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PRELIMINARY STUDY OF THE SUBASSEMBLY RESHUFFLING IN FAST BREEDERS

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INTRODUCTION

The aim of this paper is to present the conclusions which are drawn from a preliminary study devoted to the subassembly reshuffling for fast breeders of the SUPER PHENIX type.

The main goals which are looked for with the reshuffling technic are :

- the fabrication of fissile subassemblies with a single enrichment for the equilibrium cycle operation,
- the burn up homogeneisation of the unloaded and reprocessed subassemblies which provides a better use of the fuel.

In order to get an estimation of the improvement which may be hoped from this technic, one looks in this paper the influence of :

- the reloading frequency,
- the residence time of the fissile subassemblies,
- the fuel pin diameter.

This study is restricted to the neutronics problem and does not take into account the mechanical (e.g. swallowing effect) or thermohydraulical (e.g. pressure drop) problems.

I. HYPOTHESIS AND CALCULATIONS PERFORMED

I-1. Basic hypothesis

The reference reactor of this study uses the classical concept : a two zone core fueled with UO_2 - PuO_2 and cooled by Na. For this reference core, a classical fuel management is used : at the beginning of cycle, the core is loaded by half with fresh and half used subassemblies which are estimately mixed in each core zone.

The main core characteristics are :

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a) total power : 1800 MWe
b) subassembly residence time limitated by the maximum number of displacement per atom : 140 DPA is the value choosen for the present study
c) 30 control rods located in three rings
d) enrichments which are fixed in order to be critical at the end of cycle
e) maximum linear power : 450 w/cm
f) pin diameter : 5,5 mm.

The cores using the reshuffling technic respect the criteria a) c) d).

The spatial calculations are performed with the multigroup cross sections of the CARNAVAL IV formulaire, in 1 D cylindrical geometry, with the diffusion approximation.

I-2. Reshuffling study

For the cores using the reshuffling proceeding, the equilibrium core parameters are determined as a function of the subassembly residence time for :

- two reloading schemes
- two fuel pin diameters (5,5 and 7,14 mm, with the same subassembly number for each core zone)

Reloading schemes

a) Reloading by one third of the core

The core is divided in three concentric zones having the same volume and with mean burn up decreasing from the core center to the periphery. The fresh subassemblies are loaded in the external zone. The rod rings are located respectively in the central zone at the core 1/core 2 and core 2/core 3 interfaces.

b) Reloading by half of the core

The core is divided in two concentric zones having the same volume

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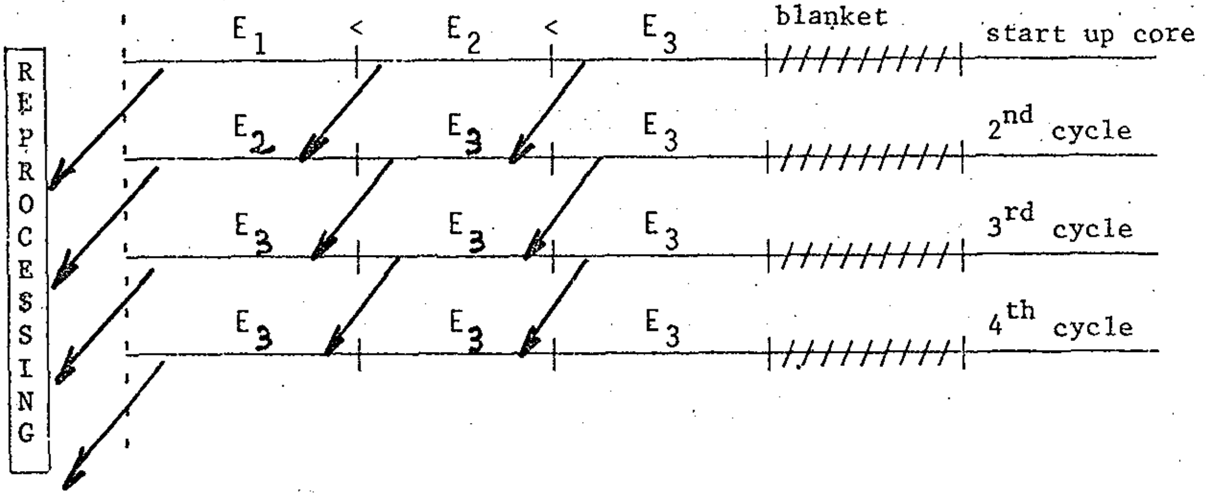
and the rods are inserted in three rings, respectively located in the inner core (two rings) and at the inner core/outer core interface.

