MINOR ACTINIDES TRANSMUTATION STUDIES AT CEA: SOME REACTOR PHYSICS ASPECTS

M. SALVATORES
CEA/DRN/DER/SPRC
CEN Cadarache, **France**

AN EXAMPLE

"SELF-RECYCLING" IN A SUPERPHENIX-TYPE REACTOR (IN AN HOMOGENEOUS MODE):

- **INITIAL REACTOR LOADING FROM STANDARD-PWR PU (AT 33GWd/t), INCLUDING MINAC;**
- **SUCCESSIVE RECYCLING:**
  - **IRRADIATION CYCLE OF 960 DAYS AT NOMINAL POWER**
  - **COOLING TIME/AGEING: 1 YEAR**
  - **NO LOSSES AT REPROCESSING**

THE EQUILIBRIUM IS OBTAINED AFTER -12 CYCLES

(THE INITIAL PU LOADING IS EQUIVALENT TO WHAT WOULD COME OUT FROM THE OPERATION OF A STANDARD PWR DURING 30 YEARS).

Mass inventory of MINAC at equilibrium

Tableau 15 : Inventaire massique des actinides mineurs à l'équilibre

g/t heavy met. g/tHL	^{237}Np	^{241}Am	^{242m}Am	^{243}Am	^{243}Cm	^{244}Cm	^{245}Cm
Initial fuel Combustible initial	9300	8000	7.2	2100	-	54	26
Equilibrium fuel Combustible équilibre	720	2500	290	1900	50	2100	440

BASIC DATA

INTEGRAL EXPERIMENTS

CORE AND FUEL CYCLE STUDIES

BASIC DATA

1- THE **JEF-2** DATA BASE **IS AVAILABLE** (February **1990**)
MINAC NEUTRON DATA MOSTLY FROM **JEF-1.**

2 - VALIDATION : **CADARACHE**
KfK
SATISFACTORY RESULTS

3 - NEW AND WIDER BENCHMARKING UNDERWAY

4 - DATA/VALIDATION (PARTLY) MISSING UP-TO-NOW :

- RESONANCE SELF-SHIELDING
- DELAYED NEUTRON DATA
- DECAY HEAT RELATED DATA
- COVARIANCES
- PHOTON PRODUCTION DATA

INTEGRAL EXPERIMENTS AT CEA

IRRADIATED FUEL EXPERIMENTS :

a) **FBR** SPECTRA **(PHENIX) :**

- SEPARATE ISOTOPE SAMPLES IRRADIATION **(PROFIL-I AND PROFIL-II)**
- **SPECIAL FUEL** PINS IRRADIATION **(TRAPU)**
- **ACTINIDE** PINS IRRADIATION **(SUPERFACT)**

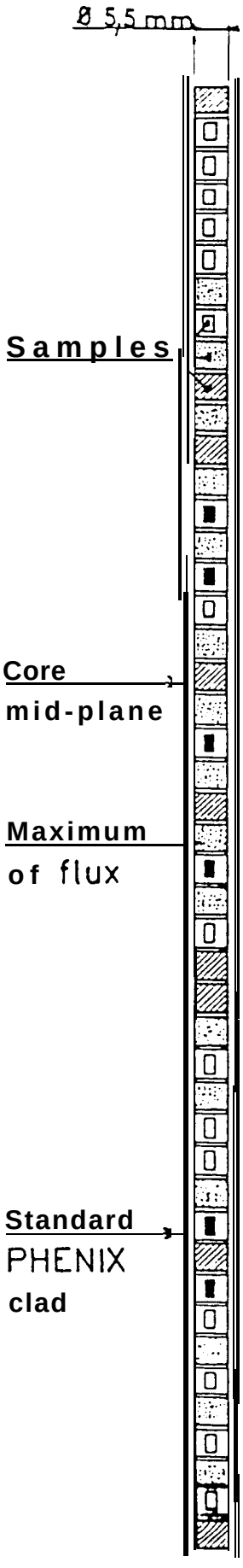
b) **LWR** SPECTRA **(MELUSINE)**

- SHERWOOD *(5 x 5* SQUARE **LATTICE** WITH STANDARD 17 x 17 **PWR** FUEL)
  CENTRAL PIN WITH UO_2 PELLETS, DOPED WITH **MINAC**

