Bulletin of the JSME
Mechanical Engineering Journal
Vol.7, No.4, 2020

【Technical Note】

Design and construction rules for mechanical components of high-temperature, experimental and fusion nuclear installations: the RCC-MRx Code last edition

Jorge Enrique MUÑOZ GARCIA*, Cécile PÉTESCH*, Thierry LEBARBÉ*, Dominique BONNE**, Claude PASCAL*** and Martine BLAT****

* CEA - French Alternative Energies and Atomic Energy Commission
Paris-Saclay Centre, 91191 Gif-sur-Yvette, France
E-mail: jorge-enrique.munoz-garcia@cea.fr
** Framatome DTI, 69006 Lyon, France
*** TechnicAtome, 13115 Saint-Paul-Lez-Durance, France
**** EDF Research and Development, Les Renardières, 77250 Moret-sur-Loing, France

Received: 28 January 2020; Revised: 27 June 2020; Accepted: 7 July 2020

Abstract

The very last edition of the RCC-MRx Code (Design and Construction Rules for Mechanical Components in high-temperature structures, experimental reactors and fusion reactors) was published end of 2018 by AFCEN, the French Association for the rules governing the Design, Construction and Operating Supervision of the Equipment Items for Nuclear installations. The RCC-MRx Code is a consistent set of technical rules to be applied on the design of research reactors (derived from the last edition ever of RCC-MX Code in 2008, code especially developed for the Jules Horowitz Reactor (JHR)), on high temperature structures (derived from the last edition ever of RCC-MR Code in 2007, code devoted to high temperature reactors, the ITER Vacuum Vessel and to the French Fast Breeder Reactors) and on Fusion reactors. The scope of the RCC-MRx Code is restricted to mechanical components of high temperature structures, Sodium Fast Reactors (SFR), Research Reactors and Fusion Reactors (ITER/DEMO), but the RCC-MRx Code can also be used for mechanical components of other types of nuclear installations, as the European Spallation Source Target (ESS) for example. This paper is presenting the content and organization of the last edition, the RCC-MRx Code 2018, and the recently incorporated feedback from users, such as ITER project, JHR (Jules Horowitz Reactor) in France, ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) project in France, PFBR project (Prototype Fast Breeder Reactor) developed by IGCAR (Indira Gandhi Centre for Atomic Research) in India, and MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) project in Belgium.

Keywords : Codes and standards, RCC-MRx Code, Design, Research reactors, High temperature structures, Fusion, Nuclear installations

1. Introduction: the AFCEN Codes

AFCEN Codes are used as reference for nuclear components in over 100 power plants currently in operation (92), under construction (21) or in planning stages (7) around the world. Information on how AFCEN Codes are used around the world during planning, design, construction and operation of different reactors is provided in detail here (afcen, 2020a). In addition to these formal applications of AFCEN Codes, they have also served in France for designing many other nuclear facilities like nuclear steam supply systems for marine propulsion. AFCEN is an organization of operators, manufacturers, equipment suppliers, organizations, consulting firms, training providers, actively involved not only in the French but also in the international nuclear industry. In 2018, AFCEN has more than 67 institutional members, representing more than 650 experts who contribute to the development and continuous improvement of AFCEN Codes at international level. In 2018, 126 nuclear power plants and experimental reactors were currently designed and/or built using AFCEN Codes. The international AFCEN association proposes a complete codes collection for the design and

Paper No.20-00052
J-STAGE Advance Publication date : 14 July, 2020
[DOI: 10.1299/mej.20-00052]

construction of nuclear plants and related equipment. AFCEN Codes are published in English and French and are continually updated with feedback from international industrial best practices and changes to regulations, while striving to achieve harmonization with the other nuclear codes used around the world. AFCEN has extended the range of technical fields covered, with three codes for mechanical components: RCC-M Code (design and fabrication for PWR), RSE-M (in-service inspection) and RCC-MRx Code (design and fabrication for high-temperature reactors, experimental reactors and fusion reactors); one code for PWR electricity and IC systems (RCC-E Code); one code for PWR nuclear fuel (RCC-C Code); one code for PWR civil engineering works (RCC-CW Code), and one code for PWR fire protection systems (RCC-F Code) as shown in Fig. 1. AFCEN design and construction codes are prefixed with RCC-, while the in-service code is prefixed with RSE. AFCEN currently publishes seven codes, including five RCC- codes, one RSE- code and one ETC- code:

RCC-CW Code: Design and construction rules for PWR civil engineering works

RCC-M Code: Design and construction rules for PWR mechanical equipment

RCC-E Code: Design and construction rules for electrical equipment

ETC-F Code: Design and construction rules for PWR fire protection systems

RCC-C Code: Design and construction rules for PWR fuel assemblies

RSE-M Code: In-service inspection rules for mechanical components of PWR

RCC-MRx Code: Design and construction rules for mechanical components in high-temperature structures, experimental reactors and fusion reactors.

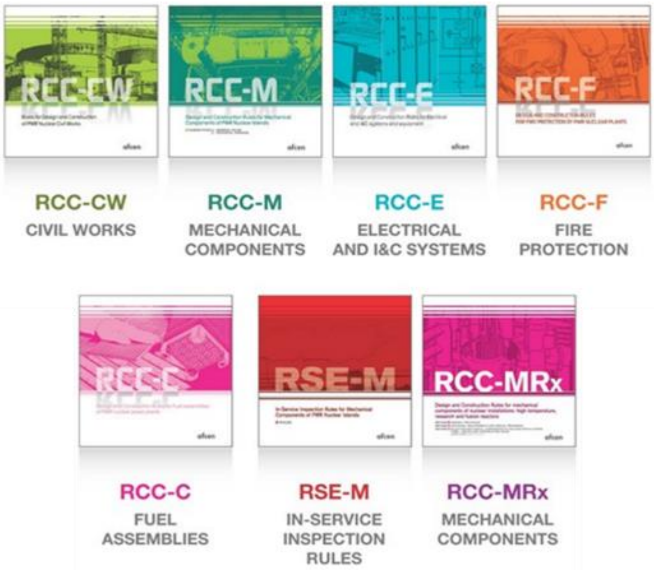

Fig. 1 The AFCEN Codes.

2. The origin of RCC-MRx Code

AFCEN was initially founded by electric utility EDF (Electricité de France) and nuclear steam supply system manufacturer FRAMATOME (ex AREVA). Ever since its inception in 1978, AFCEN has been driven by a mission to establish a series of technical rules reflecting on-the-ground practices, feedback from industry and the latest knowledge in a bid to guarantee the superior level of quality and safety required for operating nuclear reactors.

