



# Why a fast flux for a research reactor ?

## The Phenix experimental program

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# EXPERIMENTAL CONDITIONS AT PHENIX



## COMPARISON OF NEUTRON FLUX

		Fast flux (n/cm <sup>2</sup> .s)	Thermal flux (n/cm <sup>2</sup> .s)	Dose rate
PWR power reactor		1.3.10 <sup>14</sup>	0.9.10 <sup>14</sup>	2 dpa/year
OSIRIS, HFR, BR2 type research reactor ...		2 to 4.10 <sup>14</sup>	4 à 7.10 <sup>14</sup>	3 dpa/year
Phénix reactor	Fast spectrum	4.4.10 <sup>15</sup>		18 dpa/ 6-month cycle



Neutron Flux in a fast reactor increases test efficiency.



# EXPERIMENTAL CONDITIONS AT PHENIX

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## TEMPERATURE

**Core inlet/outlet: 380/550°C**



## MEASUREMENTS

**S/A inlet/outlet T°: 380/550°C**

**Sodium sampling at S/A outlet**

**Argon gas blanket analysis**

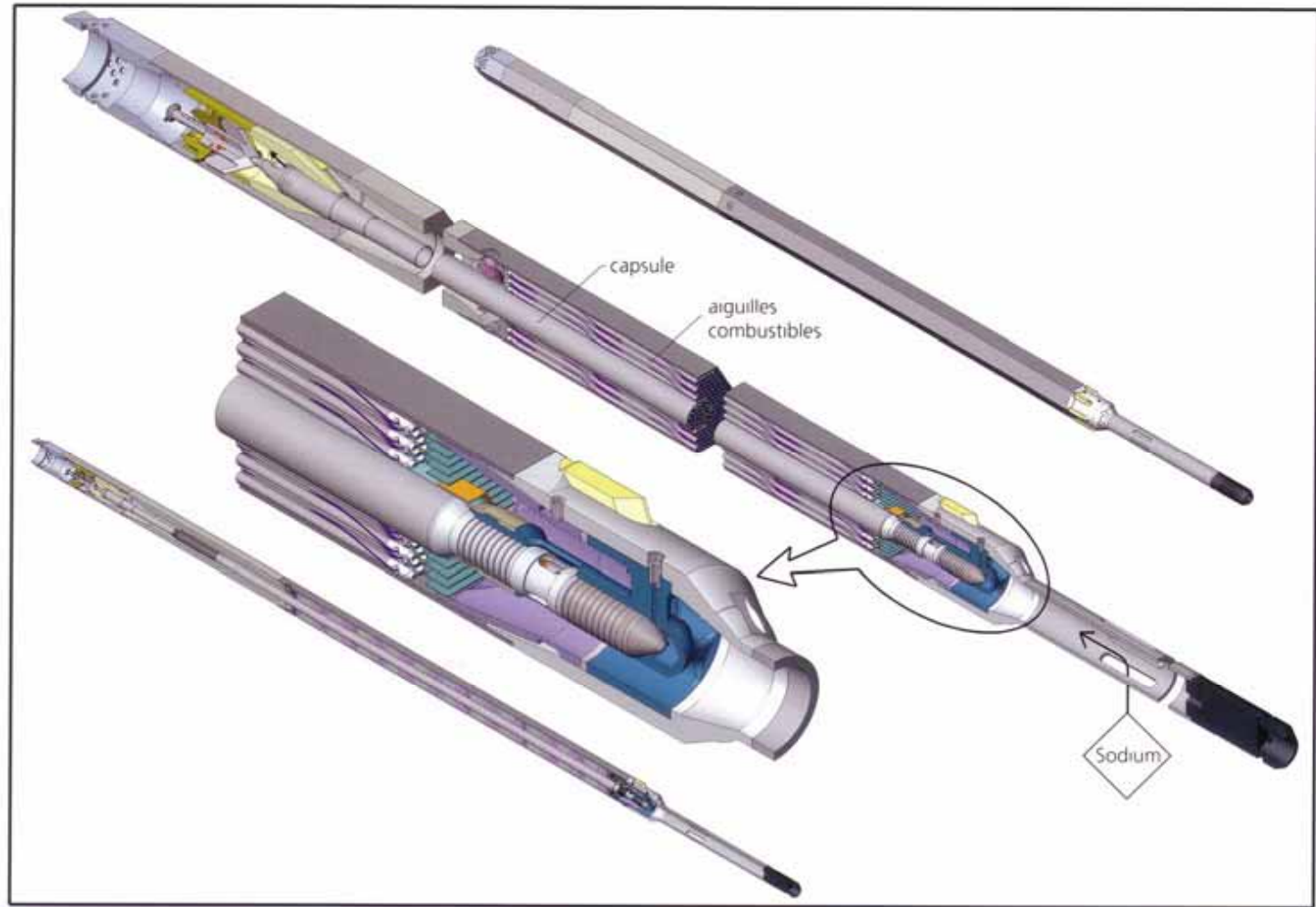
**Failure pin location  
system**



# EXPERIMENTAL CONDITIONS AT PHENIX



## EXPERIMENTAL RIG AND CARRIER





# NON DESTRUCTIVE EXAMINATION at PHENIX HOT CELLS

# PHENIX HOT CELLS



The hot cells of PHENIX are directly connected to the external fuel storage drum where irradiated assemblies decay after their discharge from the reactor.