- ANALYSIS OF IRRADIATED FUEL IN STANDARD **PWRs** (WITH VARYING BURN-UP), AND IN PWR WITH **MOX** RECYCLING

Fig. 2

Scheme of a PROFIL pin irradiation in PHENIX



Position (mm)	Isotope	Chemical form	Mass (mg)
180	U235	uO_2	22
170	Nd145	Nd_2O_3	22
160	Pd105	Pd	21,7
150	Cs133	Cs F	23,4
140	Ru101	Ru	19,6
130	M095	Mo	21,5
120	Pu238	PuO_2	14
110	Mo97	Mo	21,7
100	Pu 239	PuO_2	~10
90	u 235	uO_2	22,5
80	Am241	AmO_2	10,0
70	U238	uO_2	22,3
60	Pu240	PuO_2	3,7
50	Li nat.	Li F	3,8
40	Pu 242	PuO_2	29
30	B nat.	B"	1,1
20	5mU9	Sm_2O_3	25,8
10	Pu 241	PuO_2	4,3
0	U 235	uO_2	24,1
-10	Pu 239	PuO_2	~10
-20	B nat.	B	1,0
-30	Pu240	PuO_2	6
-40	U238	UO_2	23
-50	Pu241	PuO_2	5
-60	Li nat.	Li F	3,7
-70	Pu239	PuO_2	~10
-80	Ru101	Ru	20
-90	U235	UO_2	23,9
-100	U238	UO_2	23,7
-110	Pu240	PuO_2	6,3
-120	Cs133	Cs F	22,4
-130	Pu 242	PuO_2	27
-140	Mo 95	Mo	21,9
-150	Pd 105	Pd	20
-160	Pu 241	PuO*	12,5
-170	B nat.	B	1,3
-180	U 235	uO_2	24,5
-190	Li nat.	Li F	4,2
-200	Ru 101	Ru	19
-210	Pu 242	PuO_2	25
-220	Nd 145	Nd_2O_3	20,2
-230	Pu 238	PuO_2	12,6
-240	Mo 97	-MO	19,7
-250	Am 241	AmO_2	13,7
-260	Sm 149	Sm_2O_3	22,7
-270	U 235	UO_2	25

