

Status of the French Design and Construction Rules Applicable to Fast Breeder Reactors

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The design basis of the first French Fast Breeder units was partially derived from ASME Code III and ASME CC 1331 (for PHENIX) or ASME CC N47 (for SUPERPHENIX).

The pool type design on the one hand, and the absence of ASME rules for components other than class 1 under high temperature conditions, on the other hand, rendered the application of these texts not entirely satisfactory and a counterpart set of rules and procedures was consequently elaborated.

At the beginning of the French FBR industrial phase, a Code of applicable rules had to be compiled, based mainly on CEA and EDF research and on the know-how acquired by NOVATOME during the design and construction of SUPERPHENIX.

The first formulation of this document was undertaken by EDF, CEA and NOVATOME at the beginning of 1979, with provision for a 3-year schedule and periodical up-dating to integrate data derived from subsequent research work.

An important part of the code (RCC) deals with the design and examination rules (RCCM) comprising.

- RCCM Vol 1 : Equipment design rules
 - Vol 2 : Materials
 - Vol 3 : Examination methods
 - Vol 4 : Welding
 - Vol 5 : Manufacturing

The present paper describes the design basis rules for class 1, 2 and 3 components having an activity barrier or structural support related function, with reference to both high and low temperature conditions (with or without creep).

1. Introduction

Two fast breeder reactors (FBRs) have been in service in FRANCE for several years : the experimental reactor Rapsodie and the 250 MWe demonstration plant PHENIX.

On the basis of experience already acquired, it was decided in 1974 to undertake construction of a commercial size scale-up from PHENIX. A rated power of 1200 MWe was finally selected for the new breeder SUPERPHENIX. In the same year, a number of European utilities, ENEL (Italy), EDF (France), SBK (Germany), opted for the creation of a joint company NERSA, for the design, construction and operation of the CREYS-MALVILLE breeder plant. Among the orders placed by NERSA for the construction of SUPERPHENIX, one covers the turnkey supply of the NSSS, entrusted to a consortium formed by NOVATOME (France) and NIRA (Italy).

The construction of SUPERPHENIX started in 1977 and the plant is scheduled for criticality in 1983. This, of course, represents a major step forward in breeder development, but it was important to undertake without delay design studies for the next generation of breeders. NOVATOME was consequently entrusted by EDF (Electricité de France) with engineering studies for the breeders to come, with a view to safeguarding the general design continuity of these reactors, and deriving maximum benefit from the experience acquired during the design and construction of SUPERPHENIX.

In the framework of these studies, a 3-party committee was formed, grouping the CEA (licenser), EDF and NOVATOME to elaborate the design part of the FBR design and construction rules.

The present paper recalls the French regulations applicable to nuclear reactors and describes briefly the general organization, the salient features and present status of the document prepared by the aforementioned committee.

2. Regulation Applicable to Mechanical Structures of Nuclear Reactors

In France, besides regulations specifically concerning nuclear safety, the construction and operation of water-cooled nuclear reactors is subject to regulations as stipulated in the decree of April 2, 1926 concerning steam pressure vessels and the administrative decision and departmental order of February 26, 1974 concerning the application of these pressure vessel regulations to water-cooled nuclear reactors and their main primary circuits.

However these official regulations are not formulated as a design code and the constructor has to demonstrate that his construction is in compliance with the regulatory stipulations and justify his methods. With this in mind, FRAMATOME and EDF joined forces to write a code, known as the RCC-M (Design and Construction Rules) for PWR NSSS mechanical equipment. This document is published by the AFCEN (French Association for the Design and Construction Rules for NSSS equipment).

No equivalent FBR regulations presently exist in FRANCE. In the case of SUPERPHENIX these rules were defined in the NERSA-NOVATOME contractual documents. However, it was considered preferable for the satisfactory development of future breeder plants to codify PHENIX and SUPERPHENIX know-how in a form applicable to this type of reactor in general and so constituted as to the function of the aforementioned RCC-M, and to respect the same trends, as the corresponding PWR regulations. The writing of this FBR design and construction code started over an year ago.

In the present paper, we shall deal only with the design aspect, corresponding to that part of the code to be written by the 3-party Committee.

As mentioned previously, the SUPERPHENIX design rules are defined in the NERSA-NOVATOME contractual documents. In most cases, these rules consisted in recommending the application of ASME Code Section III and Code Case N47. In order to comply with such recommendations, the SUPERPHENIX design engineers and technicians were confronted with the following difficulties:

- The ASME code is basically a pressure vessel code, i.e., well adapted to the most common loadings and shapes of such vessels. In a pool type breeder, owing to the low values of primary loads, the structures are generally thin relatively to their others dimensions. In another hand, this type of design provides by itself that the most important structures work in normal operation or current incidents at moderate temperature, the creep being only involved in accidental occurrences.
- Although frequently similar to the US steels grades, as specified in the ASME Code, some differenties in the composition of steels used in the French FBR lead to mechanical properties not identical with those given in this code.
- The area, where creep is negligible and where the ASME Section III and Code Case N47 application-limits lie, is not explicitly defined. In some cases, there is a certain lack of consistency between the two documents.
- The buckling rules are ill-adapted to FBR structures.
- It is not easy to transpose the ASME Code III component classes and types (class 1, 2, 3 - vessels, pumps, valves, piping, internals ...) to fit the FBR structures. The case of the reactor roof slab is a good example of this.
- Difficulties also arise from the fact that the ASME code was not compiled to satisfy the requirements of a government decision in the spirit of the 26/2/74 documents, which require assessment of the capacity of an equipment to withstand various types of damage and justification of the related safety factors. This aspect is not explicitly formulated in the ASME code.

