximum force) and A_t (percentage total elongation at fracture). This curve and its values cannot be considered intrinsic to the material and the material values (local tensile curve and local fracture variables) can only be accessed through interpretation or fine measurement, which is difficult to perform systematically.
Therefore, it was agreed to:

- use the maximum point of the tensile curve R_m, A_{gt} to limit only the general membrane stress (P_m + Q_m) to avoid localization of the deformation by reduction in area that appears after this maximum and is specific to the uniform membrane load used in the test. This is very conservative because this type of stress is rarely uniform in complex structures. Traditional construction starts from point [R_m; A_{gt}] and adds margins leading to the membrane's elastic allowable stress S_{em}.
- For other stress (total stress P+Q+F), a realistic limit for deformation should be based on the local fracture variables taking into consideration the effects of the structure upon fracture (three dimensional testing and elastic follow-up onto secondary stresses). Given the difficulty in accessing these limit values and the effects on the structure upon fracture, use the instability limit provided by the tensile specimen with additional elastic follow-up factor and section coefficient k_b. This method, which could be judged insufficiently close to reality (too conservative) has the benefit of using easily accessible variables through experimentation with reasonable conservatism (before margins), in conjunction with stress analysis on non-irradiated materials (presence of section bending coefficient k_b that varies from 1.5 for a non-irradiated material to 1). Traditional elastic-follow-up construction starting from point [R_m; (A_{gt} + A_t)/2], a form factor k_b that is closer to 1 and the addition of margins lead to total elastic allowable stress S_{el} .

In addition, it has become necessary to keep the additional rule introduced in RCC-MX which aims to predict a structure's susceptibility (and thus its material) to the crack which could initiate fast fracture. The rule in RB 3250 for class 1 and 2 use mechanical fracture parameters and methods; it consists of ensuring that the value of parameter J calculated in normal operating conditions and assuming the existence of a conventional defect remains less than J_{IC}.

The accumulation of significant irradiation and significant thermal creep was provided in a specific case: annealed 316 and 316L grade stainless steel under temperature conditions such as $450°C \leq \theta \leq 625°C$. Under these conditions, the rules provided are applicable within a total irradiation limit of 25 dpa. In evaluating creep usage factors, the reference times used for non-irradiated conditions, t_r, should be replaced by $t_r^{ir} = t_r /10$. This also applies to creep damage calculations performed as part of a fatigue - creep analysis.

Finally, RCC-MRx provides in Appendix A3 “Properties Groups” maximum irradiation limit curves for various materials. These curves are based on ductility or swelling criteria (specifically in the case of steels where a saturation effect appears in the changes in tensile properties due to irradiation.

<u>Properties of materials (appendix A3) and welded joints (appendix A9)</u>

Application of the design rules in Tome 1 necessitates the introduction of a certain number of properties of the materials used in different parts of the component. The goal of Appendix A3 is to cover as broad a range of such properties as possible in view of the potential scope of characterization and the service conditions envisaged (high or low temperature, irradiated or unirradiated).

Appendix A3 contains a part providing general information and some Groups of Properties with a common table of contents and section numbering system.

Appendix A9 is dedicated to welded joints. Whenever necessary, it supplements or modifies, for an item of welded component, the properties of Appendix A3 which apply to it.

<u>Tests and examination methods</u>

Tome 3 of the RCC-MRx indicates the procedures to be applied for testing and examination prescribed by the code 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.

Tome 3 covers:

- in RMC 1000, the mechanical, physical and chemical tests,
- in the other chapters, the various non-destructive examination techniques:
  - ultrasonic,
  - radiographic,
  - penetrant,
  - magnetic particle,
  - eddy current for tubes,
  - other methods of inspection (visual, video, determination of surface finish, detection of leaks),
- a last chapter covering qualification and certification of non-destructive examination staff.

Many standards based on nuclear and non-nuclear practices relate to these different techniques of testing and examination. The standards are continuously evolving to allow for changes in the practices and the types of equipment used, and above all to achieve European Union level harmonization (such standards are designated NF EN in their French language versions) if not at a broader international level (standards designated NF EN ISO in their French language versions). Tome 3 of the RCC-MRx applies to the most recent versions of these standards. But it is not sufficient simply to quote them, as interfacing is necessary to resolve the options offered in the standards, but to indicate the parts of the standards that are integrally applicable and to supply further information and additional requirement elsewhere. The following sections cover certain aspects of this interfacing.

Welding

General provisions for welding of class 1, 2 or 3 components are given in RB 4400, RC 4400 and RD 4400. RK and RL 4400 present detailed rules applying respectively to examination or handling mechanisms, and irradiation devices. These chapters refer to Tome 4 which deals in detail the elements relating to welding.
The aluminium and zirconium alloys welding requires allowance for special precautions that are provided by RCC-MRx.

Fabrication

Tome 5 gives 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 assure 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 must make allowance for any additional rules and tolerance limits that may be specified either in the various subsections of Tome 1 or, in the Equipment Specification.
For all items of Tome 5, the RCC-MRx specificities are requirements concerning aluminium alloys, zirconium alloys and irradiation devices.

