RCC-MRx 2015 CODE: CONTEXT, OVERVIEW AND ON-GOING DEVELOPMENTS

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ABSTRACT

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 code has been issued in French and English versions by AFCEN (Association Française pour les Règles de Conception, de Construction et de Surveillance en Exploitation des Matériels des Chaudières Electro-Nucléaires) in 2012, and a new edition has been published at the end of 2015.

A significant work has been performed for this edition to improve the code in order to facilitate its use and understandability, and also to have a better fit with the feedbacks of the users.

In parallel, in compliance with the EC's objectives and its own policy of openness, AFCEN proposes to make its codes evolve, taking into account the needs and expectations of European stakeholders (operators, designers, constructors, suppliers…) threw a workshop called CWA phase 2.

This paper gives an overview of the realized work and also will identify the work to be done for an opening of a standard such as RCC-MRx code.

INTRODUCTION

The design and construction rules for mechanical components of nuclear installations (RCC Codes) published by AFCEN primarily apply to safety class components. These Codes are used as a basis for contractual relations between Client and Supplier, in which case they shall be accompanied by a list of components to which they shall be applied.

RCC-MRx, developed especially for Sodium Fast Reactors (SFR), Research Reactors (RR) and Fusion Reactors (FR-ITER). It is the result, in 2009, of the merger of the RCC-MX in the RCC-MR 2007.

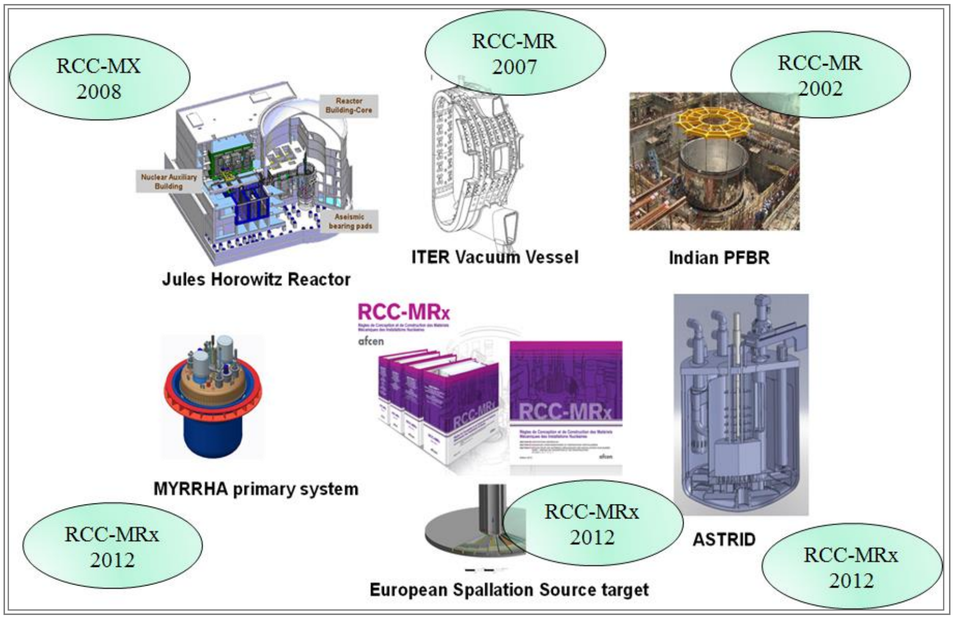


Figure 1: Illustration of code references

The scope of application of this Code exclusively covers mechanical components of a Nuclear Installation:

- important from a safety or availability point of view,
- having a leaktightness, partitioning, guidance and retaining or supporting role,
- classified as vessels, pumps, valves, piping, bellows, box structures, heat exchangers, irradiation devices and their supports, handling or drive mechanisms.

The design rules for components which are subject to irradiation were drawn up on the basis of standard nuclear installations [1]. The use of these rules for other types of irradiation (e.g. proton irradiation, irradiation producing large amounts of helium, etc.) is not covered by the Code.

