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BURN-UP STUDIES AT CEA FOR FAST BREEDER REACTORS

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I - INTRODUCTION

Among the main fast reactors characteristics that must be studied by reactor physics, the burn-up problem must be considered as one of the most important for economical optimisation, fuel cycle and operation of the plants.

The first priority concerning the studies of mixed oxyde, sodium cooled fast reactors, considered in the French program, was devoted naturally to clean cores without burn up. The increase of the power range, for PHENIX to SUPER PHENIX, and of the length of the cycle, the doubling time optimisation now required, have considerably increased the importance of burn up parameters :

1 - The net production of Plutonium relative to the fuel irradiation acts directly on fuel cycle cost, and in the future on the penetration and success of breeder reactors. The breeding gain characterises the equivalent Plutonium production, for one fission : internal breeding gain (GRI) for the core, the externed one GRE for the blanket and the global one (GRG).

2 - The reactivity loss per cycle, directly connected to the internal breeding gain (GRI), and the variation of the volumic power during irradiation have an influence on critical enrichments, number of control rods and use of the control system. The ideal solution of a null reactivity loss, for example compensation between the negatif effect of fission products and the positive one due to a positive Plutonium balance in the core (GRI > 0), requires a perfect knowledge of the different burn up components.

3 - Finally, the problems connected to the fuel cycle analysis concerning for example transport, reprocessing, refabrication and waste problems involve the determination of the amount of transactinides and fission products inside the fuel versus the burn-up and cooling time.

The approach followed at CEA from 1973 to study the burn up problems is identical to that one used for the other

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parameters on reactor physics /1/.

The starting points concern theoretical methods and microscopic data measurements and evaluation. The results are put all together in a system including code and nuclear data called "Formulaire CARNAVAL".

The efforts were directed between 1973 and 1977 towards two points :

- higher Plutonium isotopes
- fission products.

An extensive specific program of integral experiments was performed on critical facilities and power reactors. The results were used globally to adjust the "Formulaire" and to obtain in february 1977 the Version IV of CARNAVAL now used at CEA for plant calculations (SUPER PHENIX and commercial Fast breeder reactors).

This paper describes firstly the experimental programs (chapter II). The results concerning the higher Plutonium isotopes and the fission products are then presented (chapter III and IV).

The calculated results are performed with the CARNAVAL IV system ; the gain between Version III and IV of CARNAVAL is described in Reference 2.

II - EXPERIMENTAL PROGRAMS

The experimental programs devoted to the burn up studies are carried out at CEA on two critical facilities :

- MASURCA, large reference critical facility, able to deal with 6000 l core volume.
- ERMINE, fast-thermal coupled assembly to minimise the fuel inventory, dealing mainly with local parameters, especially on irradiated fuel measurements.

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In addition, irradiations, either of samples or of normal fuel pins are performed in power reactors : OSIRIS, RAPSODIE and PHENIX, followed by isotopic analysis of the composition variations using very accurate techniques. These results give an unique contribution of integral data on burn-up problems and of capture rate ratios on higher Plutonium isotopes, fission products and transactinides.

II.1 - PLUTO program

The experimental program devoted to the study of higher Plutonium isotopes, is based on the availability of Plutonium with various isotopic contents of 240 Pu and 241 Pu.

Two types of Plutonium with a large content of higher Plutonium isotopes are available :

1) 25 kg of "dirty Plutonium" : 44% of 240 Pu, 10% of 241 Pu

2) 55 kg of "light water reactor Plutonium" : 18% of 240 Pu, 9% of 241 Pu.

These fuels are manufactured in rods of mixed uranium-plutonium oxide. The enrichments are chosen to get the same reactivity than with the "clean" PuO_2-UO_2 mixed oxyde fuel (8% of 240 Pu, 1% of 241 Pu), that is the reference MASURCA fuel.

All the originality of the program relies in this reactivity equivalence. The three fuels have neutronic characteristics very similar. It is therefore possible to get for the same spectrum, three types of lattices, where 240 Pu and 241 Pu have different weights and thus to separate the 240 Pu and 241 Pu effects.

II.1.1 - Experimental techniques

Three types of measurements permit to reach the integral characteristics of higher Plutonium isotopes :

1 - Cell neutron balances : due to the fuel manufacture, the direct and adjoint balances for one type of cell with "clean" or "dirty" Plutonium, are very similar. The experimental

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techniques are therefore adapted to get "zero measurement".

- δB^2 measurements : change of the material buckling by the progressive substitution method. This method /3/ is accurate only if the substituted mass represents about one quarter of the critical one.

- k^+ measurements (production to absorption ratio) : this method applicable to all the lattices, is mainly accurate when k^+ is close to unity : "$K_\infty = 1$ method".

We can mentionned also, that we can get by cell substitution the k^+ variations (δk^+). When k^+ differs appreciably from unity, this method is more accurate than direct k^+ measurements.

2 - Fission rates ratios : fission rate measurements are carried out for ^{240}Pu, ^{241}Pu and ^{242}Pu, relative to the ^{235}U and ^{238}U ones, using miniaturized fission chambers.

3 - Irradiations : irradiations of pure samples in PHENIX, OSIRIS and RAPSODIE /5/ give direct informations on capture rates ratios : σ_{c40}/σ_{c8} and σ_{c41}/σ_{c8}. In this regard it is the more accurate method /5/, but the number of spectra in which irradiations can be carried on is limited.

II.1.2 - Lattices choice

1 - Choice criterion : the program aims at measuring the core parameters in an energy range corresponding to fast power reactors

a) Power energy range : experiments are performed in sodium diluted cores, one sodium rod for one fuel rod. To vary the basic enrichment, depleted uranium oxide rods replace partially the fissile rods.

b) Low energy range : low enrichments are used to study the low energy range (< 10%). This corresponds also to the characteristics of zero leakage cores studied by the "$K_\infty = 1$" technique.