## Purposes of the hot cells

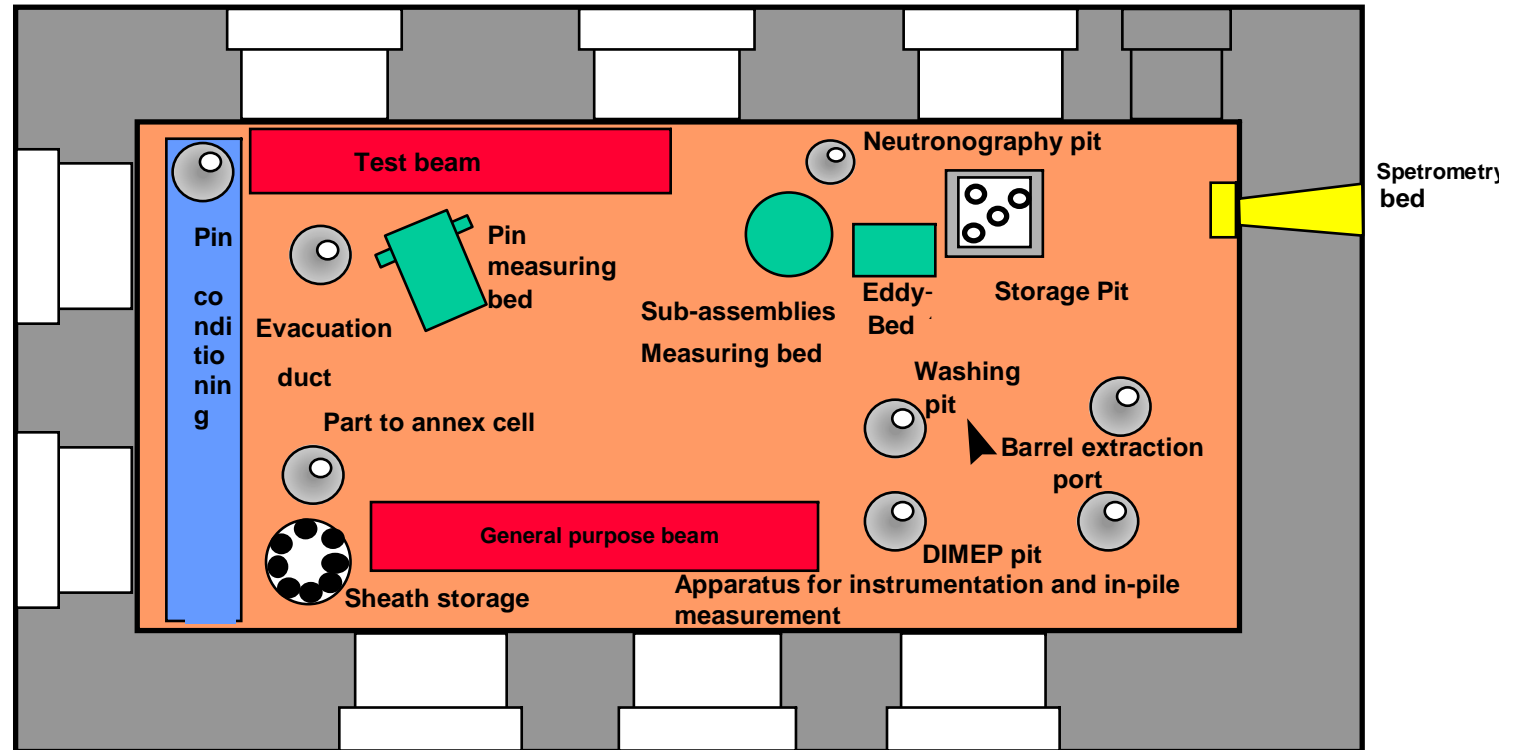
- Dismantling of spent subassemblies and rigs :
- Non destructive test subassemblies and pins after dismantling.
  - subassemblies and pin deformations (visual inspection and profilometry),
  - eddy currents,
  - neutronography,
  - gamma spectrometry.

quick results can be obtained on the subassemblies and pins behaviour (less than 6 months after discharge from the core).

- Pins failure identification.
- Remanufacture of new rigs with irradiated pins.



# IRRADIATED ELEMENT CELL



Dimensions : 14 m length – 6,5 width – 9 m height :  $\cong 800 \text{ m}^3$

Atmosphere : nitrogene < 2 %  $\text{O}_2$ .