The first edition of the code has been published in 2012, in French and English, by AFCEN under the name RCC-MRx. A new edition has been published at the end of 2015 [2], including the intermediate addenda of 2013 and additional modifications accepted since this addenda.

The next edition is now planed in 2018. The main objectives for the next edition are always to integrate the feedback of users, but also to develop other types of publication such as backgrounds of the rules or guidelines, for instance on the integration of a new material in the standard [3]. This paper sums up the main evolutions of the 2015 edition, and gives an overview of the next on-going developments.

NOMENCLATURE

AFCEN	French Association for NPP Design and Construction
ASN	French Nuclear Safety Authority.
ASTRID	Advanced Sodium Technological Reactor for Industrial Demonstration
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
COLEN	Comité de Liaison des Equipements sous pression Nucléaies
CWA	CEN Workshop Agreement
ETSON	European Technical Safety Organisation Network
JHR	Jules Horowitz Reactor
MDEP	Multinational Design Evaluation Programme
RCC-M	Design and construction rules for mechanical components of PWR nuclear islands

RSE-M	In-Service Inspection Rules for Mechanical Components of PWR Nuclear Islands
RPP	Rules in a Preliminary Phase
RPS	Reference Procurement Specification
REACH	Registration, Evaluation and Authorisation of Chemicals
SFR	Sodium-cooled Fast Reactor
WENRA	Western European Nuclear Regulators Association

RCC-MRx 2015 EDITION

Context

RCC-MRx is one of the seven codes published by Afcen (see figure 2).