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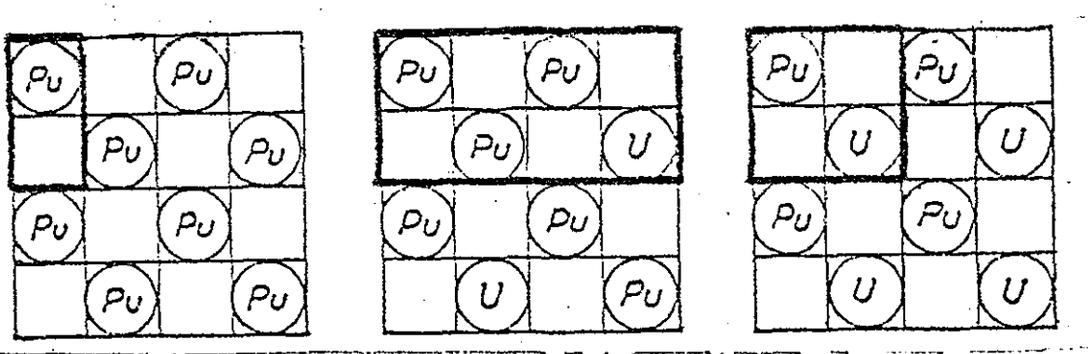
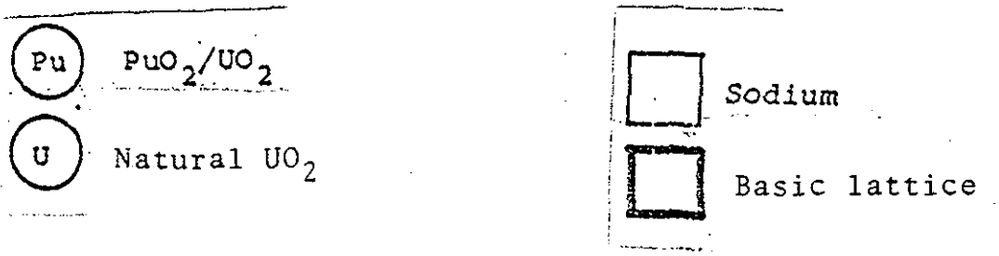
c) High energy range : due to the MASURCA basic fuel enrichment (25% in equivalent Plutonium), the higher part of the spectrum will be studied in "compact" cores. These cores contain only fuel, and the enrichment is varied by replacing partially fissile rods by depleted uranium oxide rods.

2 - Basic lattices :

- Power energy range : ZONA core : all these lattices have a Plutonium oxide fuel with a sodium diluent. Enrichment variations are obtained by using depleted uranium oxide rods. Three lattices were studied :



ZONA 2 (E ∿ 25%) ZONA 1 (E ∿ 18%) ZONA 3 (E ∿ 12%)



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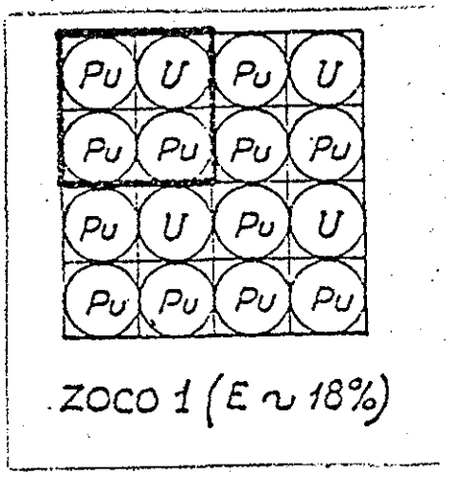
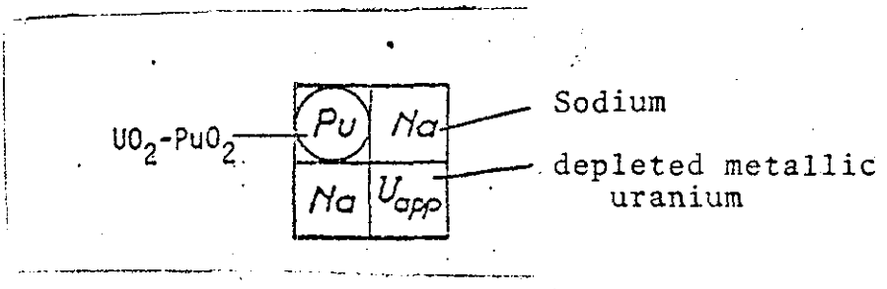
- compact cores : one lattice ZOCO 1 with only oxide was studied



- "k_∞ = 1" cores : for this type of core the enrichment is defined to obtain a zero leakage. To get variable spectra, various diluents were used.

a) Cores with sodium diluent : OP 11 ("clean" Pu), OP 41 ("dirty" Pu), OP 51 ("light water" Pu). The basic lattice is the following one :



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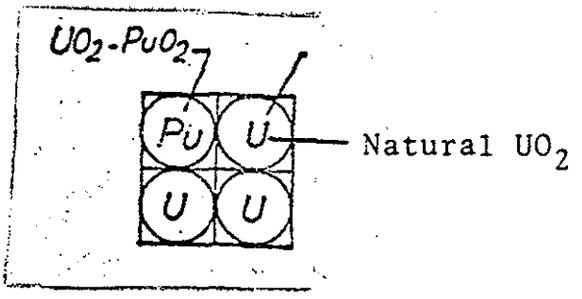
b) Cores without diluent : OP 10, OP 40 and OP 50 (same definition as above § a)).



The energy range covered by the lattices studied is given on figure 1 versus the spectrum parameter r./1/. The power energy range cores and the compact ones were studied by the substitution method in MASURCA. The OP cores were carried out in ERMINE by using the "k_∞ = 1" method. In all there cores fission rates ratios were measured. In addition fission measurements performed in all the cores preciously studied in MASURCA and ERMINE are available. Further more pure samples of 239Pu, 240Pu, 241Pu and 238U were irradiated in PHENIX (3 cycles), RAPSODIE and OSIRIS.

