First steps towards a European design and construction code for research reactors

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Research reactors have the following specificities:

- use of low neutron capture material such as aluminum or zirconium alloys for the reactor block components operating at low pressure and temperature,
- use of slender structures for the experimental device operating up to extremely severe pressure and temperature,
- highly aggressive irradiation conditions inducing nuclear heating and neutron embrittlement of mechanical structures.

So it results in specific mechanical damages to be prevented by design and construction rules.
Existing nuclear design and construction codes are not appropriate because the lack of coverage of the above specificities.

So the CEA and 2 AREVA’s companies (AREVA TA and AREVA NP) launched in 1998 the preparation of a new design and construction code called RCC-MX. The objective is to have a code available for the design and procurement of the JHR (Jules Horowitz reactor) component and the design and procurement of new irradiation devices. A first draft has been issued in 2002, then 2 releases occurred in 2005 for JHR component design and 2008 for JHR component procurement.
This new design and construction code dedicated to research reactor components, their auxiliaries and irradiation devices integrates the lessons learned of several tenths (60 years) of French research reactor design and operation and is founded on up-to-date standards (ISO International or EN European standards).
A huge effort has been done by collecting the irradiated material data and is continued through an important characterization program of material especially focused on irradiated material properties and aluminum and zirconium alloys.

The presentation presents:

- the general structure of code, the scope and give an overview of rules,
- the contributions of this code for a construction project from a reactor constructor point of view using the JHR project as an example.

Finally the development strategy of the code for the future will be presented: European and international collaborations are starting using this design and construction code as baseline.

1 INTRODUCTION

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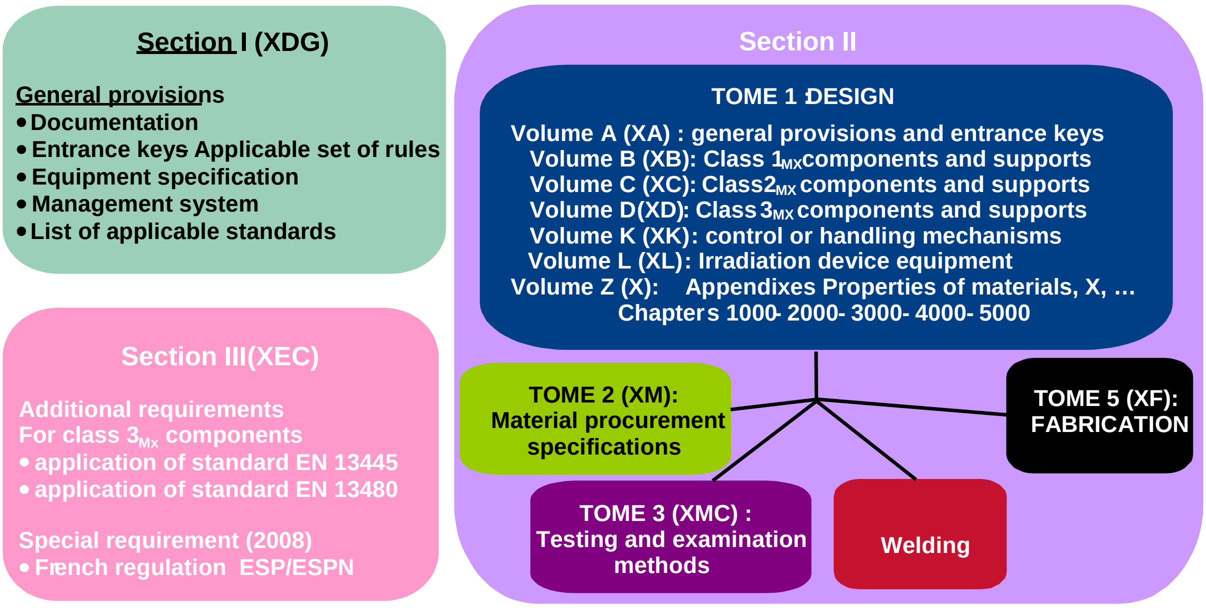
2 GENERAL PRESENTATION OF THE RCC-MX

2.1 OVERVIEW

The scope of the RCC-MX design and construction rules covers metallic mechanical components of research reactors, their auxiliaries and associated irradiation devices:

– Important for nuclear safety and/or operability,
– Ensuring containment, partitioning, guiding, securing and supporting,
– Containing fluids such as pressure vessels, pumps, valves, pipes, bellows, box-type structures, heat exchangers and their supports.