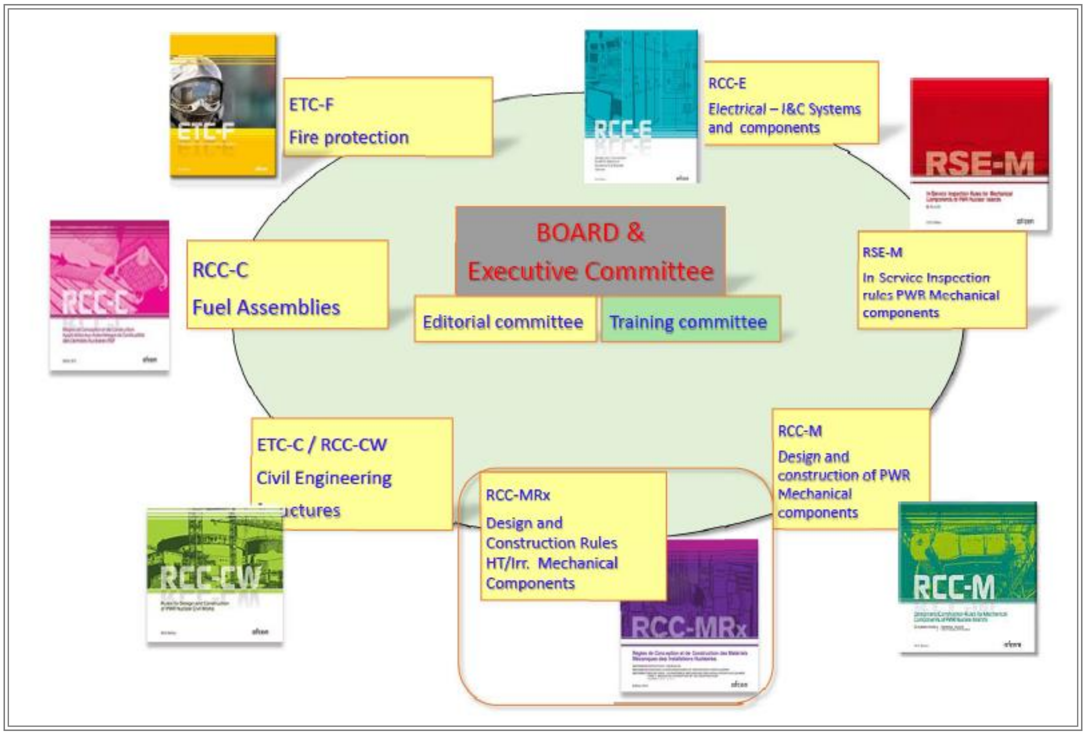


Figure 2: Afcen codes

During the last years, Afcen has diversified its offer and it includes now not only codes but also technical publications such as backgrounds of the codes (so called "criteria"), guidelines etc…It corresponds to the needs highlighted with the opening of the association to international members.

Afcen has also set up Users Groups for dedicated countries. Today, two users groups are operating, the UK users group and the Chinese users groups. Such organisations allow to collect in a more efficient way the feedback and the needs of the users to an international level, with the benefits of quality structure of Afcen (Afcen has been certified ISO 9001 for four years). Codes are modified through the following process (figure 3):

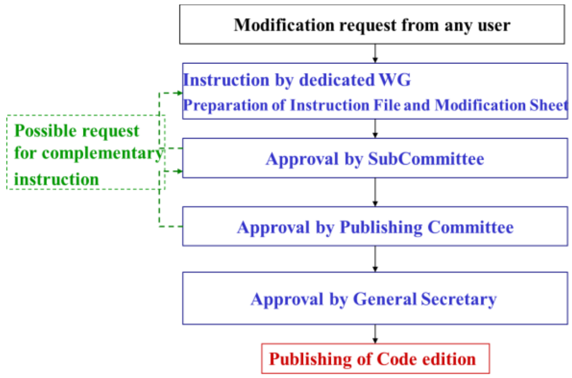


Figure 3: Evolution process of Afcen codes

The 2015 edition of the RCC-MRx reflects this context. The new edition includes more than 65 modifications (compared to the 2013 addenda, more than 110 modifications compared to the 2012 previous edition).

These modifications have two major roots:

- 67% are directly issued from users feedback,
- 21% are coming from the actions of harmonisation with other sets of rules.

These two points are developed later.

If we look know the repartition of the modifications in the different technical fields (see figure 4):

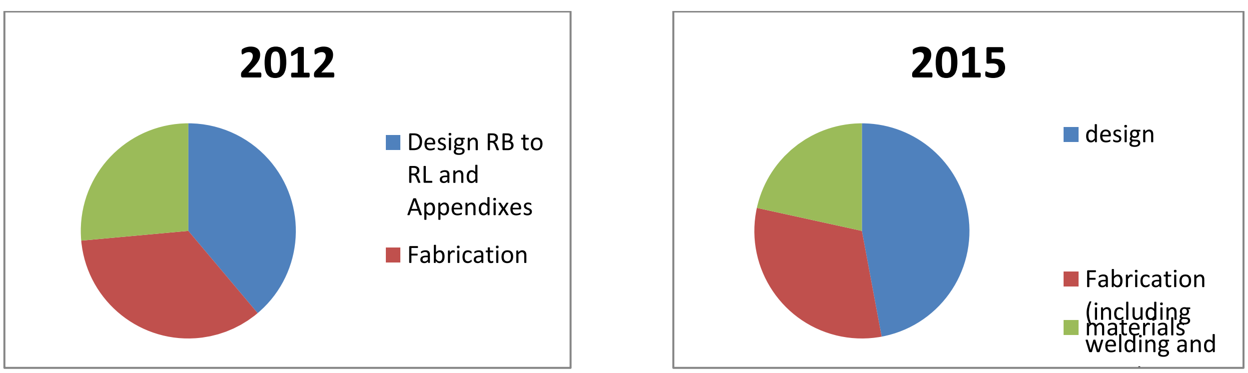


Figure 4: 2012-2015 repartition of Code Modifications

We can see that the majority of the modifications are on the design, and this trend is increasing through the past three years. The following paragraphs provides some example of code evolutions.

