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Plutonium Burning and Minor Actinides Transmutation in Fast Reactors: First Results Obtained Within the Frame of the CAPRA Programme

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1. Introduction

The CAPRA programme has been established by the CEA in early 1993 with the primary goal of investigating the feasibility of a fast reactor core optimised to burn plutonium. CAPRA is now being jointly pursued by the European R&D organisations (CEA in France, AEA in the UK and KFK in Germany) and the design companies grouped under the European Fast Reactor Associates umbrella.

The first phase of the CAPRA programme is planned to last until the end of 1994. Its goal is to deliver an overall assessment on the feasibility of fast reactor plutonium burner cores. This assessment will also include the minor actinides transmutation capability of such cores.

The objective of this paper is to present the progress made so far. After an introduction to the basic physics boundary conditions of burner cores, a description of the studies performed and the main results are given. Then the efforts made towards the definition of an accompanying experimental R&D programme are summarised, followed by the conclusions and an outlook to the future work.

2. Basic Physics Boundary Conditions

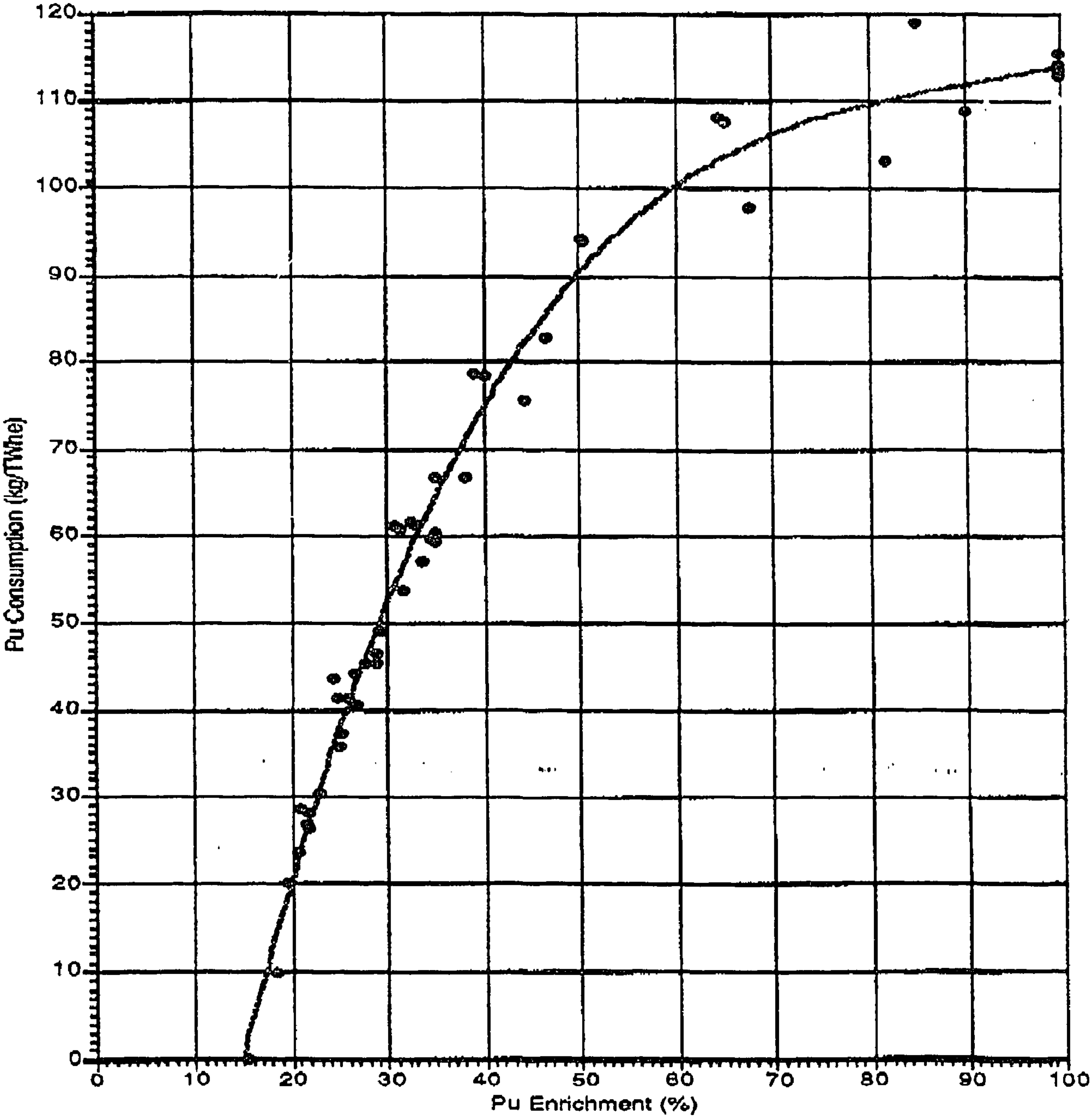
One of the most important characteristics of fast reactors, from a neutronics point of view, is the fact that practically all plutonium isotopes as well as the minor actinides yield a positive contribution to the core reactivity. This characteristic has two main consequences: on the one hand, the fast reactor has a very favourable neutronic economy and the potential to deliver high fluxes, and, on the other hand, it can accomodate fuels with practically any isotopic vector. The first consequence offers a considerable design flexibility, which can be used towards the definition of "multi-purpose" fast reactors (e.g. breeders or burners of plutonium, transmuters of minor actinides and of other long lived radioactive nuclides) and/or be used to design "transparent" cores, thus enhancing the inherent safety characteristics. The second consequence makes the fast reactor the only presently known reactor type to be really flexible with regard to the fuel cycle (e.g. by allowing multiple recyclings).