II.2 - Fission products capture measurement

Taking in account the accuracy required for the reactor design, the only pratical value to know is in fact the total F.P. capture rate. Then the French experimental program is based on a global direct measurement of the capture rate of the F.P. produced in an irradiated fuel, as a whole.

Compared to other programs essentially based on F.P. separated isotopes measurements, this program seems more realistic due to the following reasons :

- The F.P. effect is measured in a state that represents directly a reactor fuel for the spectrum or for self-shielding effect. That permits a more easy transposition from the measurement to the real effect in a power reactor.
- The purchase of signifiant quantities for a lot of separated isotopes is avoided. These isotopes are usually uncommun elements and only available in rather complex mixtures.

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- The use of intermadiate parameters such as yields and gaseous migration is by-passed. Such quantities are not well known at present.

The F.P global capture adjustment scheme that has been adopted at CEA is :

1) Evaluation of an original cross section library starting from the best available datas including a reestimate for the main separated F.P. isotopes.

2) For these main F.P., adjustment of their capture cross sections. It is based on integral measurements carried out in cores with spectra similar to those of fast power reactors.

3) Calculation of lumped F.P. relying on the readjusted or reestimated separated isotope capture cross sections.

4) Final fit of the lumped F.P. capture cross section onto the irradiated fuel experimental results.

Following on this adjusting scheme, the French program is divided in two main parts :

- For the separated isotopes playing a major role in the global capture rate, previous measurements of their separated integral capture cross sections to adjust the cross sections.
- Direct measurements of the F.P. global effect from irradiated fuel pins to finally fit the lumped F.P.

II.2.1 - Measurement on the separated isotopes

In the framework of the adjustement of F.P. separated isotope capture cross sections, different foreign experiments have been analysed. For the most important products, specific CEA experiments are performed on fast power reactor typical cores.

1) Foreign experiments :

- Oscillation measurements in STEK fast thermal couled facility into 5 cores with different spectra.

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This experimental /6/ program has been analyzed in the framework of a CEA-RCN agreement.

- Oscillation measurements in the FRO facility in 3 cores /7/.

- Activation measurements in CFRMF fast thermal coupled assembly of the ARMF II facility /8/.

2) CEA specific program : due to the isotope availabilities and characteristics, 3 types of measurements have been chosen for the different separated F.P.

- Oscillation measurements in MASURCA facility and in ERMINE fast thermal coupled assembly of the MINERVE facility. This kind of measurement has been devoted to the products for which a mass of a few was available in order to reach the resuested accuracy. To get the capture, this method needs slowing-down and self shielding corrections. The accuracy that can be obtained is about ± 10%.

- Activation measurement in ERMINE fast thermal coupled assembly. Such a method gives a direct access to capture, but its use is restricted to those isotopes whose the capture decay nuclide is radioactive and measurable by γ spectrometry.

- Irradiation in PHENIX : provided an irradiation tool like PHENIX, allowing to reach quickly the necessary fluence with neutronic spectrum in the desired range is available, this method is very attractive. On one side the nuclide inventory used is very small. On the other side, capture integral cross section measurements are obtained by mass spectromety analysis with a high level of accuracy (3 to 4%). In the special case of successive captures, it is possible to obtain with a pretty good accuracy the deduced capture for the son isotopes in some cases.

In table I we present a list of the measured F.P. including the number of different measurements with the uncertain-

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ties for each of the 3 techniques. The progress brought by the PHENIX irradiations is valuable.

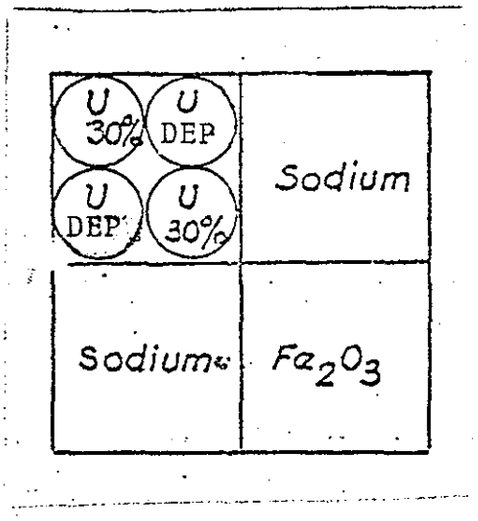
II.2.2 - Global effect measurement

F.P. global effects are measured by oscillations of fast breeder irradiated fuels in the fast thermal coupled ERMINE assembly.

To get the required result, it is necessary to deduce the reactivity difference between a fresh fuel and the same irradiated fuel, and to substract the reactivity effect due to the burn-up of the fissile fuel itself during irradiation.

After oscillation, the fuels are chemically analysed to know their composition very accurately. The experimental program, carried in France, is divided in 2 parts :

1) A preliminary phase in 1973 during which RAPSODIE and FORTISSIMO (UO_2 - PuO_2 20 to 25% of Pu, and U 60 to 80% of 235U) irradiated fuels have been oscillated in a uranium lattice with a spectrum in the SUPER PHENIX range (R3 Lattice) /9/ whose elementary cell is drawn below :



R3 CELL

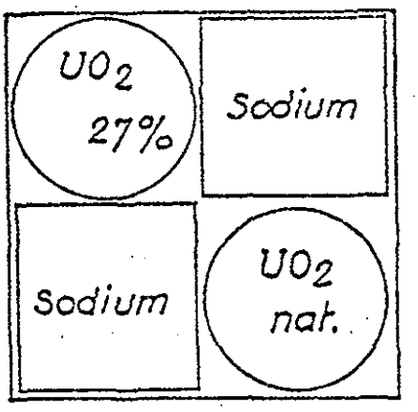
The main aim of this "phase" was to test the oscillation and chemical analysis techniques for highly irradiated fuels.