Users feedback: essential element of the code evolution

As said before, the main part of the code modifications is the result of the code application in a frame of a project.

The French projects JHR and ASTRID [4] through dedicated organizations have chosen to propose code evolutions in parallel with the progress of the project. Such evolutions can be very useful for all the projects using the code, it indeed allows to have a code always up to date and to integrate feedback from all kind of projects in the Code. As an illustration, figure 5 shows origin of Modification Requests for RCC-MRx 2015.

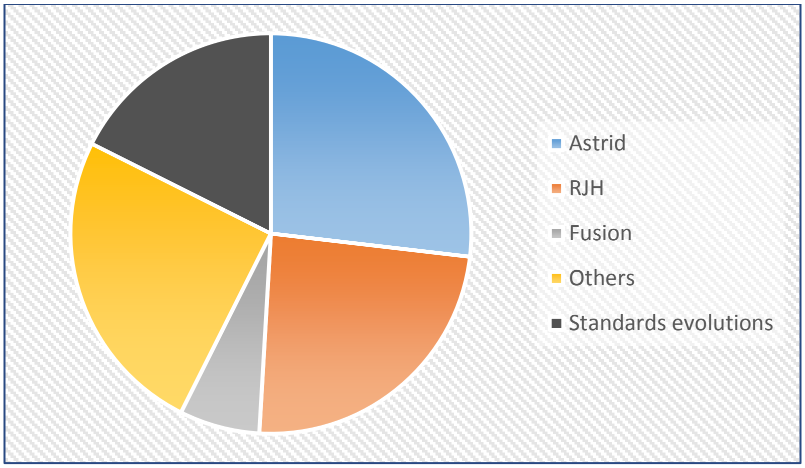
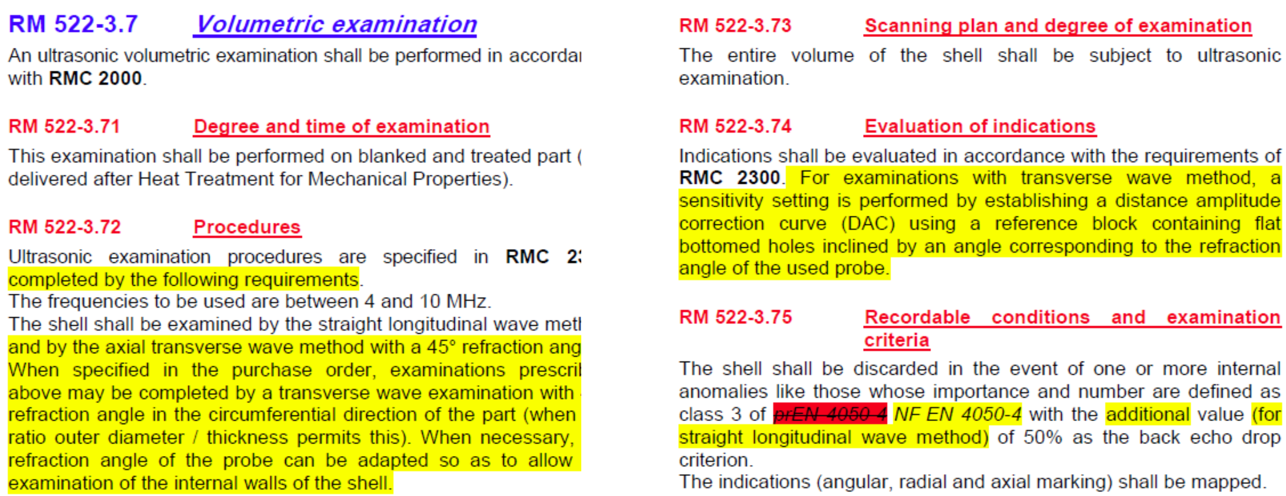


Figure 5: origin of modifications in RCC-MRx 2015

For instance the application of the volumetric examination on Aluminium parts of the JHR led to complete significantly the concerning texts in the code (parts underlined are parts added in 2015):



RM 522-3.7 ***Volumetric examination***

An ultrasonic volumetric examination shall be performed in accordai with **RMC 2000**.