1 300 subassemblies dismantled

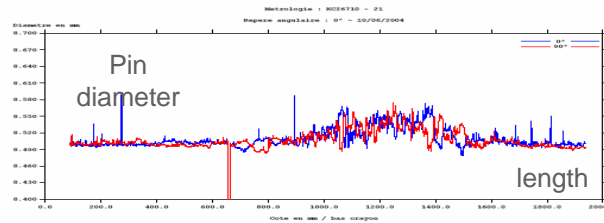
Few hundred examinations



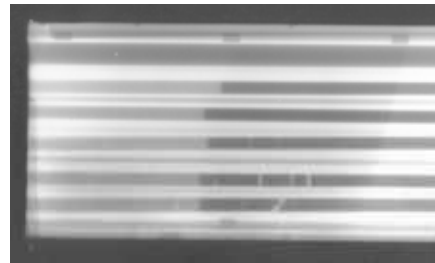
# NON-DESTRUCTIVE TESTING



Pin diameter measurement by LASER technic

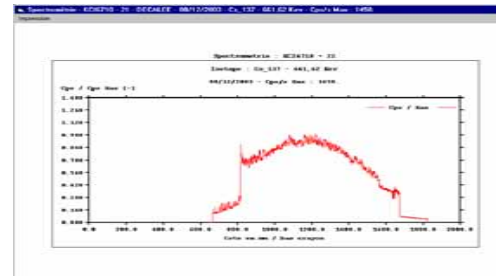


Neutronography

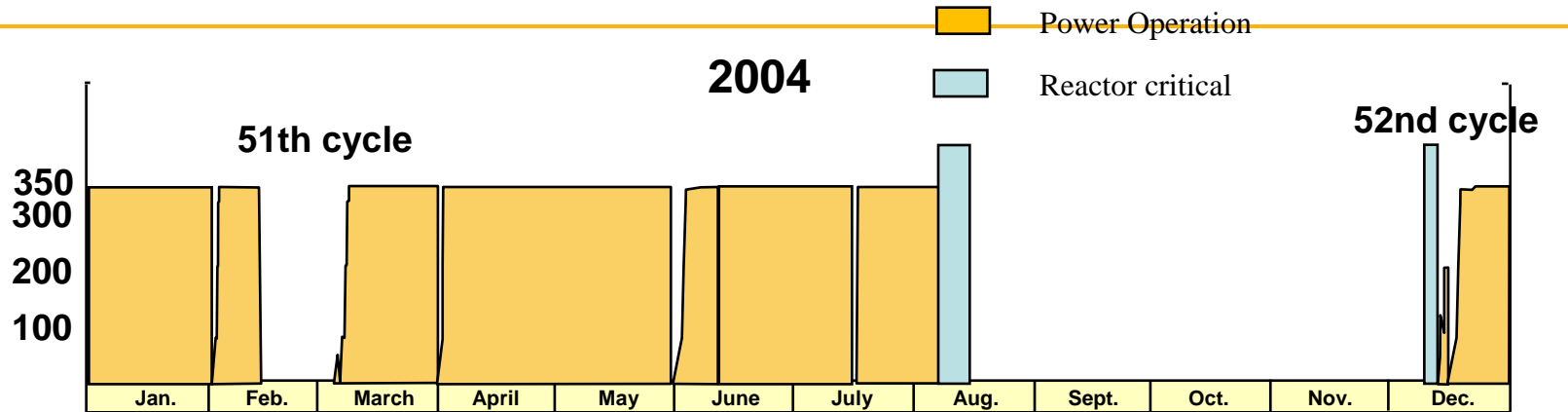


Tir N°760,  
Nimphe 2,  
KCI 6710, 04-12-03

Gamma spectrometry



# 2004 OPERATION DIAGRAM



**14th Feb. to 6th March**

**Planned shut-down for refuelling and maintenance. The experiment MATINA 1A was removed.**

**8th of Aug.**

**End of 51st cycle (131 EFPD)**

**From mid August to November**

**Planned shutdown for maintenance, control and refuelling; removal of the experiment METAPHIX.**

**15th of Dec.**

**Connection to the grid**

**in 2004**

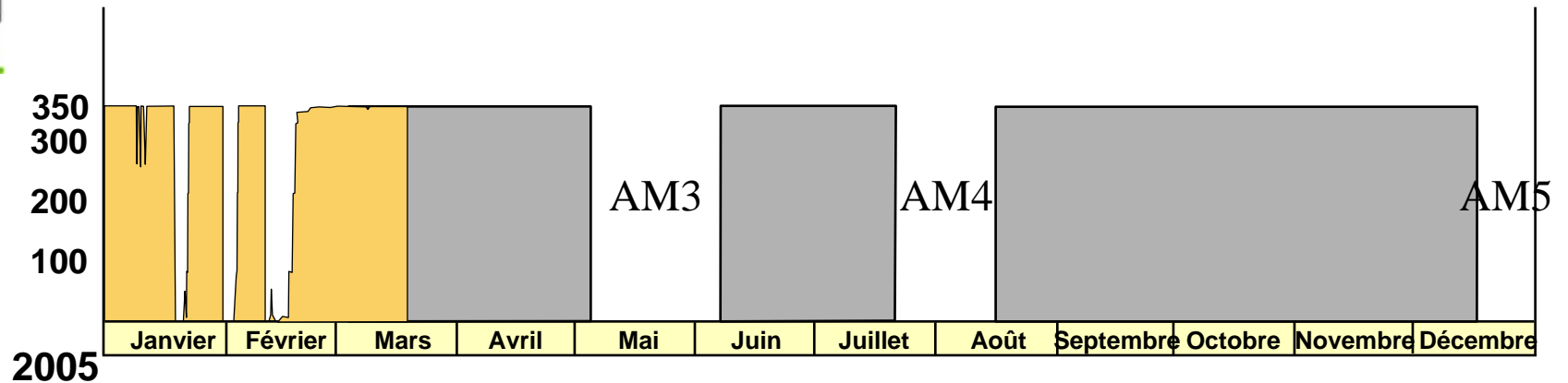
**Nb of days of operation: 202**

**Availability factor: 73.6 %**

**Net electricity production : 626 Gwh electric**



# 2005 OPERATION DIAGRAM



- Power Operation
- Reactor critical
- Planned operation