2) A "main phase" in 1975-1976 during which 2 types of irradiated fuels have been oscillated

- pure 235U fuels (PROFIL U) irradiated in RAPSODIE
- PHENIX fuels (S3) with an irradiation time of 3 cycles (≃ 30000 MWD/T).

The irradiated samples have been oscillated in 3 oxide fuel lattices : 1 uranium lattice in the SUPER PHENIX range (RONA 3 lattice) ; and 2 plutonium lattices in the SUPER PHENIX (ZONA 3) and PHENIX (ZONA 1) ranges.

The RONA 3 elementary cell is drawn below : ZONA 3 and ZONA 1 cells have been described previously (§ II.1.2).



RONA 3 CELL

A summary of these measurements is given in table II. Figure 2 gives an overall view of the spectrum range covered by all the studied lattices.

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III - PLUTO PROGRAMS RESULTS

The available results are taken into account to adjust 240 Pu, 241 Pu, 242 Pu, 241 Am and 238 Pu cross sections of the CARNAVAL system. The experimental results are compared with CARNAVAL IV calculations.

III.1 - Cell neutron balance

Table III gives the deviations between calculations and experiments for substitution and "$k_\infty = 1$" techniques. The results concern the relative values δB^2 and δk^*, the clean Plutonium core being the reference. Two main conclusions can be drawn out from these comparisons :

1 - Good agreement between calculations and experiments inside the errors limits.

2 - Coherence of the results between the two types of experiments.

III.2 - Reaction rates ratios for higher Plutonium isotopes

III.2.1 - Fission chambers measurements

The discrepancies between experiments and C IV. calculations are given respectively for $\sigma f_0/\sigma f_8$, $\sigma f_{41}/\sigma f_8$ on figures 3 to 5. We observe a very good agreement inside the error limits. The deviation seems however to be slightly greater ($\simeq \pm 5\%$) than the experimental uncertainties ($\pm 3\%$).

III.2.2 - Capture rates measurements by irradiations in PHENIX and RAPSODIE

C/E comparisons for 240 Pu and 241 Pu are presented in table V.

The discrepancies are compatible with the experimental uncertainties.

III.3 - Reaction rates ratios for transactinides

The first fission and capture measurements, performed for 238 Pu and 241 Pu, are taken into account to modify the cross

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sections of these isotopes in CARNAVAL IV. Figures 6 and 7 show the discrepancies between C IV calculations and experiments for Am 241 fission and capture rates. The capture cross section is correctly adjusted. For the fission cross section, the deviation seems to be lightly larger than the experimental accuracies.

For a first adjustment of the Pu 238 cross sections, the fission rates measurements performed at ERMINE and the irradiation of pure samples in PHENIX have been used /2/.

All these results show the coherence of the program and the complementariness of the experiments, to get an accurate definition of the cell neutron balance.

It must be mentionned that the capture results for Pu 240 and Pu 241, coming from the cell neutron balance analysis (δk^* and δB^2) and from fission rates measurements, are in very good agreement with the direct measurements performed by irradiation in PHENIX, but remain necessarily less accurate.

All the results lead to define the following accuracies for the different adjusted cross sections.

1 - σf Pu 241 better than ± 3%

2 - σf Pu 240 and σf Pu 242 ±5%

3 - σ_c Pu 240 and σ_c Pu 241 ± 5 to 10%.

These results must permit (studies in progress) to minimize the uncertainty due to the higher Plutonium isotopes to ± 0.3% $\frac{\Delta k}{K}$

IV - FISSION PRODUCTS PROGRAM RESULTS

IV.1 - Initial library

For the adjustment scheme foreseen at CEA, an original F.P. cross section library is necessary. It must be sufficient to get a correct description in energy concerning lumped fission product cross sections. Separated isotopes cross sections are

weighted by their fission effective yields. During the burn-up calculation the parameters taken into account are : fuel burn-up, cross sections, fluxes, migration in the fuel, radioactive decay.

A 188 F.P. isotopes library has been obtained with the following content :

- 24 isotopes of main importance from a common CNEN-CEA evaluation
- a complement coming from the CEA library /10/ and the Australian ona /11/.

IV.2 - Main separated isotopes capture cross sections

French measurements together with foreign (STEK, FRO, CFRMF) experiments have been used on a common analysis basis. This work results in an adjustment concerning the capture cross sections of 34 separated isotopes. In importance, they cover 90% of the global capture effect with energies well spread over the fast power interesting range.

The adjusted cross section uncertainties and their contribution to the lumped F.P. capture general uncertainty are detailed in table IV.

The gain coming from the use of PHENIX irradiation values for the accuracy and the adjustment level is given in table VI.

Uncertainties in this case are almost systematically lowered by 2 to 3%. In the case of ^{105}Pd, ^{101}Ru and ^{149}Sm the gain seems slighter only because for these isotopes there is a large number (8) of other measurements in spectra differing from that of PHENIX. The irradiation technique remains, when it is possible, the most accurate technique to reach directly the capture cross section.

IV.3 - Lumped fission products elaboration

Starting from the separated F.P. adjusted library, we calculate the cumulated yields in a model representative of

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SUPER PHENIX. We distinguish between the isotopes produced from 235U or Plutonium fission rate in order to create 2 kinds of lumped F.P. by weighting on 2 corresponding sets of yields.

These 2 lumped F.P. are available in CARNAVAL IV /2/

- one lumped F.P. from 235U fissions
- one standard lumped F.P. corresponding to the standard composition of the plutonium SUPER PHENIX fuel.

IV.4 - Global lumped F.P. capture cross section deduced from irradiated fuel measurements

To measure the F.P. global effect by comparison between fresh and irradiated fuel, it is necessary to reach a high burn-up in order to obtain a sufficient F.P. amount. Also, in the fast spectrum range, the balance between the 2 effects of F.P. and of fissile isotopes necessitate :

1) to get a high precision in the reactivity effect measurement by oscillation.

2) to measure accurately the burn-up of the main fissile isotopes during irradiation.