2.1 The RCC-MR Code

Since its creation, AFCEN has considerably broadened its scope of activities. AFCEN's name is often associated with the RCC-M Code (Design and Construction Rules for Mechanical Components of Pressure Water Reactors) initiated in 1981, but AFCEN also developed a code for Fast Breeder Reactors, the RCC-MR Code, based on CEA (French Alternative Energies and Atomic Energy Commission) and EDF research and on the experience and knowhow accumulated by NOVATOME (nuclear steam supply system manufacturer FRAMATOME, ex AREVA) during the design and construction of the SuperPhénix Reactor (fast breeder reactor commercial prototype) in France.

The first edition of the RCC-MR Code appeared in 1985 and subsequent editions in 1993, 2002 and 2007. The

[DOI: 10.1299/mej.20-00052]

framework of the RCC-MR Code was very precise and delimited by the needs of its authors: after the construction of the first experimental FBR (Phénix) and the design of SuperPhénix at the end of the 1970s, there was the beginning of a postulated French FBR industrial phase, then a Code of applicable rules had to be compiled. Phénix and SuperPhénix reactors were designed based on ASME boiler and pressure vessel code Section III published by American society of mechanical engineers (ASME) and its Code case N47, but the application of these codes was not entirely satisfactory because of the high cyclic thermal loading and slender structures of these reactors. The scope of RCC-MR Code was limited to fast breeder mechanical components, important for the safety of the reactor, within the frame of French FBR project.

Subsequent RCC-MR Code editions (1993 and 2002) were focused on the improvement of the code mostly on the design chapters. The RCC-MR Code 2002 was used to design and build the prototype Fast Breeder Reactor (PFBR) developed by IGCAR (Indira Gandhi Centre for Atomic Research) in India (Aithal et al., 2018).

In 2005-2006, new collaborations led to an evolution of the RCC-MR Code 2007 edition. The first major improvement was the introduction of a dedicated appendix to the ITER (International Thermonuclear Experimental Reactor) vacuum vessel (VV). This improvement represented not only the introduction of a new type of component, but the possibility to apply the code to a different type of reactors: fusion reactors (Aubert et al., 2019). Nevertheless, its application was restricted to one component of the ITER installation, the VV.

2.2 The RCC-MX Code

In parallel to evolution of the RCC-MR Code, a new document was developed by both CEA and TechnicAtome (compact nuclear reactors manufacturer, ex AREVA) to answer to the needs of a new irradiation installation project: the Jules Horowitz Reactor (JHR) (Gay et al., 2017). That was the origin of the RCC-MX Code. The new needs were very specific: the design should take into account irradiation phenomena, specific materials such as aluminium and zirconium, and to have the possibility to cover diverse components inside the reactor (small components, on-the-shelf-commercial components). CEA published two editions of RCC-MX Code in 2005 and 2008. The RCC-MX Code is currently being used in the construction of the JHR, as illustrated in Fig. 2.

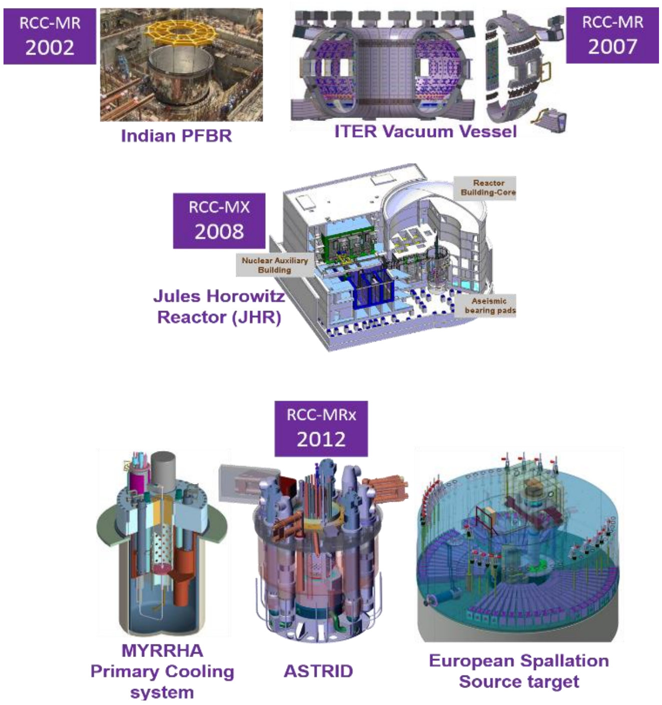

Fig. 2 Use of RCC-MR, RCC-MX and RCC-MRx codes around the world.

2.3 The RCC-MRx Code

In 2009, a decision to integrate the RCC-MX Code into the RCC-MR Code in a draft document called "RCC-MRx Code" was taken based on the evidence that most of the technical tools were common to the two projects JHR (Jules

Horowitz Reactor) and ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) so it was possible to extend the scope of the RCC-MR Code. Finally, both the scope and the structure of the code were modified, as illustrated in Fig. 3.

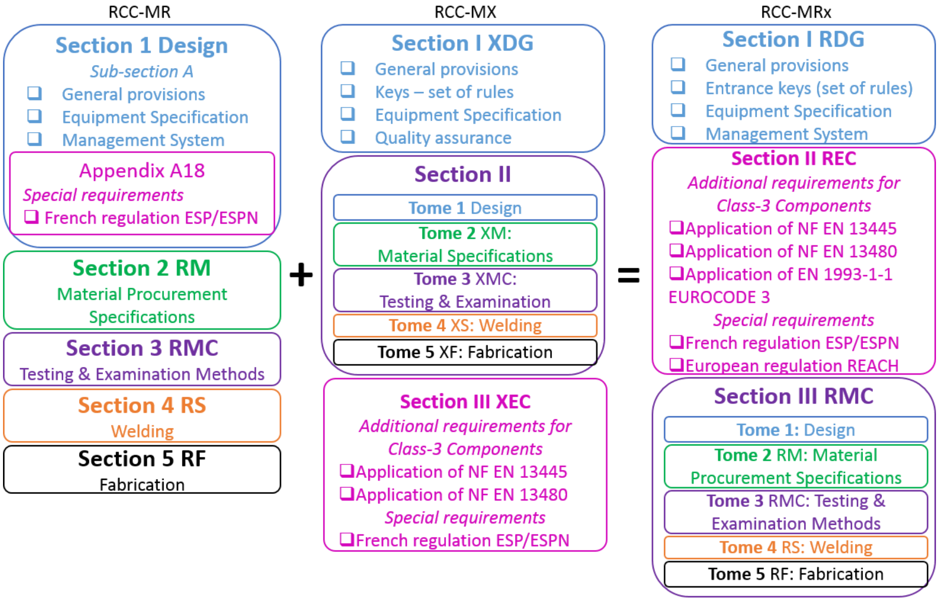

Fig. 3 Structure of the RCC-MR and RCC-MX and the resulting structure of RCC-MRx.

