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CALCULATIONS OF THE LOSS OF FLOW ACCIDENT IN LARGE LMFBR : INFLUENCE OF CORE PARAMETERS

Y. BALLOFFET, R. De FREMONT, F. JOSSO,
D. De LAPPARENT and R. ROSSIGNOL

RESUME :

When comparing the behaviours of a heterogeneous core configuration and a homogeneous core configuration of a large LMFBR subject to a LOF type HCDA, it is necessary to understand the influence of many different core parameters. We present the results of the comparative calculations made with the SURDYN code, up to the end of the primary power excursion. They show that, if sodium does boil, the energy yield is larger with the heterogeneous core, but the preboiling time is then longer. Parametric calculations, with gradual modifications from the homogeneous core to the heterogeneous core, show that the power and temperature distribution and, to a smaller extent, the fuel reactivity feedback, are the main contributors. Doppler and void coefficients (somewhat smaller in the heterogenenous core) have less influence.

INTRODUCTION

In the French LMFBR system, sodium boiling is not reached in a LOF accident without scram, in the best estimate conditions. However, pessimistic calculations are made, in which boiling is reached, causing voiding and a primary power excursion followed by disassembly. These calculations were made on a homogeneous (HO) core and a heterogeneous (HE) core of a large 1800 MWe LMFBR, in order to assess which core would be preferable in this safety respect. A lower void reactivity in the fuel zone of the HE core was initially thought to be an advantage. Our main concern is to understand the influence of this parameter, and others, in a separate way if possible.

ACCIDENT SCENARIO

Cause

All the pumps are supposed to fail simultaneously, but the flow rate takes some time to decrease (inertia on the pump electrical supply) : the flow is reduced to 50 % in 50 s and 10 % in 400 s. It is assumed that all control and safety rods fail to fall.

Preboiling

In the French concept, the preboiling time is always long (a few hundred seconds), and in best estimate calculations, even no boiling at all occurs. This is due to a strongly negative net reactivity feedback effect. Besides the usual feedback effects (sodium, clad and diagrid expansion, fuel expansion), there is a strongly negative leaning pad coefficient (due to the free standing core concept), and a strongly negative control rod coefficient (due to the pool system, which allows differential expansion between sodium and structures, which results in a slight reentry of the control rods within the core). In the following calculations, we will not take this last coefficient into account (if we would, boiling would not occur) ; so we do reach boiling. Finally, we shall consider :

- the "preboiling" reactivities (sodium, diagrid, cladding and fuel expansion, leaning pad).
- the Doppler reactivity.

Subsequent events

The progressive voiding of the core leads to a power excursion, causing the other rows to be voided in a very short time ; slumping occurs (for fresh fuel) and then disassembly. No clad motion is taken into account, and neither is FCI (in rows that have only started to void).

CODE

The SURDYN code was used. It can be recalled that it has been compared to other codes in a european comparative analysis of a LOF accident, on the so called EUROPE reactor, within the EEC/WAC group [1]. For the present study, we carried out two major improvements :

- geometry : 13 rows with 13 different types of subassemblies can now be used, which allows the treatment of the HE core.
- disassembly modelling. It is now calculated with hydrodynamic fuel motion effects in the axial direction (a calculation on the hexcan temperature has shown that melting of the hexcan could only be reached at the latest stages of disassembly). The disassembly criteria are the same as before (saturation temperature for molten fresh fuel, melting temperature for irradiated fuel). The driving pressures are from fuel vapor only for fresh fuel, and from fuel vapor plus volatile fission products for irradiated fuel.

Voiding by boiling (0,4 s for reactivity insertion) and slumping are treated as before.