4. CEN-WORKSHOP-MRx

Background

In the SET-Plan (Strategic Energy Technology) of the European Commission, the European Industrial Initiatives (EII) constitutes key elements with the aims to strengthen industrial energy research and innovation and to mobilise the necessary critical mass of activities and actors in order to accelerate deployment of new technologies.
With these objectives, the creation of European Technology Platforms has brought together stakeholders to define common research agendas and deployment strategies. For the nuclear energy, this is the Sustainable Nuclear Energy Technology Platform (SNETP).
The SNETP has set up a Task Force comprising research organisations and interested industrial partners to define the European Sustainable Nuclear Industrial Initiative (ESNII).
The ESNII's Task Force has prioritised the fast neutron systems and is proposing to develop a three tracks programme following the scheme below:

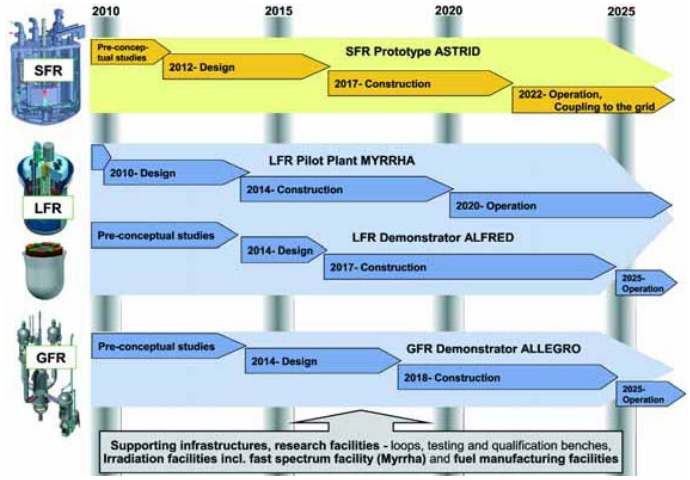

Figure 2: ESNII Road Map

Considering the choice already made in France and in Belgium to build the mechanical components for ASTRID and MYRRHA on the RCC-MRx basis, the ESNII Task Force recommended, at its March 2010 meeting, to bring together all the relevant stakeholders in a CEN Workshop in order to develop, on the RCCMRx basis, the European code for the design and fabrication of mechanical equipments for ESNII innovative nuclear installations.

Goals and Program

The proposed CEN Workshop will allow the Workshop members to consider the draft RCC-MRx 2010 and to propose modifications to be included in the RCC-MRx 2012 edition to meet the needs of MYRRHA and ASTRID projects and to prepare the design and construction of ALFRED and ALLEGRO, as well as other projects like ESS (European Spallation Source).
This will contribute to share a common European approach on structural integrity for innovative nuclear installations components by:
• rationalising pre-normative R&D activities in Europe and capitalizing European R&D results into an European Framework,

• capitalising European and international feedback of experience gained in the design and construction of innovative nuclear systems (ITER, PFBR (India), etc….)
• meeting the WENRA objectives to develop a common European approach for innovative nuclear prototypes in the field of structural integrity,
• reinforcing the links between European mechanical engineering standards and the nuclear industry.
The Workshop (whose total duration is about 18 months) will work in two steps:

- Modification files proposed by the Workshop participants will be sorted into (during the first 6 months of the Workshop):
    - short-term modifications for which data and justifications are available and do not need pre-normative R&D. They could be linked with the RCC-MRx acceptability for specific projects.
    - medium-term modifications for which modification review needs some pre-normative R&D activities and should be delayed to a future Workshop agreement.
    - long-term modifications which need to acquire further R&D results before review.

  The modification files sorting will be concluded by a report.

- Preparation of Modification review files for each short-term modification which should be completed in time for the RCC-MRx 2012 edition (during all the Workshop duration).

After endorsement, the modification review files will be transmitted to AFCEN which, acting as maintenance organization, is in charge to update the RCC-MRx and to issue the next edition according to its own procedure.

Organization of the work

The Work will be shared between four Working Groups that deal with different sections of RCC-MRx Code:

- WG 1 in charge of Chapter 1: Design rules
- WG 2 in charge of Chapter 2: Materials specifications
- WG 3 in charge of Chapter 3: Tests and non-destructive examinations
- WG 4 in charge of Chapter 4: Welding and Chapter 5: Fabrication (Manufacturing)

The Kick-Of-Meeting of this CEN-Workshop took place in the beginning of February 2011 with about 20 potential partners from all over Europe. This Workshop will end by the end of September 2012.

5. CONCLUSION

Today, RCC-MRx code provides tools for design and construction of Nuclear Installations including High Temperature applications such as Sodium Fast Reactors, the ITER Vacuum Vessel, Research Reactors and related devices. Since the previous RCC-MR edition, the draft RCC-MRx 2010 edition includes a lot of improvements such as:

- Specific materials of research reactors and irradiation devices such as aluminium alloys or zirconium alloys are now added in the code.
- Specific material properties and rules developed for such irradiated components.

The RCC-MRx will continue to evolve regarding industrial developments, supplier experience, project needs, operation experience, and evolution of regulation and standards. Given the large number of projects underway in Europe (MYRRHA, ASTRID, ALLEGRO …), the fifth edition which will be published by the end of 2012 in French and English by AFCEN and will be named RCC-MRx 2012. This next edition will take into account all the modifications coming from the CEN Workshop.

NOMENCLATURE

RCC-MRx 2010: Design and Construction Rules for Mechanical Components of Nuclear Installations

CEN: European Committee for Standardization

ESNII: European Sustainable Nuclear Industrial Initiative

REFERENCES

[1] RCC-M - Design and Conception Rules for Mechanical Components, 2010 AFCEN Code, Association Française pour les Règles de Conception et de Construction des chaudières Electro-Nucléaires. www.afcen.com.

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[3] RCC-MX 2008 - Design and Construction Rules for Mechanical Components of Research Reactors and their experimental devices, 2008 CEA Code, Commissariat à l'Energie Atomique et aux énergies alternatives.

[4] Draft RCC-MRx 2010 - Design and Construction Rules for Mechanical Components of Nuclear Installations", *working document to prepare the fifth edition of RCC-MR named RCC-MRx* by AFCEN, Association Française pour les Règles de Conception et de Construction des chaudières Electro-Nucléaires. www.afcen.com.