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

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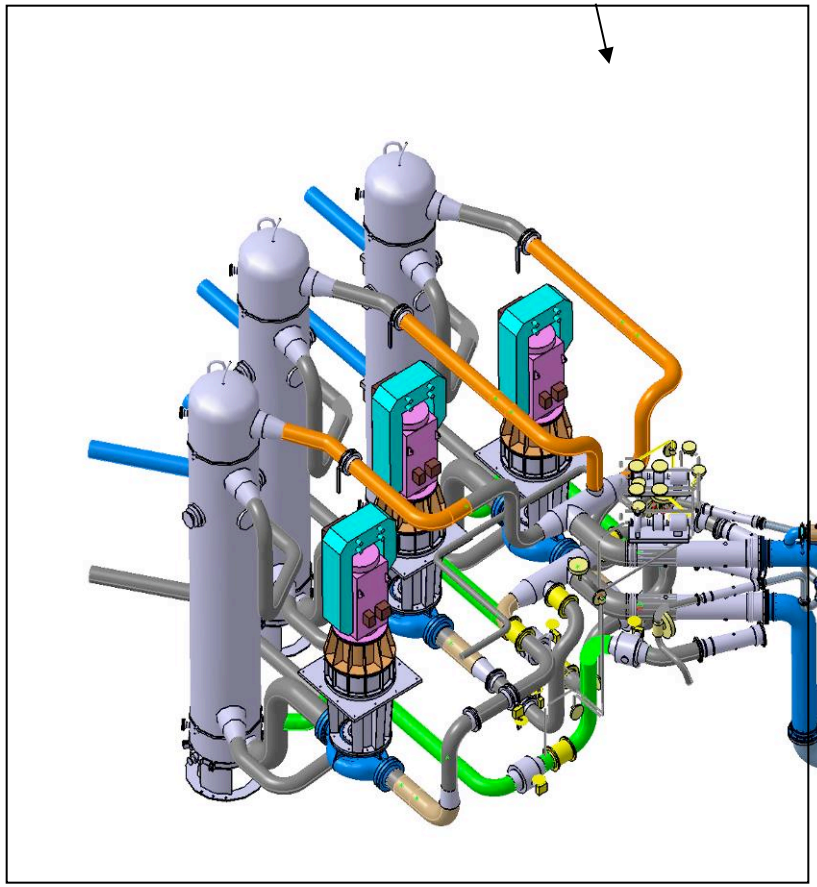
Overview of the presentation

- Need for a nuclear design and construction code for research reactors
- Overview of the RCC-MX
  - Design, Material specification, Examination and testing methods, Welding, Fabrication
- Use for projects
- Future of the code
- Conclusion

Need for research reactors

Reactor

Stainless steel
Demineralized water
e.g. Ps 16 bars T < 80°C



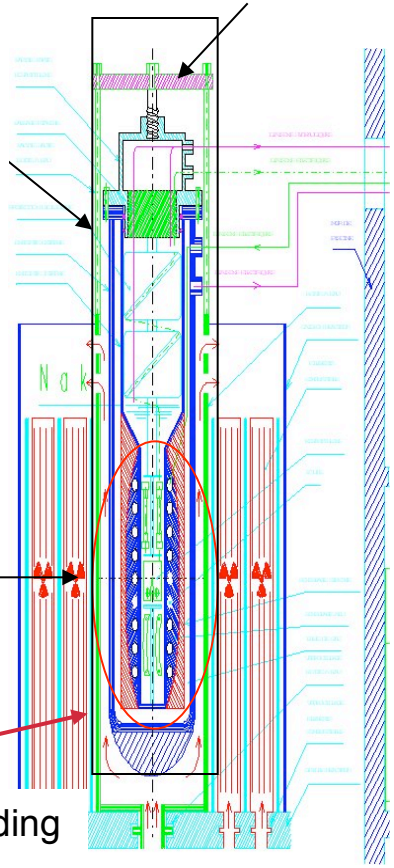
Irradiation devices

Coolant , temperature and Pressure depending on the experimental program

Zirconium or aluminum alloys or stainless steel

Aluminum alloy

Irradiation subjected structures



Electron beam welding

No existing, appropriate, design and construction code meeting all these requirements