I-3. Equilibrium cycle determination

I-3. 1. Reloading by one third of the core

The equilibrium cycle is reached according to the following figure :



The start up core includes three different enrichments E_1 E_2 E_3 with :

$$E_1 < E_2 < E_3$$

$$E_2 = \frac{E_1 + E_3}{2}$$

E_3 is the enrichment value for the reloadings of the intermediate cores and for the equilibrium core itself.

The enrichments E_i are issued from parametric studies performed with cell calculations (infinite media), providing the reactivity variation as a function of time for various enrichments. The cycle length and the end of cycle criticality condition fix the value for the mean enrichment E_2 and the E_1 and E_3 are then deduced graphically.

It has been checked that this simple method is sufficient for a preliminary study of the reshuffling : as shown in the table I it converges

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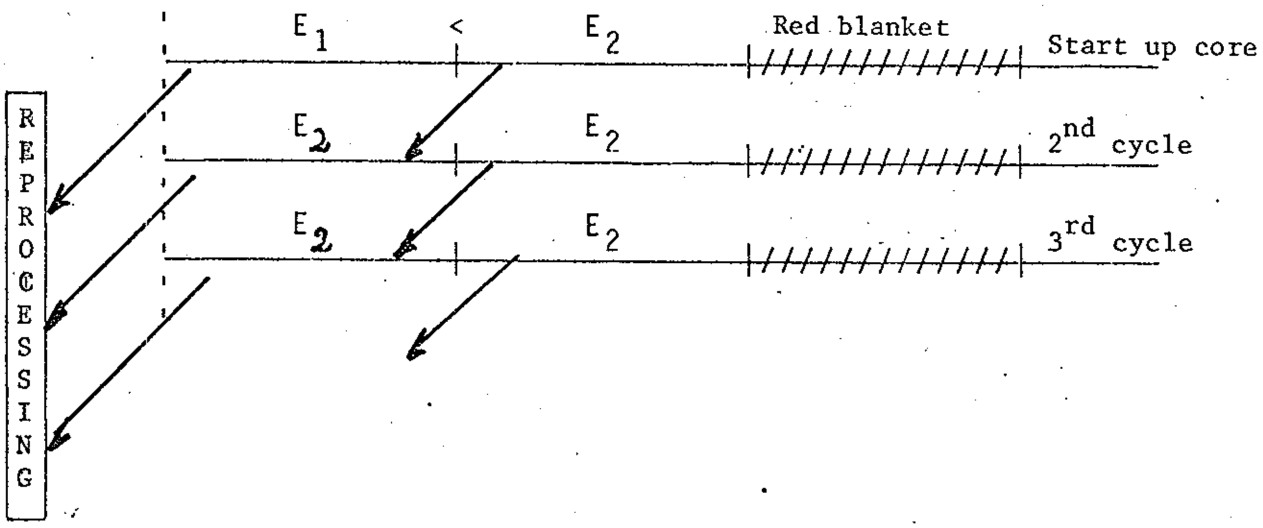
rapidly to a "stable" cycle.

I-3. 2. Reloading by half of the core

The equilibrium cycle is obtained according to the following scheme :



In this case : $E_2 > E_1$

E_2 is the enrichment for the loading of the intermediate core and for the equilibrium core itself.

The table I given in page 6 confirms that, according to the method previously described in II.2.1, the stable cycle is rapidly obtained.

One observes that the radial form factor of the start up core is significantly higher than those of the equilibrium core. In the PWR reactors this desavantage can be compensated by consumable poison which can't be used in last breeders.

II. RESULTS

The results of the spatial calculations are summarized on tables II, III, IV.

II-1. General observations

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a) One cannot get simultaneously a good radial power form factor and an acceptable maximum number of displacements per atom (< 140), for example, with a reactor using a 5,5 mm fuel pin diameter and reloaded by one third of the core :

- with the same residence time, as the reference core, one gets a radial power form factor of 1.85 instead 1,20 for the reference core,
- if one wants to get the same power form factor (1.20) the associated residence time (1380 days) corresponds to an increase of the DPA rate of 140 % - with respect to the reference core DPA member.