The main advantage of the new structure of the code is to separate the technical tools from other requirements specific to one country or to one project. This modular system allows the use of the RCC-MRx Code for different reactors such Fast Breeder Reactors or irradiation facilities. RCC-MRx Code was first published in 2012, then in 2015 and the new edition in 2018. The RCC-MRx Code is serving as a reference for the design of the ASTRID project in France, for the design of the primary circuit in MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) in Belgium, and the design of the target station of the ESS project (European Spallation Source) in Sweden (afcen, 2020b).

3. Application scope of the RCC-MRx Code

The scope of application of the RCC-MRx Code is limited to mechanical components:

- considered to be important in terms of nuclear safety and operability
- playing a role in ensuring leak tightness, partitioning, guiding, securing and supporting
- containing fluids such as pumps, valves, pipes, bellows, box structures, heat exchangers, irradiation devices, handling and driving mechanisms and the associated supports, when existing

4. Organization of RCC-MRx Code

RCC-MRx Code is organized in three sections. Section III is divided into 6 Tomes. Tome 1 is sub-divided into sub-sections:

- **Section I**: general provisions common to the entire code.
- **Section II**: additional requirements for the alternative use of other applicable sets of rules (EN 13445 and EN 13480) for Class $N3_{Rx}$ component, and special instructions for components subject to regulations such as (conventional) pressure equipment or nuclear pressure equipment.
- **Section III**: set of applicable rules, adopting the format of RCC-M, RCC-MR or RCC-MX codes with five Tomes, Tome 1 being sub-divided into subsections:

Tome 1 contains the design and construction rules and comprises subsections that are alphanumerically numbered:

- Subsection **A**: general provisions for Section III,
- Subsection **B**: class $N1_{Rx}$ components and supports of the nuclear reactor and its auxiliary systems,
- Subsection **C**: class $N2_{Rx}$ components and supports of the nuclear reactor and its auxiliary systems,
- Subsection **D**: class $N3_{Rx}$ components and supports of the nuclear reactor and its auxiliary systems,

[DOI: 10.1299/mej.20-00052]

- Subsection **K**: examination, handling or drive mechanisms covering all classes,
- Subsection **L**: components of irradiation devices covering all classes,
- Subsection **Z**: technical appendices (seismic analysis of equipment, materials properties groups, properties groups for welds, design rules for mechanical connectors, design of bolted assemblies, design rules for shells of revolution, for linear type supports, for formed heads, prevention of fast fracture, leak before break analysis and defect assessment, constructive requirements linked to in-service inspections).

Tomes 2 to 6 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,
- **Tome 6**: collection of probationary phase rules.

The three classes of design and construction proposed ($N1_{Rx}$, $N2_{Rx}$ and $N3_{Rx}$) correspond to decreasing levels of assurance of ability to withstand different types of mechanical damages to which the component might be exposed as result of loading corresponding to specific operating conditions. These classes are connected to the safety class of the component.

Table 1 List of PPR included in RCC-MRx Code 2018 edition.

Title	Purpose
RPP1-2012-RA5000 Introduced in 2012 Management system	Requirements applicable to the establishment and implementation of a quality management system in association of RCC-MRx Code
RPP2-2012-9%Cr Introduced in 2012 Properties of chrome alloy steels from Annex A3.18AS	Properties of chrome alloy steels from Annex A3.18AS (normalized and tempered, or quenched and tempered X10CrMoVNb9-1 alloy products and parts) – cyclic behaviour and creep
RPP3-2012-RM 243-2 Introduced in 2012 RM 243-2 thick plates	Extension of application of RM 243-2 to the fabrication of X10CrMoVNb9-1 alloy steel plates with thickness over 150 mm up to 250 mm
RPP4-2012-Eurofer Introduced 2012, **Modified 2018** Steel X10CrWVTa9-1	Introduction of the reduced activation alloy Eurofer-97 ® in the Code **New irradiation data included in RCC-MRx Code 2018 edition**
RPP5-2012- Casing 6061-T6 Introduced 2012, **Modified 2018** A3.2A casing 6061-T6	Complement to Appendices A3.GEN and A3.2A to be considered when using S-RPS RM 522-7: Type 6061 T652 Al-Si-Mg alloy forged blanks for the core casing **New material properties before and after irradiation in new edition**
RPP6-2012 Aluminium welds Introduced 2012, **suppressed** US inspection of welds on aluminium alloys	Introduction of measures for US inspection of welds on aluminium alloys **Rule reincorporated in the RCC-MRx Code 2018 edition**
RPP7-2012-A16 Introduced in 2012 A16 – Locating defects	Definition of a general procedure for locating defects. General procedure to specify the position of the section or defect in relation to the part as a whole
RPP8-2013-SMC2 Introduced 2012, **Modified 2018** Use of the SMC2 method	Extension of the method of Seismic Moments Classification SMC2 to type S damages. **Complementary SMC2 seismic moments classifications included**
RPP9-2013-800H Introduced 2012 800H Alloy	Introduction of bars and tubes RPS in alloy 800H (nickel-chromium-iron alloy X8NiCrAlTi32-21 type) and the associated appendix A3
RPP10-2015-A3.2A.69 Introduced 2012 Swelling of 6061-T6 alloy	Modification of chapter A3.2A.69 dealing with swelling law (after irradiation) of Aluminium 6061-T6
RPP11-2018-18MND5 Introduced in 2018 18MND5 steel	Introduction of two G-RPS for the procurement of 18MND5 alloy steel forgings and plates, and of the associated properties group A3.12AS
RPP12-2018- A3.7SA Introduced in 2018 NiCr19Fe19Nb5Mo3 Alloy	Introduction of Inconel 718 ®
RPP13-2018- RMC6134 Introduced in 2018 Eddy current examination of steam generator tubes procured following RM 414-1	Introduction of requirements regarding the reference tube to be used for eddy current examination of steam generator tubes procured following RM 414-1
RPP14-2018-RDG2320 Introduced in 2018 Innovative coolants guidelines	Introduction of guidelines for the use of RCC-MRx Code in innovative coolant environment
RPP15-2018-OAD Introduced in 2018 Al-alloys hard anodizing	Introduction of hard anodizing surface treatment for Aluminium alloys