The general structure of the code is outlined below:



The code meets the following requirements:

- Same philosophy as the RCC family: 3 classes of components Class 1MX, Class 2MX , Class 3MX corresponding to a decreasing assurance of the safety level with regard to different mechanical damages they may be subjected to
- Covers ambient conditions during operation: irradiation, high temperature (creeping)
- Covers all materials used in the research reactor field including aluminum and zirconium alloys
- Compliance with regulations in the fields of quality for nuclear safety, pressure equipment directive (PED) and the French regulation for nuclear pressure equipment (called ESPN)
- Integrates and formalizes the best industrial practices on the basis of international industrial standards
- Uses of COTS (off-the shelve Components) for irradiation device components or class 3 components
- Includes lessons learned from several decades of research reactor design, construction, operation, and decommissioning
- Applicable for new research reactor projects (JHR) and new components (i.e. OSIRIS ISABELLE 4 Irradiation device) or replacement of components (i.e. in pile assembly of the ORPHEE's cold neutron sources).

In the design, as usually for nuclear design and construction codes, 4 operating conditions plus test conditions and several levels of design criteria are considered (A, C, D)

Special care in the preparation of the code was taken for the homogeneity of the rules in the different chapters of the document. In particular,

Material/products selection	Tabulated characteristics X3 Calculations
Procurement specification (Standards and Technical reference specification products/parts)	Checking Acceptance tests : Verification of specified values
Cutting, forming, machining	Maintain characteristics
Selection of welding products, Design of welding joints	Non destructive testing capability Joint efficiency: X5
Qualification of workers, Welding operating procedure	Good welding joints

A specific set of rules aiming to take into account the influence of irradiation on the material properties have been introduced for Mx Classes 1 and 2. In this case, the stress criteria take into account primary stresses and the primary plus secondary stresses as well. Limiting curves (significant irradiation, maximal irradiation) have established on the basis of ductility criterion. So the design rules can be summarized in the following table:

	Negligible Creep	Significant creep
Negligible irradiation	Classical rules (type P damage, type S damage) + notch effect (Fracture mechanics) buckling	type P damage: Sm including correction for thermal ageing Sr, St : tabulated values = f(θ, t)) type S damage: deformation criteria, fatigue criteria
Significant irradiation	New rules : extended (type P damage, type S damage) + notch effect (Fracture mechanics) P+Q et P+Q+F	rules (type P damage, type S damage) New rules (limited domain: material, temperature range)

2.2 DESIGN AND CONSTRUCTION RULES (TOME 1)

The tome 1 includes general rules for analysis, rules for specific types of components (vessels, supports, pumps, valves, piping, bellows, box structures, heat exchangers) and the following technical appendices:

- X1 Guide for seismic analysis
- X2 Design of bolted assemblies
- X3 Characteristics of materials
- X4 Design rules for mechanical connectors
- X5 welded joint factors
- X6 Shells under external pressure
- X7 Design rules for dished heads
- X8 Rules for linear type supports

2.3 MATERIAL (TOME 2)

The possible routes for material procurement are the following:

- Compliance with section II requirements XB,XC, XD, XL 2000 referring to:
  - Reference Procurement Specification from tome 2 including lessons learned from past procurement and/or qualification of parts
  - Use of standards defined in tome 2 : Acceptable standards and grades in EN or ASME standards completed by mandatory option selection, additional requirements such as additional tests
- Alternative for class 3MX: EN standards 13445 (Vessels) and 13480 (pipes)
- For class 3MX :
  - possibility of procurement without specific checking
  - Possibility to use standards for finished product,
- Special provisions for procurement of small quantities of products

The rules defines general provisions, and as usually in such a code specific provisions for mechanical characteristics, Technical qualification of parts, Heat treatment, Procurement on the basis of standards, Standards and grades applicable for different type of products: casting, forging, plates, pipes & tubes, rolled bars and flats, bolts, studs and threaded parts, Chemical analysis of melts and heat treatment, Manufacturing program, Additional tests.