RM 522-3.71 **Degree and time of examination**

This examination shall be performed on blanked and treated part (delivered after Heat Treatment for Mechanical Properties).

RM 522-3.72 **Procedures**

Ultrasonic examination procedures are specified in **RMC 2:** completed by the following requirements.
The frequencies to be used are between 4 and 10 MHz.
The shell shall be examined by the straight longitudinal wave metl and by the axial transverse wave method with a 45° refraction ang When specified in the purchase order, examinations prescril above may be completed by a transverse wave examination with refraction angle in the circumferential direction of the part (when ratio outer diameter / thickness permits this). When necessary, refraction angle of the probe can be adapted so as to allow examination of the internal walls of the shell.

RM 522-3.73 **Scanning plan and degree of examination**

The entire volume of the shell shall be subject to ultrasonic examination.

RM 522-3.74 **Evaluation of indications**

Indications shall be evaluated in accordance with the requirements of **RMC 2300**. For examinations with transverse wave method, a sensitivity setting is performed by establishing a distance amplitude correction curve (DAC) using a reference block containing flat bottomed holes inclined by an angle corresponding to the refraction angle of the used probe.

RM 522-3.75 **Recordable conditions and examination criteria**

The shell shall be discarded in the event of one or more internal anomalies like those whose importance and number are defined as class 3 of ~~prEN 4050-4~~ *NF EN 4050-4* with the additional value (for straight longitudinal wave method) of 50% as the back echo drop criterion.
The indications (angular, radial and axial marking) shall be mapped.

Figure 6: illustration of code modification

Such complements have been added for examinations, welding but also procurements (exchangers).

In a similar way, the work on Eurofer material [5] continues and the set of material characteristics (in PPR, A3.19AS) has been completed with the creep data, the work is nevertheless still on-going for the irradiated data.

The following table gives an illustration of the possible panel of modifications issued from users' requests:

Modified part	Topic
RS 8241	Introduction of Ni Gr6 and Inconel 625 coatings.
RS, RM	Addition of an alternative rule for temporary attachments on thick stainless steel plates.
A3.5SA.2	Additional physical properties for A3.5SA (800SPH).
RPP 4 RM 243.3	Integration of Eurofer feedback of thick plates procurement.
RPP4 A3.19AS	Additional creep characteristics for Eurofer.

RD RK RL 2220	Clarification of the procurement rules for boltings according standards in D, K and L volumes.
RB 4231.4 RC 4230 RS	Improvement of the understanding of the high temperature weld assemblies requirements.
RB 3200	Introduction of a temporal partitioning in the ratchetting rule in significant creep.
RB 3251	Limitation of membrane plus bending stresses for negligible creep rule.
A3.1S.83	Update of the minimal flux dependant toughness curves for 316L(N) including new ITER (SDC-IC) data.
RB 3500	Introduction of finite element calculation for primary stresses in RB 3500.
RS 2600	JHR feedback: integration of the use of filler metal with automatic metal inert gas welding used for 6061 T6 housing.
RB 3282	Following DIRx 15-032, modification of RB 3282.12 for text clarification.
A3.2A.69	Modification of A3.2A.69 on 6061-T6 swelling.
A3.7S	Mechanical properties Rp0.2%min, Rm min, and Sm above 450°C. 7S limitation use for negligible creep damage.
RM 522-3 RM 522-7	JHR feedback for ultrasonic examination.
RB 2210 RD 2223	JHR feedback for exchanger procurement.
A3.xx.54	Precision on creep strain data.

