# GENERAL PRESENTATION OF THE CORE MECHANICAL BEHAVIOUR APPROACH IN FRANCE

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## ABSTRACT

This French review paper presents the evolution along time of the FBR core mechanical behaviour approach, from RAPSODIE to SPX2, through PHENIX and SPX1 : core designs, knowledge of the irradiation laws, project criterias, calculation codes, and R and D fields.

In this introducing presentation, the statement of the core mechanical behaviour under normal operating conditions will be presented through its time evolution, following the different steps of the FBR development in France. Thus, the evolution of the general knowledge, the evolution of the design of the successive cores and the evolution of the calculation tools will be presented according to their natural connexions.

For the 3 french reactors, RAPSODIE, PHENIX and SUPER-PHENIX, we will see what the state of the core behaviour knowledge was, what considerations led to define the corresponding core design, what computer code was available, and what the observed behaviour during operation pointed out for the following project.

Finally, the status of work concerning the project "RAPIDE 1500" will be presented.

## 1. THE RAPSODIE CORE

When the first core of RAPSODIE was designed, in 1964, the specific knowledge of the core mechanical behaviour was very poor : steel swelling and creep under the fast flux were quite not known at all, and the only mechanical requirement for the design of a fast core was to avoid the core compaction accident of EBR I.

In this context, the free flowering (or free clamping) core concept was selected and the spacer pads were located exactly at the mid-core level.

Of course, no computer codes were available as no problems were to be solved. There was just a simple model to evaluate the efficiency of the pads during a $\Delta T$core perturbation.

Then, the RAPSODIE core behaviour during operation, gradually pointed out the problems of the distortions due to swelling and creep under irradiation. The corresponding observations were mainly the bowing of the wrapper tubes (WT), pads subsiding and typical deformation of the faces of the wrapper tubes due to sodium internal over-pressure. Next, the head displacements during handling operations were soon also observed.

So all these problems were known, if not overcome, when the PHENIX core had to be designed.

## 2. THE PHENIX CORE

At this time, two computer codes were developed :

- The first one was ARGO : this code calculated the individual behaviour of the wrapper tube. Swelling and creep laws were introduced and the code calculated the increase of length, the variation of the distance over flats, and the free bowing of the wrapper tube.

- The second one was ORGUE : this code calculated in 2D, ring by ring, the mechanical behaviour of the whole core, and specially the interactions between the subassemblies submitted to their different bowing values. A post processor of this code was used to evaluate the handling forces.

ARGO allowed to optimize the wrapper tube thickness and the gaps between them, according to the given value of the core pitch. The corresponding criterion was that the distance over flats of the wrapper tubes should reach the value of the pitch (no more gap between the WT) at the end of the life. Of course, the irradiation laws, obtained from RAPSODIE examinations, were not very well known before the first PHENIX results were available.

The PHENIX core behaviour brought (and is still bringing) many useful informations concerning the wrapper tube behaviour. But mainly, the more significant point was the need to develop a 3D computer code to investigate more accurately the very heterogenous core of this reactor. We will see furtherly that even with such a 3D code, it is not very easy to survey precisely such a core, because of its experimental vocation.

## 3. THE SUPER PHENIX CORE

The SPX1 core design was made in the direct continuity of the PHENIX core.

It is a free flowering core, and stamped pads are just above the fuel area. The wrapper tube design optimization was performed with swelling and creep laws fit to PHENIX. The titanium stabilised 316 cold worked stainless steel was chosen.

The mechanical behaviour studies of the SPX1 core use the 3D codes system HARMONIE, developped in the same time.

For these studies, the project mechanical criterias to be verified by the calculation are clearly defined as the following ones :

- wrapper tube optimization criterion : the maximum distances over flats reach the value of the pitch (no more gap) at the end of the life,

- criterias at the nominal power situation :

  - head displacements of the surveyed subassemblies (fuel subassemblies) limited to assure the efficiency of the detectors,

  - head displacements of the control rod subassemblies limited to assure the operation of the moving system,

- criterias at the zero power situation (handling situation) :

  - limitation of the increase in length of the wrapper tube,

  - limitation of the head displacements,

  - limitation of the handling forces.
    These limitations correspond to the handling machine capability.

- criterion for the subassemblies out of the core : free bowing limitation for handling and transport problems,

- criterion concerning the reactivity response of the core to a variation of the ΔT core. This requirement corresponds to operation and safety general requirements and is related to the efficiency of the "pads coefficient".

This was the summary of the state of the core behaviour problems till SPX1.

