# Rapide 1500-reactor unit – Core support structure design evolution between SPX1 and SPX2

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## 1 INTRODUCTION

In the French design fast breeder reactors, the strongback is a welded structure whose main role is to support the core.

As regards the SUPERPHENIX sized reactors, because of the vessel large diameter it is difficult to adopt the same core support principle as in PHENIX, where the core is hanging to the main vessel through a conical shell (in tension).

Since it is difficult to manufacture a large diameter forged connecting part, the selected solutions consisted in a direct support of the core by the vessel bottom through a cylindrical shell in compression.

## 2 THE SELECTION OF A CREYS MALVILLE TYPE DESIGN

### 2.1 Design requirements

- According to the functional requirements, related to the control rod drops and to the fuel assemblies handling, overall deformations should be reduced.

This requires a geometrically stable diagrid and a vessel bottom stiff enough to limitate the overall deformations and especially during earthquakes.

- The consideration of the core melt accident and the diagrid removability required for SPX1 resulted in the discarding of a disk-type solution for the strongback and in the selection of a ring-type solution.

### 2.2 The evolution of the ring-type basic concept

#### 2.2.1 Ring-type strongback and supporting diagrid

In this case, the diagrid resting on the strongback inner shell must ensure the compliance with the deformations-related requirements on the one hand, and an appropriate hydraulics at the core inlet, on the other hand.

Because of its load transferring function in this configuration, the diagrid must be provided with a high rigidity, which requires the

achievement of a compartmenting that is hardly compatible with an appropriate hydraulics of the diagrid.

Indeed, as regards the transients that entail a significant hydraulic assymetry in the feeding, it was deemed that the best solution would be to adopt a diagrid and a diagrid support structure which would allow to uncouple the supporting and core hydraulic feeding functions.

### 2.2.2 Strongback with a crey type diagrid support structures

Various solutions were contemplated (figure 1) and what was mainly aimed at was to maintain the compressive stresses at the most possible low values in order to prevent plates buckling hazards. Indeed, the strongback is a ring-type structure whose section shape is maintained by radial stiffeners. Under axial axisymmetric loads, its resistance is due, on the one hand to the circumferential forces that develop in the upper and lower plates and which prevent the section rotation when subject to loads, and on the other hand, to the shear stresses that are generated in the radial stiffeners in order to maintain the section shape and to transfer the vertical forces to the supporting shell.

On the contrary, under unsymmetrical loadings, the structure is mainly subject to torsional stresses inducing shear stresses in the shells.

Therefore, the structure resistance is mainly determined by stability requirements in the upper plate and in the radial stiffeners.

## 3 THE STRONGBACK DESIGN IN THE RNR 1500

### 3.1 Basic assumptions

The problems that arise from a strongback design can be classified as follows :

- the selection of the supporting diameter :
  This depends upon the solution retained for the components supporting system, and the economic optimization of the vessel bottom and strongback assembly as well as the retained assumptions regarding seismic loads.

- the selection of the structure type :
  For a given outside diameter, and taking account of the core loading, what is intended is to find the most economic structure.
  a) Selection between a CREYS-type ring structure and a PHENIX-type disk structure.
  b) Search of the material optimum distribution in the welded box structure, taking account of the buckling resistance.

- analysis of thermal loads
  A ribbed structure such as the strongback, which is immersed in plena with different temperatures during transients, is highly sensitive to the cyclic thermal loadings induced by various operational disturbances on the primary system or the secondary loops.

- feedback from the CREYS-MALVILLE operating experience
  For instance, it should be noted that during manufacturing, the CREYS strongback had to be stiffened by the addition of ribs on radial plates since buckling margins were too low.
  It was demonstrated by the first studies achieved that for similar

loads ans stresses, a "disk-type" structure allows a significant mass gain as compared to the ring-type structure and diagrid support assembly.

Since the CREYS design requirements which take account of the core melt accident cannot be applied to the SPX2 preliminary design, the disk-type structure STRONGBACK was selected.

### 3.2 Studies of the supporting diameter

The first parametric achieved studies allowed to assess the various contemplated solutions.

