Analysis of the optimization of the secondary hot piping for a sodium fast reactor

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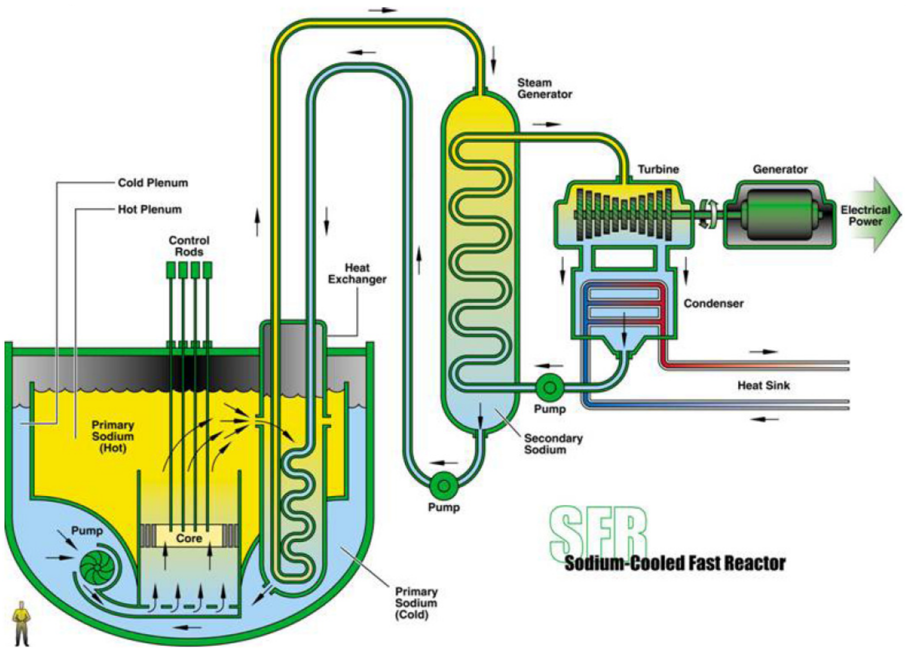
Introduction

President J. Chirac decided to launch a new prototype of generation IV reactor in France in 2020.

One type of reactor investigated is a sodium fast reactor (SFR) with an expected live of 60 years as minimum, a high temperature of 550°C, a good disponibility (small time of repair, inspection, maintenance), a higher level of security.

For this reactor some 'new' material are investigated in order to replace the 316L(N) stainless steel

The 9 Cr steel is a candidate material for Generation IV reactor for its thermal propriety (for secondary loops, steam generator and heat exchanger). For that T91 and P92 steels are investigated in the CEA.



Picture of SFR reactor (pool system)

Content of the presentation

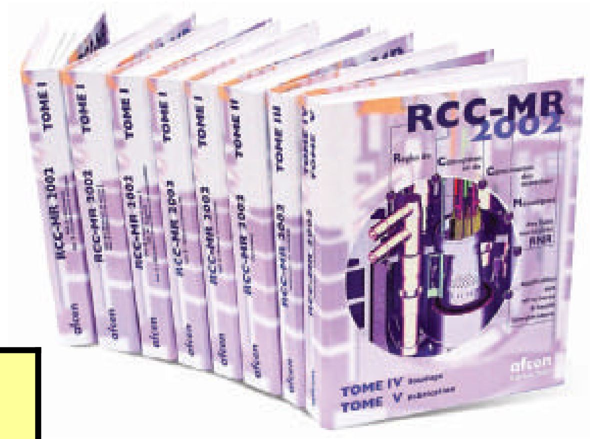
1. general overview of the RCC-MR
2. Introduction
3. Presentation of the study
4. Optimization of a piping line
5. conclusion

General objectives

- This document describe either:
  - Design rules
  - The fracture mechanics parameter calculation (A16 appendix)
  - The associated criteria
  - Material data for the investigated materials
- This document constitute a reference for assessment at high temperature in France:
  - For FBR design and inspection
  - For GEN IV design (HTR and VHTR reactors)
  - For ITER (Vacuum vessel)
- At low temperature, the coherence with PWR code is ensured (RCC-M code)