CORE DATA

Maps of HO and HE cores are shown on Fig. 1. On the HE map, one can see 5 different rows of internal breeder (IB) subassemblies, including the IB subassembly in the center. The SURDYN row arrangment is the following :

row°N°		1	2	3	4	5	6	7	8	9	10	11	12	13
HO	Number of subassemblies	7	12	12	24	30	30	42	48	54	42	66	120	270
	Subassembly type	F	F	F	F	F	F	F	F	F	F	F	F	EB
HE	Number of subassemblies	1	12	18	54	36	96	60	84	18	66	54	60	276
	Subassembly type	IB	F	IB	F	IB	F	IB	F	IB	F	F	F	EB

HOMOGENEOUS (HO)

○ 487 FUEL SUBASSEMBLIES (F)
▨ 270 EXTERNAL BREEDER SUBASS. (EB)
◉ 30 CONTROL SUBASSEMBLIES
(FOR THE WHOLE CORE)

HETEROGENEOUS (HE)

○ 426 FUEL SUBASSEMBLIES (F)
◌ 133 INTERNAL BREEDER SUBASS. (IB)
▨ 276 EXTERNAL BREEDER SUBASS. (EB)
◉ 30 CONTROL SUBASSEMBLIES
(FOR THE WHOLE CORE)

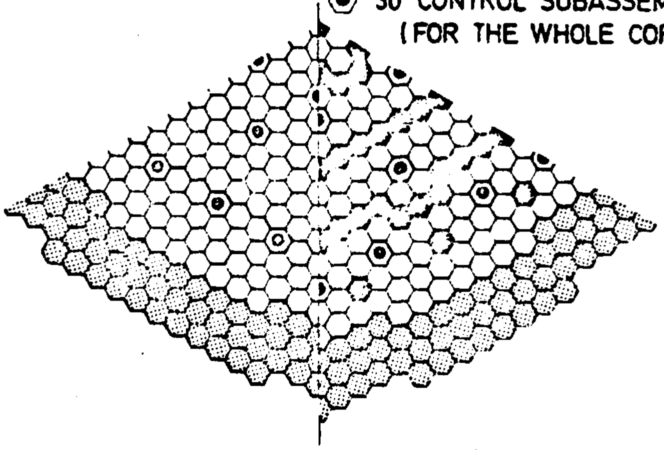

FIGURE 1

1800 MWe CORE MAPS

Two situations are considered : beginning of equilibrium cycle (BOEC) and end of equilibrium cycle (EOEC) :

	BOEC	EOEC
HO	128 days	384 days
HE	154 days	462 days

The maximum linear power rating is 450 W/cm on F and 380 W/cm on IB. The nominal inlet-oulet temperature are 380°C - 540°C.

The radial distributions of power and temperature increase are shown on Fig. 2. In the BOEC situation, power and ΔT curves (F parts only in HE) follow one another fairly well, and maxima are obtained in the periphery (row