3) to know from chemical analysis the fresh and irradiated fuel exact composition. The masses of uranium and plutonium must be measured with an accuracy in the order of ± 0.1%.

The MINERVE experimental technique has allowed us to reach the required accuracy level concerning the oscillation methods.

The chemical analyses have been able to reach the expected levels for the uranium and plutonium mass contents into irradiated fuels.

Final uncertainties presently obtained are :

± 12% for pure 235U samples (PROFI U) that where

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hightly irradiated (about 10% burn-up) in RAPSODIE

± 16% for the PEHNIX fuels with a lower burn-up (about 3%).

The consistency of all the values obtained for these irradiated fuels is shown in the table VII where the dispersion of the calculation experiment differences is reported. On can see that :

1) For the different samples coming from the same fissile nuclide (U or Pu) :

A very good consistency for the different studied lattices.

2) A very good agreement between the results obtained separately for be fission products of 235U (PROFI U) and of Plutonium (PHENIX)

Concerning the lumped F.P. coming from the separated isotopes adjusted library, their level are comparable to these experimental values, within the error bars related to yields and cross sections for the separated F.P. library /12/.

The future completion of the irradiation program will bring us the requested accuracy i.e. 10 to 12% on the global effect of F.P. Studies are in progress on this point in order to finally fit the lumped F.P. to these experiments.

V - CONCLUSION

The program of integral experiments, performed at CEA from 1973 to 1977, have brought very large improvements to the knowledge of the burn-up problems due to the higher plutonium isotopes and fission products, now determined with the following accuracies :

1 - Reactivity : concerning SUPER PHENIX, about ± 0.3% Δk/k for the higher Plutonium isotopes ; ± 0.4% Δk/k for the fission products.

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2 - Breeding gain : the breeding gain of SUPER PHENIX is defined with an uncertainty of ± 0.03 in absolute, including the burn-up problems.

The future burn-up program at CEA is directed towards two points : to still improve the accuracies first on fission products and second on the other fuel cycle problems.

a) fission products : the efferts will be carried on in fours directions :

- new evaluations : 60 evaluated fission products (CNEN/CEA) giving ≃ 98% of the global signal.
- new yields library of other isotopes, essentially
- integral experiments of capture cross sections by irradiation in PHENIX (107 Pd, 151 Sm, 153 Eu, 143 Nd, 93 Zr) or by activation in MASURCA and ERMINE (147 Pm, 135 Cs, 155 Eu, 152 Sm).
- irradiated fuel oscillations : pure Plutonium samples coming from RAPSODIE and normal PHENIX fuel irradiated during 6 cycles.

All these measurements must lead to improve the accuracy on the lumped fission products and to reach a final uncertainty of ± 0.3% $\Delta k/k$ on the fission products effect.

b) Fuel cycle : the transactinides studies will be continued with two aims :

- evaluation of a large number of isotopes
- integral measurements of capture cross sections by irradiations in PHENIX (241 Am, 243 Am, 243 Cm, 244 Cm, ...) and by fission chambers in MASURCA and ERMINE (238 Pu, 241 Am, 242 Am, 243 Am, 245 Cm).

These measurements must improve the in core burn-up problems and lead to a better understanding of the fuel cycle out of pile problems, especially for wastes analyses.

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- R E F E R E N C E S -

/1/ J.P CHAUDAT, J.Y BARRE, A. KHAIRALLAH — Improvements of the predicted characteristics for fast power reactor from integral experiments : Cadarache Version III multigroup cross section set. Tokyo 1973 Papier A 34

/2/ J.P CHAUDAT, A. DESPRETS, G. LANGLET, A. FILIP — Formulaire CARNAVAL IV NEACRP L - 185

/3/ P. CAUMETTE, A. MEYER HEINE — Etude de milieux à neutrons rapides par la méthode de substitutions progressives. Colloque EACRP Ispra 12-14 mai 1969

/4/ P. BIOUX — Etude expérimentale des isotopes supérieurs du Plutonium dans l'assemblage couplé thermique - rapide ERMINE. Thèse de 3ème cylce - Orsay juin 1973

/5/ J. BOUCHARD Et al — Fast reactor physics at CEA : higher plutonium isotopes and burn-up studies. Tokyo 1973 - Papier B 14

/6/ H. GRUPPELAAR Et al — Evaluation, uncertainty estimation and adjustement of capture cross section for fission product nuclei. Proc. conf. "Nuclear cross sections and technology", NBS SP 425, Vol. I p. 165 Whashington D-C 1975

/7/ T.L ANDERSON — Integral measurement of fission products IAEACN 26/51 Vol. II Helsinki 15/19 juin 1970

/8/ Y.D HARKER Et al — The use of CFRMF integral data in cross section evaluations. ANS Kiameshalake septembre 1972

87120021

L. MARTIN DEIDIER — Capture des produits de fissio n dans un réacteur de puissance à neutrons rapides - Etude fondamentale et expérience préliminaire.
Thèse de 3ème cycle - Orsay - mai 1974

/10/ P. RIBON Et al — Evaluation des sections efficaces de capture et de diffusion inélastique de 26 produits de fission.
NEANDC (E) 167 L décembre 1975

/11/ J.L. COOK — Fission product cross sections
AAEC/IM 549 (1970)

/12/ G. LANGLET Et al — Uncertainties on lumped fission products for fast power reactors
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TABLE I : Separated fission products measurements : number of experiments and experimental accuracies (%)