Moreover the breeding gain is reduced by 0,05 and the reactivity loss per cycle increases by 128 % with respect to the reference core. This would lead to increase the control number.

The incompatibility between a good radial power form factor and a short residence time appears to be unavoidable as far as the three core zone enrichments remain quite close to each other for short cycles.

b) The form factor for the burn up of the subassemblies which are unloaded for reprocessing present the same tendancies as the one observed for the power form factors.

c) On the other hand, if one assumes that the same power form factor could be reached for all the cores (including the reference one), we notes that the reshuffling technic improves the burn up homogeneization for the subassemblies which are unloaded at the end of the cycle (This is shown in tables II and III by the values of the $\bar{\gamma}/_{\beta}$ ratio).

II-2. Influence of the reloading procedure

For a given fuel pin diameter, and for a given residence time, one observes the following differences between the reloading by one third and by one half of the core :

- the radial power form factor, and at a less extent the burn up form factor, is slightly improved in the reloading by core half with respect

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to the reloading by one third of the core,

- the numbers of displacements per atome are pratically the same for both types of reloading,
- the mean value of the fuel enrichment is significantly higher for the reloading by half of the core (due to the longer cycle) and therefore the breeding gain is lower than for the reloading by one third of the core

II-3. Influence of the pin diameter

As shown in table IV, to increase the fuel pin diameter from 5.5 mm to 7.14 mm permits :

- to reduce the value of the displacement per atom number for a given residence time,
- to reduce strongly the reactivity loss per cycle for a given cycle length.

On the other hand the power form factor increases with the fuel pin diameter. An eventual solution, under the restriction that it is possible to reduce the power form factor from 1.50 to ≃ 1.20, would consist in using a reloading by half of the core fueled with 7.14 mm diameter pins : the maximum DPA would be close to 150 for a 330 day residence time.

Such a solution would provide :

- a residence time increased by ≃ 40 %,
- a burn up form factor reduced by ≃ 10 % with respect to the reference core.

CONCLUSION

The reshuffling procedure used to improve the fuel managment according to the hypothesis choosen in this study, cannot provide simultaneously a good power form factor and a maximum DPA number lower than the present limits.

With the present limitation on the DPA values, the effort to be done in order to use the reshuffling technic could only consist an improving the

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radial power distribution eventually by :

- reshuffling the fissile subassemblies inside each core zone,
- using the control rods (eventually with a new location of the rods),
- using fertile subassemblies (heterogeneous core concept).

Nevertheless this preliminary study provides the following tendances :

- with respect to the reloading by half of the core, the reloading by one third of the core provides :
  - a better burn up homogeneization for the unloaded subassemblies (by ≃ 10 %) for a given form factor,
  - a higher power form factor,
  - a higher breeding gain,
- the increasing of the fuel pin diameter reduces the DPA number but increases the power form factor.

Complementary studies are necessary to solve the power form factor problem before determining the other reactor characteristics (fuel inventory, doubling time, load factor) which would permit to choose a particular solution. Presently the burn - up form factor seems to be lower by ≃ 10 % than the one corresponding to classical core when the solution adopted uses a reloading by half of a core fueled with 7.14 mm diameter pins.

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TABLE I.

	Start up core		1st cycle		2nd cycle		3rd cycle	
	BOC	EOC	BOC	EOC	BOC	EOC	BOC	EOC
Keff	1.04333	1.0051	1.03942	0.99560	1.03855	0.99495	1.03844	0.99487
γ	1.683	1.446	1.518	1.348	1.509	1.344	1.508	1.344
GBG	- 0.070	- 0.031	- 0.080	- 0.038	- 0.079	- 0.0374	- 0.078	- 0.0373

	Start up core		2nd cycle		3rd cycle		4th cycle		5th cycle	
	BOC	EOC	BOC	EOC	BOC	EDF	BOC	EOC	BOC	EOC
Keff	1.04024	1.00567	1.03694	1.0007	1.03741	0.99922	1.03680	0.99870	1.03672	0.99870
γ	1.758	1.603	1.549	1.441	1.519	1.377	1.507	1.368	1.502	1.368
GBG	- 0.057	- 0.031	- 0.075	- 0.048	- 0.085	- 0.051	- 0.085	- 0.050	- 0.085	- 0.050