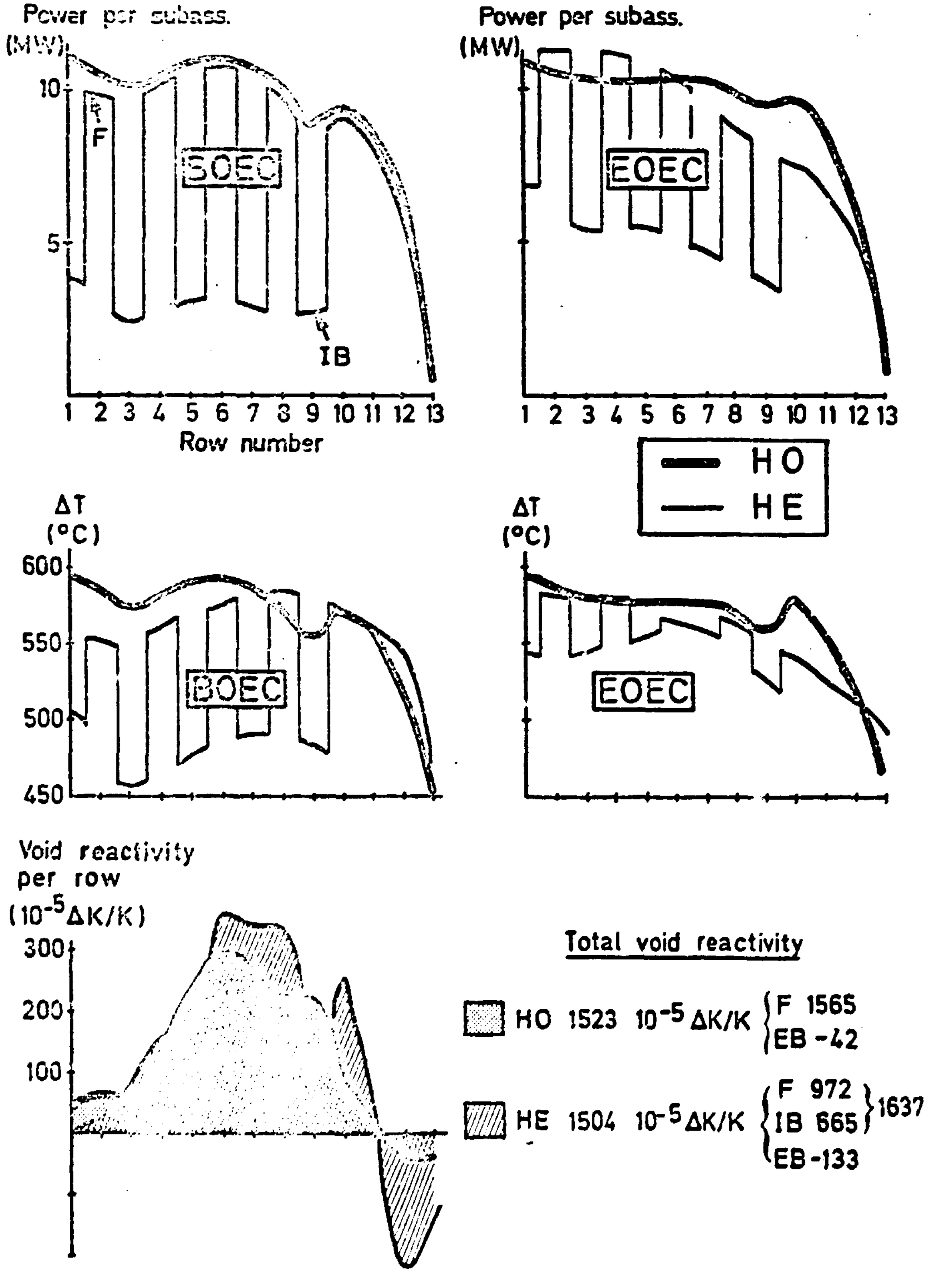

Fig. 2 CORE DATA

6 for power, row 8 for ΔT) for HE, and in the center for HO. In the EOEC situation, distributions have become much flatter in HO ; in HE, the IB level has of course increased, and distributions give now maximum in row 2.

The void reactivity is shown in Fig. 2. Up to row 11, the HE core has a larger positive coefficient than HO. Then, row 12 has a very negative coefficient ($-220\ 10^{-5}$ ΔK/K), much more than in HO ; thus the HE coefficient becomes more similar to the HO coefficient. Including EB, we have $1523\ 10^{-5}$ ΔK/K for HO, and $1504\ 10^{-5}$ ΔK/K for HE. The void reactivity in F zone only (rows 2, 4, 6, 8, 10, 11, 12) of HE is $972\ 10^{-5}$ ΔK/K. It is $1565\ 10^{-5}$ ΔK/K in F zone (rows 1 to 12) of HO ; these $1565\ 10^{-5}$ ΔK/K would be reduced to $955\ 10^{-5}$ ΔK/K in HO, for the same volume as the 7 F rows of HE.

The Doppler coefficient is smaller in HE ($-786\ 10^{-5}$ ΔK/K) than in HO ($-1025\ 10^{-5}$ ΔK/K). It includes different parts :

	HO	HE
F (without blanket)	$-911\ 10^{-5}$ ΔK/K	$-436\ 10^{-5}$ ΔK/K
IB		$-253\ 10^{-5}$ ΔK/K
EB	$-114\ 10^{-5}$ ΔK/K	$-97\ 10^{-5}$ ΔK/K

NB. The dollar is $359\ 10^{-5}$ ΔK/K in HO, and $357\ 10^{-5}$ ΔK/K in HE.