In most cases, as the SUPERPHENIX project progressed, these difficulties arose and were solved by the efforts of the CEA, EDF and NOVATOME-NIRA. In this connection, we would draw particular attention to the work of the RAMSES Committee (1) (created to formulate rules for the stress analysis of structures subjected to high temperatures), which, within the CEA has for several years, been issuing recommendations based on its own FBR experience. Certain RAMSES recommendations were adopted in the SUPERPHENIX project.

3. General Layout of the Code

The aim is to produce an FBR code or set of rules presented along the lines of the RCC-M elaborated for the PWRs.

The rules are thus presented in five volumes :

- Volume 1	Section A	General provisions
	Section B	Level I components
	Section C	Level II components
	Section D	Level III components
	Section H	Component supports
	Section Z	Technical appendices

- Volume 2 Materials
- Volume 3 Examination methods
- Volume 4 Welding
- Volume 5 Manufacturing

Sections B, C, D are further divided into chapters as follows :

- 1000 : General information
- 2000 : Materials
- 3000 : General design rules (Table 1)
- 4000 : Manufacturing
- 5000 : Tests

The rules under Chapter 3000, General design rules, formulated by the 3-party committee, are subdivided according to the types of structures encountered in the FBRs, e.g. thin shell vessels, box structures (roof slab, diagrid).

The organization of this chapter is based on FBR operating conditions and each text deals with rules applicable to both moderate and high temperature operation (Table 2). Indications as to the operating conditions involved in each case are provided beforehand in a test (fig. 1) defining the absence or not of significant creep (2).

Every attempt has also been made to clarify the types of damage likely to occur. These are divided into two groups :

- P : immediate or delayed excessive strain
 - immediate or delayed plastic instability
 - immediate or delayed rupture
 - immediate or delayed elastic or elasto-plastic instability
- S : Ratcheting
 - fatigue or fatigue-creep induced cracking

Three distinct levels of safety criteria were adopted : A, C and D ; each corresponding to different safety factors with respect to the types of damage listed above.

The rules formulated in this code thus depend on :

- the type and safety level of the equipment considered
- the operating time-temperature range
- the damage involved
- the specified criterion level
- the type of analysis envisaged (elastic, inelastic, experimental).

4. Present Status and Special Features of the Code

4.1 Present Status

Most headway has been made so far on the chapters dealing with general design rules (RB 3100), general analysis rules (RB 3200) and piping design rules (RB 3600) for level I equipment.

Discussion is presently focussed on rules pertaining to materials, manufacturing and inspection with a view to defining the objectives of the different levels I, II and III and the means to attain them. FBR rules for level II and III equipment are expected to be issued shortly.

The mechanical properties of the FBR materials are listed in a technical appendix, which presently comprises 10 sets of characteristics (5 for stainless steels, 4 for ferritic steels and 1 for bolt steel) with elastic and inelastic analysis data indicated separately.

4.2 Main Features

The main features of the document as it stands at present are as follows :

- Definition of a time-temperature range where creep is negligible, which can be used to determine whether the rules applicable to a given equipment are of the significant creep or negligible creep category. With this text, elaborated by the RAMSES Committee (ref. 2), creep effects can be disregarded for equipment required to operate at high temperatures for very short periods.

- In the case of variable loads, a mechanical structure could be subjected to ratcheting, increasing with each successive cycle. Since the FBR thermal loads are extremely high, this aspect has to be carefully checked and a rule is proposed with a wider field of application than the ASME Code or Code Case N47.

For elastic analysis, such a rule (reference 3) has been derived from CEA experimental results. It is based on the fact that the strain resulting from the combination of a primary stress P and a secondary stress variation ΔQ can be represented by introducing a single stress, known as the Effective Primary Stress, defined as that which, under the same conditions of application, would produce the same strain. The rule proposed to verify the absence of ratcheting consists in checking that the effective primary stress does not exceed limits identical to the primary stress limits (S_m and S_t).

For inelastic analysis, apart from the problem of modelling the behaviour of the material, inherent in this type of analysis, checking the absence of ratcheting would theoretically require calculation of all cycles to which the structure will be subjected. In practice, this would be far too long and too expensive. A large number of R and D studies have consequently been launched with a view to finding methods of extrapolating the end-of-life behaviour of a structure from results obtained with 1, 2, 3 or 4 cycles. Present extrapolation methods have to be used with discrimination and are not always applicable to all types of load (ZAC method, in reference 4, for instance).