[DOI: 10.1299/mej.20-00052]

4.1 Probationary Phase Rules

The Tome 6 of the code gathers the probationary phase rules. There are good practices, processes, products, material grades and material data providing solutions to technical problems of interest to RCC-MRx Code but without enough industrial feedback to be included yet in the code. A careful consideration was taken on how to make these solutions available in order to obtain from users the needed feedback for its inclusion in the RCC-MRx Code. This consideration resulted on the creation of a dedicated part of the code for research and development results or pre-normative developments, with not enough feedback to be included in the code. This part of the code, called collection of Probationary Phase Rules (PPR), identifies the elements to be provided for a proposed rule to be considered as receivable for the code. The PPR are periodically revised in order to verify whether new elements are available for the rule justifications or not. If it is not the case, the probationary status of a rule remains unchanged, or the rule can be suppressed. The new edition of the RCC-MRx Code contains fifteen PPR and are listed in Table 1. The structure of a Probationary Phase Rule is described as follows:

- Purpose of change: it consists in a brief description of the goal of the modification.
- Modification status: this part indicates whether the proposal rule intends to replace an existing part of the code or just to complete it. This part indicates the considerations that lead to the probationary status of the proposed rule as well as the complementary elements of justification needed for an update of the status.
- Text: the proposed rule

4.2 New Probationary Phase Rules in RCC-MRx Code 2018 edition

The new PPR introduced in the new edition are highlighted in Table 1. A brief description is provided:

- **RPP11** related to the introduction of 18MND5: This low-alloy steel grade is already codified in other standards (EN 10222, EN 10228 and RCC-M Code for instance), but a work was needed to adapt available data to ASTRID needs within RCC-MRx Code context. It has been proposed to implement two Reference Procurement Specifications (RPS-G 212-3 and 212-2) based on those already existing for 16MND5 grade in RCC-MRx Code (Fig. 4), and with the consideration of the available feedback on the EPR® (European Pressure Reactor, a GEN III pressurized water reactor) procurements for forged parts and plates.

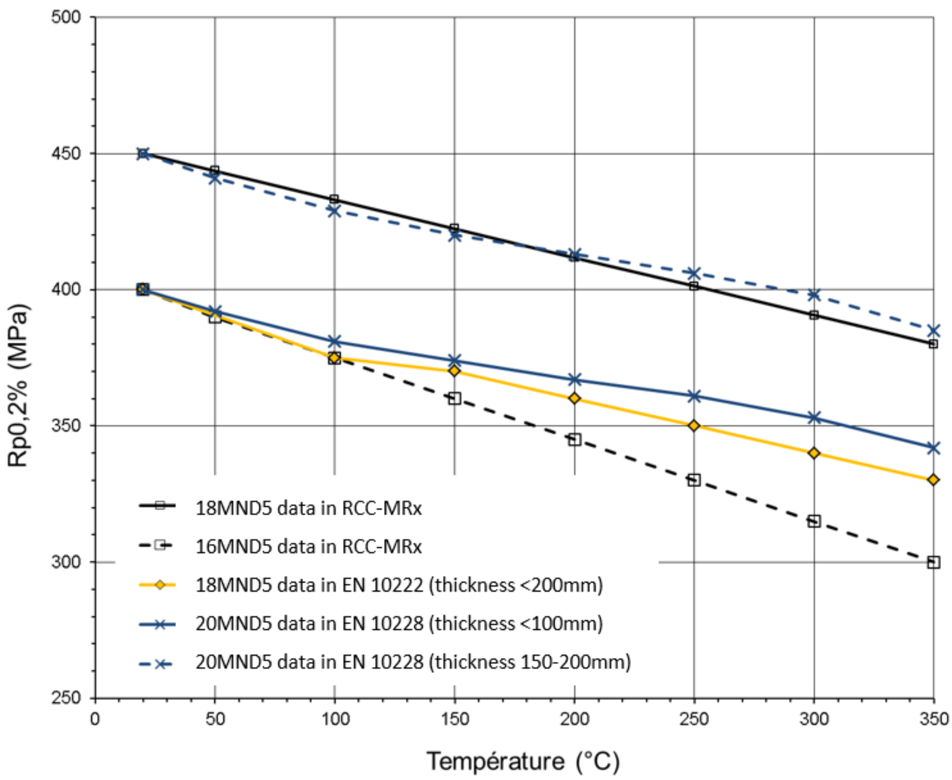

Fig. 4 Available data in view of the introduction of 18MND5.

- **RPP13** related to Eddy current examination: This rule introduces provisions regarding the reference tube to be used for eddy current examination of seamless X5NiCrTiAl33-21 annealed at 980°C alloy tubes for steam generator bundles of Sodium Fast Reactors, procured following the S-RPS (SFR) RM 414-1. This reference tube was used for the examination of a tube lot manufactured as part of the feasibility studies for the procurements in the frame of the ASTRID project. Taking into account the constituted defect catalogue and the obtained level of background noise, the tube manufacturer confirmed the possibility to control tubes using this reference tube, with same dimensions for the reference holes than those used for the examination of PWR steam generator tubes. Analysis of feedback from applying this RPP as part of the procurement of a significant quantity of tubes with same properties will enable to reassess the status of this RPP and thus consider incorporating this rule definitively in the RCC-MRx Code.

- **RPP14** related to Innovative installations: New reactors are under development and are going to use innovative coolants like LBE (Lead-Bismuth Eutectic), Lead, or supercritical water. There is no feedback about and mechanical components of such reactors are not explicitly covered by the present code. However, some recommendations are provided to be taken in consideration to ensure structural integrity under operating conditions. For example, some considerations on the interaction of innovative coolant with the structural material are given. These recommendations should orient the research and development efforts and guide the designer in the choice of material with respect to the compatibility of different material families with such environment.