Plutonium and Américium

References

Uranium

Fission products

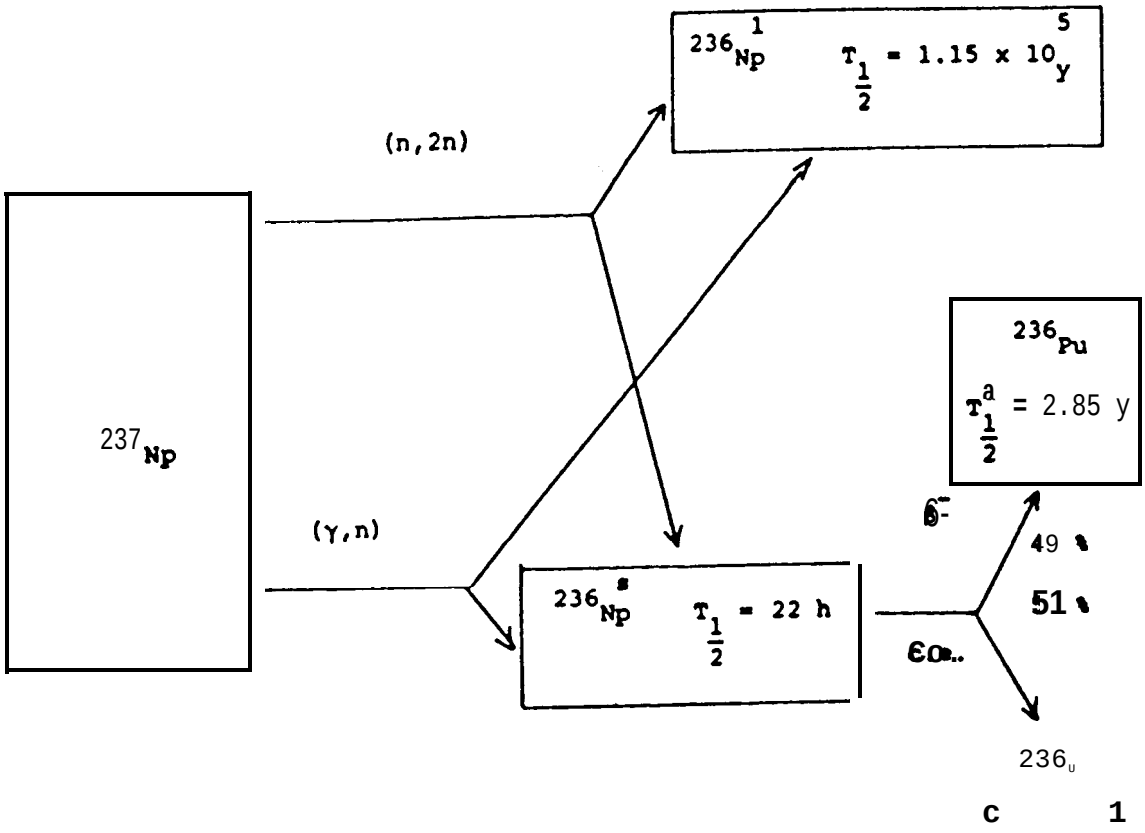
TABLE V

C/E values with JEF-1 data on ^{237}Np reaction rates, obtained from ^{237}Np sample analysis after irradiation in the PHENIX core.

Reaction	C/E
σ_c ^{237}Np	0.90 ± 0.05
$\sigma_{n,2n}$ ^{237}Np	1.19 ± 0.15 (a)

(a) This results is associated to a specific branching ratio of the reaction ^{237}Np —(n,2n)→ ^{236}Np(long lived) / ^{236}Np (short lived) consistent with GARDNER and, GARDNER evaluation.

FIGURE 5



DECAY SCHEME RELATED TO

$^{237}Np(n,2n)$ and (γ,n)

TABLE I
ISOTOPIC COMPOSITION OF THE THREE TRAPU FUEL PINS

Experiment	% Pu isotope composition				
	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
TRAPU- 1	0.1	73.3	21.9	4.0	0.7
TRAPU-2	0.8	71.4	18.5	7.4	1.9
TRAPU-3	0.2	34.0	49.4	10.0	6.4

TABLE II
SEPARATE ISOTOPES IRRADIATION IN PROFIL EXPERIMENTS

Experiment	Th	U	Np	Pu	Am	Cm
PROF I L-1		235 238		238 239 240 241 242	241	
PROFIL-2	232	233 234 23S 238	237	238 239 240 242	241 243	244

TABLE 3

C/E VALUES FOR THE PROFIL EXPERIMENTS USING JEF-1 DATA

DATA TYPE (A)	C/E WITH JEF-1
	AVERAGE VALUE (PROFIL-1+PROFIL-2)
$\sigma_c(^{235}U)$	**0.97 ± 1.4%**
$\sigma_c(^{238}U)$	**0.96 ± 1.6%**
$\sigma_c(^{237}Np)$	**0.90 ± 4.1%**
$a_{n,2n}(^{237}Np)$	1.19 ± 15 %
$\sigma_c(^{238}Pu)$	**0.95 ± 3 %**
$\sigma_c(^{239}Pu)$	**0.97 ± 1.8%**
$\sigma_{n,2n}(^{239}Pu)$	**1.38** ± 11%
$\sigma_c(^{240}Pu)$	1.06 ± 1.6%
$\sigma_{n,2n}(^{240}Pu)$	0.83 ± 14 %
$\sigma_c(^{241}Pu)$	1.11 ± 3.7%
$\sigma_c(^{242}Pu)$	1.16 ± 3.5%
$\sigma_c(^{241}Am)$	1,03 ± 1.4%
$\sigma_c(^{243}Am)$	0.94 ± 5 %
$\sigma_{tot}(^{10}B)$	

(A) All the results are average reaction rate ratios ("spectral indices") **related to the ^{235}U fission rate.**