Number of Experiments	OSCILLATIONS				ACTIVATIONS				IRRADIATIONS		Total number of Experiments
	STEK	FRO	ERMINE MASURCA		C F R M F		ERMINE		PHENIX		
	n	n	n	± ε	n	± ε	n	± ε	n	± ε	
Pd 105	5		3	10.					1	4.0	9
Ru 101	5	3		9.					1	3.3	9
Rh 103	5	3	6	8.	1	20.					15
Tc 99	5	3	6	10.	1	20.					15
Pd 107	5			17.							5
Sm 149	5	3		10.					1	3.3	9
Sm 151	5			50.					1	9.9	6
Pm 147	5	3	2	13.	1	25.					11
Mo 97	5	3		10.					1	4.4	9
Nd 145	5			13.					1	4.0	6
Cs 133	5		5	14.	1	20.			1	4.0	12
Ag 109	5		2	14.	1	20.					8
Ru 102	5	3	3	25.	1	30.	1	5.0			13
Eu 153	5		2	10.	1	20.					8
Nd 143	5			13.							5
Ru 104	5	3		17.	1	20.	2	3.3			11
Mo 95	5	3		14.					1	4.3	9
Mo 100	5			17.	1	16.	1	5.9			7
P 141	5		4	17.	1	28.	1	5.9			11
Zr 93	5			17.							5
Mo 98	5			17.	1	21.	2	3.8			8
Pd 108	5			17.			1	6.6			6
Pd 106	5			80.					1	9.0	6
Sm 147	5		4	10.							9

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- T A B L E II -

GLOBAL MEASUREMENTS OF FISSION PRODUCTS EFFECT ON IRRADIATED FUELS

	STUDIED LATTICES	IRRADIATED FUELS MEASURED	NUMBER OF OSCILLATED SAMPLES	FISSION PRODUCTS MASS IN THE SAMPLES
PRELIMINARY MEASUREMENTS	R 3	RAPSODIE	1	20 g
		RAPSODIE - AURORE	1	18 g
		RAPSODIE - FORTISSIMO	1	10 g
PRINCIPAL MEASUREMENTS	RONA 3	RAPSODIE - PROFI U	2	10 g
		PHENIX 3 cycles	2	4,5 g
	ZONA 3	RAPSODIE - PROFI U	1	10 g
		PHENIX 3 cycles	1	4,5 g
	ZONA 1	RAPSODIE - PROFI U	2	10 g
		PHENIX 3 cycles	1	4,5 g

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- T A B L E III -

CELL NEUTRON BALANCE MEASUREMENTS (δB^2 and δk^*) : COMPARISON OF EXPERIMENT AND CIV CALCULATIONS

CORE	FUEL	TYPE OF MEASUREMENTS	E - C
ZOCO 1	"H_2O" Pu	δB^2 (m^{-2})	+ 0,46 ± 0,50
	"dirty" Pu		- 0,47 ± 1,10
ZONA 2	"H_2O" Pu		- 0,35 ± 0,40
OP 50	"H_2O" Pu	δk^* (pcm)	+ 350 ± 400
OP 40	"dirty" Pu		- 10 ± 480
OP 41	"dirty" Pu		+ 350 ± 500

1 pcm = 10^{-5} $\Delta k/k$

- T A B L E IV -

IRRADIATIONS : COMPARISON OF EXPERIMENT AND CIV CALCULATIONS

EXPERIMENT	CORE	$\frac{E - C}{C}$ (%)
σ_{c0}/σ_{c8}	PHENIX	- 0,7 ± 2,9
	OSIRIS	+ 4,0 ± 6,2
σ_{c1}/σ_{c8}	PHENIX	- 2,4 ± 3,4
	OSIRIS	+ 9,0 ± 6,2

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- T A B L E V -

SEPARATED FISSION PRODUCTS : UNCERTAINTIES AFTER ADJUSTMENT

ISOTOPE	WEIGHT %	ACCURACY 2σ (%)	PART IN THE GLOBAL ACCURACY (%)
Pd 105	9.95	± 9	5.9
Ru 101	8.95	± 8	5.1
Rh 103	7.34	± 8	3.9
Tc 99	7.17	± 10	4.8
Pd 107	6.36	± 17	7.0
Sm 149	5.90	± 9	3.5
Sm 151	5.88	± 19	7.2
Pm 147	4.13	± 12	3.4
Mo 97	3.38	± 9	2.1
Nd 145	3.08	± 11	2.4
Cs 133	3.01	± 10	2.0
Ag 109	2.62	± 14	2.4
Ru 102	2.42	± 13	2.1
Eu 153	2.17	± 9	1.3
Nd 143	2.09	± 13	1.8
Ru 104	2.04	± 12	1.7
Mo 95	1.34	± 11	1.0
Mo 100	1.29	± 13	1.1
Pr 141	1.26	± 13	1.1
Zr 93	1.03	± 17	1.1
Mo 98	0.91	± 13	0.8
Pd 108	0.89	± 15	0.9
Pd 106	0.78	± 17	0.9
Sm 147	0.43	± 10	0.3
Residue	15.58	± 36	36.3

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- T A B L E V I -

SEPARATED FISSION PRODUCTS : IMPROVEMENTS DUE TO THE PHENIX IRRADIATIONS

ISOTOPE	EFFECT ON THE ADJUSTED CAPTURE CROSS SECTION (%)	ACCURACY (%)	
		WITHOUT PHENIX	WITH PHENIX
Pd 105	+ 1,0	10	9
Ru 101	- 4,4	9	8
Sm 149	- 2,7	10	9
Sm 151	- 9,3	50	19
Mo 97	+ 11,1	12	9
Nd 145	- 4,2	13	11
Cs 133	+ 6,3	14	10
Mo 95	+ 14,3	15	11
Pd 106	+ 22,7	80	17

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- TABLE VII -

GLOBAL FISSION PRODUCTS EFFECT :

DEVIATION $\frac{E - C}{C}$ (%) RELATIVE TO THE MEAN DEVIATION

ON ALL EXPERIMENTS

Irradiated fuel / CORE	PROFI U 1	PROFI U 2	PHENIX 1	PHENIX 2
RONA 3	+ 1,0 ± 16	+ 3,9 ± 15	+ 9,6 ± 19	- 2,9 ± 17
ZONA 1	- 3,4 ± 13	- 0,3 ± 12	-	- 0,8 ± 18
ZONA 3	- 1,0 ± 13	-	-	- 0,7 ± 16