Codification

- **CEA member of the AFCEN**
  - RCC-M : PWR Design and construction (ASME Sec. III – II – V - IX)
  - RCC-MR : High temperature reactors and ITER (ASME Sec. III & NH)
  - RCC-MX : Research reactors and related devices
  - RSE-M : In-Service code – applicable to PWR (ASME XI)



- **Important activities in LISN**
  - Pilot of the RCC-MX production
  - Leader with AREVA on the RCC-MR production
  - Participation to WGs for the RSE-M section
  - Some exchanges with ASME

RCC-M (PWR)	RSE-M (PWR)	RCC-MR (FBR, ITER, …)	RCC-MX (Research R)
1st edition : 1980			
2nd edition : 1983			
3rd edition : 1985			
4th edition : 1988		1st edition : 1985	
5th edition : 1993	1st edition : 1990	2nd edition : 1993	
6th edition : 2000 ➢ 1er addendum : june 2002 ➢ 2ème addendum : dec. 2005 ➢ 3ème addendum : june 2007	2nd edition : 1997 ➢ 1er addendum : 1998 ➢ 2ème addendum : 2000 ➢ 3ème addendum : 2005	3rd edition : 2002	1st edition : 2005
7th edition : 2007		4th edition : 2007	2nd edition : 2008
		5th edition : RCC-MRx Nov. 2011	

Introduction

- the objective of the present work is to compare the 2 materials for an creep-fatigue analysis (which is generally the most critical point for design) of a secondary hot piping for a sodium fast reactor
- No buckling are taken into account in this study

- Study based on the secondary hot piping considered for European Fast Reactor (EFR) and originally designed
  - *for a period of 40 years with a disponibility rate of 80%*
  - *With the 316L(N) stainless steel*
  - *With a maximum temperature of 525°C*
  - *With the RCC-MR 1993 creep-fatigue rules*

- Since that time, some changes took place:
  - *A potential new material : Mod.9Cr-1Mo*
  - *An increased required life from 40 to 60 years*
  - *A new issue of the RCC-MR rules in 2007 with an important improvement of the creep-fatigue rules*

Optimization of a piping line

- This part is aimed at optimizing the design of the secondary hot piping between the heat exchanger and the steam generator for the EFR project.

- It was originally designed for 316L(N) stainless steel in 1995, which leads us to ask some questions :
  - *what are the consequences of the new modification of the RCC-MR 2007 rules ?*
  - *Can we shorten the piping line with the use of mod.9Cr-1Mo ?*