CALCULATIONS

First, calculations of HO and HE cores were made in both BOEC and EOEC situations. Then, in these two situations, starting from the HO core, we gradually modified the HO data (stages A, B, C, D on Fig. 3), stage D being the last one before the fully HE core. This sequence of changes of data was chosen because it is the best way to separate their effects. In fact, it follows chronology : first, we switch to the HE preboiling reactivities (A), then to the HE Doppler effect (B), then to the HE row arrangment, powers and flowrates (C), then to HE void reactivity (D) ; the last move from D to fully HE core deals only with HE fuel reactivities. These changes are cumulative. In stage C, we get the HE core preboiling time.

RESULTS AND COMMENTS

The preboiling time and the thermal energy in the molten fuel (above solidus) will be the main parameters of this comparison (see Fig. 3).

Overall comparison

Boiling is reached after ∿ 850 s in HE, ∿ 300 s in HO. HE is more advantageous in this respect : the operator has more time to manage to evolve the scram. Molten fuel energy is always higher in HE, especially in BOEC ([illegible] % higher), only 39 % higher in EOEC.

In HO, 11 F rows become voided in BOEC, all 12 in EOEC. In HE, only the 7 F rows become voided in BOEC, these 7 F rows plus the 5 IB rows in EOEC.

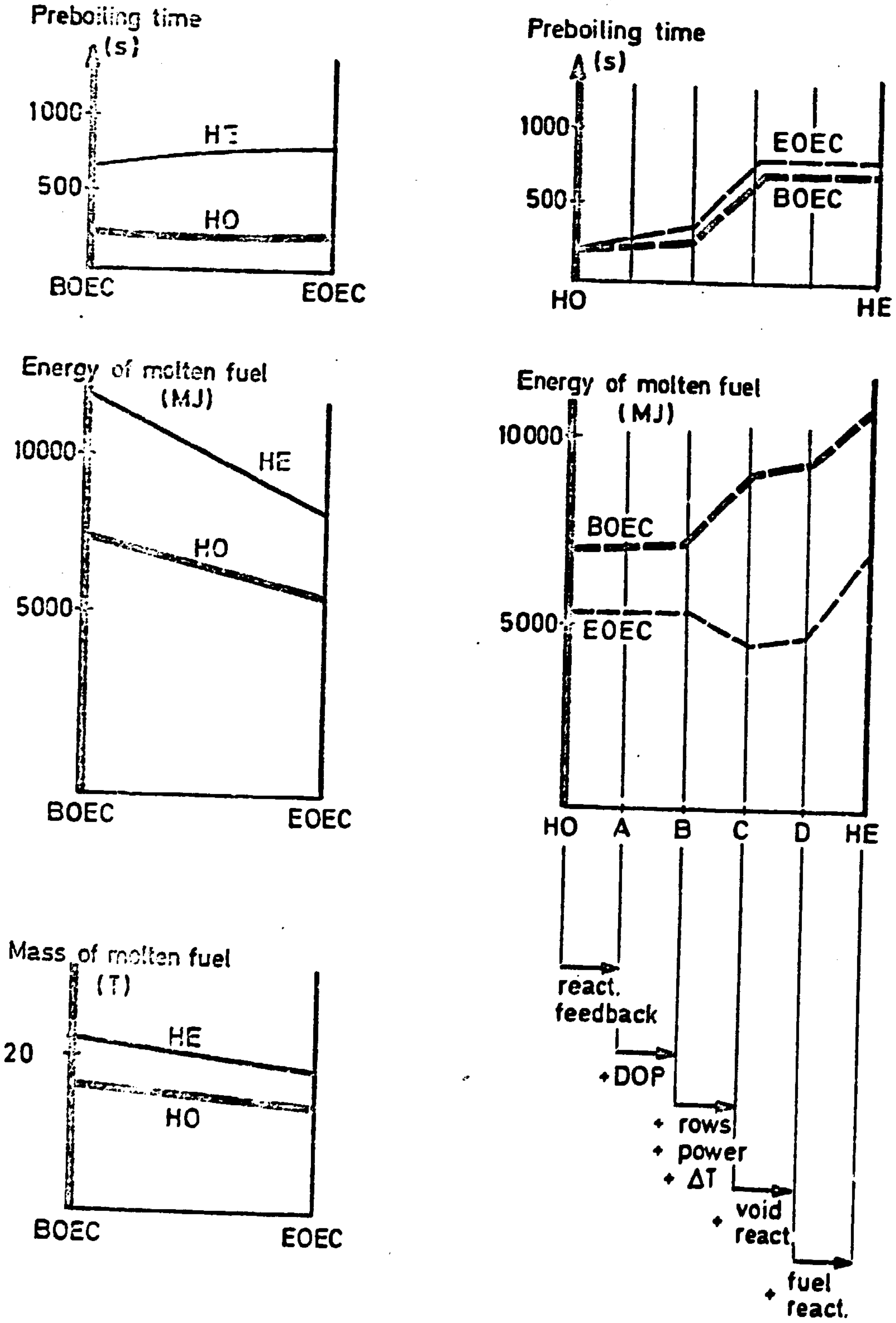

Fig. 3 RESULTS

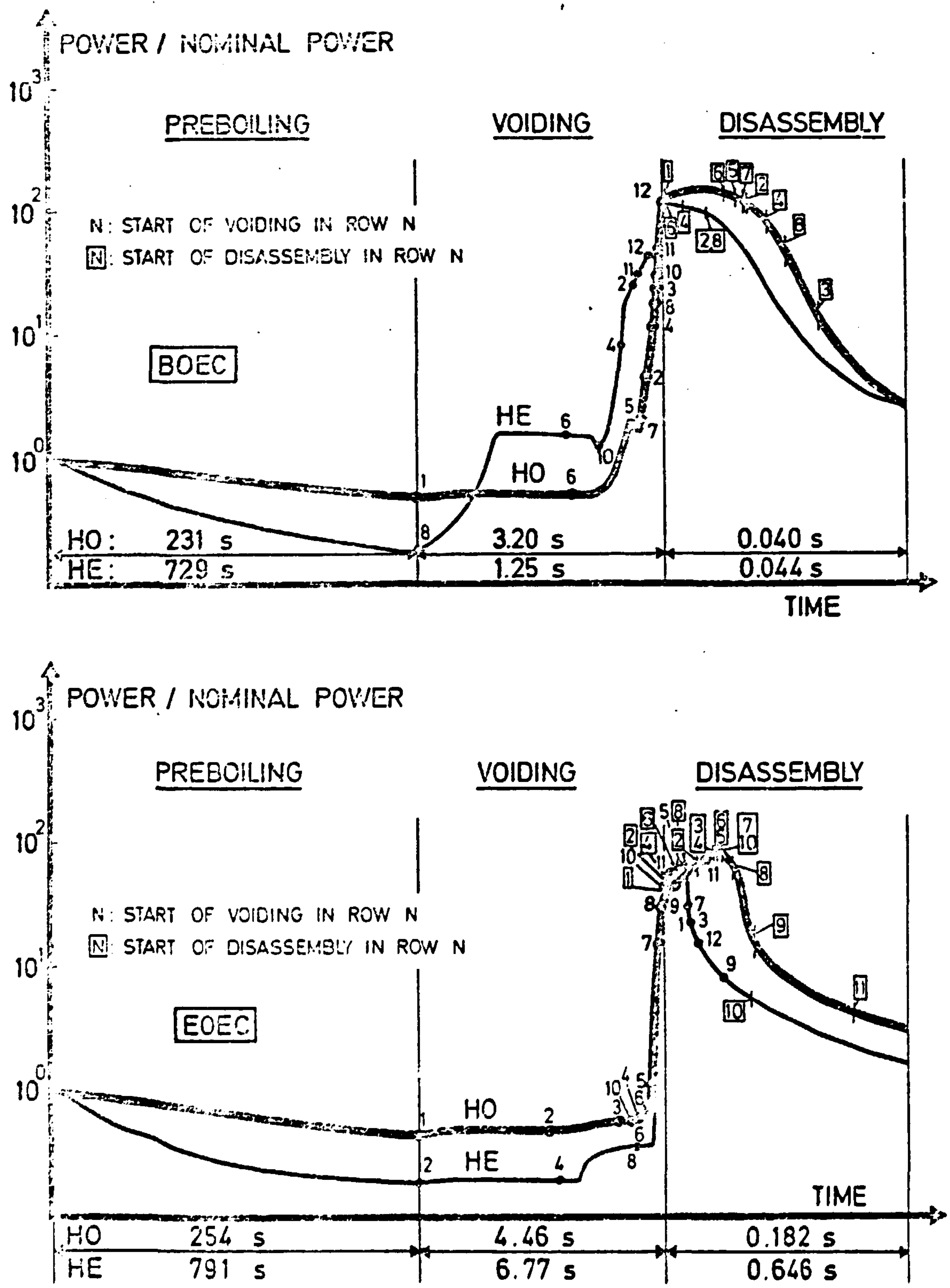

FIGURE 4

POWER CURVES

The molten fuel always belongs to F subassemblies only (no breeder reaches melting in HE).

The percentage of molten fuel in F decreases from 66 % to 52 % through the cycle in HE (total fissile : 34.2 T), from 41 % to 35 % in HO (total fissile : 39.1 T). The power histories can be seen in Fig. 4.

Step by step comparison

Using the HE preboiling reactivities, then the HE Doppler feedback hardly changes anything (case A, then B).

The big change appears between B and C (when rearranging rows, power and flowrates in the heterogeneous manner). First, the preboiling time strongly increases, mainly because of the smaller average temperature through the total oxide mass in the HE core, resulting in a smaller positive Doppler feedback. Second, the molten fuel energy increases in the BOEC. This is due to a combination of causes:in C, voiding starts in row 8,where the power to flow