γ : Radial power form factor

GBG : Global breeding gain (1 D calculated)

TABLE II. Pin diameter = 5.5 mm – Reloading by one third of the core

Cycle length (day)	170	260	310	460	Ref 260
Residence time (day)	510	780	930	1380	520
γ^* BOC EOC	1.85 1.65	1.50 1.37	1.38 1.27	1.24 1.19	1.20 1.25
E_1 E_2 E_3	14.9 15.5 16.2	15.1 15.8 16.6	14.9 15.9 16.7	15.1 16.8 18.6	15.2 18.5 -
$\overline{GBG} - \overline{GBG}_{ref}$	- 0.024	- 0.028	- 0.035	- 0.051	0.00
$\dfrac{\Delta\rho_{cycle} - \Delta\rho^{ref}}{\Delta\rho^{ref}_{max}}$ %	15	23	43	128	0
$\dfrac{DPA^{max} - DPA^{ref}_{max}}{DPA^{ref}_{max}}$ %	- 4	45	70	140	0
$\dfrac{TCF_{max} - TCF^{ref}_{max}}{TCF^{ref}_{max}}$ * %	17	54	79	136	0
$\beta = \dfrac{TCF_{max}}{\overline{TCF}}$ *	1.38	1.22	1.18	1.09	1.18
$\overline{\gamma}/\beta$	1.27	1.18	1.12	1.12	1.038

* 1 D calculations

γ : Power form factor ($\overline{\gamma}$) : mean value for one cycle
β : " " " burn up
BOC : Beginning of cycle
EOC : End of cycle
$\Delta\rho$: Reactivity loss
TCF : Burn up
$\overline{GBG}$: Global breeding gain (mean value per one cycle)

TABLE III. Pin diameter 5.5 mm - Reloading by core half

Cycle length (day)	260	310	465	Ref. 260
Residence time (day)	520	620	930	520
Y BOC	1.56	1.42	1.30	1.20
Y EOC	1.33	1.31	1.22	1.25
E_1	15.52	15.60	16.26	15.17
E_2	16.14	16.24	17.54	18.50
$\overline{E}$	15.89	15.92	16.90	16.98
$\overline{GBG} - \overline{GBG}_{ref}$	- 0.016	- 0.025	- 0.049	0
$\frac{\Delta\rho_{cycle} - \Delta\rho^{ref}_{cycle}}{\Delta\rho^{ref}_{cycle}}$ %	20	41	123	0
$\frac{DPA^{max} - DPA^{max}_{ref}}{DPA^{ref}_{max}}$ %	- 2%	+ 15	+ 60	0
$\frac{TCF_{max} - TCF^{ref}_{max}}{TCF^{ref}_{max}}$ %	1	26	73	0
$\beta = \frac{TCF_{max}}{\overline{TCF}}$	1.28	1.25	1.17	1.18
$\overline{Y}/\beta$	1.160	1.140	1.080	1.038

TABLE IV. Fuel pin diameter influence

$\frac{\phi(7.14) - \phi(5.5)}{\phi(5.5)}$	Reloading by $\frac{1}{3}$ of the core T_c = 310 j T_s = 930 j	Reloading by $\frac{1}{2}$ of the core T_c = 465 j T_s = 930 j
$\Delta\gamma$ (%) BOC	+ 54	+ 16
$\Delta\gamma$ (%) EOC	+ 34	+ 11
Start up core		
ΔE_1	- 12.3	- 16.5
ΔE_2	- 15.8	- 19.6
ΔE_3	- 18.7	-
$\Delta \overline{E}$	- 15.8	- 18.1
$\Delta \overline{GBG}$ (absolue difference)	+ 0.101	+ 0.110
$\Delta\rho$ (%)	- 61	- 60
DPA^{max} (%)	- 8.6	- 18.5
TCF_{max} (%)	- 18.3	- 22.2
$\beta = \frac{TCF_{max}}{\overline{TCF}}$	13.5	7.2
$\overline{\gamma}/\beta$ %	+ 23	+ 5.8