Enhancing the plutonium burning capability of a fast reactor requires - in addition to the trivial measure of removing all fertile zones - the reduction of the breeding gain in the fissile zones. This in turn requires a high plutonium content (enrichment). Figure 1 shows the relationship between the plutonium burning rate and the fuel enrichment. As can be seen, the plutonium consumption rate can be enhanced up to values of 50 - 80 kg/TWhe (assuming a load factor of 0.8, this corresponds to about 350 - 560 kg/GWe•Year), if the plutonium enrichment is raised to levels of 30 - 45 %. In the limit of a fuel without uranium, the theoretical limit of the plutonium burning rate of approximately 115 kg/TWhe (about 800 kg/GWe•Year, assuming a load factor of 0.8) is approached asymptotically.

However, fast reactor core designs with high burning objectives have significant consequences on the core performance and safety characteristics: trade-offs between the high burning goals and those parameters are inevitable. Qualitatively summarised, the enhanced burning cores have to deal with the following consequences: removing all fertile zones will influence the core dimensioning features and the shielding characteristics;

increasing the plutonium enrichment will, on the one hand, increase the burnup reactivity loss - and thus also the absorber worth requirements - , and, on the other hand, have an important impact on the sodium void effect and on the Doppler constant: the absolute value of the latter will decrease, while the influence on the former will strongly depend on the design adopted (e.g. reduced sodium void effect in cores with less uranium content, increased sodium void effect in designs which introduce absorber materials).

Figure 1: Plutonium Burning Rate as Function of the Fuel Enrichment



Last but not least, there are two important global design parameters to be considered: core size and fuel type. Concerning the latter, none of the basic physics considerations made above are significantly alterded by considering nitride or metal fuel; moreover, these fuels offer additional interesting options with regard to safety characteristics and fuel cycle features.

For what concerns the core size, it is obvious that small cores, given their higher leakage rate, have also a higher plutonium enrichment. It is therefore easier to design smaller cores with a high plutonium content, and therefore enhanced burning capability, than larger ones.

3. Studies Performed

3.1 Description

In the first phase of the CAPRA programme, the bulk of the effort was concentrated on physics (neutronics and safety) and fuel studies, as well as towards the definition of an experimental R&D programme in support of the CAPRA design work.

In line with the general physics constraints (cf. section 2), an envelope case has been defined for these studies: an oxide fuelled 1500 MWe core based on the EFR Consistent Design [1]. For this case, the studies focused on two lines of research:

- increase of the burning capability of fast reactor cores based on the current experience with mixed (Pu, U) oxide fuel,
- investigation of the feasibility of fast reactor cores based on fuel without uranium support.