ratio is highest ; however, the voiding reactivity of this row is small and has little influence on total power ; once it is fully voided, the fuel of the 84 subassemblies of this row heats up faster than that of the other still cooled rows, and reaches temperatures of ∿ 500°C higher than these rows. The voiding of row 6,with its high reactivity feedback starts the power excursion, and accelerates the arrival of voiding in rows 2 and 4. As rows 2, 4 and 6 have a higher power than row 8, they now heat up faster and, at the onset of disassembly, all rows 2 to 8 (60 % of F) have mid plane temperatures within 50°C of one another. The total energy in the core is therefore larger in C than in B, although the void reactivity is smaller in C (955 10^{-5} ΔK/K) than in B (1565 10^{-5} ΔK/K), since 7 rows are voided in C, instead of 12 in B.

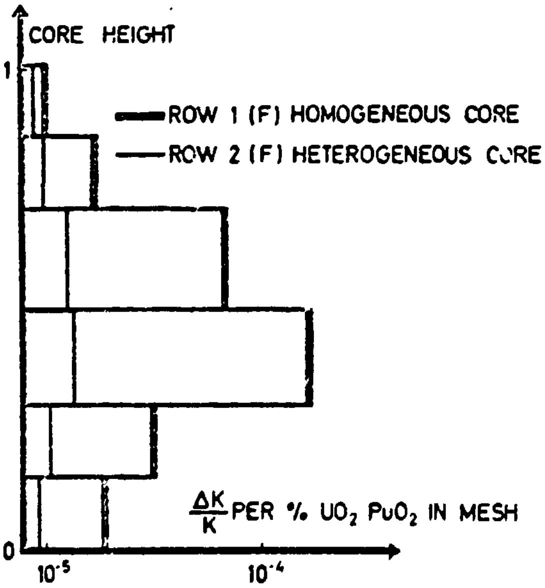

FIGURE 5

AXIAL DISTRIBUTIONS OF FUEL REACTIVITY COEFFICIENT

The energy decreases in EOEC, when switching from B to C ; this is due to much flatter distributions on the HO side (case B). In EOEC, the void reactivity is the same in both cases (1565 10^{-5} ΔK/K) : 12 rows are voided.