**3 Planned shut-down for refuelling and maintenance**

**Reactor fortuitous shutdowns:**

**19 Jan: feedwater leak**

**30 Jan: secondary pump trip**

**6 Feb :power trip treshhold setting**

**19 March: loss of compressed air circuit**

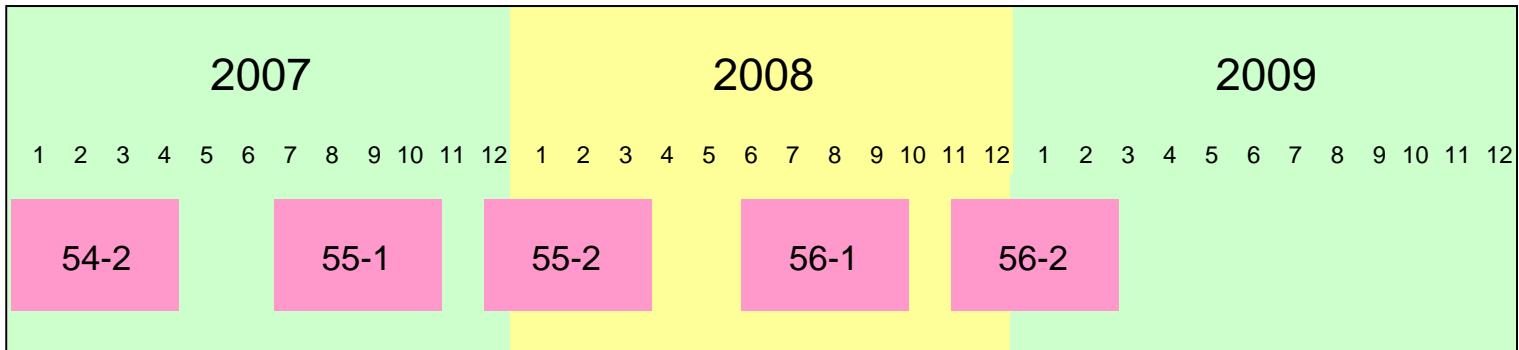
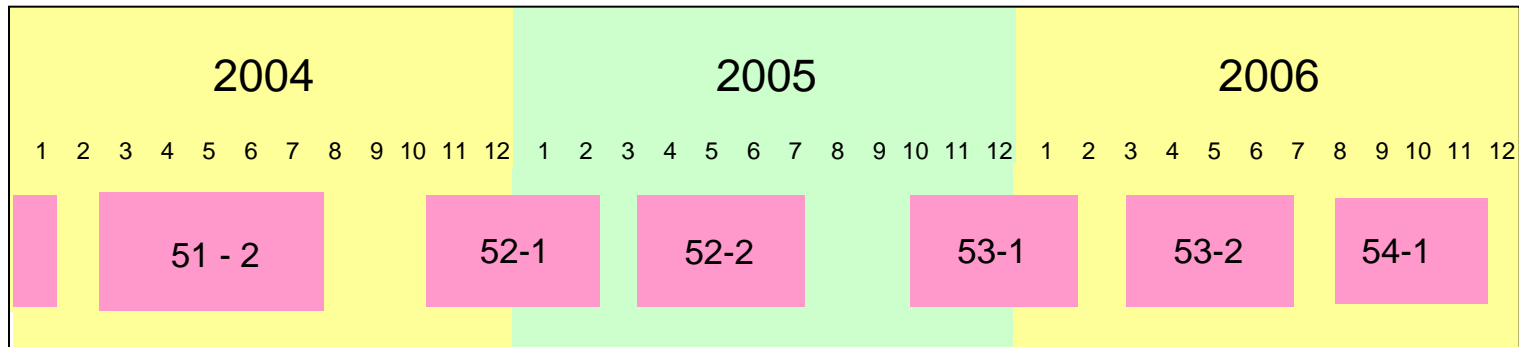
**in 2005 EFPD : 51**  
**Availability factor: 80 %**



# FUTURE OPERATION of the PLANT



5 cycles of 120 EFPD  
equivalent to about 4.5 years of operation



80% Load factor



# PHENIX EXPERIMENTAL IRRADIATION PROGRAMME



## GENERAL IRRADIATION DATA ACQUISITION

- ☐ Neutronic data (cross sections of MA and FP)
- ☐ Structural material testing

**PROFIL R – M**

**MATRIX**



## TRANSMUTATION TESTS

- ☐ **Fuel irradiation for homogeneous mode**
- ☐ **Target irradiation for heterogeneous mode**
  - ☐ Constituent materials (Inert matrices, moderators)
  - ☐ Irradiation of actinide-based compounds (Americium)
  - ☐ Irradiation of targets containing long-lived fission products (Technetium 99) -
- ☐ **Fuel irradiation for future systems**
  - ☐ Fuels with high minor actinide compound.