In the first case, the studies determined the plutonium enrichment limits compatible with the present fuel cycle technologies (concerning, mainly, the homogeneity problems at the fabrication, and the solubility problems at the reprocessing stage).

In the second case, a first assessment of the safety consequences of cores without uranium support (near-zero Doppler constant and βeff decrease), and of the feasibility of inert fuel support materials has been performed.

In both cases, the studies also addressed the problem of minor actinides production and/or transmutation capability.

For what concerns the experimental R&D programme, studies aiming to define irradiations and critical experiments, in order to validate the enrichment options and the basic physics parameter choices, have been initiated.

3.2 Results

3.2.1 Physics and Fuel Studies

The maximum plutonium enrichment of the evolutionary design (cf. section 3.1) is established at 45%. Both the "dilution" (reduction of the fuel volume content) and the "poisoning" (introduction of absorber materials) approach are considered.

In the "dilution" appraoch, the fuel volume fraction is reduced by approximatively a factor of two as compared to the EFR Consistent Design. This reduction is the result of design measures on the levels of the fuel pellet (small diameter, large central hole), the bundle (reduced pin diameter, introduction of fuel-free pins) and, finally, the core (introduction of diluent subassem-blies). In the "poisoning" approach, the absorber materials are introduced in the diluent subassemblies. The "dilution" approach has the drawback of increased burnup reactivity loss. Core "poisoning" is beneficial with respect to this problem, but the Doppler constant and sodium void effect characteristics are worsened.

Figure 2 shows the core layout of the evolutionary design. Table 1 gives the related design and performance data (and the comparison to the EFR Consistent Design).

The results obtained for a core based on fuel without uranium support are also summarized in Table 1. A ceramics fuel matrix has been considered for this case: the PuO_2 particles are dispersed in the ceramic support. It is important to note the strong decrease of the sodium void reactivity effect (due to the moderating effect of the oxygen), a crucial feature for cores with near-zero Doppler constants.

An important result is also that the burner core designs offer the possibility to return to the breeding mode. This is the result of the design flexibility of fast reactor cores (cf. section 2).

The results obtained from the fuel studies support the choice of the upper bound of the plutonium enrichment (45%) in the evolutionary cases.

For what concerns the minor actinides transmutation capability, the results obtained so far

Figure 2: Layout of an Evolutionary Burner Core (Dilution Approach)