## 4. THE SUPER PHENIX 2 CORE

Super Phenix 2 is a fast breeder reactor of 1500 MW whose pre-design, realized by NOVATOME, will end in 1985. With regards to the general mechanical behaviour, the main options of French breeder reactors are kept :

- a strong foot staked in the diagrid,
- one pad plane above the active core,
- natural restraint of the fuel core by blanket and shielding subassemblies around it.

Subsequently, we emphasize the main differences between this reactor and Super Phenix 1 with respect to subassemblies and core design.

### 4.1 SPX2 subassemblies (figure 1)

On the table 1 are summarized the geometrical specifications of fuel subassemblies of SPX1 and SPX2.

For the SPX2 subassembly, the distance between flats is a little larger but the heights of the pad plane and of the head above the diagrid are quite equivalent.

The main difference is the shorter spike. The comparison shows that the SPX2 subassembly is stiffer than the SPX1 subassembly of about fifty percent, mainly due to the short spike.

### 4.2 SPX2 core (figure 2)

The subassemblies set on the diagrid are distributed in the following way :

- 8 rings for the first zone (208 s.a)
- 3 rings for the second zone (180 s.a)
- 33 control rods
- 1 blanket ring (78 s.a)
- 3 rings for the shielding subassemblies between blanket and 2 rings of internal storage.

All these subassemblies have an hexagonal wrapper tube with pads pressed on it, like the fuel subassembly. Their flexibility is also quite equivalent.

Round the internal storage there is one or two rings of shielding subassemblies which are billets without pads.

A present assumption is that the four rings between fuel core and internal storage allow to uncouple them on a mechanical point of view. The works on core behaviour, which are now performed by NOVATOME with codes developed by CEA for the SPX1 project, have to confirm that there is no contact between internal storage and the third ring of shielding subassemblies.

Beyond the diagrid, are 3 shielding billet rings set on a lateral support. They are not concerned by the core mechanical behaviour.

### 4.3 Core performances

The life time of the subassemblies and their doses are presented on the table 2. For SPX2 these values represent an objective. The forexpected dose for the start up is 180 dpa, and life time is about 1150 EFPD.

One has to notice also a large difference between SPX2 and SPX1, with respect to the neutronic core behaviour, which has consequences on the mechanical behaviour : SPX1 is a power flattening core and SPX2 is a dpa flattening core. So the dpa doses on the first ring of the second fuel zone are in proportion more important for SPX2. It was already one of the most sollicited rings by thermal and neutronic gradients and we expect strong efforts between this ring and the next one.

### 4.4 Criteria

The design criteria related to primary and secondary handling, the control system operability that we have to check, are for the moment identical to those already presented for SPX1. But with the evolution of the subassembly design, the short spike and the core design dpa flattening which leads to important gains concerning the reactor block and the fuel cycle, it seems to be difficult to respect the criterion of 1500 daN concerning the subassembly extraction. For one given value of elastic bowing, the friction efforts are 2.5 greater for a SPX2 subassembly than for a SPX1 one, and it cannot be balanced by the gain on the weight between the two subassemblies.

### 4.5 Research and development

Because of the ambitious performances aimed for the fast breeder SPX2, it is necessary to have a constant Research and Development program. It has been defined by NOVATOME and CEA together and the main directions are the following ones :

Structural material : an important irradiation program has been set up to search and find a material that doesn't swell.

Modelization

The codes actually used for pre-project will be developed to take into account :

- the evolution of irradiation characteristics (flux, temperature) on a long time,
- management of the subassemblies, that is subassemblies of different irradiations in core at the same time,
- the spike gaps and friction between pads.

Test

The program concerns subassembly handling with regards to the short spike and bowed subassemblies.

Introduction and extraction tests will be realized in air at CADARACHE with deformation of the lattice and of the subassemblies.

Data

Tests and codes will be set up to improve datas of modelization.

Tests concern :
- pads behaviour
- friction coefficients

and codes concern the wrapper tubes temperatures.

## 5. CONCLUSION

This general presentation concerned the time evolution of the core mechanical behaviour approach, from RAPSODIE to SPX1, and in more details, the status of the work as to the SPX2 core. The following papers will not bring up again the SPX2 works, and will focus on the codes, the experiments, and the calculations used in the framework of the SPX1 project.