**METAPHIX**

**MATINA 1A / 2-3**

**ECRIX**

**CAMIX-COCHIX**

**ANTICORP**

**FUTURIX**



## OTHERS EXPERIMENTS

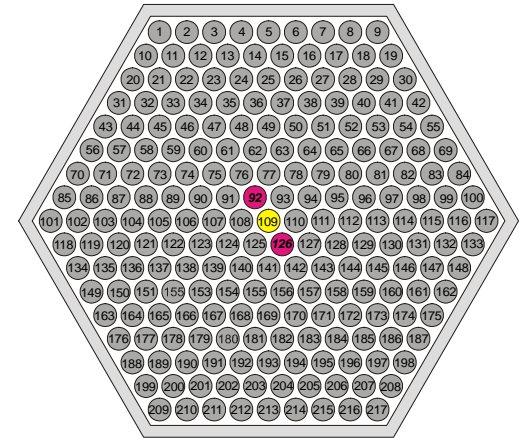
- ☐ **Irradiation of high Pu content fuel**

**CAPRIX**

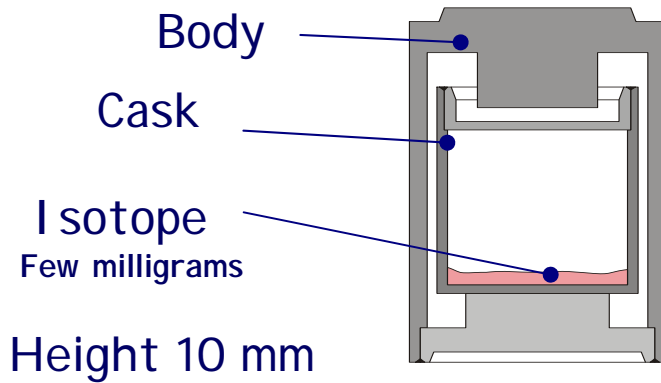
# PROFIL-R SUB-ASSEMBLY



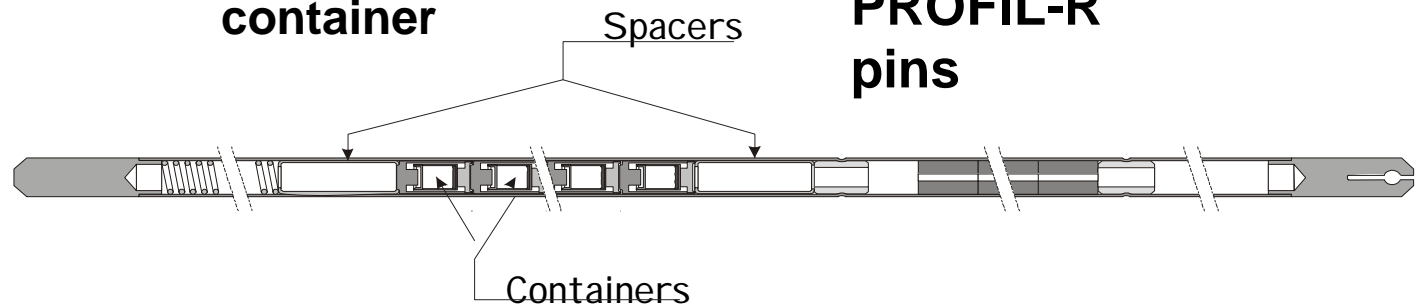
Measurement of MA and LLFP cross sections in fast (PROFIL-R) and moderated (PROFIL-M) neutron flux