TABLE IV

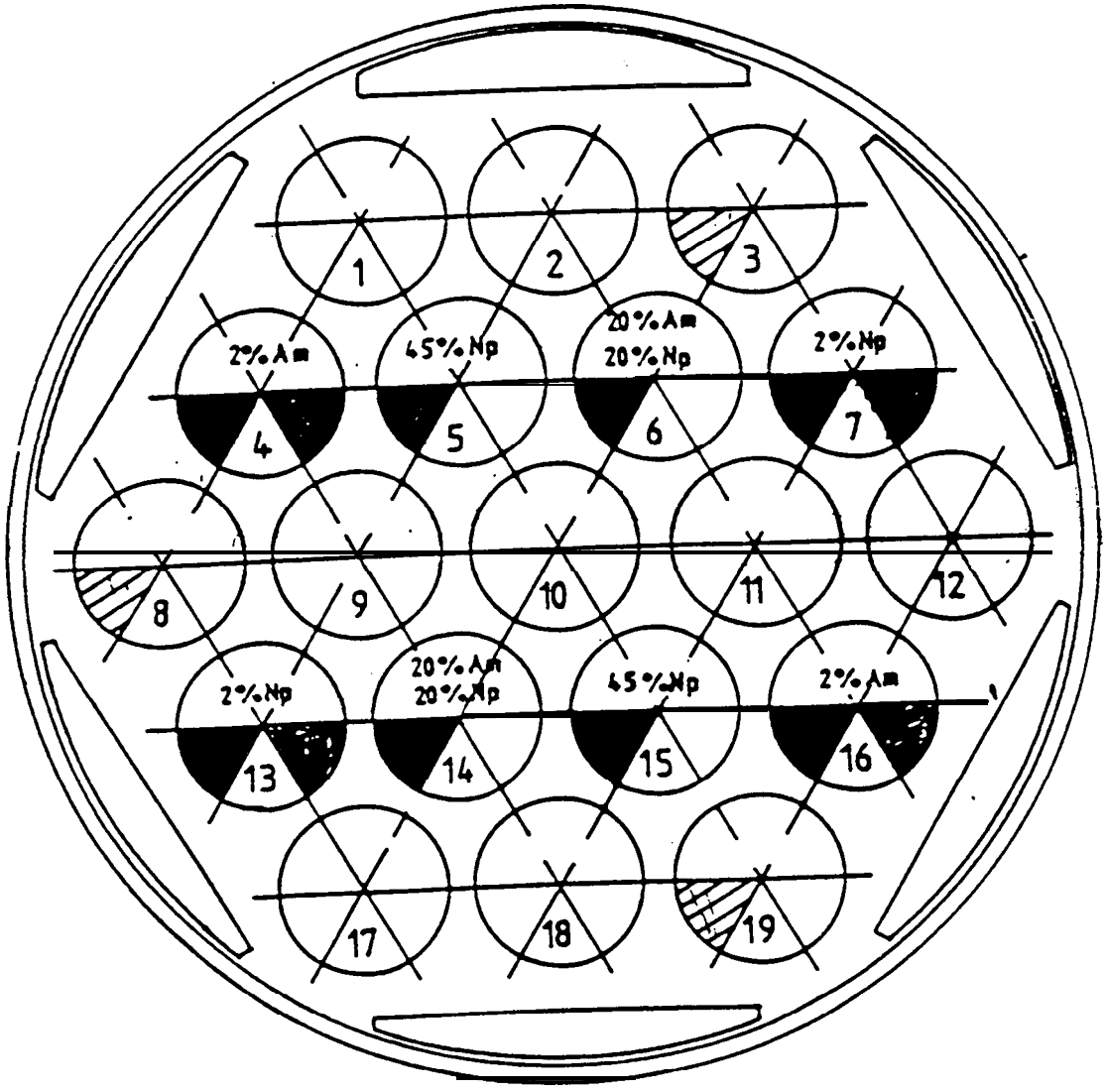
C/E **VALUES ON** FINAL (END **OF IRRADIATION) COMPOSITIONS IN** THE **TRAPU** EXPERIMENTS **(PERCENTAGE VALUES)** USING **JEF-1** DATA

^{238}U=100	TRAPU-1	TRAPU-2	TRAPU-3
^{234}U	0.98 ± 2.5%	1.00 ± 1.3%	1.04 ± 1.0%
^{235}U	0.99 ± 0.3%	1.01 ± 0.2%	1.01 ± 0.2%
^{236}U	0.98 ± 0.5%	1.00 ± 0.4%	0.99 ± 0.3%
^{237}Np	0.91 ± 6.82	0.90 ± 3.3%	0.85 ± 3.2X
^{238}Pu	1.02 ± 0.92	1.00 ± 0.4%	0.99 ± 0.4%
^{239}Pu	1.00 ± 0.4%	0.98 ± 0.3%	0.98 * 0.3%
^{240}Pu	0.99 ± 0.42	0.98 ± 0,3%	0.98 ± 0.3%
^{241}Pu	1.03 ± 0.4%	1.00 ± 0.3%	1.02 ± 0.3%
^{242}Pu	1.08 ± 0.5%	1.03 ± 0.42	1.01 * 0.3%
^{241}Am	0.95 ± 3.02	0.96 ± 3.6%	0.97 ± 2.12
^{242}Am	1.36 ± 3.6%	1.41 ± 4.0%	1.36 ± 2.5X
^{243}Am	1.08 ± 3.6%	1.05 i 4.0%	1.08 ± 2.5%
^{242}Cm	0.96 ± 2.42	0.95 ± 2.62	0.94 ± 2.1%
^{243}Cm	—	1.13 ± 2.7%	1.13 ± 2.6%
^{244}Cm	1.03 ± 2.02	1.15 * 2.2%	1.16 ± 1.7%′