## TABLE 1

GEOMETRICAL SPECIFICATIONS OF FUEL SUBASSEMBLIES
(SPX1 and SPX2)

| | SPX1 | SPX2 |
|---|---|---|
| Distance between flats | 173 mm | 178.3 mm |
| Wrapper tube thickness | 4.6 mm | 4.6 mm |
| Total length | 5.4 m | 4.85 m |
| Spike length | 1.15 m | 0.6 m |
| Pads plane height above diagrid | 2.6 m | 2.75 m |
| Height of the end of hexagonal section | 3.9 m | 4 m |
| Pads gaps | 0.4 mm | 0.4 mm |

## TABLE 2

CORE PERFORMANCES

| | SPX1 | | | SPX2 | | |
|---|---|---|---|---|---|---|
| | LIFE TIME | DOSE | NUMBER OF CYCLES | LIFE TIME | DOSE | NUMBER OF CYCLES |
| Fuel | 640 EFPD | 127 dpa | 2 | 1400 EFPD | 220 dpa | 4 |
| Blankets | 960 EFPD<br>1600 EFPD | 75 dpa | 3/4/5 | 1750 EFPD | ~ 160 dpa | 5 |

novatome

Fig 1 : SUBASSEMBLIES COMPARATIVE DESIGN

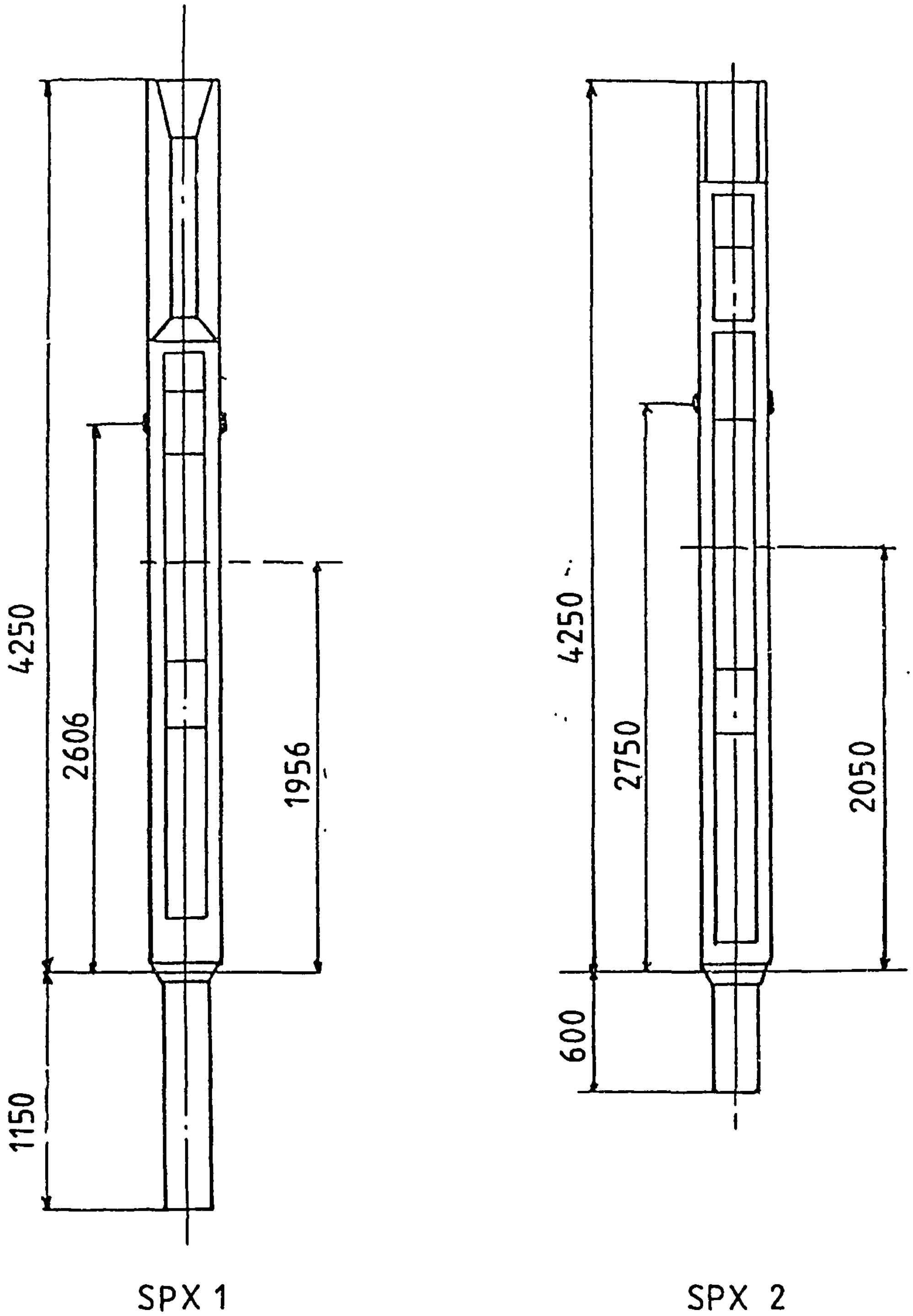
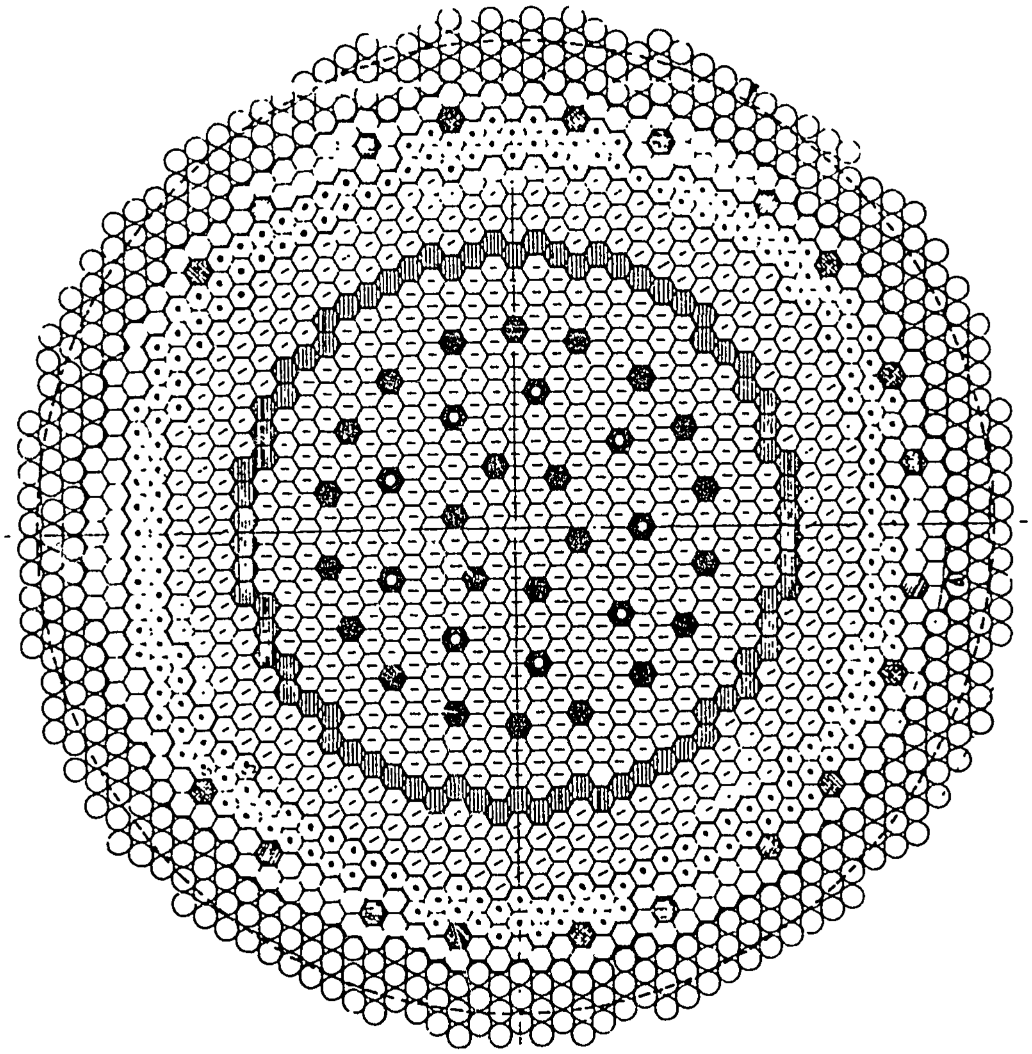


Fig 2: SPX 2 CORE



| | | | |
|---|---|---|---|
| DIAGRID | 24 | 1147 | control and safety s.a. |
| | 9 | | safety s.a. |
| | 388 | | fuel s.a. |
| | 78 | | blanket s.a. |
| | 270 | | shielding s.a. |
| | 200 | | internal storage |
| | 10 | | debugging |
| | 5 | | empty |
| | 5 | | exceptional storage |
| | 158 | | shielding s.a. |
| LATERAL SUPPORT | 396 | 396 | shielding billet |