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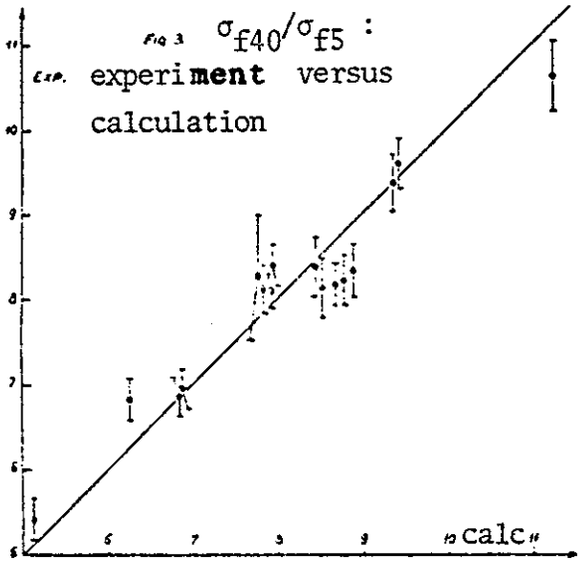

Fig 3 σ_{f40}/σ_{f5} : experiment versus calculation

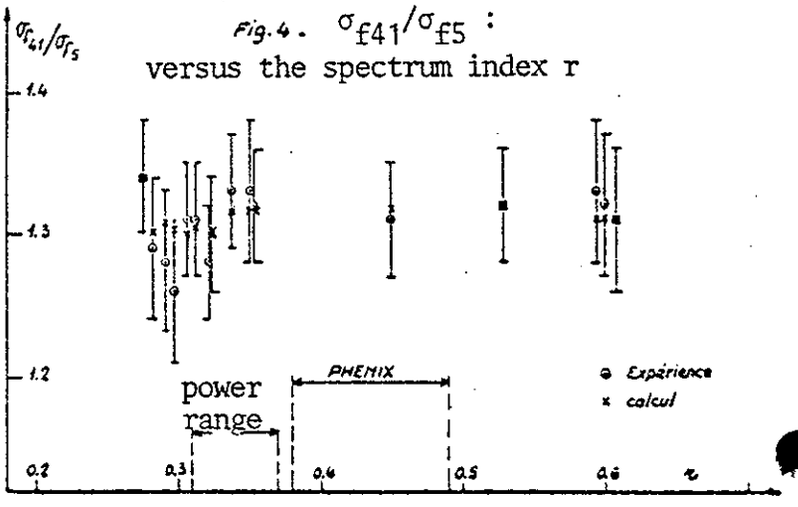

Fig. 4. σ_{f41}/σ_{f5} : versus the spectrum index r

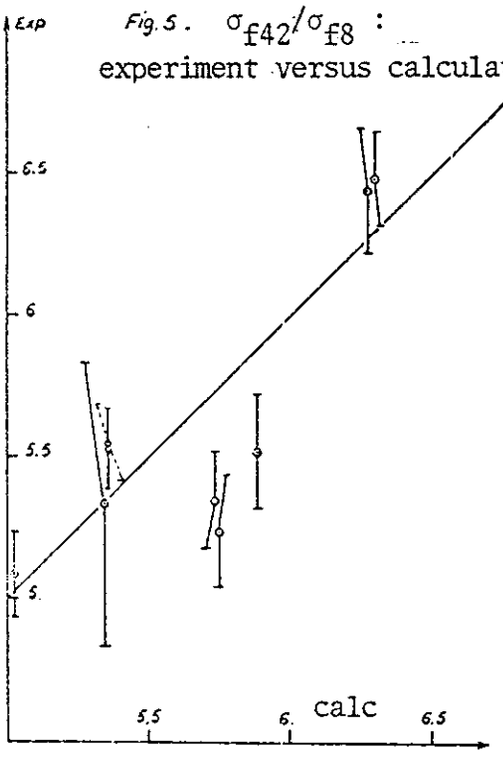

Fig. 5. σ_{f42}/σ_{f8} : experiment versus calculation

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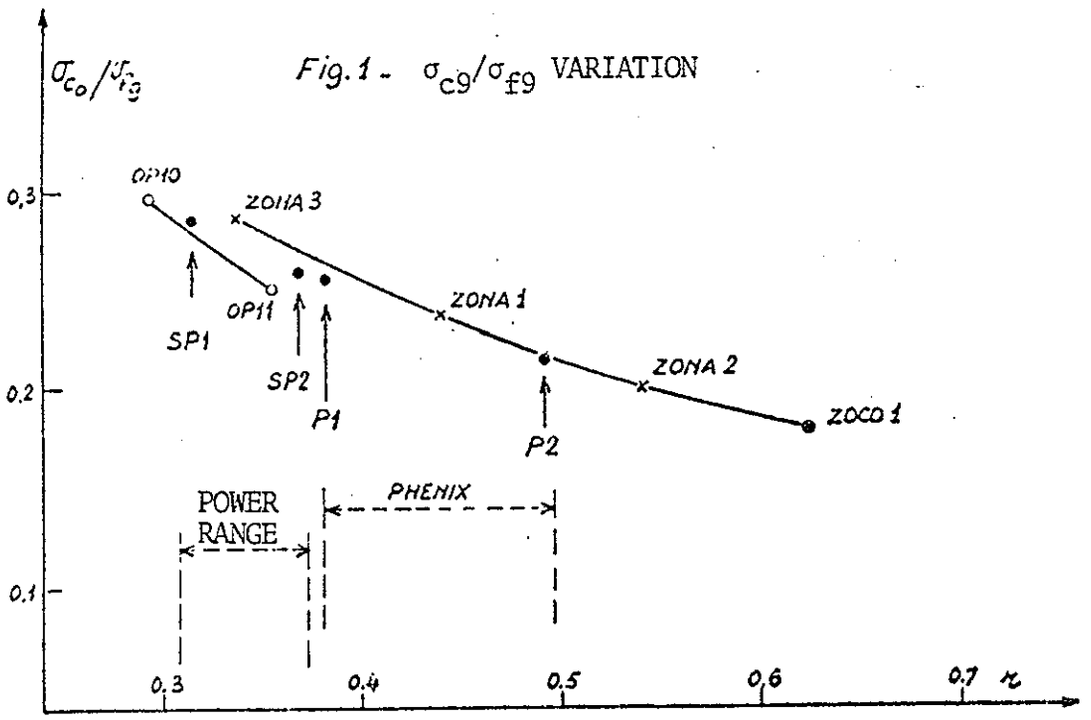