Table 1: Modifications list, feedback roots

Harmonization actions

The other source of modifications included in the 2015 edition is the actions performed to maintain the consistency of the RCC-MRx with other sets of rules linked with it.

First, the code includes references to other systems (identified for instance in table RA 1300):

- Regulations texts,
- ISO standards,
- European standards,
- ASME/ASTM/AWS texts,
- technical publications.

The RCC-MRx refers to more than 200 standards and publications. We can see in table 2 that the modifications could come from an evolution of the reference standard (one third of the European standards are reviewed each year) or of the regulation text, or it could come also from the working group and sub-committee decision to ensure consistency or pathway with other set of rules (as for instance with RCC-M [6] or EN 13445 [7], EN 13480 [8]).

Modified part	Topic
RS 7433	Update of the requirements on the check of instruments used for measuring welding parameters accordingly with RCC-M and EN ISO 17662 evolutions.
RS 3242.12	Modification of steels grouping, accordingly with RCC-M.
RS 2120	Procurement of filler materials others than RCC-MRx.
RS 7700	Ensuring consistency for acceptance criteria for radiographic examination.
RB,RD, RM	Consistency between procurements according RCC-MRx, RCC-MR and RCC-M.
RB 3700	Bellows design rules harmonization.
RA 1300 RMC	Update of the standards references listed in the tome 3 and consequences on synthesis table RA 1300.
RA 1300 RM	Update of the standards references listed in the tome 2 and consequences on synthesis table RA 1300.
A9.J3S	Consistency between Jr and Sr,St values.
RDG 4000 RD 3650	Clarification of the possibility to use EN 13445/13480 alternatively to N3Rx and anchors movement consideration.
RMC 2000	Consideration of the RCCM evolution for RMC 2000 chapter.

Modified part	Topic
RDG 3310	Homogeneisation with RCC-M : correction corrective action /preventive action.
RB 5240	Homogeneisation with RCC-M: consideration of the supports during hydraulic test.
RA 1300 RF	Update of the standards references listed in the tome 5 and consequences on synthesis table RA 1300.
RM RMC	Homogeneisation with RCC-M (2013, 2014 and 2015) for tomes 2 and 3.
REC	Integration of the 2005/12/12 order modification.
RS	Update of the standards references listed in the tome 4.
RS 4000	Integration NF EN ISO 9606-1 standard.
Tomes 4 , 5	Consideration of the RCC-M modifications since 2012.
A14.2450	Precision added consistent with RCC-M evolution.
REC 3200	Put in conformity of the welding and fabrication disposition with the COLEN interpretation sheets validated by ASN.
REC 3200	Put in consistency of Section II with ESP order modification.
Tome 1	Update of the standards references listed in the tome 1.

Table 2: Modifications list, harmonization roots

The update of references include to follow the evolution of material or process (welding..) standards, but also more complex structures when it deals with references such as RCC-M or EN 13445 for instance.

In these cases, specific benchmarks may be needed to evaluate the consistency of two standards, but also to have the possibility for the experts to share their knowledges. We can quote OECD or CORDEL initiatives as examples ([9] and [10]).

In a similar way, an action of comparison of EN 13445 and RCC-MRx rules concerning creep rules has been engaged ([11], [12]).