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RCC-MX

- To address these issues, CEA and 2 AREVA entities (AREVA TA and AREVA NP) launched, in 1998, the preparation of a new design and construction code called RCC-MX
- Requirements:
  - Reference for technical and contractual relationship for the entire project
  - Scope: research reactor components and associated irradiation devices (metallic structures)
  - Covers ambient conditions during operation: irradiation, high temperature (creeping)
  - Covers all materials used in the research reactor field including aluminium and zirconium alloys
  - Compliance with regulations in the fields of quality for nuclear safety, pressure equipment directive (PED)
  - Integrates best industrial practices and use of industrial standards
  - Use of COTS (off-the shelve 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 or replacement of components

RCC-MX Structure

Section I (XDG)

General provisions
- Documentation
- Entrance keys - Applicable set of rules
- Equipment specification
- Management system
- List of applicable standards

Section III(XEC)

Additional requirements
For class 3_{Mx} components
- application of standard EN 13445
- application of standard EN 13480

Special requirement (2008)
- French regulation ESP/ESPN

Section II

TOME 1 : DESIGN

Volume A (XA) : general provisions and entrance keys
Volume B (XB): Class 1_{MX} components and supports
Volume C (XC): Class 2_{MX} components and supports
Volume D (XD): Class 3_{MX} components and supports
Volume K (XK) : control or handling mechanisms
Volume L (XL) : Irradiation device equipment
Volume Z (X): Appendixes Properties of materials, X, …
Chapters 1000- 2000- 3000- 4000- 5000

TOME 2 (XM): Material procurement specifications

TOME 5 (XF): FABRICATION

TOME 3 (XMC) : Testing and examination methods

Tome 4 Welding

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RCC-MX Key features

- **The scope of application of the RCC-MX design and construction rules is limited to metallic mechanical components:**
  - **Considered to be important in terms of 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.**

Key Code Design Features

- **Same philosophy as the RCC codes family**
- **3 RCC-MX classes:**
  - **3 design and construction classes Class 1MX, Class 2MX , Class 3MX corresponding to a decreasing assurance of the safety level:**
    - regard to different mechanical damages they may be subjected
    - due to various loads in different specified conditions.
- **Irradiation devices with :**
  - **Possibility of using COTS (component off the shelve)**
- **4 conditions are considered:**
  - **3 levels of design criteria are considered: A, C, D**
- **Formalize the best practices**

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RCC-MX Tome 1 design rules

Tome 1 includes:

- **General Rules for analysis**
- **Specific design rules for vessels, supports, pumps, valves, piping, bellows, box structures, heat exchangers**
- **Technical appendixes**
  - **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**

RCC-MX (X3 appendix) :

	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

Consistence: Product acceptance / values for analysis

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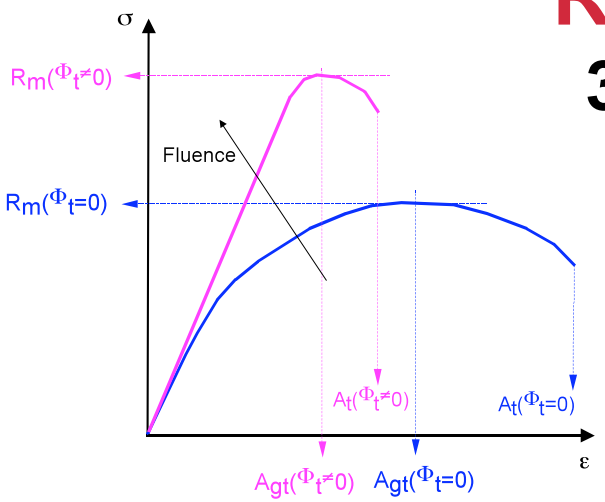
RCC-MX design (XB / XC / XL 3000): stress analysis rules



Under significant irradiation decrease of ductility At

Limiting curves:

maximal irradiation

significant irradiation

N1&N2 Mx	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)

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RCC-MX tome 2 : Material specifications

- **Possible routes for material procurement:**
  - **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 :
      - Option selection, additional requirements
      - Additional tests
  - **Alternative for class 3_{MX}: EN standards 13445 (Vessels) and 13480 (pipes)**
  - **For class 3_{MX} :**
    - possibility of procurement without specific checking
    - Possibility to use standards for finished product,
- **Special provisions for procurement of small quantities of products**