Fig. 1 - σ_{c9}/σ_{f9} VARIATION

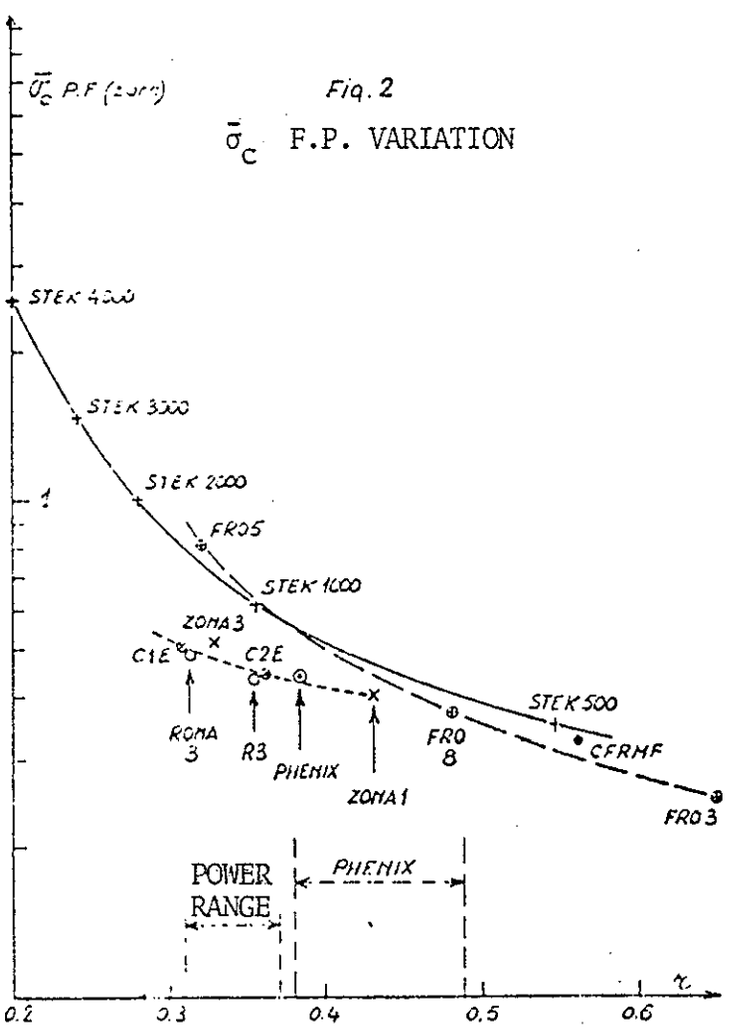

Fig. 2

$\bar{\sigma}_c$ F.P. VARIATION

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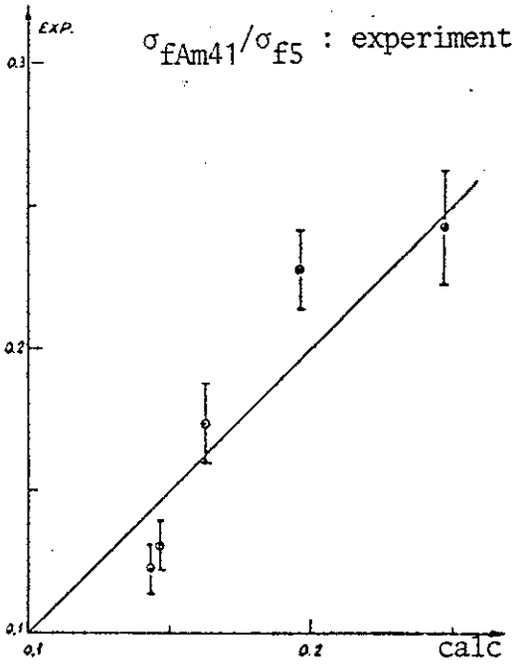
Fig. 6



$\sigma_{fAm41}/\sigma_{f5}$: experiment versus calculation

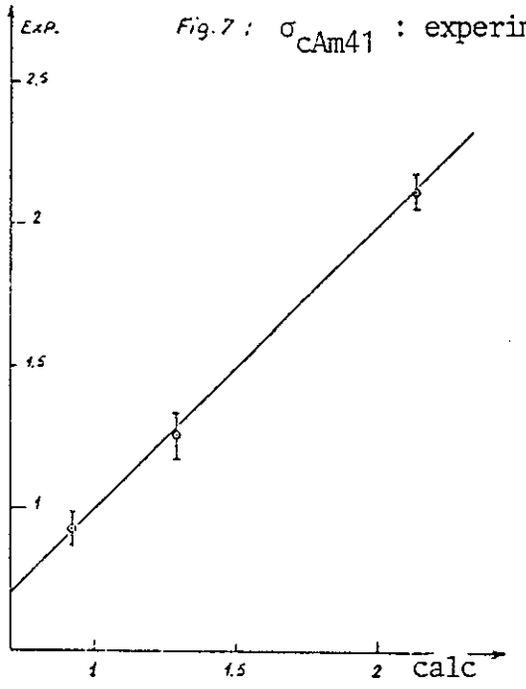


Fig. 7 : σ_{cAm41} : experiment versus calculation

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