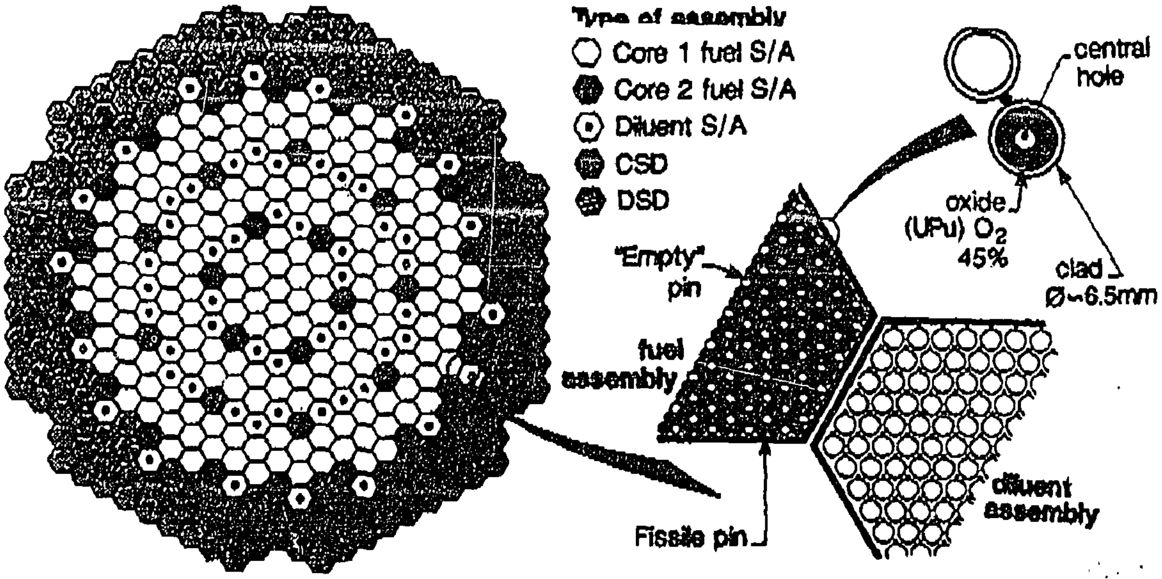


Table 1: Design and Performance Data of 1500 MWe Burner Cores

Type of Core	EFR Consistent Design	Evolutionary Burner Design		Fuel Without Uranium Support
		Reference	Introduction of MA (^{237}Np)	
Fuel	(U,Pu) 0_2	(U,Pu) 0_2	(U,Pu) 0_2	(Pu,Ce) 0_2
Number of fissile total pins	331/331	320/469	320/469	469/469
Diameter of pellet/hole(mm)	6.94/2.0	5.42/2.5	5.42/2.5	5.42/2.5
Fuel management	5 x 340 EFPD	3 x 265 EFPD	3 x 265 EFPD	6 x 170
BOC reactivity (pcm)	2900	7644 ?	6626 ?	8628 ?
Pu burning rate (kg/TWhe)	20	74	59/77*)	114
Linear Rating, [illegible]	520	437 ?	463 ?	310
Sodium void reactivity (pcm)	2100	1213	1346	272
Doppler constant (pcm)	- 650	- 388	- 505	- 56