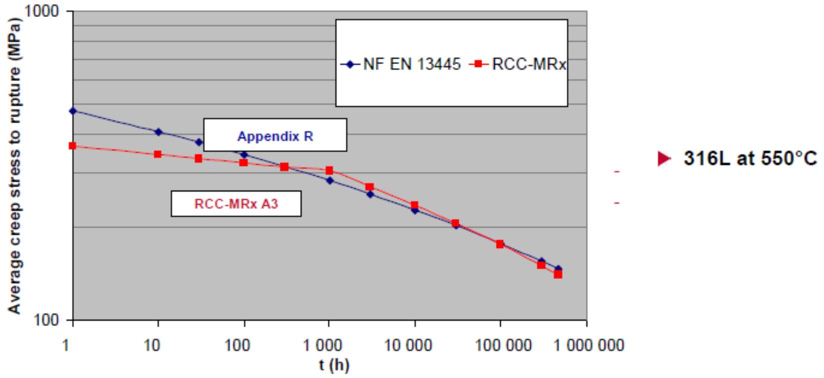


Figure 7: comparison EN 13445/ RCC-MRx

This work has been shared with the EN 13445 working group dealing with creep (WG 59 of Technical Committee 54) and will lead to code modification in the future.

This work of harmonization is also engaged through an European workshop (CEN workshop 64, see below).

Evolutions of the code: benefit for any project

Feedback from projects are continuous

2014-2018 CEN WORKSHOP 64

Objectives

The proposal consists into a voluntary mechanism for a broad set of partners involved with design and construction of nuclear facilities in Europe. It will allow partners not yet using AFCEN codes to learn about these codes. It will also give the opportunity to all participants to express their specific requirements for the long term modifications of the Codes including identification of pre-normative research where necessary.

During this process, other solutions in existing codes shall be considered. In ideal case, the result should be a combination of solutions from others codes, sometimes also allowing alternate approaches.

The prospective work to be done would be applicable to GEN III and IV NPPs and long-term operation/lifetime extension for GEN II NPPs.

First results

The prospective group dealing with GEN IV reactors has already identified a list of technical points as potential topics for a code improvement or a research and development topic:

- Environmental degradation of material in innovative coolants,
- Weld procedures and weld performance,

- High temperature data for accident situations,
- Europeanization,
- Miniature test Procedures such as small-punch and nano-indentation,
- Long-term degradation, 60 years design life, property extension,
- New materials, fabrication, codification,
- Coating and surface treatments,
- On-line enabled material data base
- Modernized Design Rules – Design by Analysis including FEM,
- High temperature degradation (creep, creep-fatigue, ratcheting, buckling, cyclic softening/hardening..),
- High irradiation degradation,
- Fuel cladding design rules,
- Residual stresses…

These topics have been prioritized and first proposals of modification and R&D have been established by the PG (Prospective Group).

Some modifications proposals of RCC-MRx code have also been proposed within the Workshop and are now under instruction threw Afcen procedure:

- Use of the code in innovative coolant environment,
- Negligible creep curve,
- Extension of Temperature Range for Mechanical Properties of Specific Materials in RCC-MRx,
- Extension of creep strain and rupture data range.

OTHER DEVELOPMENTS: GUIDELINE IN SUPPORT TO CODIFICATION

With the first feedbacks of the code uses, it appears that there is a particular expectation on how to proceed with the introduction of new materials in the code. It leads to develop other kind of publications such as guidelines, to answer to this need. One guideline [3] as been published in 2017 with the aim to present the procedure to be followed for acquiring and gathering the data which describe the physical and mechanical behaviour of the material, necessary to apply the component design rules available in the RCC-MRx code.

The purpose of the guide is to help the user to establish his material file, with a clarification of the content expected by the code organisation.

For the moment the guideline is limited to base metal material, candidate to an introduction in the RCC-MRx. The different characteristics needed for design are identified in the code and summarised:

Table 3: material properties required in the material application file for introduction of a new material in the RCC-MRx, according to the envisaged service conditions