When the supporting diameter is increased from 11 m to 14 m, the strongback mass concurrently increases from 150 t to 200 t, yet the 50 tons addition is compensated by a lightening of the vessel bottom.

What was first aimed at when optimizing the main vessel was to obtain a shape that could provide a membrane resistance rather than a bending one at the triple point level, and that could reduce the most possible the buckling risks trough balancing by means of the internal hydrostatic pressure the circumferential stresses induced by weight in the vessel torical part.

The studies carried out on the main vessel bottom gave better results as regards the 14 m supporting diameter. The stress level is significantly lower for this geometry ; besides, the vertical rigidity is increased by 50 %, which combined to a larger diameter, yields a resistance to rocking nearly twice as high as that of the 11 m diameter. Thus, this is more concerns both core stresses and displacements.

These considerations led to the selection of a 14 m supporting diameter.

### 3.3 Preliminary design of the "disk-type" structure

The studied concept consists in a disk-type strongback resting on a supporting diameter of around 14 m, at the vessel bottom.

The aim is to achieve a box-type structure stiffened by vertical plates welded to a thick upper plate in compression.

What remains to be defined is the distribution type of the vertical stiffening ribs, i.e either a radial lattice or a square pitch lattice.

The radial lattice provides the disadvantage of requiring a central connecting part which is generally subject to unallowable loads.

The square pitch lattice results in an excess of material at the periphery.

Therefore, a mixed structure has been retained : a square pitch lattice in the center, and a radial one at the periphery (figure 2).

The design objective was to obtain relatively uniform stress conditions in the whole structure, and besides, to have low membrane compressive stresses with respect to tension stresses, with a view to getting a balance between resistance against buckling in the compressed area and resistance against excessive strain in tensed area.

The mechanical design of the whole strongback was carried out according to the following four criteria :

- a deflection criterion (SPX1 : F MAX = 3.5 mm)
- $\sigma_{13}$ MAX = 2 hb to avoid buckling (compression)
- $\sigma_{22}$ MAX 3 hb with respect to excessive deformation
- $\sigma_{11}$ MAX 1 hb in stiffeners

compliance with preceeding criteria could be assessed. A few details remained to be optimized as regards the geometring and connecting areas.

Thus, the following steps aimed at analyzing this strongback behavior with respect to thermal phenomena and the safety features.

3.4 The strongback thermomechanical behavior

a) Step 1

The strongback thermomechanical study takes account of the inner vessel support effect which contributes, in fact, to the strongback stiffness (figure 3).

The studied transients have brought out relatively high compressive stresses which, combined to primary loads, can give rise to problems.

The results of these studies led to the investigation of hydraulic adaptations aiming at :

- balancing the upper plate temperatures distribution.
- supplying sodium appropriately to the upper part of the peripheral strongback areas.

b) Step 2

The achieved study takes account of the adaptations proposed in step 1, and the overall model is similar. The whole strongback structure behavior is satisfactory. However, a problem has arisen at the level of the upper plate of the inner vessel box-type supporting structure which will be modified in the following step.

The main results with respect to the analyzed failure modes are summarized in the following table.

| Analyzed damages (1) | RESULTS |
|---|---|
| BUCKLING | Safety factor K $\simeq$ 4 |
| Progressive deformation | Min. margin 48 % |
| FATIGUE | $D_{Fat} \simeq 0.02$ |

c) Step 3

The study carried out in step 2 had shown that the upper plate of the inner vessel box-type supporting structure resulted in buckling instability, especially during the cold shock.

What lied at the roots of such a phenomenon was the difficulty in reaching an homogeneity in temperatures distribution during transients, due to the direct connection between the upper plate of the inner vessel box-type supporting structure and the strongback trough radial stiffeners.

Therefore, it was decided to eliminate the system hyperstatic feature by separating the strongback motions from those of the inner vessel support, i.e by removing the radial stiffeners.

The design evolution in the aim of improving safety.

The strongback is a safety-related structure which cannot be inspected in service ; it was decided to improve its reliability by carrying out two additional design modifications :

- the addition of a lower plate (figure 4).
- the connection of stiffeners by means of forgings (figure 5).

* The added lower plate includes large holes facing each box so as not to distrub the sodium flow in the strongback and to facilitate the construction.