As the purpose of the RCC-MRx Code is also to be adapted to innovative installations, it was important, in parallel to a better definition of the current scope of the code, to guide a potential user by offering tools to adapt or to develop the RCC-MRx Code. A proposal (coming from the CEN WS 64 Phase 2, see 7.2) was to give these recommendations for the use of the code in an innovative coolant. These recommendations, completed with other tools already available and with the possibility to implement rules in a PPR can help innovative concepts to reach a first stage of industrialization.

- **RPP15** related to Aluminium alloys hard anodizing: This rule defines both the execution and process qualification for the hard anodizing treatment of aluminium alloy parts. The treatment aims at producing an oxide layer at the surface of the part, in order to protect it from potential phenomena such as galvanic corrosion. This rule takes into account the feedback from the JHR project for this type of treatment, including the surface preparation to be considered as well as all the tests to be performed during the process qualification and the final quality control. It is to be noted that this treatment behaviour has not been studied under irradiation conditions, neither for temperatures exceeding 70°C.

5. RCC-MRx Code 2018 edition highlights

Since the RCC-MRx Code 2015 edition in (Lebarbé et al., 2017), they were more than 140 modifications of the code (Pétesch et al., 2018a). All parts were impacted, but mostly Tome 1 Design, Tome 2 Materials, Tome 4 Welding and Tome 5 Fabrication. The new edition RCC-MRx Code provides the synthesis of three years of developments articulated mainly around two axes (RCC-MRx, 2018):

1. Development of rules to answer to the projects needs from the three communities: high temperature reactors (Lee et al., 2018) with initiation of adapting the RCC-MRx Code to be applicable for all GEN IV reactors (Pétesch et al., 2018b), research reactors and fusion reactors (Pétesch et al., 2017). As an example, improvement of rules to take into account irradiation, new organization of chapters addressing fast fracture and progressive deformation, completion of A3 appendix dealing with Eurofer (Muñoz Garcia et al., 2018). A comparison of RCC-MRx Code and ASME for elevated temperature design is provided here (Lee, 2016).
2. Harmonization with other codes and standards: a number of modifications come from harmonization actions. We find updated standards (ISO and EN standards, RCC-M Code) referred in the code, but also the actions initiated within the frame of the European Committee for Standardization (CEN).

The distribution of the modifications according to the various items is illustrated in Fig.5. Only a few highlight examples are presented hereafter to illustrate the diversity of modifications introduced in the RCC-MRx Code 2018 edition:

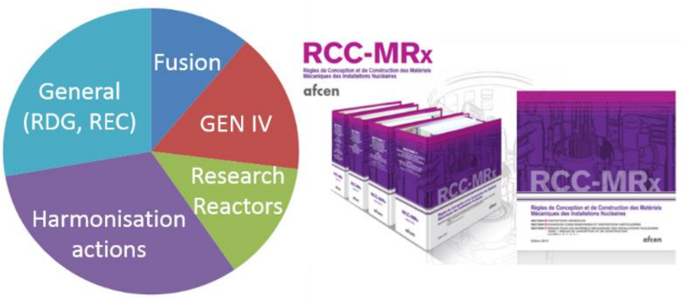

Fig. 5 Scope of modifications included in RCC-MRx Code 2018 edition.

5.1 Ratchetting: the RCC-MRx Code Efficiency Diagram Rule

In order to evaluate the design of nuclear reactor components, codes and standards provide a set of rules to analyse different kind of damages. Nevertheless, the analysis procedures are different depending on the code or the standards. The RCC-MRx Code proposes a method called "efficiency diagram rule" to evaluate ratchetting damage in negligible and significant creep. This rule has been modified to improve its representativeness of this damage and to deal with several loading types and different materials since the first edition of RCC-MR Code because existing ratchetting rules seemed to be over conservative and not appropriate, like the "3 Sm rule" from ASME. Indeed, they were based on over-simplified behaviours not taking into account the ductility and the cyclic behaviour of the material while these characteristics are favourable for austenitic stainless steels. Besides, these rules were only valid in the domain of negligible creep. For these reasons, a large experimental program was performed in CEA in order to propose a new type of rule: the efficiency diagram. This program was essentially composed of tension-torsion tests on austenitic stainless steels at different temperatures in negligible creep and significant creep domains, with the main advantage of having a procedure close to the physical and mechanical phenomenon, and consequently it is less conservative than the classical rules based on over-simplified material behaviour.

In previous editions of RCC-MR Code, RCC-MX Code and RCC-MRx Code, the ratchetting rule, the efficiency diagram and the associated limits were located in the "General analysis rule" Chapter (RCC-MRx Code Chapter RB 3000). In the new edition, the rule remains in this chapter, but the efficiency diagram and its associated limits have been shifted to RCC-MRx Code Appendix A3 material characteristics appendices. This means that each material can have its own efficiency diagram and its own limits (Fig. 6). The introduction of the efficiency diagram goes hand to hand with the introduction of specific limits for negligible and significant creep domain. The EN X10CrMoVNb9-1 is the first material that presents a new efficiency diagram different from its original one. With this new structure, the RCC-MRx Code can include new diagrams for other materials already included in the code (Martin et al., 2018).

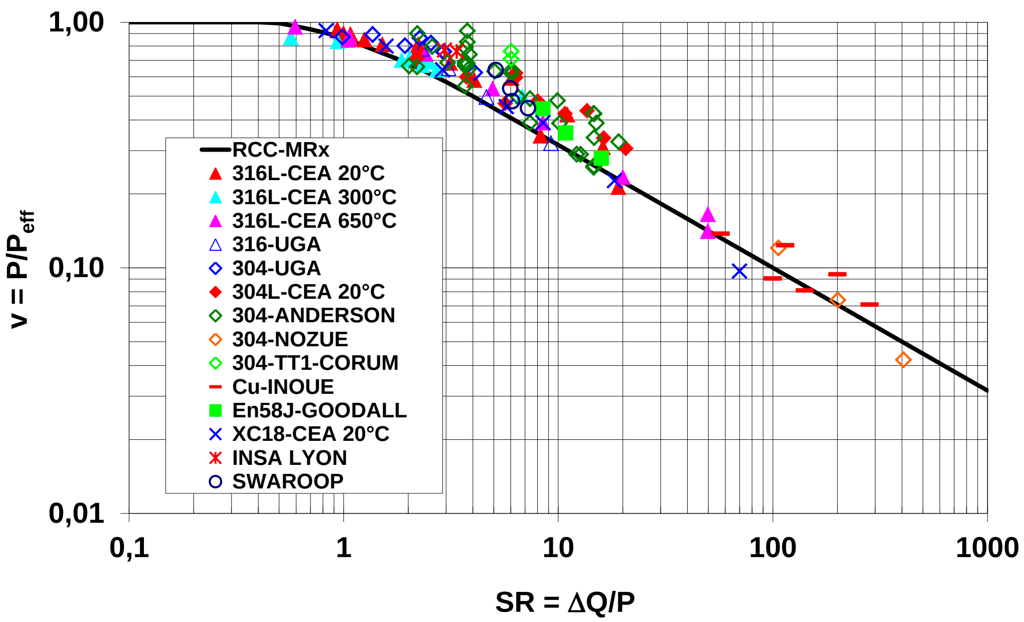

Fig. 6 Efficiency Diagram with experimental results.