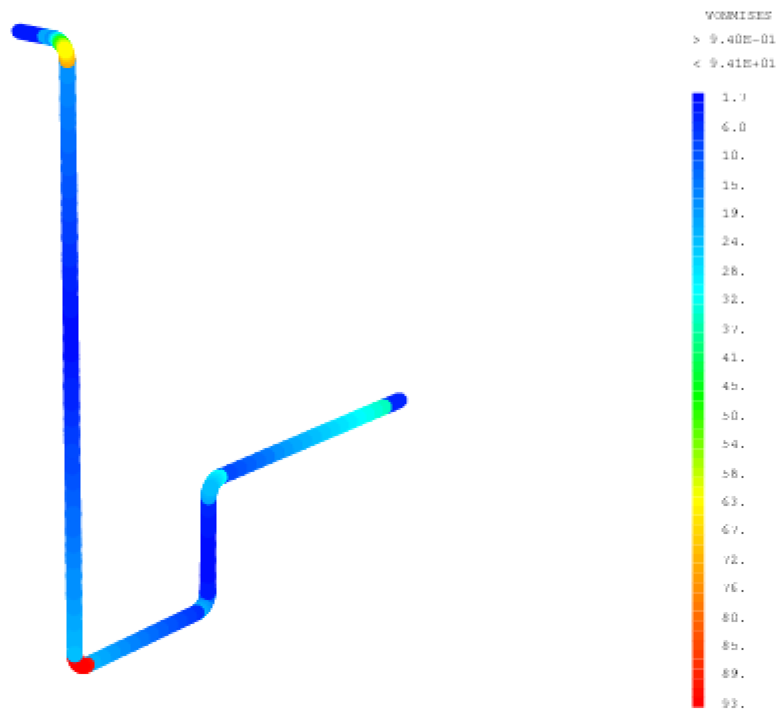
- Description of the analysis :
  - *The analysed piping line has a length of 82 meters and contains 4 elbows. The outside diameter of the piping is D = 711 mm with a thickness of hc = 11 mm. The radius of curvature of the elbow is R = 1067 mm and the thickness is hc = 14.2mm.*
  - *The cycle loading choice, based on the previous analyses, corresponds to the cycle which maximize the secondary stress range (i.e. the creep fatigue damage) with a hold time of 524 hours. Forces coming from weight and supports are neglected, but a pressure stress is included in the study.*
  - *All the calculations were performed with the finite element software CAST3M.*
  - *The material data for 316L(N) and mod. 9Cr-1Mo steels are taken from the appendix A3 of the RCC-MR (2002 or 2007) for a maximum temperature of 525°C.*

Optimization of a piping line with the RCC-MR 2002

- for the 316L(N) steel, the maximum reference thermal stress is 94 MPa which implies a creep-fatigue damage for 100 cycles of d=0.0870 with the RCC-MR rules of 2002.
- for the Mod.9Cr-1Mo steel, the maximum reference thermal stress is 62 MPa which implies a creep fatigue damage for 100 cycles of d=0.0511 with the old RCC-MR rules of 2002.

CAST3M calculations with 316L(N)

Distorted EFR's IHX-SG pipe (amplification 10)



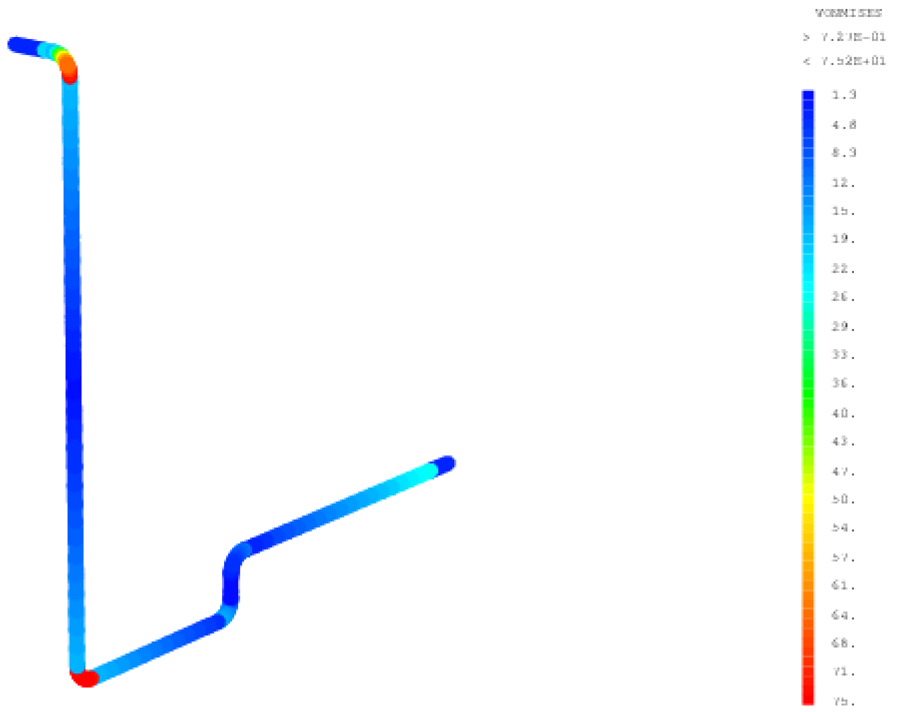
reference stress field under temperature cycling and components displacements between 525 and 20°C