- As regards fatigue or fatigue-creep cracking, only a preliminary version of the rule is available. A large number of surveys have been undertaken on this subjected and should shortly permit formulation of a rule, assuring consistency between significant and non-significant creep areas and proving easier-to-apply than the Appendix T rule of Code Case N47.

- For structures made of a complex network of welded steel plates, the use of the collapse load and reference stress methods have been extended to such complex structures which can hardly be analyzed by the classical stress classification approach.

5. R and D Backing for the Code

EDF and the CEA have focussed considerable efforts on the financing and performance of research and development (R and D) work, with the active participation of NOVATOME.

The main subjects dealt with are as follows :

- ratcheting : additional tests to continue validation of the rule proposed
- fatigue : use of tests to determine the incidence of sodium on fatigue, with or without hold-time

- buckling : study of the influence on stability of residual stresses, shape defects, thermal stresses and seismic dynamic loading
- inelastic analysis : improvement of material behaviour models, elaboration and justification of methods of extrapolating the end-of-life behaviour of structures subjected to load cycles. Method of defining load histograms
- piping : scale model tests at high temperatures
- fracture mechanics : calculations and tests to define defect instability, growth and acceptability
- the reference stress method, which has already been applied successfully to simple structures would be a way of avoiding the stress classification approach. But it still needs to be validated for the analysis of complex structures.

References

- 1 "Design Methods and Criteria Recommended by the RAMSES Committee"
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C247/80 Second International Conference on Engineering Aspects of Creep.
University of Sheffield. 15-19 September 1980
- 2 "Creep range cross over curve" Working group on Codes and Standards - G.E.C.
- 3 "Ratchetting-Experimental Tests and Practical Method of Analysis"
P. COUSSERAN, J. LEBEY, D. MOULIN, R. ROCHE, G. CLEMENT
C208/80 Second International Conference on Engineering Aspects of Creep
University of Sheffield - 15-19 September 1980
- 4 "A Practical Method to Determine Elastic or Plastic Shakedown of Structures"
J. ZARKA - F.C. ARNAUDEAU - J. CASIER and G. BAYLAC in "Simplified Methods in
Pressure Vessel Analysis, PVP-PB-029" edited by R.S. BARSOUM, 1978

RB 3000	DESIGN RULES FOR CLASS 1 COMPONENTS
RB 3100	General Design
RB 3200	Design by Analysis <ul style="list-style-type: none"> - General - Definitions - Constitutive equations of the material for each analysis method - Rules for protection against type P damage - Rules for protection against type S damage - Rules for protection against buckling - Rules for bolts
RB 3300	Vessel Design
RB 3400	Pump Design
RB 3500	Valve Design
RB 3600	Piping Design
RB 3700	Expansion Joint Design
RB 3800	Box Structures Design

TABLE 1 - Article RB 3000 - CONTENTS

<div style="text-align: center;"> RULES CREEP EFFECTS </div>	RULES FOR LOW TEMPERATURES	RULES FOR HIGH TEMPERATURES
Creep effects are negligible during the service lifetime	For Levels A, C and D	
Creep effects are negligible during the service lifetime without considering Level D - Loads	For Levels A and C	For Level D
Creep effects are not negligible during the service lifetime (even if level D - loads are excluded)		For Levels A, C and D

TABLE 2 - Organization of the Code
According to the Creep Effects

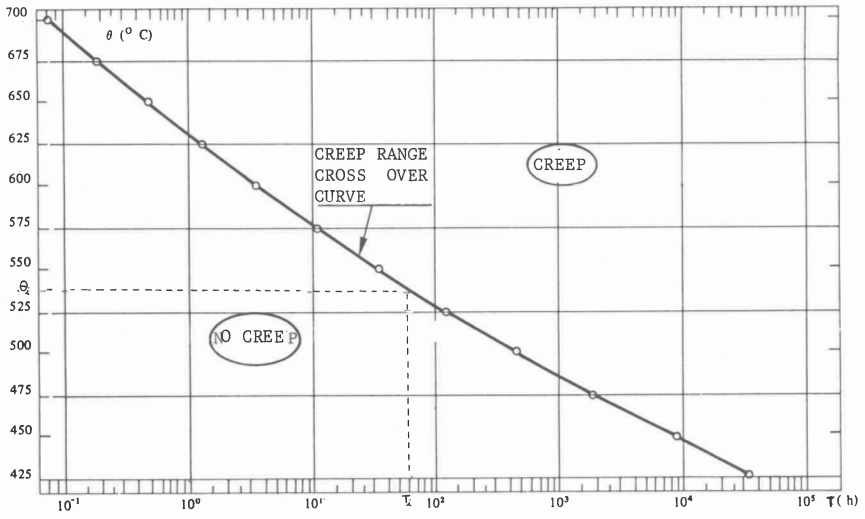


Fig. 1 - CREEP RANGE CROSS OVER CURVE