5.2 Clarification of the scope: Irradiation

A working group was launched in 2016 to improve the scope definition of the code around three axes:

1. A better understanding of the damage,
2. A better definition of the methodology used for the rule and for the border curves (Dubiez-Le Goff et al., 2016),
3. A work of consolidation of the data used for the design.

[DOI: 10.1299/mej.20-00052]

It appeared clearly that the applicability of the code to a given installation needed some clarification on the nature of the irradiation. A re-interpretation of the database used for the RCC-MRx Code has been conducted and the result in term of irradiation definition has been integrated (Fig. 7) in the general part of the A3 appendix (data design).

A3.GEN.4 DETERMINATION OF IRRADIATION

*Material characteristics available in **A3.6** enable to apply rules of this Code in significant irradiation domain.*
The characteristics are issued from tests carried out at a temperature close to the irradiation temperature.

*A3.GEN.413 **AUSTENITIC STAINLESS STEELS***

Irradiation damage is expressed using the displacements per atoms (dpa) NRT as defined by M.J. Norgett, M.T. Robinson and I.M. Torrens.
The experimental validation domain for the data provided in appendices A3.1S, A3.3S and A3.4S corresponds to:

- *Total fluence (n/cm²) : $9x10^{19}$ – $3x10^{23}$*
- *Fast fluence E > 0.1MeV (n/cm²) : $3x10^{19}$ – $3x10^{23}$*
- *Produced Helium (appm) : 10 – 6000*
- *Temperature (°C) : 25 – 575*

*A3.GEN.414 **ALUMINIUM ALLOYS***

The experimental validation domain for the data provided in appendices A3.1A corresponds to:

- *Conventional thermal fluence (n/cm²): $2x10^{21}$ – $3x10^{23}$*
- *Fast fluence (n/cm²): $4x10^{20}$ – $2x10^{23}$*
- *Thermal or conventional fluence / Fast fluence Ratio: 0.8 – 8*
- *Temperature (°C) : 20 – 200*

Fig. 7 Abstract of A3.GEN chapter; the 2018 edition modification in yellow.

5.3 Update of material characteristics: Charpy impact test criteria for 316L(N)

It happens that an evolution need does not come from something missing but from evolution of technics. As the code is based on the state of the art and on projects feedbacks, some elements concerning fast reactors had to be updated to take into account evolution in materials and technics since past editions. It is the case for instance for Charpy impact test criteria for 316L(N) stainless steel. The test is required by the requirement specification to check the residual ductility of the product after thermal ageing. It was originally based (in the RCC-MR Code) on Charpy U specimens but it has been switched to Charpy V specimens. A first proposal for new criteria has been implemented in RCC-MR Code 2007 edition, based on a factor 8/5 (undernotch surface ratio KU-KV, as illustrated in Fig. 8). A reflection on the validity of the conversion has been launched with the objective of new procurements for ASTRID project. The analysis led to a proposition of new values (RCC-MRx Code Mechanical properties RM 332-1.51, 332-3.51, 332-4.51).

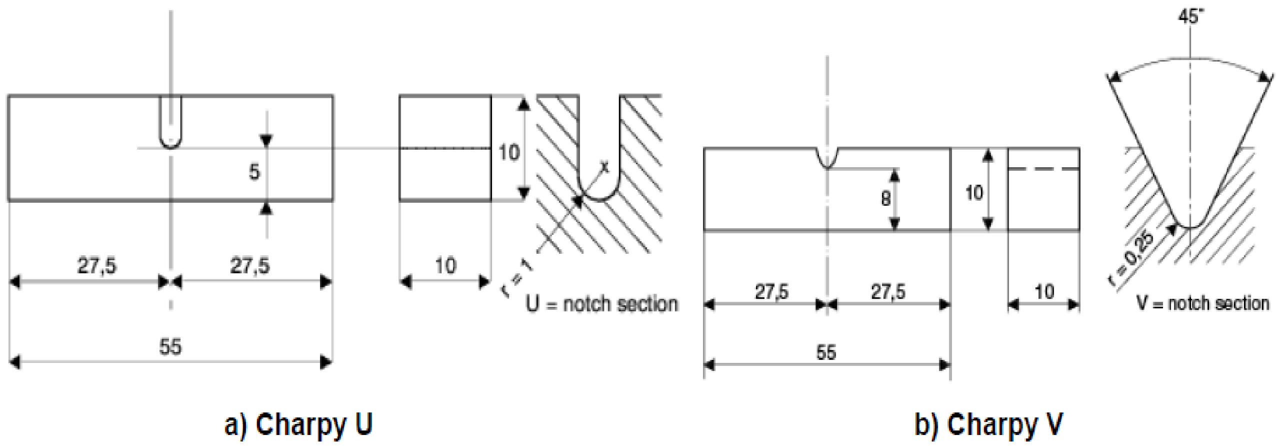

Fig. 8 Charpy impact test criteria for 316 L(N) stainless steel: originally based (RCC-MR Code) on Charpy U specimen tests, but from now on Charpy V specimen.

[DOI: 10.1299/mej.20-00052]

5.4 RCC-MRx Code harmonization with RCC-M Code: according to French regulation

Important work has been implemented for the RCC-M Code to demonstrate conformity with French regulation (Triay, et al., 2018). Because there is a RCC-MRx/RCC-M common domain (pressure, low temperature, low irradiation), the RCC-MRx Code got benefit from this work and a RCC-MRx Code update with RCC-M Code inputs was initiated in parallel:

RCC-M Code introduced a clarification concerning the type of certificate to provide for base metal and filler metal (specific or non-specific certificate for material procurement) to be in line with regulation requirements for base metal and filler metal. This clarification was implemented in RCC-MRx Code Section II REC regulatory part too. The main modifications resulted from this work:

- New definitions in Section II REC: differentiation between *Filler metal* and *auxiliary consumable products (flux, shielding gas…),*
- Type of certificate according to European Pressure Equipment Directive (PED) and Nuclear Pressurized Equipment French Order (ESPN) requirements (ESPN N1, N2, N3 component classification).