- Profil-R pins
- Reference standard pin



**PROFIL-R container**



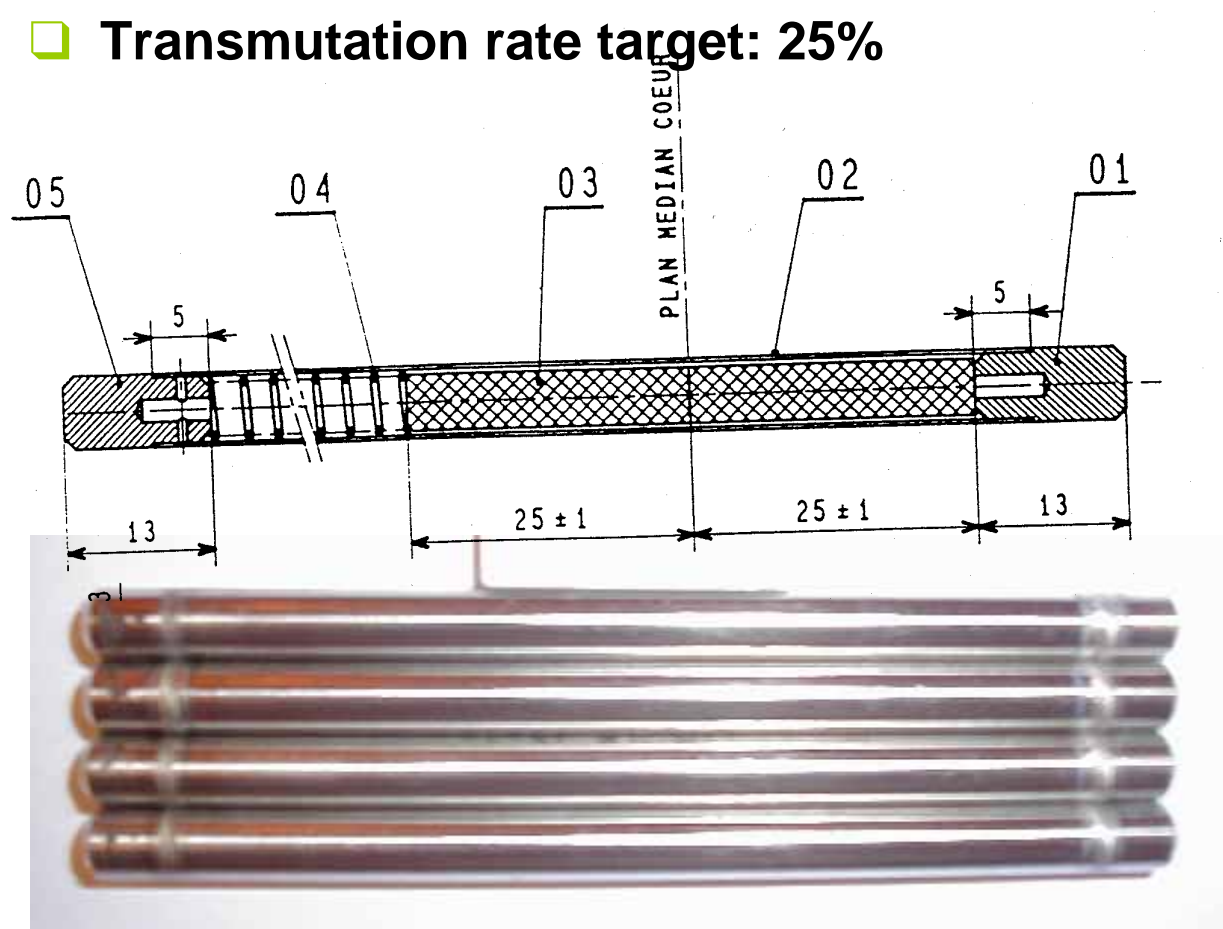
**PROFIL-R pins**



# LLFP TRANSMUTATION: ANTICORP 1



- ❑ Capsule: 3 pins with two pieces of  $^{99}\text{Tc}$  metal
- ❑ Moderator carrier
- ❑ Transmutation rate target: 25%



# ECRIX EXPERIMENTS: OBJECTIVES



**First experiment of Am transmutation in specific target in a fast reactor**

**Testing two concepts of « once trough » transmutation by using local moderation spectrum:**

1.  $^{11}\text{B}_4\text{C}$  : ECRIX-B
  2.  $\text{CaH}_2$  : ECRIX-H
- Transmutation rate objectives 80 – 90 %



**Development of fabrication and characterisation techniques**

1. Fuel fabrication process (metallurgy powder) which can be applied to the industrial scale (Fabrication of 100 pellets)
2. Property measurements\*

**Irradiation started at Phenix in 2003.**

**\* Collaboration with ITU/Karlsruhe**



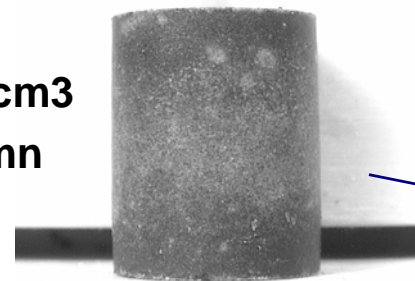
# ECRIX EXPERIMENTS: PIN DESIGN



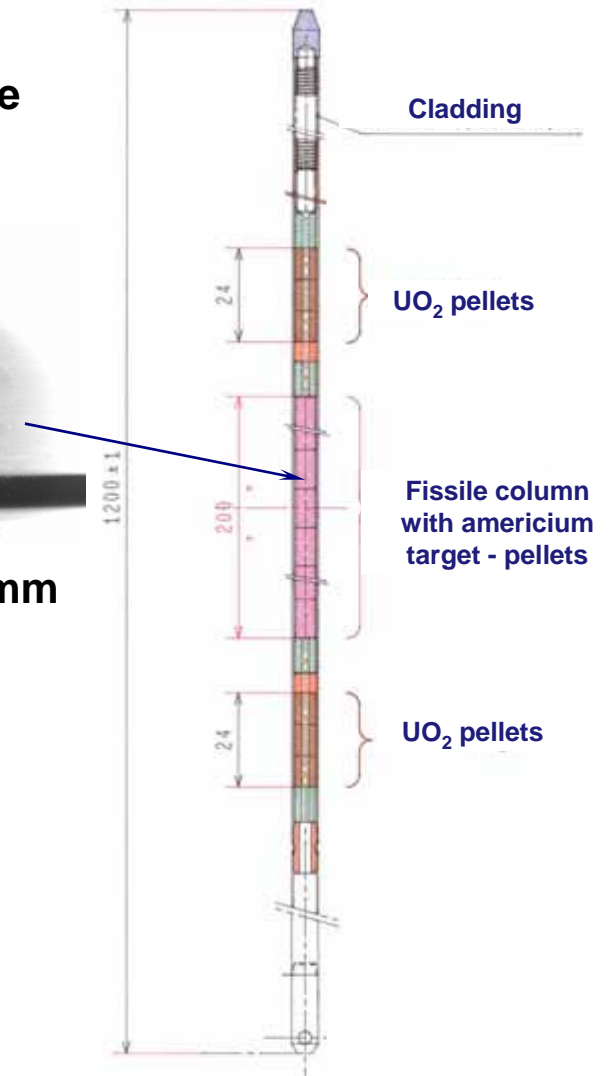
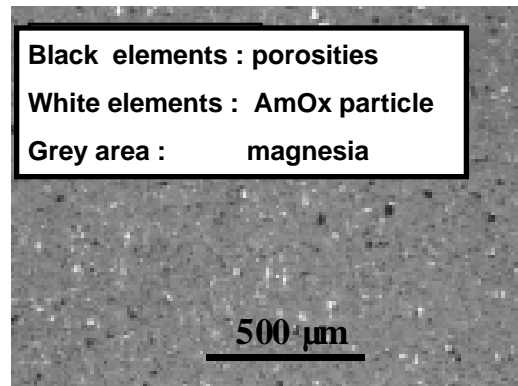
**Microstructure :** CERCER Microdispersed type  
**Inert matrix :** MgO  
**Fuel Particles:** AmO<sub>1,62</sub>