The main added value as regards as others codes are in the rules covering the introduction of a new grade or a new fabrication mode and those covering the supplier qualification for an alloy or steel used in the creep domain.

There 49 reference procurement specifications cover a wide domain: different types of products: casting, forging, plates, pipes & tubes, rolled bars and flats, screws, studs and threaded parts,
9 of them are for unallied steels, 5 for low-allied steels, 23 for stainless steels, 9 for aluminium alloys, 4 for zirconium alloys.
Reference procurement specification is confirmed by a qualification process and a technical manufacturing program.

A huge effort has been developed by collecting and defining the X3 appendices presenting the detailed material characteristics at working different temperatures and different irradiation conditions. The following table presents the list of the materials presented in X3 appendices and highlights when relevant the existence of creep data and irradiation data.

	Ref.	**Material**	**Creep data**	**Irradiation data**
1	X3.10NAS	Carbon steels type P235GH		
2	X3.11NAS	Carbon steels type P265GH		
3	X3.12NAS	Carbon steels type P295GH		
4	X3.11AS	Low-alloyed steel type 25CrMo4, 42CrMo4, 30CrNiMo8		
5	X3.13AS	Low-alloyed steel type 16MND5		
6	X3.1S	Austenitic stainless steel X2CrNiMo17-12-2(N) solution annealed (316 LN)	X	X
7	X3.3S	Austenitic stainless steel X2CrNiMo17-12-2 solution annealed (316 L)	X	X
8	X3.4S	Austenitic stainless steel X2CrNi18-9 ou X2CrNi19-11 solution annealed	X	
9	X3.7S	Austenitic stainless steel X2CrNiMo17-12-2 work hardened (about 20%)	X	X
10	X3.8S	Martensitic stainless steel X4CrNiMo16-05-01 quenched tempered	X	
11	X3.10S	Austenitic stainless steel X6NiCrTiMoVB25-15-2 secondary hardened	X	
12	X3.1A	Aluminum alloy 5754-O (AG3 NET)	X	X
13	X3.2A	Aluminum alloy 6061-T6	X	X
14	X3.1Z	Zirconium alloy ASTM R60802 recrystallized (Zircaloy 2)	X	X
15	X3.2Z	Zirconium alloy ASTM R60804 recrystallized (Zircaloy 4)	X	X

The irradiated material properties are the swelling and mechanical characteristics. The Irradiation damages are assessed as function of:

- Dpa for stainless steel (displacement per atom calculated by Norgett-Robbinson-Torrens method)
- Conventional thermal neutron fluence for aluminum alloys (E=0,0254eV)
- Fast neutron fluence E > 1 MeV for zirconium alloys

2.4 MANUFACTURING, WELDING AND TESTING

The tome 3 “testing” includes as usually a complete set of manufacturing welding and testing rules dealing with mechanical, Physical and chemical test, ultrasonic examination (Castings, Forged parts, Plates, Tubes, Welded joints), radiographic, liquid penetrant; and magnetic particle examination, eddy current examination of tubular products, visual examination, determination of surface conditions,
Leak detection methods and qualification and certification of NDT personnel

The Tome 4 “welding” includes as usually a complete set of rules dealing with acceptance and qualification of filler materials, welding procedure qualification, arc welding of steels and nickel alloys, aluminium alloys, zirconium alloys , weld repair, heterogeneous welding joints, welding of tubes on exchanger plates, socket weld of pipes, technical qualification of production workshops, production welds and rules dedicated to modern welding processes such as electron beam welding, laser welding, diffusion welding, friction welding and rules for special processes such as seal lip weld, fillet welds not having a mechanical strength function, cladding, homogeneous filling.
In particular special provisions have been defined for the aluminium alloy welding and zirconium alloy welding