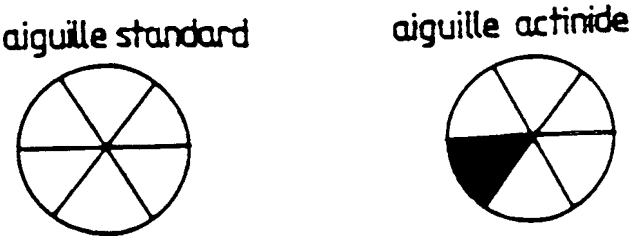
SUPERFACT 1

CAPSULE EXPERIMENTALE **PHENIX**

REPARTITION DES AIGUILLES



VUE de DESSUS



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Reaction Rate	Experimental value normalized to the ^{235}U fission reaction rate
^{235}U Absorption	1.233 ± 0.017
^{235}U Capture	0.233 ± 0.003
^{238}U Capture	0.01917 ± 0.00014
^{239}Pu capture	1.508 ± 0.010
^{240}Pu Capture	5.100 ± 0.075
^{241}Pu Capture	1.022 ± 0.029
^{242}Pu Capture	0.604 ± 0.016
^{241}Am capture	3.18s ± 0.065
^{243}Am Capture	1.248 ± 0.025
^{244}Cm Capture	0.316 ± 0.015

TABLE VI

SHERWOOD EXPERIMENT

Initial enrichment

Burn-up

	enrichissement Initial	Domaine de taux d combustion
REP standard PWR	2.1% 2.6% et 3.1%	===> 33 GWj/t GWd/t
hauts taux de combustion	3.1%	===> 58 GWj/t
Enrichissement initial élevé	4.5%	===> 45 GWj/t

HIGH BURN-UP

HIGH ENRICHMENT

PLAGES D'ENRICHISSEMENT INITIAL

ET DE TAUX DE COMBUSTION ET UDIES

LWR irradiated fuel analysis

c) HCLWR SPECTRA (MELUSINE)

- **ICARE** EXPERIMENTS:

  TWO EXPERIMENTAL PINS WITH UO_2 PELLETS, DOPED WITH **MINAC, AT THE CENTER OF 261 PIN LATTICE** OF **MOX FUEL (8,5% ENRICHMENT)**