At the next step (C to D), only the void reactivity is changed from HO to HE. In both BOEC and EOEC, we have some increase in energy which is due to an increase in void reactivity. In BOEC, the void reactivity increases from 955 to 972 10^{-5} ΔK/K and from 1565 to 1637 10^{-5} ΔK/K in EOEC (in fact, both differences in void reactivity between C and D are higher during most of the voiding time, because row 12, with its negative reactivity, only voids at the end and has therefore little effect).

The last step (D to HE) gives another strong increase of energy. This comes from a much flatter distribution of fuel reactivity feedback in the HE core, resulting in larger disassembly displacements, necessary to obtain the same feedback (see Fig. 5).

Summarizing, we find that the Doppler coefficient, 20 % smaller in HE than in HO, has practically no effect. The void coefficient has little effect : in EOEC, where the same volume of voiding (12 rows) is concerned in both HO and HE, we have some increase in energy, because there is some increase in void reactivity (when switching from HO to HE) ; in BOEC, where 7 rows only are voided in HE (12 in HO), with therefore much less void reactivity in HE than in HO, we have,unexpectedly, a very shap increase in HE energy. This is due to the primary importance of the radial distributions of power and flow rate which is rather flat in F zone and gives the maxima for power and ΔT towards the periphery of HE core in BOEC only, and this overcomes the benefit obtained from a lower void reactivity in HE. Besides, radial distributions of power and flow rate have also an influence in EOEC : they are shaper in HE than in HO with the maximum towards the center, and hence tend to decrease the energy. On top of that, the fuel reactivity feedback distributions, flatter in HE than in HO, tend to increase the energy in HE, in both BOEC and EOEC.

The net effect is a higher energy in HE than in HO, especially in BOEC.

CONCLUSION

Our main conclusion for our 1800 MWe core is that, if boiling does occur, the heterogeneous configuration yields more energy than the homogeneous one, but that the preboiling time is longer in the heterogeneous one. We set up a method for understanding the influences of the different core data. We found that the void reactivity, which was supposed to be more advantageous for the heterogeneous configuration in the beginning of cycle calculation, had in fact little influence, compared to power and flow rate radial distributions. In our design, flattening powers and ΔT in the fuel subassemblies was optimised at the beginning of cycle for the heterogeneous configuration, and at the end of cycle for the homogeneous one, resulting, for the heterogeneous configuration, in a trend for higher energy at the beginning of cycle and lower energy at the end of cycle. Fuel reactivity feedback is also an important parameter, which tends to increase the energy in the heterogeneous configuration.

With a different core design with different configurations and different optimisation strategies, the results could be changed.

It is not therefore surprising that different results have been obtained elsewhere [2], [3], [4] : heterogeneous cores yield rather less energy than homogeneous cores, the main reason quoted for that being a lower void reactivity in heterogeneous cores. We think that different power, power/flow and void reactivity distributions from ours can mainly account for the opposed differences, and also variations in the scenario.

ABBREVIATIONS USED

LMFBR	Liquid Metal Fast Breeder Reactor.
HCDA	Hypothetical Core Disruptive Accident.
LOF	Loss of Flow.
HO	HOmogeneous.
HE	HEterogeneous.

BOEC	Beginning Of Equilibrium Cycle.
EOEC	End Of Equilibrium Cycle.
F	Fuel.
IB	Internal Breeder.
EB	External Breeder.
CEC/WAC group	Commission of the Europeans Communities/Whole core Accident Code group.

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