**Am content :** 0,7g of Am/cm<sup>3</sup>  
 2,75 g/column



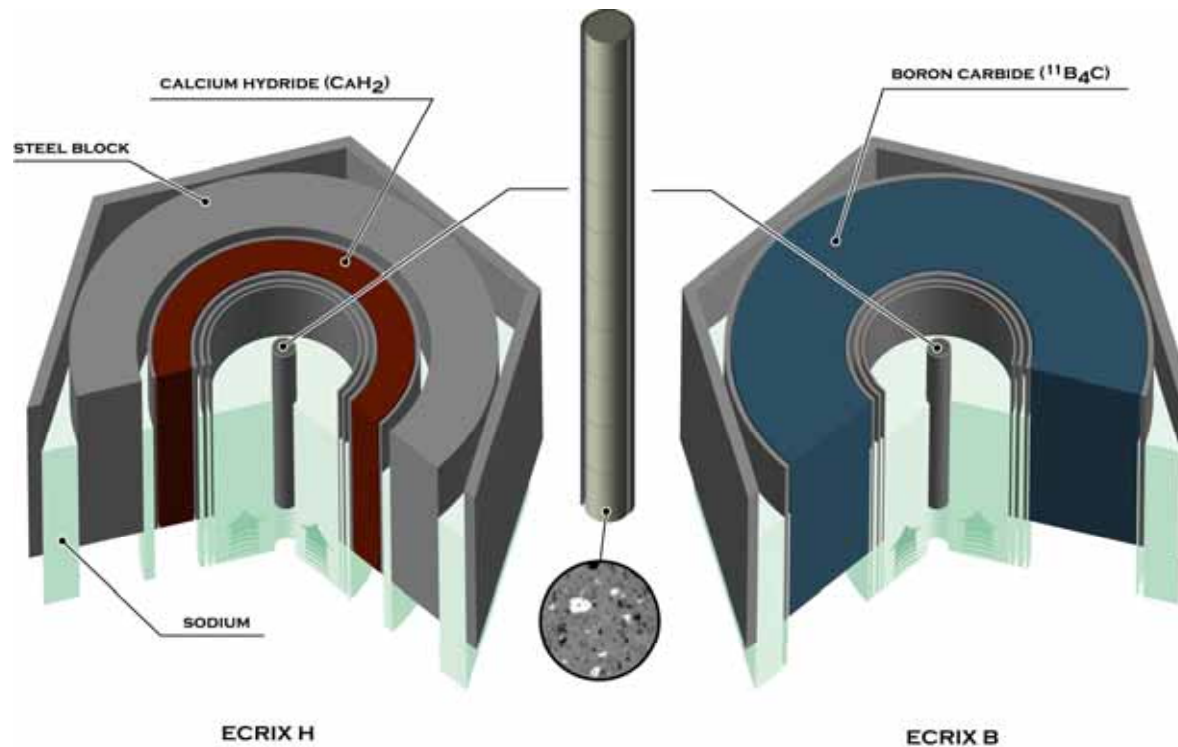
$\phi = 5,25 \text{ mm}$



# ECRIX EXPERIMENTS: SUB-ASSEMBLY DESIGN



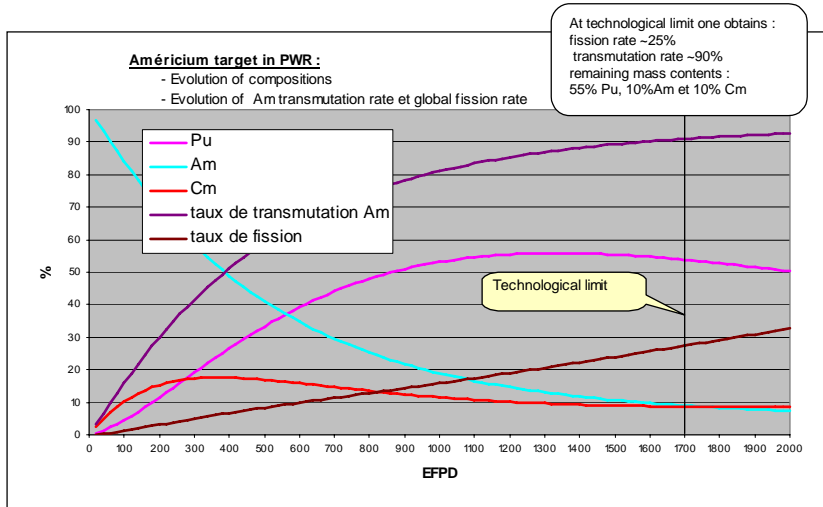
- ECRIX B and H : Transmutation of Americium in MgO inert matrix, pins located inside special moderating carriers)