This lower plate makes the strongback stiffer and enables it to accommodate an assumed failure of one of its structural members.

* A cruciform forging is used in the new type of connection between stiffeners at each lattice nod. The cross arms are butt-welded to the stiffeners in order to male a continuous lattice. With this type of achievement, the vertical weldings between forgings and stiffeners can be inspected during manufacturing.

Thermohydraulic studies

As regards complex thermohydraulic phenomena, it appeared to be necessary to implement a mock-up, in the aim of studying the thermohydraulic behavior of the strongback and inner vessel box-type supporting structure assembly, and analyzing the local effects which can hardly be represented by a reasonable computation model (turbulent flow distribution under the diagrid, jet effects through the upper plate holes).

Concurrently with these tests, some studies were performed. They allowed to define preliminary thermal loadings which confirmed the strongback appropriate behavior during transients ; margins are satisfactory and local and three-dimensional effects must still be analyzed ; yet, they should not question the design of this structure.

4 CONCLUSION

As regards the RNR 1500, the strongback design mainly aimed at :

- reducing the steel mass
- limitating the compressive stresses in the upper plate
- obtaining a radially uniform overall stresses level under primary loads
- reaching a high reliability (necessary for the core supporting structure which cannot be inspected in service)

This led to a solution according to which the strongback and the diagrid support were replaced by a single structure, on which the diagrid is resting.

The strongback thus defined allows to comply with the RCC-MR rules with respect to the main failure modes and to meet the requirements defined by the Safety authorities regarding the failure risks limitation. However, with a view to improving the core supporting structure safety, some modifications were achieved :

- the addition of a lower plate
- the connection of stiffeners by means of cruciform section forgings allowing to achieve butt-weldings that can be easily inspected.

Detailed thermohydraulics studies, based on computations/mock-ups

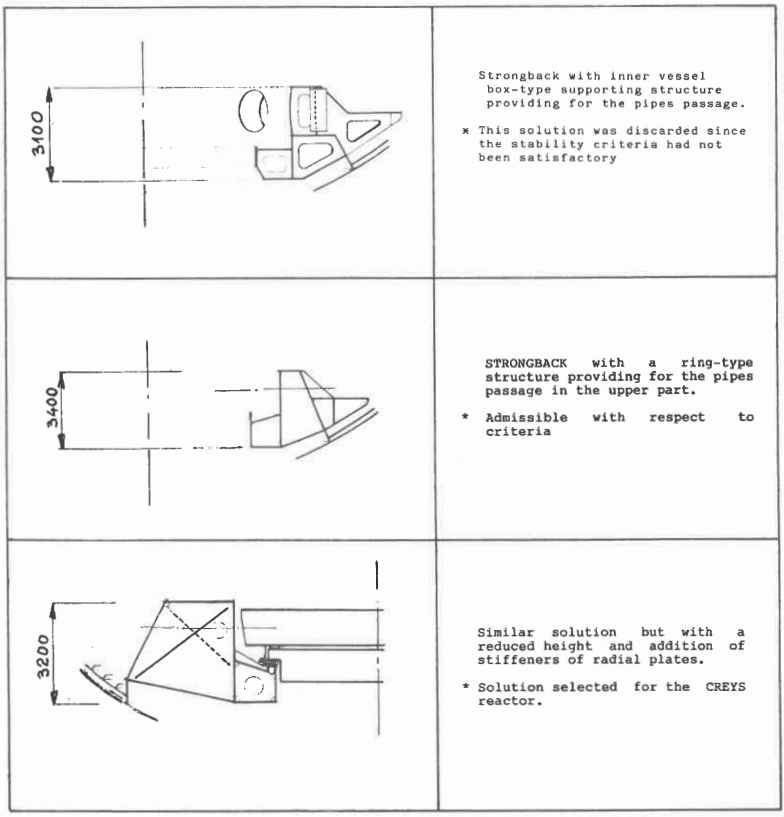
comparaisons gave satisfactory results with respect to the main failure modes (1) :

- excessive deformation
- progressive deformation
- fatigue
- stability (buckling)