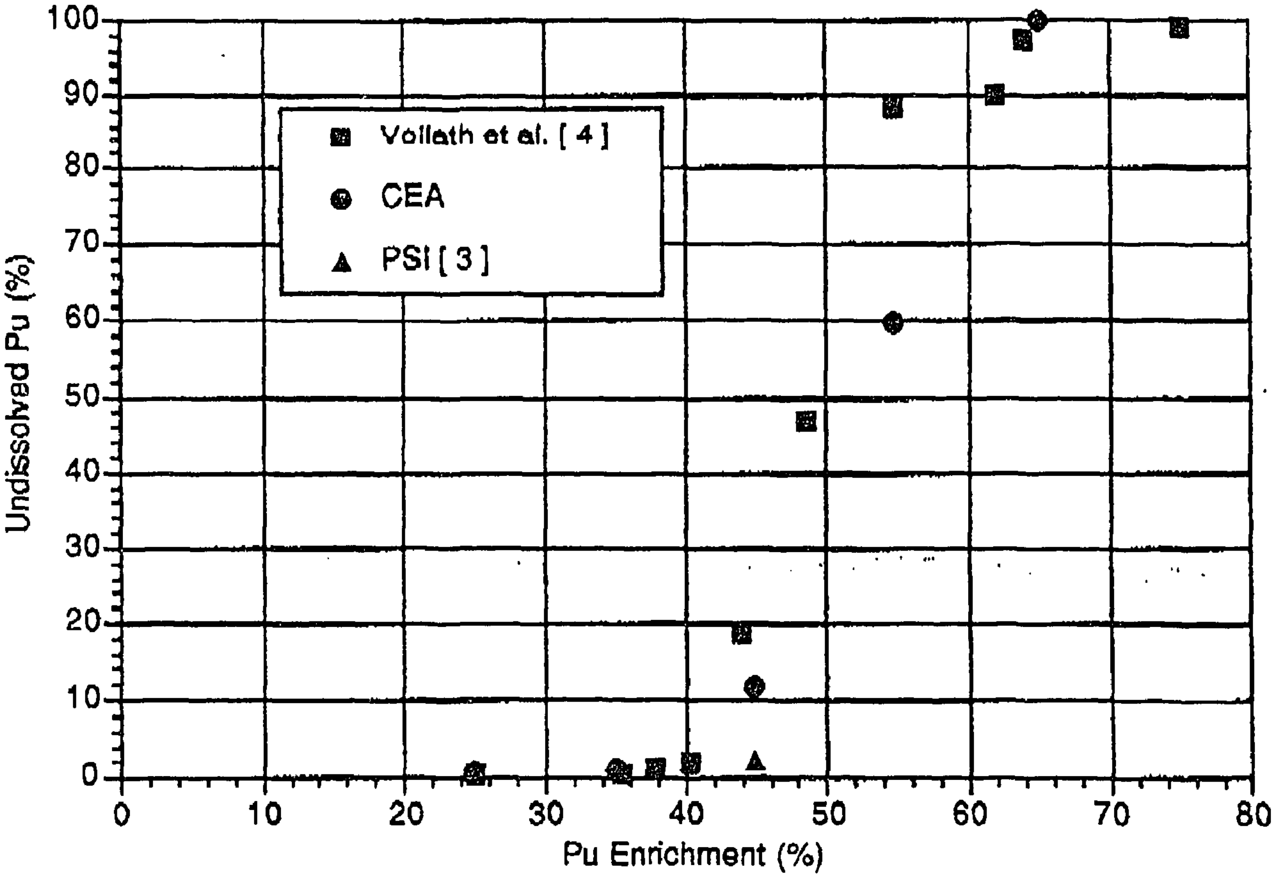
*) Pu + Np burning rate

are very encouraging (cf. Table 1). According to the recommendations of the SPIN programme [2], neptunium has been considered homogeneously blended into the fuel, and americium loaded into targets at the core periphery. The good minor actinides transmutation characteristics are a direct consequence of the "dilution" approach, allowing for a considerable number of void pins which can be used to accomodate boron carbide (as moderator, possibly enriched in ^{11}B) to counteract the negative effects on sodium void reactivity and Doppler constant.

Oxide fuels were fabricated with plutonium contents varying from 25 to 65% . Particular care has been taken to ensure as much as possible the homogeneity of the fuel (extension of the milling time and of the sintering time, humidification of the sintering gas). The chemical and physical properties of the fabricated pellets are - for all the plutonium enrichments - very close to the classical MOX fuel specifications (95.5% of the theoretical density, O/M ≈ 1.98, low open porosity and small grain size).

The results of the solubility studies performed on these fuels at CEA and PSI [3] are given in Figure 3, as well as the comparison to older results by Vollath et al. [4].

Figure 3: Solubility Results on Mixed Oxides with High Pu Content



It can be seen, that between 35 and 55% plutonium content, the decrease of the dissolution kinetics requires renewal of the nitric solution, which leads to an important reduction of the undissolved residue content. The dissolution is impossible above 55% plutonium content.

