PRESENT STATUS OF THE PARAMETRIC NEUTRONIC STUDIES
DEVOTED TO THE OPTIMIZATION OF FAST BREEDER POWER PLANTS

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INTRODUCTION

1 - An important effort is presently in progress at CEA to improve the design of fast power plants, taking into account the following goals:

- optimization of the penetration's rate of fast breeders and therefore reduction of their doubling time. This involves a minimization of the fuel inventory in and out of pile;
- improvement of the safety characteristics, particularly the sodium void effect;
- minimization of the fuel fabrication costs.

In order to reach these goals, parametric studies have been undertaken concerning the SUPER-PHENIX type cores and the heterogeneous core concept.

2 - As far as the SUPER-PHENIX 1 core is concerned a reduction of the critical mass might be reached by increasing the core zone number in order to reduce the power form factor. In this paper one looks to the consequences of using three core zones instead of two.

3 - The heterogeneous core concept is already a well known solution to get a higher breeding ratio than the SUPER-PHENIX 1 solution and a longer residence time for the core subassemblies /1/. Moreover the heterogeneous core concept is attractive from the fuel fabrication and fuel management point of view because of its single enrichment for the fissile pins. Nevertheless the first comparison performed at the CEA shows that the fuel inventory in the core of an heterogeneous reactor is greater than the critical mass of the comparable homogeneous two zone core. Therefore the first aim of the parametric studies reported in this paper is to optimize the quantity and the location of the
fertile zones in order to reduce the critical mass of a fast power plant using the heterogeneous core concept. Two heterogeneous core types have been investigated:

- a core including an internal fertile slice (axial heterogeneity),

- a core including internal rings of fertile material (radial heterogeneity).
I - HYPOTHESIS FOR THE PARAMETRIC STUDIES -

All the parametric studies are performed with respect to the present solution which is used for the commercial fast power plants: a two zone core using PuO2-UO2 fuel cooled by Na.

The characteristics which are fixed for all the cores studied concern:

- the total power (4500 MWth)
- the pin diameter (PHENIX value)
- the subassembly size
- the core height and the blanket characteristics
- the core reactivity level at the end of the equilibrium cycle.

The residence time of the core subassemblies is for each core determined by the acceptable maximum number of displacements per atom (140 DPA) on the stainless steel pin clad.

The volumic composition of each reactor zone are issued from design studies:

<table>
<thead>
<tr>
<th>ZONES v/o %</th>
<th>Fertile or fuel</th>
<th>Stainless steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>34.43</td>
<td>23.64</td>
</tr>
<tr>
<td>Axial blanket</td>
<td>34.43</td>
<td>23.64</td>
</tr>
<tr>
<td>Internal radial blanket</td>
<td>43.45</td>
<td>22.17</td>
</tr>
<tr>
<td>External radial blanket</td>
<td>52.62</td>
<td>18.61</td>
</tr>
</tbody>
</table>

All the neutronic calculations are performed with the 6 groups design scheme deduced from the CARNAVAL IV cross section set /2/.
II - SOME TYPICAL RESULTS -

II.1 - Homogeneous core using three enrichment zones -

Increasing the number of core enrichments is looked at to reduce the critical mass, but will lead to an increase of the fuel fabrication cost and to a more complex fuel management. Therefore three enrichment zones have been considered as a maximum practically acceptable. Moreover these zones are distributed only radially because it seems quite difficult to fabricate fissile columns including different axial enrichments.

The parametric studies are devoted to cores with various volumic fractions of enrichments for the three zones.

The main conclusion is that the maximum reduction of the power form factor is ≈ 6% with respect to the reference design (two core zone) and the minimum critical mass is lower by ≈ 3% than the reference one. These points do not seem to give a significant advantage to the three enrichment zone configuration which would compensate the practical problems related to the fuel fabrication and management.

II.2 - Radial heterogeneous core -

To perform parametric studies on the radial heterogeneous core concept which could lead to propose an optimized configuration, the following approach is used:

1) In a first step one studies parametrically a simple model of the radial heterogeneous core: the fertile zones are included as complete rings, the control rods are not taken into account.