5.5 RCC-MRx Code harmonization with RCC-M Code: according to European harmonized standards

Concerning *weld metal*, the RCC-M Code text is based on regulatory interpretations (CLAP 185i and CLAP 292, French Pressure Equipment Consultation Committee) and also on the European harmonized standards such EN 13445 Unfired Pressure Vessels. The following RCC-MRx Code modifications have been introduced based on RCC-M Code and on regulatory inputs, in a consistent way:

- All the tests modalities are gathered in Section III Tome 3 Testing and Examination Methods RMC 1221, which includes the possibility to use reduced specimens when the use of a standard specimen is not possible,
- For *weld assemblies*, this possibility is introduced in the regulatory Section II REC 3253, REC 3263 and REC 3273 with a reference to Section III Tome 4 RS Welding.

5.6 RCC-M Code harmonization with RCC-MRx Code

In similar way, a modification was introduced in RCC-M Code 2016 edition concerning the K_v impact tests on reduced specimens for welded assemblies. This RCC-M Code modification, strongly related to regulation, was introduced as a result of previous work on base metal and a dedicated modification already introduced in RCC-MRx Code 2013 edition (RCC-MRx addenda, 2013).

6. Future editions of the RCC-MRx Code

After the RCC-MRx Code 2018 edition, the next edition of the code is preliminary planned for 2022 and new challenges are already launched such as a major modification for fast fracture parts in the code, development of parts dealing with fusion technology, complete integration of Jules Horowitz Reactor (JHR) feedback and new developments for fast reactors with the collaboration of ASTRID project (Fig. 9). And we also look for feedback from the PFBR Indian reactor.

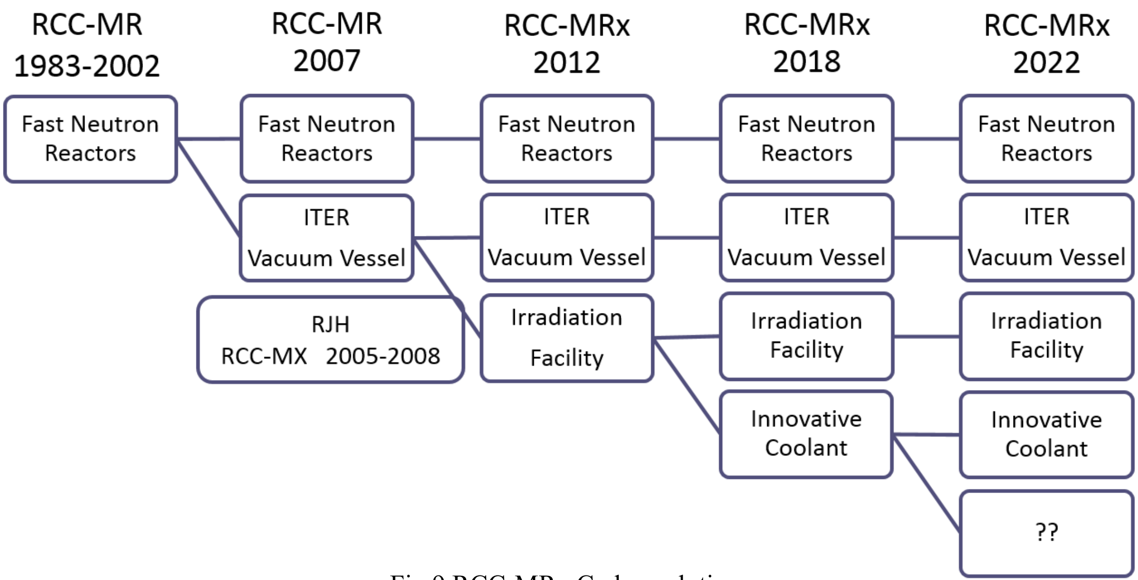

Fig.9 RCC-MRx Code evolution.

7. International developments: CEN WS 64

The European Commission (EC) published its Strategic Energy Technology (SET) Plan in 2007, "*Towards a Low Carbon Future*". This document recognizes the Europe needs to act now, together, to deliver sustainable, secure and competitive energy. The inter-related challenges of climate change, security of energy supply and competitiveness are multifaceted and require a coordinated response. In the SET-Plan, the European Industrial Initiatives (EII) constitute key elements with the aims to strengthen industrial energy research and innovation and to mobilize 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, that 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). Considering the choice already made in France and in Belgium to build the mechanical components for ASTRID and MYRRHA on the RCC-MRx Code basis, in 2010 the ESNII Task Force recommended to bring together all the relevant stakeholders in a European Committee for Standardization Workshop (CEN WS) in order to develop, on the RCC-MRx Code basis, the European code for the design and fabrication of mechanical equipment for ESNII innovative nuclear installations. This gave rise to the workshop CEN WS 64 "*Design and Construction Code for mechanical components of innovative nuclear installations*".

7.1 The CEN WS 64 Phase 1

The Phase 1, from 2011 to 2013, was focused on the RCC-MRx Code only. The purpose was to allow the Workshop members to acquire complete knowledge of the RCC-MRx Code and to propose code modifications to meet the needs of ESNII projects.

7.2 The CEN WS 64 Phase 2

The Phase 2, from 2014 to 2018, entitled "*Design and Construction Codes for Gen II to IV nuclear facilities (pilot case for process for evolution of AFCEN codes)*" managed to create a community of experts, discussing and building consensus on a variety of aspects within a relatively short time. The technical result of the second phase of the workshop was published end of 2018 (WS 064 Phase 2, 2018). The Workshop was also acknowledged by the European Commission (EC) as a major contribution to the harmonization of standards regarding Nuclear Pressure Equipment (NPP), therefore, improving both their safety and competitiveness. There is an expectation from the experts involved in the Workshop 64 Phase 2 to fully tap its recommendations. In this respect, the process initiated with AFCEN needs to be continued. On the technical area, some consideration will be given to the reactor life extension aspects, for example the necessary provisions to be drafted in AFCEN code to supply spare parts on existing European reactors originally designed with other codes, and to the suitability of using conventional (non-nuclear) equipment complying with high quality industry standards. On the research and development point of view, the process initiated with EC DG "Research and Innovation" (Directorate-General of the European Commission) is also to be carried on. In this framework, the Workshop will have to ensure that its research and development recommendations will be integrated in the future European Commission Framework Program (DG ENER 2014-376, 2014).