Optimization of a piping line with the RCC-MR 2002

- the creep-fatigue damage with the Mod9Cr-1Mo is lower than 316L(N) value,
- It may allow to shorten the length of the piping for the first material.
  - *with the Mod9Cr-1Mo, 10 meters could be removed (on the whole 82 meters piping line).* → *d = 0.0826*

CAST3M calculations with Mod.9Cr-1Mo

Distorted EFR's IHX-SG pipe (amplification 10)



reference stress field under temperature cycling and components displacements between 525 and 20°C

Optimization of a piping line with the RCC-MR 2007

- The same analysis is performed with the same material data but with the new RCC-MR 2007 rules
  - *These rules allow to have a better creep-fatigue damage evaluation thanks to a better estimation of the stresses during the hold time.*
- For both materials, the application of the new RCC-MR 2007 rules for these cases allows to decrease significantly the creep-fatigue damage by a ratio of 8 for the 316L(N) and 25 for the Mod.9Cr-1Mo.
  - *This may allow to shorten the piping line geometry: a new creep fatigue damage evaluation was performed with a new piping shortened by 17 meters and 2 elbows.*

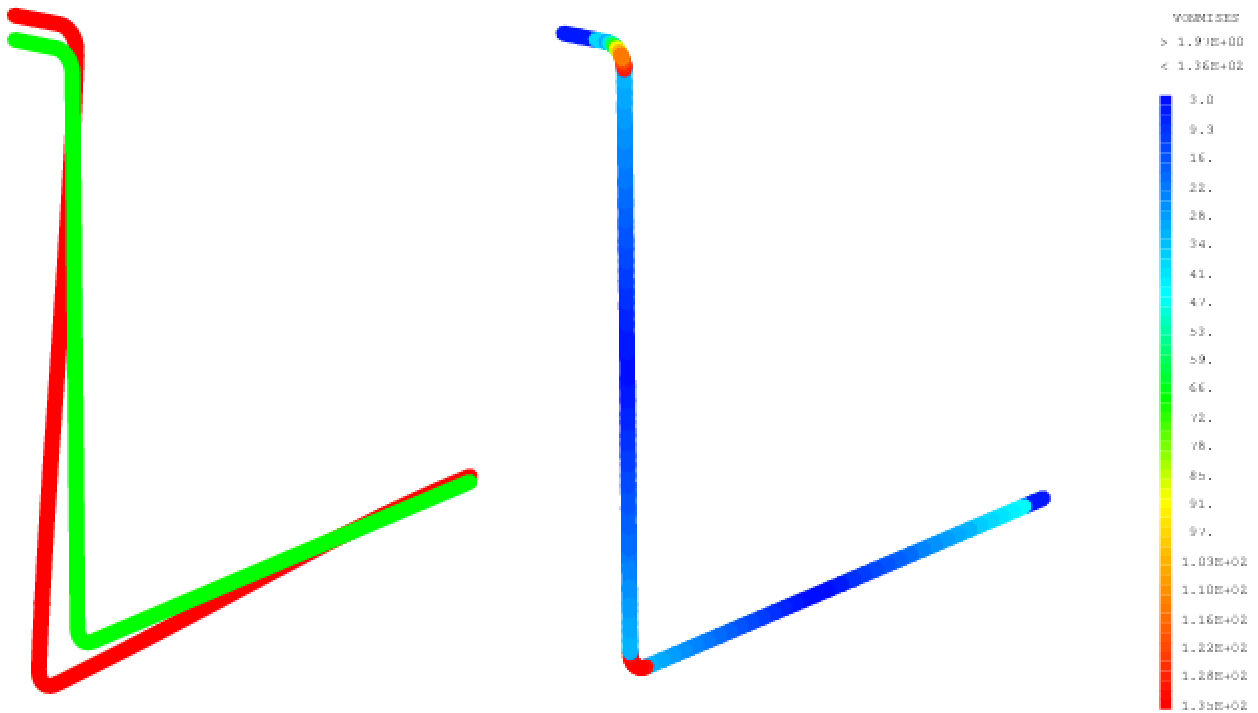
Creep-fatigue damages for 316L(N) and mod. 9Cr-1Mo with various RCC-MR rules and piping designs