Such a model is analyzed by 1D cylindrical calculations. The reference situation used for the comparison with heterogeneous configuration results is a homogeneous two zone core without rod. For such a core the lowest power form factor is obtained at beginning of life.
2) In a second step, one checks the 1D cylindrical model results with the 2D(RZ) description of the cores including the same number of rods (30).

3) At last, hexagonal calculations will be used to study the control rod location problem for the heterogeneous concept.

It must be kept in mind that for both core concepts the maximum linear power and the total power are identical.

The two parameters which are taken into account during the first step studies are:

- the fertile material amount through the ratio $X$ of number internal fertile subassemblies to the number of fissile ones which can increase from 0 to 50%;

- the geometrical characteristics of the fertile rings (thickness and position).

Among all the configurations studied for a fixed value of $X$, one selects the core which provides the lowest radial form factor. The corresponding fuel enrichment is adjusted to respect the reactivity criteria at the end of a 300 day cycle. When $X$ varies, one gets the main optimized characteristics as functions of the fertile material quantity.

The main observations issuing from this parametric approach are:

- the radial power form factor decrease very strongly (by $\approx 20\%$) versus the fertile content until $X = 20\%$. For higher values of $X$, the power form factor is not very sensitive to the fertile content;

- the critical enrichment increases from 17% to 23% when $X$ varies from 10 to 40%.
- the breeding gain increase is \( \approx 0.07 \) when \( X \) increases from 10% to 40%;

- the critical mass reach its lowest values for \( 8% < X < 20% \) and the minimum is higher by \( \approx 3\% \) than the critical mass of the homogeneous configuration.

These preliminary results have been checked by a more refined analysis - 2D(RZ) calculations - which takes into account the following design characteristics:

- the cycle length is adjusted to respect the maximum DPA number (140);

- the rods (30) are described by two rings;

- the fertile to fissile volumic ratio is taken close to 16% according to the 1D(R) calculation results.

Some results are listed hereafter:
<table>
<thead>
<tr>
<th></th>
<th>Homogeneous core</th>
<th>Heterogeneous core (X ≈ 16 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrichment</td>
<td>16.7 (mean value)</td>
<td>19.3</td>
</tr>
<tr>
<td>Cycle length (days)</td>
<td>256</td>
<td>270</td>
</tr>
<tr>
<td>Reactivity loss/day</td>
<td>100</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>($10^{-5}$ ΔK/K)</td>
<td></td>
</tr>
<tr>
<td>Critical mass</td>
<td>5087</td>
<td>5210</td>
</tr>
<tr>
<td>(Kg equivalent Pu)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass in cycle</td>
<td>7822</td>
<td>7850</td>
</tr>
<tr>
<td></td>
<td>(Kg equivalent Pu)</td>
<td></td>
</tr>
<tr>
<td>Breeding gain</td>
<td>0.23</td>
<td>0.30</td>
</tr>
<tr>
<td>Compound doubling time</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>(year)</td>
<td></td>
</tr>
</tbody>
</table>

The 2D(RZ) studies are presently in progress for higher X values (X ≈ 30%) in order to improve all the conclusion drawn from the 1D(R) parametric studies.
CONCLUSION

Parametric studies are presently in progress at CEA in order to improve the fast breeder characteristics. The first results obtained concern some of the solutions which should lead to a reduction of the fuel inventory in and out pile. These results concern cores using a fuel with a fixed pellet diameter, a given subassembly size and a given core height.

At the present moment, the following observations can be made:

1) The use of three enrichment zone core does not seem very attractive because the reduction of the fuel inventory (= 3%) does not compensate the problems related to fuel fabrication and fuel management.

2) The heterogeneous core concept using a rather low fertile to fissile subassembly ratio \( (X = 16\%) \) provides a critical mass slightly higher than the reference core one \( (+3\%) \) and a shorter compound doubling time \( (-20\%) \) due to a better breeding gain \( (+0.07) \).

Beside these characteristics one has to take into account the advantages related to the fuel fabrication (only one enrichment value) and to the longer fissile subassembly residence time.

The first studies will be completed by:
- complementary calculation using a more realistic model \( (2D \ (RZ)) \),
- studies of the control rod location problem \( (hexagonal \ calculation) \).

Other parametric studies have to be performed versus the pellet diameter or the core geometry characteristics. The next point to be investigated is the safety related parameters (sodium void effects).
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