The Tome 5 “manufacturing” includes as usually a complete set of rules dealing with marking procedure, cutting – repair without welding, forming and tolerances (including special provisions for aluminum and zirconium alloys), surface treatments, rules for cleanliness, rules to perform mechanical assemblies by bolting, heat treatments

3 USE OF THE RCC-MX FOR THE JHR PROJECT

The RCC-MX is the Reference for technical and contractual relationship for the entire JHR project:
- The code has been selected in the contract between the older (CEA) and the prime contractor,
- The code is being used for the design and procurement of reactor components, components of reactor auxiliaries and irradiation devices,
- The code has been examined by the TSO of the French nuclear safety authority and the subsequent updates are completed.

The integration of the lessons learned from design and manufacturing are being integrated by the mean of the improvement process of the code.

4 FUTURE OF THE CODE

The key issues for maintaining the code up-to-date are to reflect industrial practices, to integrate the evolution of the standards and regulations, to integrate within the code the lessons learned from applications (technical, cost, …), to complete the characteristics of irradiated materials (appendix X3)(dedicated irradiation programs, post-mortem characterization of irradiated components).

The effort is huge for the French community of Research reactors. Therefore, it was foreseen to find synergies outside this small community. 2 tracks are followed:
- To find synergies with other types of reactors from a new design,
- To find synergies with foreign partners.

The first step was to enlarge the partnership within the Afcen framework, French Society for Design and Construction Rules for Nuclear Island Components and to group together CEA RCC-MX (research, test and experimental reactors) with Afcen RCC-MR (Sodium Fast Reactors, High Temperature Reactors and Fusion Reactors).
The new AFcen code resulting from the merging of RCC-MX in RCC-MR called RCC-MRx was drafted during the years 2009 and 2010 (french and english version). The first public release of RCC-MRx 2011 edition is scheduled to be published by Afcen at the end of 2011 or 2012.

The rational for this merging could be summarized as follows::
- even if the reactor design are different, at mechanical component level, the component types, the materials, the manufacturing techniques and processes, the loads and the environmental conditions (temperature, irradiation) they are subjected to are almost the same, the potential damages to be prevented by the mean of design and construction rules are the same for both type of projects,
- both type of project are single of the kind facilities inducing challenging management of small quantity procurement
- sharing the lessons learned from other projects facing the same challenges by the mean of cross cutting fertilization between projects
- sharing the development and maintenance costs of the code
- Sharing the international standard update monitoring.

RCC-MRx is being proposed as a basis for European cooperation:
- in the frame of the FP7 ESNII Task Force for pre-normative R&D for mechanical components of GEN IV reactors such as Sodium Fast Reactors (SFR), High Temperature Reactors (HTR) and Fusion Reactors (FR – ITER)
- Under the CEN umbrella, a workshop of different institutes and industrials is starting aiming to develop the European design and construction code for innovative reactors on the basis of the RCC-MRx. The CEN workshop agreement will consists of proposals for modifications to be introduced into the code.

5 CONCLUSION

The added values of RCC-MX and RCC-MRx are:
- specific materials (aluminium alloys, Zirconium alloys, …) specific of research reactors
- Modern welding processes (Electro Beam, …;,)
- taking into account of the thermal creep : High temperature (depending on the materials), material such as aluminium alloys at intermediate temperature
- taking into account irradiation inducing an evolution of the properties of materials (stainless steel, aluminium or zirconium alloys)
- Required provisions for use of components from catalogue
- Consistent with the PED and ESPN regulations
- Taking into account up to date European standards such as “harmonised standards”.
- Used for new projects or periodic-assessment of existing items

The code has been open to international collaboration:
Some projects such as ASTRID and MYRRHA have selected this code for their project.

To support neutron science and nuclear energy development, new experimental irradiation facilities are needed; some projects such as Pallas and ESS are already starting. It would be suitable for this type of project to benefit of a design and construction rules whose are recognized throughout an international agreement.