7.3 The CEN WS 64 Phase 3

The Phase 3 public consultation was proposed in 2018. The aim of this phase is to invite proposals for code modifications from the operators, the authorities' technical support teams and industry players who could ultimately be involved in evaluating and taking part in nuclear projects using AFCEN Codes. Phase 3 has been launched in January 2019. However, it is possible to join the Workshop at any time during the development of the CEN Workshop Agreement (CWA 16519, 2012).

8. Conclusions

The RCC-MRx Code constitutes a single document that covers in a consistent manner the design and construction of reactor components 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. The previous examples showed the diversity of implemented modifications in the RCC-MRx Code 2018 edition. Most of the modifications are driven by the project needs, such ASTRID, JHR and ITER, but also by the needs of innovative projects such MYRRHA (Lamberts, 2016) or ESS, the diversity of the modifications comes also from the diversity of the projects.

References

Afcen, Use of AFCEN Codes around the world
(online), available from < afcen.com/en/about/use-of-afcen-codes-around-the-world >, (accessed on 27 June, 2020).

Afcen, The RCC-MRx Code as reference for ASTRID, MYRRHA and ESS (online), available from < afcen.com/en/about/our-codes >, (accessed on 27 June, 2020).

Aithal, S., Balasubramaniyan V., Pasha A., Athmalingam S., Krishna Prasad K., Vijayashree R., Ravichandar S.C., Raghupathy S. and Puthiyavinayagam P., Feedback based on application of code rules to design and construction of prototype Fast Breeder Reactor, Proceedings of the ASME Pressure Vessels and Piping Conference (PVP) (2018), Paper No. PVP2018-84880.

Aubert, J., Muñoz Garcia, J. E., Aiello, G., Pétesch, C. and Lebarbé, T., Feedback of designing mechanical components for fusion according a nuclear standard: opportunities and difficulties, Proceedings of the ASME International Conference on Nuclear Engineering (ICONE-27) (2019), Paper No. ICONE27-1952.

CWA 16519, Design and Construction Code for mechanical equipment of innovative nuclear installations, European Committee for Standardization (CEN) (2012).

DG ENER 2014-376 Contract, Feasibility Study on Harmonization of Nuclear Design and Construction Codes at EU level, European Commission (EC) (2014).

Dubiez-Le Goff, S., Pétesch, C., Lebarbé, T. and Pascal, C., Consideration of irradiation effect in components design: illustration of a way to introduce an environmental effect in the design process, Proceedings of the ASME Pressure Vessels and Piping Conference (PVP) (2016), Paper No. PVP2016-63567.

Gay, S. and Gaillot S., Jules Horowitz Reactor: RCC-MRx applicability for the design phase of experimental devices, Proceedings of the 18th International Group Operating Research Reactors Conference (IGORR) (2017).

Lamberts, D., Codes and standards for innovative nuclear system design, Workshop on thermal-hydraulics and thermo-mechanical issues for safety (ENEA) (2016).

Lebarbé, T., Pétesch, C., Bonne, D., Blat, M. and Pascal, C., RCC-MRx 2015 Code: Context, Overview and on-going developments, Proceedings of the Structural Mechanics in Reactor Technology Conference (SMIRT-24) (2017).

Lee, H.-Y., Comparison of elevated temperature design codes of ASME Subsection NH and RCC-MRx, Nuclear Engineering and Design No.308 (2016), pp. 142–153.

Lee, H.-Y., Min-Gu, W., Nam-Su, H. and Woo-Gon, K., Development of a program for high-temperature design analysis and defect assessment according to RCC-MRx, Proceedings of the ASME Pressure Vessels and Piping Conference (PVP) (2018), Paper No. PVP2018-84242.

Martin, A., Pétesch, C., Lejeail, Y., Lamagnère, P., Lebarbé, T., Muñoz Garcia, J. E. and Aiello, G., Efficiency diagram alternative rule for ratcheting: historical background, overview, on-going developments, Proceedings of the ASME Pressure Vessels and Piping Conference (PVP) (2018), Paper No. PVP2018-84161.

Muñoz Garcia, J. E., Pétesch, C., Lebarbé, T., Lamagnère, P. and Lejeail, Y., Development of a standard for fusion needs: example of introduction of Eurofer in RCC-MRx, Proceedings of the ASME International Conference on Nuclear Engineering (ICONE-26) (2018), Paper No. ICONE26-82337.

Pétesch, C., Lebarbé, T., Chosson, R., Bonne, D., Dubiez-Le Goff, S., Blat, M. and Vallot, D., Introduction of new materials in codes: a challenge for innovative reactors, Proceedings of the Structural Mechanics in Reactor Technology Conference (SMIRT-24) (2017).

Pétesch, C., Lebarbé, T., Gelineau, O., Vallot, D. and Blat, M., 2018 RCC-MRx Code edition: context, overview, on-going developments, Proceedings of the ASME Pressure Vessels and Piping Conference (PVP) (2018), Paper No. PVP2018-84706.

Pétesch, C. and Nilsson, K.-F., CEN Workshop 64: an innovative way to work on a harmonized set of rules for GENIV reactors, Proceedings of the GEN IV International Forum (GIF) (2018).

RCC-MRx addenda, Feedback of application of the code – Developments of rules to the evolution of project's needs, AFCEN (RCC-MRx) (2013).

RCC-MRx, Design and Construction Rules for Mechanical Components of Nuclear Installations: high temperature, research and fusion reactors, AFCEN (RCC-MRx) (2018).

Triay, M., Lefever, B., Quéré, J., Gobert, J.-L., Chantelat, E., Puybouffat, S., Cadith, J. and Meister, E., New edition of the RCC-M Code in 2018: main evolution expected, Proceedings of the ASME Pressure Vessels and Piping Conference (PVP) (2018), Paper No. PVP 2018-84409.

WS 064 Phase 2, Design and Construction Codes for Gen II to IV nuclear facilities (pilot case for process for evolution of AFCEN codes), European Committee for Standardization (CEN) (2018).

[DOI: 10.1299/mej.20-00052]