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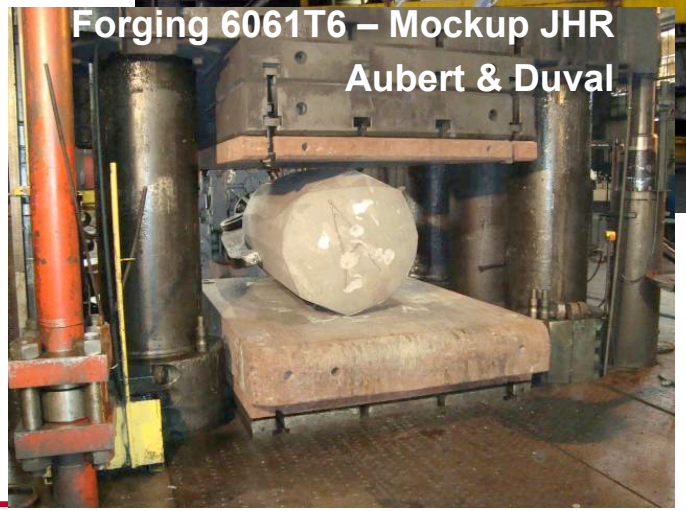
RCC-MX tome 2 : Material specifications

- **General provisions:**
  - **Mechanical characteristics**
  - **Technical qualification of parts**
  - **Introduction of a new grade or a new fabrication mode**
  - **Supplier qualification for an alloy or steel used in the creep domain**
  - **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**
- **Reference procurement specifications (49):**
  - **Covering different types of products:**
    - casting, forging, plates, pipes & tubes, rolled bars and flats, screws,
    - studs and threaded parts,
  - **9 for unallied steels,**
  - **5 for low-allied steels,**
  - **23 for stainless steels**
  - **9 for aluminum alloys**
  - **4 for zirconium alloys**
  - **Reference procurement specification is confirmed by a qualification process and a technical manufacturing program**


Quench of 6061T6 Shell
Mockup JHR
Aubert & Duval


Forging 6061T6 – Mockup JHR
Aubert & Duval

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RCC-MX tome 3: Test and examination methods

Tome 3 includes:

- Mechanical, Physical and chemical test
- Ultrasonic examination (Castings, Forged parts, Plates, Tubes, Welded joints)
- Radiographic examination
- Liquid penetrant examination
- Magnetic particle examination
- Eddy current examination of tubular products
- Others examination methods
  - Visual examination
  - Determination of surface conditions
  - Leak detection methods
- Qualification and certification of NDT personnel

RX - Phébus FPT 3
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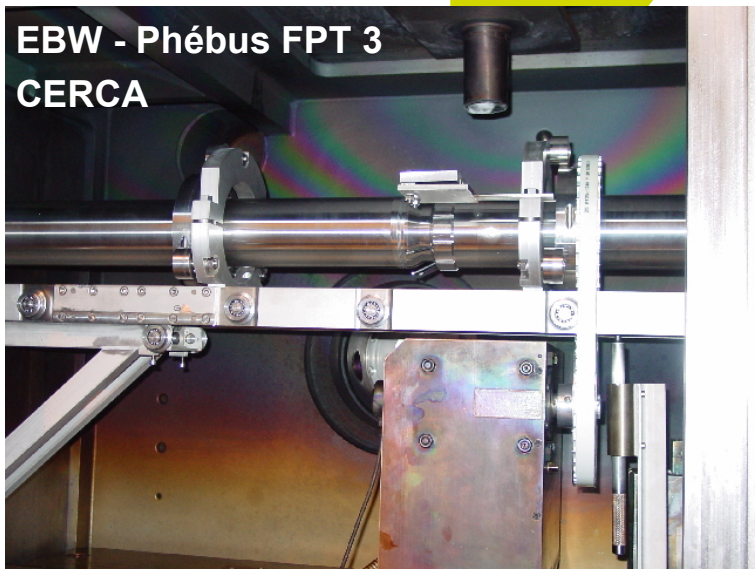
RCC-MX Tome 4: Welding

Tome 4 includes:

- Acceptance of filler materials
- welding procedure qualification:
  - Arc welding of Steels and Nickel alloys, Aluminum alloys, Zirconium alloys
  - Weld repair
  - Heterogeneous welding joints
  - Welding of tubes on exchanger plates
  - Socket weld of pipes
  - Electron beam welding,
  - Laser Beam welding,
  - Diffusion welding
  - Friction welding
  - Seal lip weld
  - Fillet welds not having a mechanical strength function
  - Cladding
  - Homogeneous filling.
- Qualification of filler materials
- Technical qualification of production workshops
- Production welds
  - In particular special provisions for the aluminum alloy welding and zirconium alloy welding