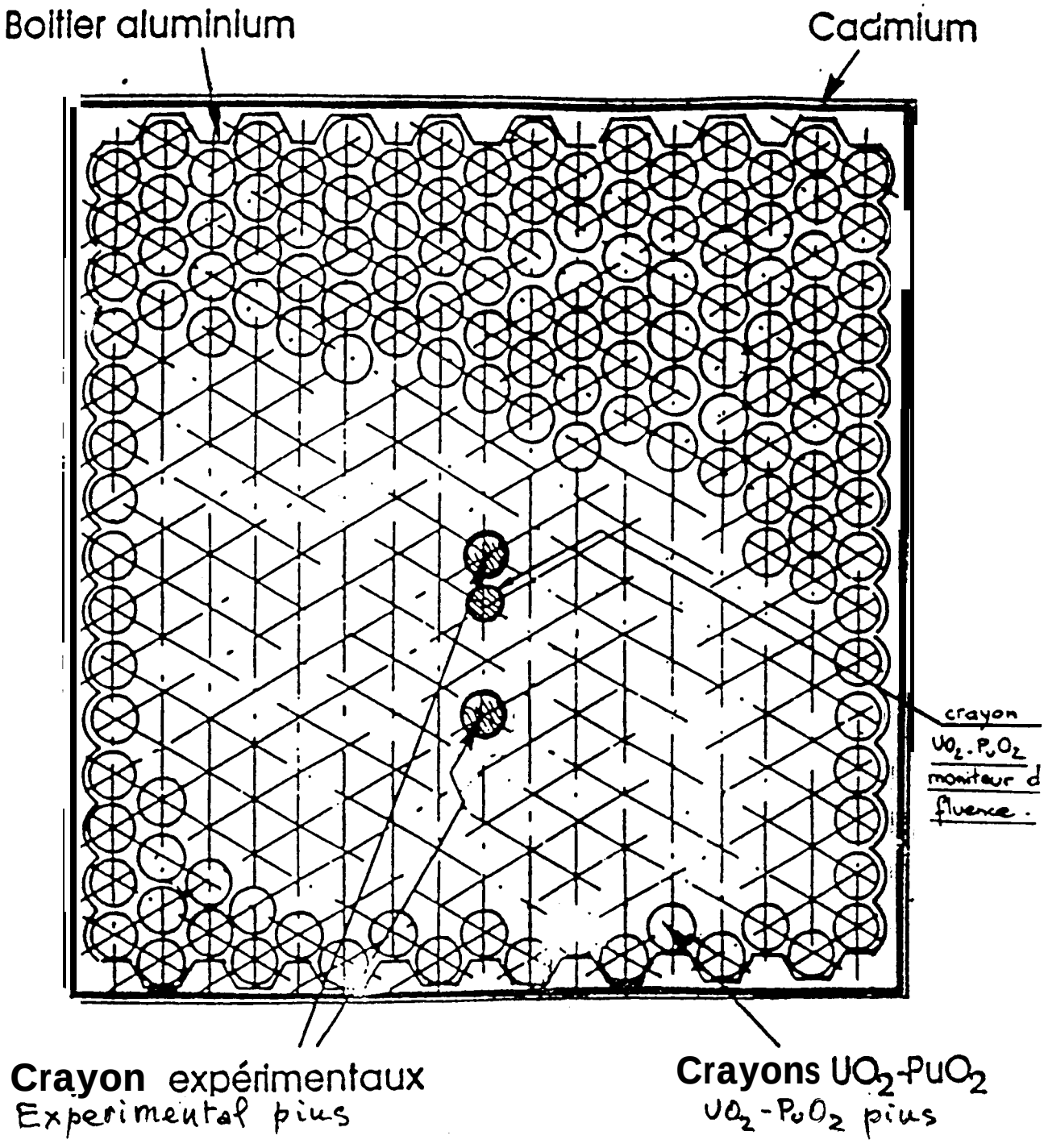
- TWO VALUES OF THE **Vm/Vf** RATIO HAVE BEEN STUDIED : V_m/V_f = **0.5** and 0.9

  (THESE EXPERIMENTS ARE CONSISTENT WITH THE CRITICAL EXPERIMENT PROGRAM **ERASME, PERFORMED IN THE** CRITICAL FACILITY **EOLE** AT CADARACHE)

"ICARE" Experiment (HCLWR lattice)