3.2.2 Experimental Programme

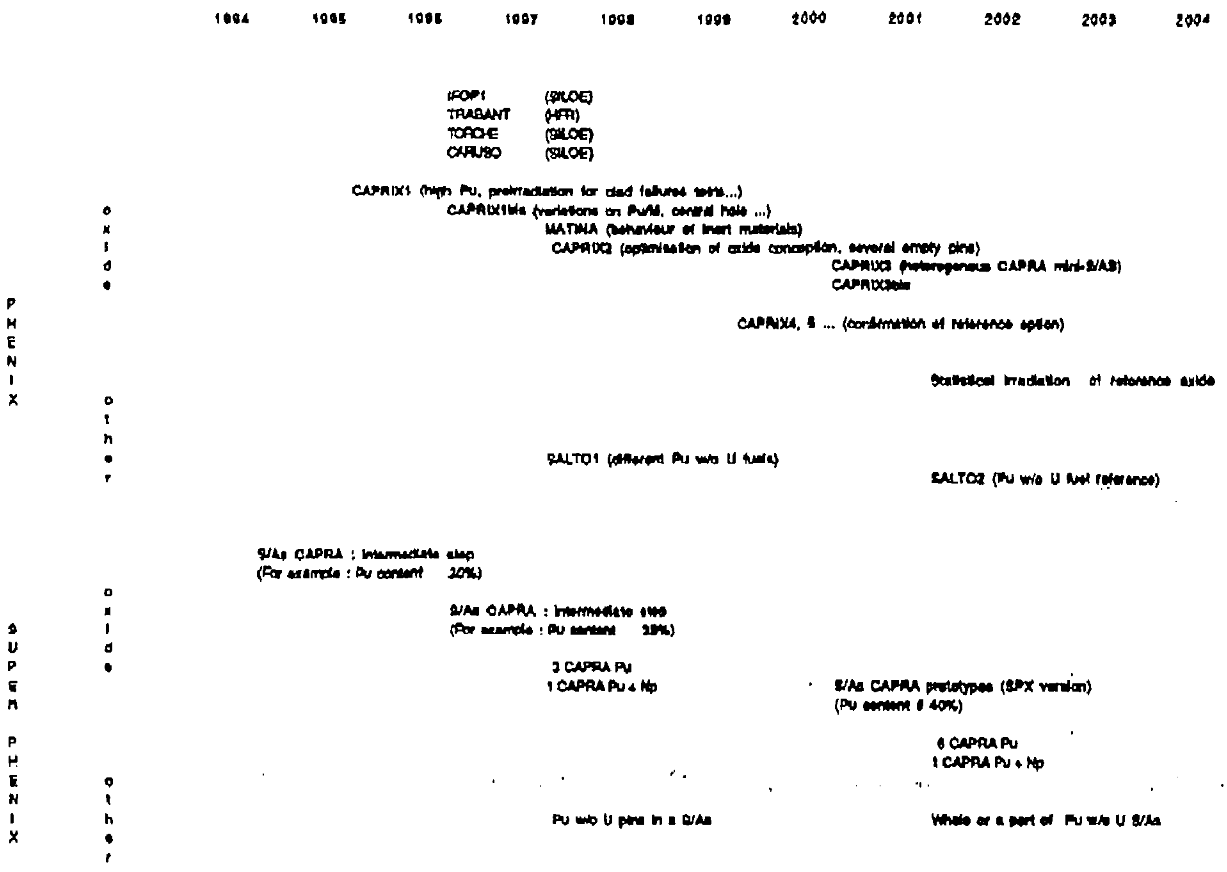
In parallel to the physics and fuel studies, an important effort has been made towards defining the experimental programme which will sustain the CAPRA design work, and eventually validate the design options.

The thrust for this significant R&D experimental programme is twofold :
- irradiation experiments and basic material studies to validate the CAPRA fuel option(s),
- physics experiments to validate the neutronics data and calculational methods for burner and transmutation cores.

The results of the work performed towards the definition of this experimental programme are gathered in Table 2.

It is important to note that within this frame, both Phénix and Superphénix will play a crucial role.

Table 2: Irradiation Programme in Support of CAPRA



4. Conclusions

The results of the studies performed up to now within the frame of the CAPRA programme have lead to
- a better understanding of the basic physics issues of burner and transmutation cores and of the sensitivities involved,
- the definition of an envelope case based on the EFR Consistent Design,
- the definition of the design characteristics and main performance and safety parameters of both an evolutionary (45% plutonium enrichment) and an advanced design (fuel without uranium support),
- proposals towards a comprehensive experimental programme in support of the CAPRA design options.

The results obtained up to now are encouraging.They clearly confirm the potential of the fast reactor to contribute towards solving the problems related to the back-end of the fuel cycle, provided reprocessing of LWR spent fuel is maintained as the basic requirement for an optimum resources- and waste-management strategy.

The dilution aproach offers a sound basis for a burner core with a plutonium burning capability of 70 - 80 kg/TWhe, yielding attractive safety features, while additional efforts are necessary to decrease the burnup reactivity loss and to increase the fuel residence time. This core has also good minor actinides transmutation characteristics, offering the possibility to introduce moderator materials in order to improve the sodium void reactivity effect and the Doppler constant.
For the future work, it is important to
- consider more comprehensively the issues related to safety in beyond design basis accidents (e.g. criticality/recriticality issues, potential of the dilution concept with regard to prevention and mitigation),
- thrive for low sodium void effect designs (a must for cores with near-zero Doppler constant),
- pursue the irradiation and physics experimental programmes.

References

[1] G. Hubert, C.H. Mitchell, EFR Programme:Large Plant Design Activities, to be presented at ENC 94, Lyon (October 1994)

[2]

[3] G. Ledergerber et al., communication at the first international CAPRA seminar, Cadarache (March 1994)

[4] D. Vollath et al., On the Dissolution of (U, Pu)O_2 Solid Solutions with Different Plutonium Contents in Boiling Nitric Acid, Nucl. Techn., 10, 71 (1985)