Envelope	Property or physical parameter	Minimum file
Physical properties	Coefficient of thermal expansion, mean and/or instantaneous	X
	Specific heat capacity	X
	Thermal conductivity	X
	Thermal diffusivity	X
	Density	X
	Young's modulus	X
	Poisson's ratio	X
Border lines	Negligible creep curve (or maximum allowable service temperature)	X
	Thermal ageing curve (or maximum allowable service temperature)	X
	Negligible irradiation curve	
	Maximum irradiation curve	
Tensile conventional plastic behaviour	Mechanical properties $R_{p0.2\%}$ (or $R_{p1\%}$) and R_m	X
	Elongation A	X
	Necking Z	
	Tensile stress-strain curve at A_{gt}	X
Fatigue behaviour	Cyclic curves, coefficients K_ε, K_ν and K_s	
	Fatigue curve	X
Viscoplastic behaviour	Creep fracture stress	
	Creep strain rule	
	- Primary creep	
	- Secondary creep	
	Fatigue-creep interaction diagram	
Fracture mechanics	Fracture toughness J_{Ic} or K_{Ic} or impact strength kV	X
Behaviour after ageing	Tensile conventional plastic behaviour	
	Fatigue behaviour	
	Short-term viscoplastic behaviour	
	Fracture mechanics	
Behaviour after irradiation	Tensile conventional plastic behaviour	
	Fatigue behaviour	
	Viscoplastic behaviour	
	Fracture mechanics	
	Irradiation phenomena (swelling, irradiation creep, etc.)	

The establishment of these properties requires a dedicated experimental program and the guideline gives general indications and good practices to perform this program in line with the background of the data already included in the code. Thus a reference to existing standards is made whenever it is possible but the door is still open to alternative practices, to be justified, taking into account the innovative aspect of the material or the process.

The tests to be performed for the eight families are indicated on the table with the following structure:

- Determined characteristics,
- Test program conditions,

- Test performance conditions,
- Documentation.

To facilitate the use, tables are also given in the end of the guideline, as illustrate below:

Table 4: Guide for introducing a new material in the RCC-MRx - extract

A3.X.2: Physical properties						
§	**Properties**	**Test type**	**Relevant standards**	**Number of tests**	**Temperature range**	**Comments or RCC-MRx requirements**
.21	Coefficients of thermal expansion	Absolute dilatometry	ASTM E228	3 per T	T_{min} to T_{max}+50°C Recommended: $\Delta T \leq 50°C$	• Recommended method: absolute dilatometry. • The mean and instantaneous values are required relative to 20°C.
.22	Young's modulus	Ultrasonic propagation	ASTM E111 ASTM E1875 ASTM E1876	1 per T	T_{min} to T_{max} Recommended: $\Delta T \leq 50°C$	• Method based on ultrasonic wave propagation.
.23	Poisson's ratio				20°C	• Method based on ultrasonic wave propagation.
.24	Density	Immersion in a solvent	N/A	1 per T	T_{min} to T_{max} Recommended: $\Delta T \leq 50°C$	• Test by immersion in water.
.25	Specific heat capacity	DSC calorimetry	N/A	3 per T	T_{min} to T_{max} Recommended: $\Delta T \leq 50°C$	• DSC calorimetry (thermal capacity).
	Thermal conductivity	Hot wire method	ISO 8894			• To be deduced from the thermal capacity and diffusivity measurements. • Or hot wire method.
	Thermal diffusivity	Flash method	ASTM E1461 ASTM E2585			• Flash method.

CONCLUSION

The new edition of the RCC-MRx has been published at the end of 2015. This edition is the conclusion of three years of application of the code. Nevertheless, work is still in progress, related to the feedback, in the scope of rules, definition and way to use them, but also in order to share this feedback at the scale of international background and request. Other works (also called studies) are on-going or will start very soon to support the code:

- two Studies are now closed :
  - New material study: closed in 2016 and concluded by Afcen technical publication on introduction of a new material ([13], [14] and [3]),
  - Irradiation study: closed in 2016, future modifications implemented in the next edition of RCC-MRx will come from this study [13].
- two Studies will start in 2017-2018 :

- fast fracture : equipment specification guideline for the drafter,
- Rewriting french regulation parts (REC 3200).

A next step is also engaged with the European Community to prepare the future standards, to anticipate their needs in term of research, to be sure to get in time answers for the GEN IV technical issues.

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