RCC-MX Tome 5: Fabrication

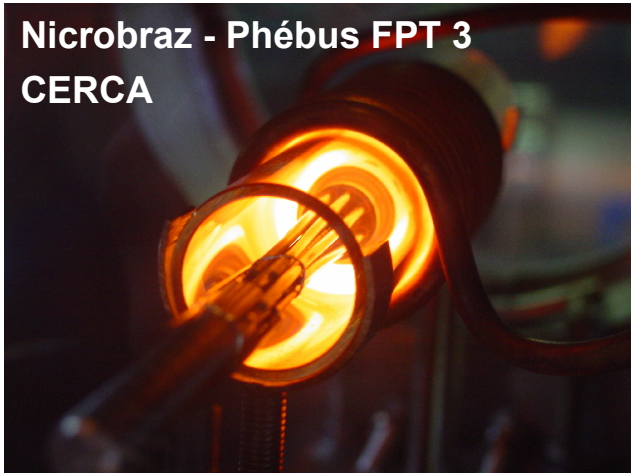
Tome 5 includes:

- Marking procedure
- Cutting – repair without welding
- Forming and tolerances

(including special provisions for aluminum and zirconium alloys)

- Surface treatments
- Rules for cleanliness
- Bolted assemblies & brazed assemblies
- Heat treatments

Drilling of barrel core
JHR mockup



Nicrobraz - Phébus FPT 3
CERCA

Zr4 sheet forming – CABRI BEP
MECAGEST

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use of the RCC-MX for Projects

JHR:

- **The RCC-MX is the Reference for technical and contractual relationship for the entire JHR project:**
  - **The code was selected in the contract between the holder (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 IRSN (TSO of the French nuclear safety authority) and the subsequent updates are completed**

OSIRIS:

- **manufacturing of an ISABELLE 4 irradiation device**

ORPHEE:

- **Manufacturing of the in-pile assemblies of the cold neutron sources**

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

Future of the code

- **Key issues:**
  - **Maintain the code up-to-date:**
    - **Industrial practices**
    - **Evolution of the standards and regulations**
    - **integrate within the code, the lessons learned from use (technical, cost, …)**
  - **Complete the characteristics of irradiated materials (appendix X3):**
    - **dedicated Irradiation programs**
    - **post-mortem characterization of irradiated components**

- *Important cost for the French research reactor community*
- **Relevance of the code driven by:**
  - **Structure design and construction**
  - **Material**
  - **Ambient conditions during operation (temperature, irradiation,…)**
  - **loadings**

- *It is possible to enlarge the scope of the code for new reactors facing the same issues*

Future of the code

Approach:

Integration within the Afcen framework, French Society for Design and Construction Rules for Nuclear Island Components

- Group together CEA RCC-MX (Research, test and experimental reactors) with Afcen RCC-MR (Sodium Fast Reactors, High Temperature Reactors and Fusion Reactors).
- RCC-MRx = Afcen code resulting from the merging of RCC-MX in RCC-MR:
  - Private drafts RCC-MRx 2009 and 2010 (french and english version),
  - Public RCC-MRx edition to be published by Afcen by the end of 2011 or 2012.

First steps towards a European design and construction code:

RCC-MRx is being proposed as a basis for the development of a European / international design and construction code for mechanical components in :

- Research Reactors (RR)
- Sodium Fast Reactors (SFR), High Temperature Reactors (HTR) and
- Fusion Reactors (FR – ITER)

Two international collaborations are starting:

- 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 adapt the code for innovative reactors (MYRRHA, ASTRID, ALLEGRO) by means of CWA (CEN workshop agreement)

Conclusion

- **The added values of RCC-MX and RCC-MRX are:**
  - **To collect and formalize the knowledge for design and construction of research reactors and fast breeders**
  - **Consistency with the PED and ESPN regulations**
  - **To propose**
    - **specific materials (aluminium alloys, Zirconium alloys, …) specific of research reactors**
    - **Modern welding processes (Electro Beam, …;,)**
  - **To take into account:**
    - **thermal creep : High temperature , Other material such as aluminium alloys at medium temperature**
    - **irradiation inducing an evolution of the properties of materials** (stainless steel, aluminum or zirconium alloys) **and irradiation creep**
    - **up to date European standards such as "harmonised standards".**
  - **Required provisions for use of components from catalogue**
  - **Living code integrating the lessons learned from past and ongoing project**
- **The RCC-MRx is proposed as basis for international collaborations**