	RCC-MR 2002		RCC-MR 2007	
	316L(N)	mod 9Cr-1Mo	316L(N)	mod 9Cr-1Mo
Original piping line	**0.0870**	0.0511	0.0104	0.0021
Piping line shortened by 10 meters	--	0.0826	--	0.0061
Piping line shortened by 17 meters and 2 elbows	--	--	0.0513	0.0294

Optimization of a piping line with the RCC-MR 2007

- The maximum reference thermal stress implies a creep fatigue damage for 100 cycles of d=0.0513 which is largely smaller than the creep-fatigue damage calculated in the previous conditions.
  - *It seems not possible to reduce the distance between the two components (i.e. steam generator and heat exchanger).*
  - *So for this piping line configuration, the use of the Mod.9Cr-1Mo do not bring any advantage about the creep-fatigue damage.*

<u>CAST3M calculations with 316L(N) (shortened pipe)</u>



Optimization of a piping line with the RCC-MR 2007

- The maximum reference thermal stress implies a creep fatigue damage for 100 cycles of d=0.0513 which is largely smaller than the creep-fatigue damage calculated in the previous conditions.
  - *It seems not possible to reduce the distance between the two components (i.e. steam generator and heat exchanger).*
  - *So for this piping line configuration, the use of the Mod.9Cr-1Mo do not bring any advantage about the creep-fatigue damage.*

- these results just underline the improvements of the creep-fatigue rule in the RCC-MR code.
  - *buckling analyses should be performed.*
  - *Moreover, some configurations described here may not be sufficiently stable under different loadings, including a seism.*
  - *future RCC-MRx rules will have improvements for the design of pipes under buckling.*

Conclusions and perspectives (1)

- Mod. 9Cr-1Mo steel (T91) is a candidate material for Sodium Fast Reactor (SFR) components and in particular for secondary hot piping. As compared to austenitic stainless steels used in the past reactors, 9Cr-1Mo steel's good conductivity and low thermal expansion let the possibility to reduce the size of the loops and thus to gain on the costs.

- A numerical analysis on secondary hot piping design has been carried out using a stainless steel 316L(N) (used in the previous SFRs Phénix and Super Phénix) and a mod. 9Cr-1Mo steel.
  - *The aim of this study is to optimize the secondary hot piping by minimizing the size of the loop and by comparing both candidate materials.*
  - *This analysis deals with the secondary piping considered for the European Fast Reactor (EFR) and the design has been made for realistic operating conditions of EFR for a period of 60 years.*
  - *The analysis is based on the creep-fatigure damage and the application of the RCC-MR rules.*

Conclusions and perspectives (2)

- The improvement of the RCC-MR rule about the creep fatigue damage evaluation in the last issue of the RCC-MR 2007 leads to a better evaluation of the creep fatigue damage.
  - *This alone improvement allow to optimize a lot the geometry of the piping.*

- The results show that the use of mod. 9Cr-1Mo steel has generally an advantage for moderate temperature (below 525°C).
- But, when the temperature is more important, stainless steel 316L(N) presents lower damage than 9Cr steel.
  - *Indeed, thanks to advantageous thermal properties of mod 9Cr-1Mo steel, the stress state due to mechanical and thermal loading for this material is 20 to 30% lower than this of 316L(N) stainless steel.*
  - *But at high temperatures this benefit is too low to compensate for the lower creep properties of 9Cr steel.*

- These results must be confirmed with buckling analyses
  - *future RCC-MRx 2011 rules will have improvements for the design of pipes under buckling.*

Thank you for your attention