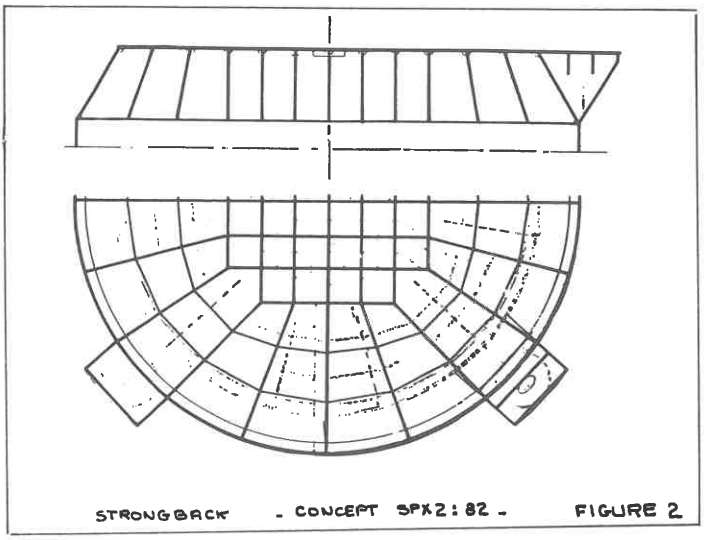
Local effects must still be analyzed, but they should not question the strongback design.

REFERENCE

(1) : RCC-MR Tome I - Volume B - Matériels de niveau 1 (Edité par l'AFCEN)




Evolution of a CREYS type design FIGURE 1



STRONGBACK - CONCEPT SPX2:82 - FIGURE 2

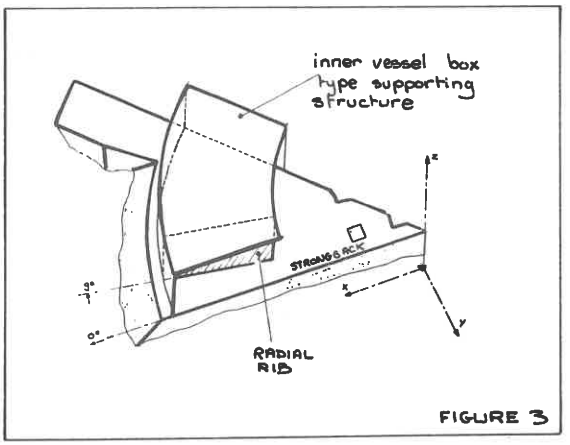



FIGURE 3

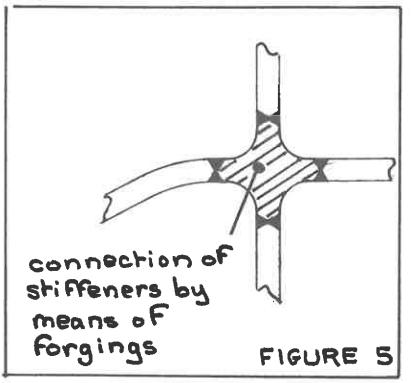



FIGURE 5

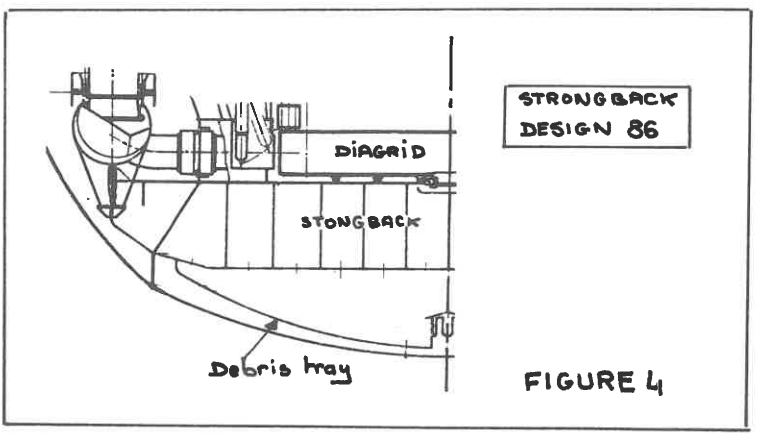



FIGURE 4