ASSEMBLAGE ICARE

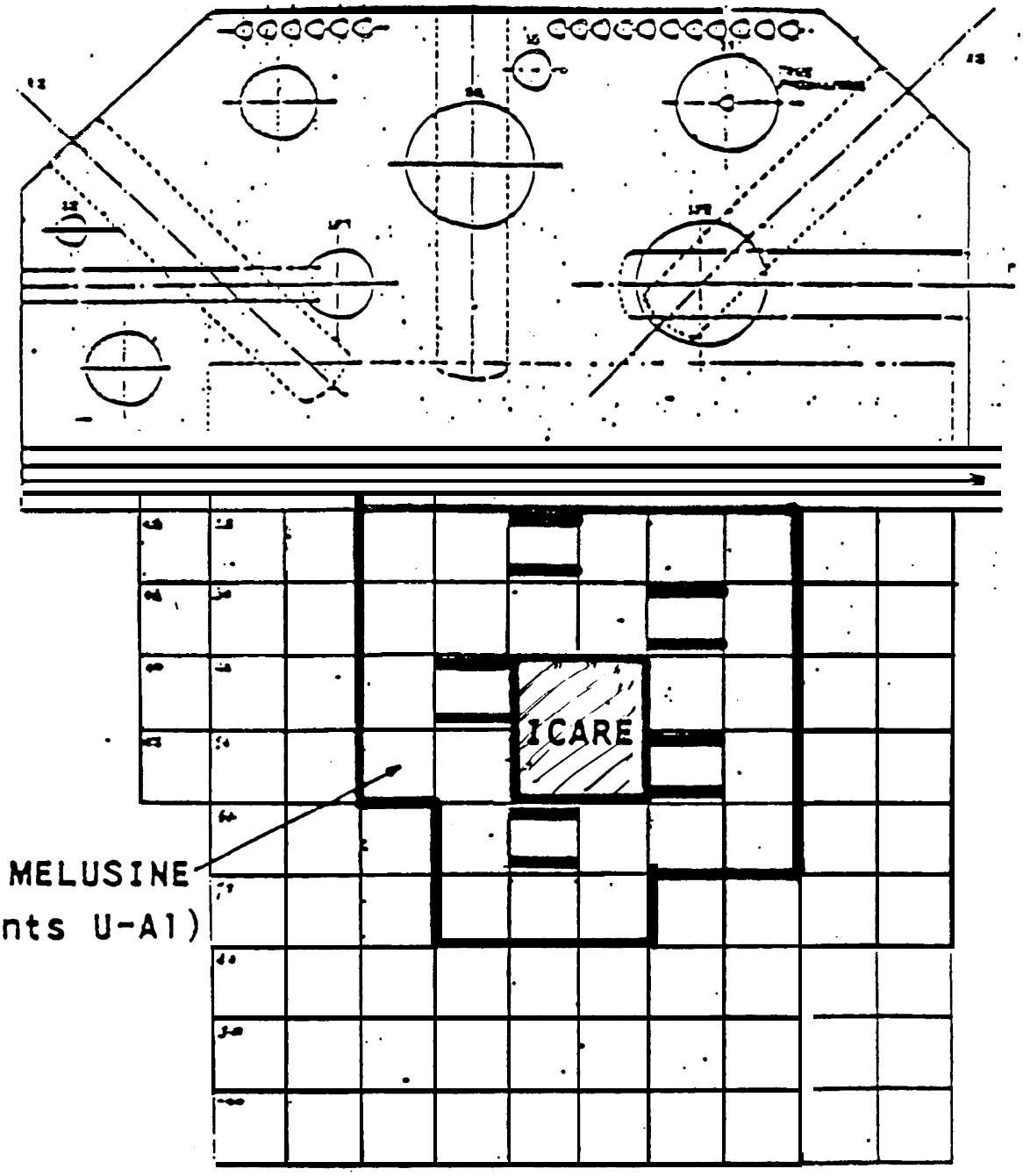
263 CRAYONS UO_2 - PuO_2 (8.5% enrich.)



Assemblage DE SECTION CARREE 150 x 150 mm²
OCCUPANT LA PLACE DE 4 ELEMENTS MELUSINE

FIGURE 6

IRRADI AT ION ICARE DANS MELUSINE



ur MELUSINE
éments U-Al)

Puissance MELUSINE : 8 MWTh

Puissance 1 inéique I CARE : 45 W/cm

Taux de combustion ICARE : 270 MWJ/t par moi

CRITICAL EXPERIMENTS

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FISSION CHAMBER MEASUREMENTS OF :

F (Np-237)

F (Am-241)

F (Am-243)

F (Cm-244)

F **(Pu-238)**

AND OTHER **Pu** ISOTOPES

A **VARIETY OF CRITICAL CONFIGURATIONS:**

FBR SPECTRA IN **MASURCA**

LWR SPECTRA IN **EOLE**

* The BALZAC experiment in MASURCA: measurement of "reactivity/atom" of minor Pu isotopes and Am-241.

CORE NEUTRONICS AND FUEL CYCLE STUDIES

- STRATEGY STUDIES (COSI CODE)
- RADIOTOXICITY IN DIFFERENT SCENARIOS
- FBR CORE STUDIES FOR TRANSMUTATION (ALSO ADVANCED LWRs) ⇒ HOW FAST AN EQUILIBRIUM (Np, Am) IS REACHED
- DESIGN PARAMETERS UNCERTAINTY STUDIES IN FBRs:

  - N_2 VOID COEFFICIENT
  - DOPPLER
  - Δq/CYCLE (IBG)

- WHAT ARE THE DESIGNS FOR AN "OPTIMUM" BURNING STRATEGY

  e.g. ⇒ "OUT OF CORE" POSITIONS IN AN LMFBR

  ⇒ IF HOMOGENEOUS RECYCLING, WHAT INTERNAL BREEDING GAIN (IBG) SHOULD BE ADOPTED