ECRIX : moderator sub-assembly and capsule cross section

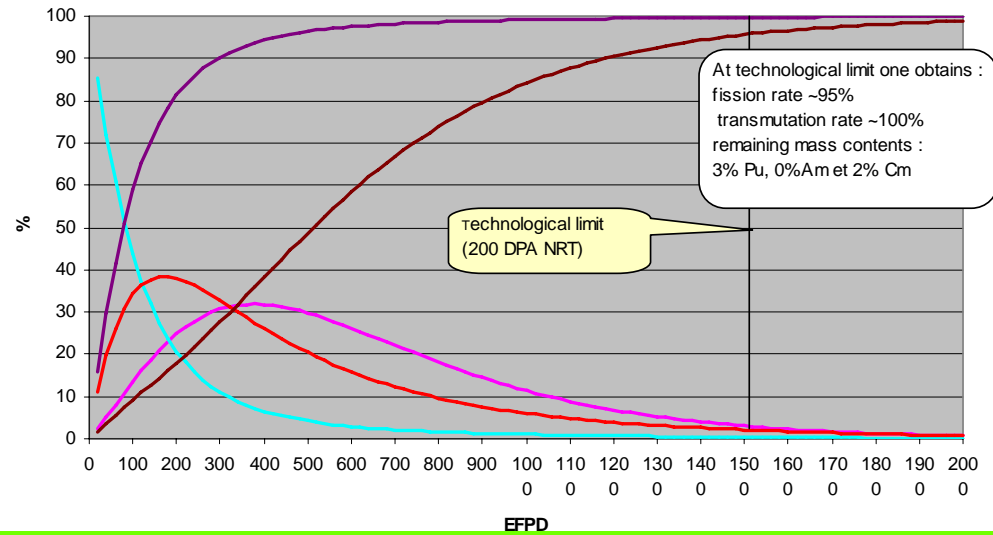


# TRANSMUTATION RATES IN PWR COMPARED TO PHENIX MODERATED FLUX

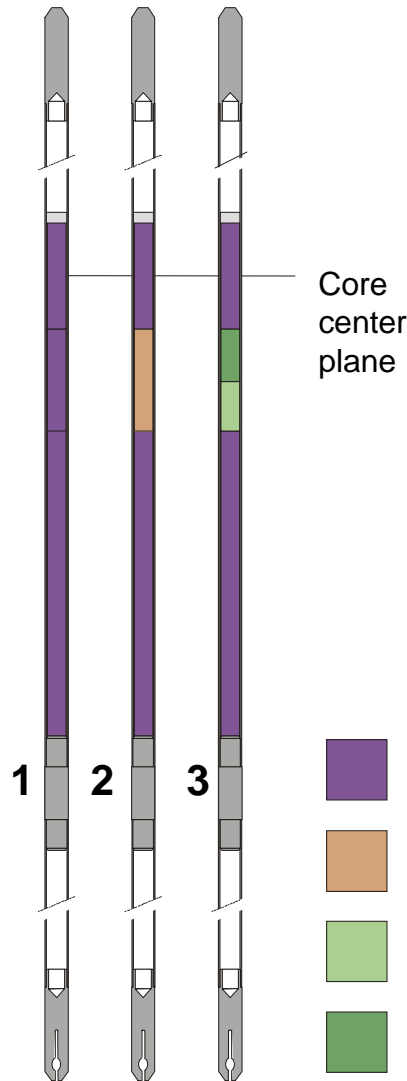


**Americium target in PHENIX moderating spectrum :**

- Evolution of compositions
- Evolution of Am transmutation rate and global fission rate



# HOMOGENEOUS TRANSMUTATION EXPERIMENT



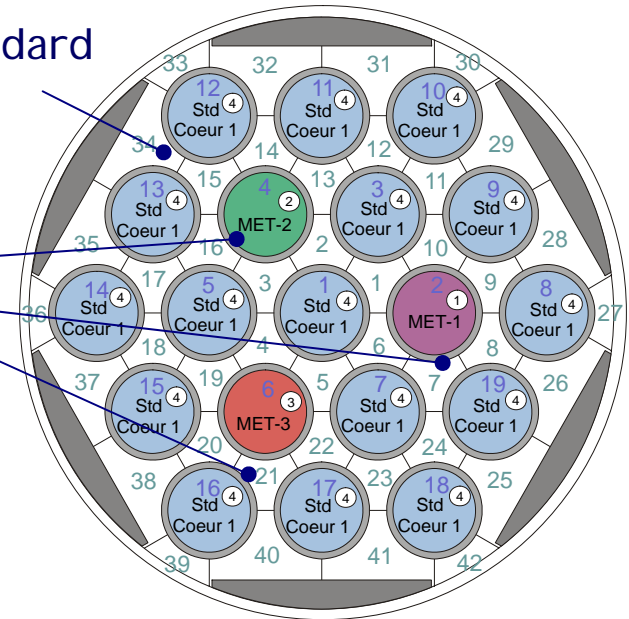
## METAPHIX: Irradiation of Actinides diluted in metal fuel (UPuZr+MA+RE)

Contract with ITU Karsrhue for CRIEPI

3 capsules containing 3 pins each

Experimental pins

Standard pins



Capsule content

# INERT MATRIX TESTING

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## **MATINA 1A :**



**Re-irradiation of MATINA 1 experiment dismantled in 1996 (first selection of most promising matrices).**

**Remove in 2004, non destructive testing did not show any disturbances (swelling, fractures).**



# CAPRIX 1 EXPERIMENT

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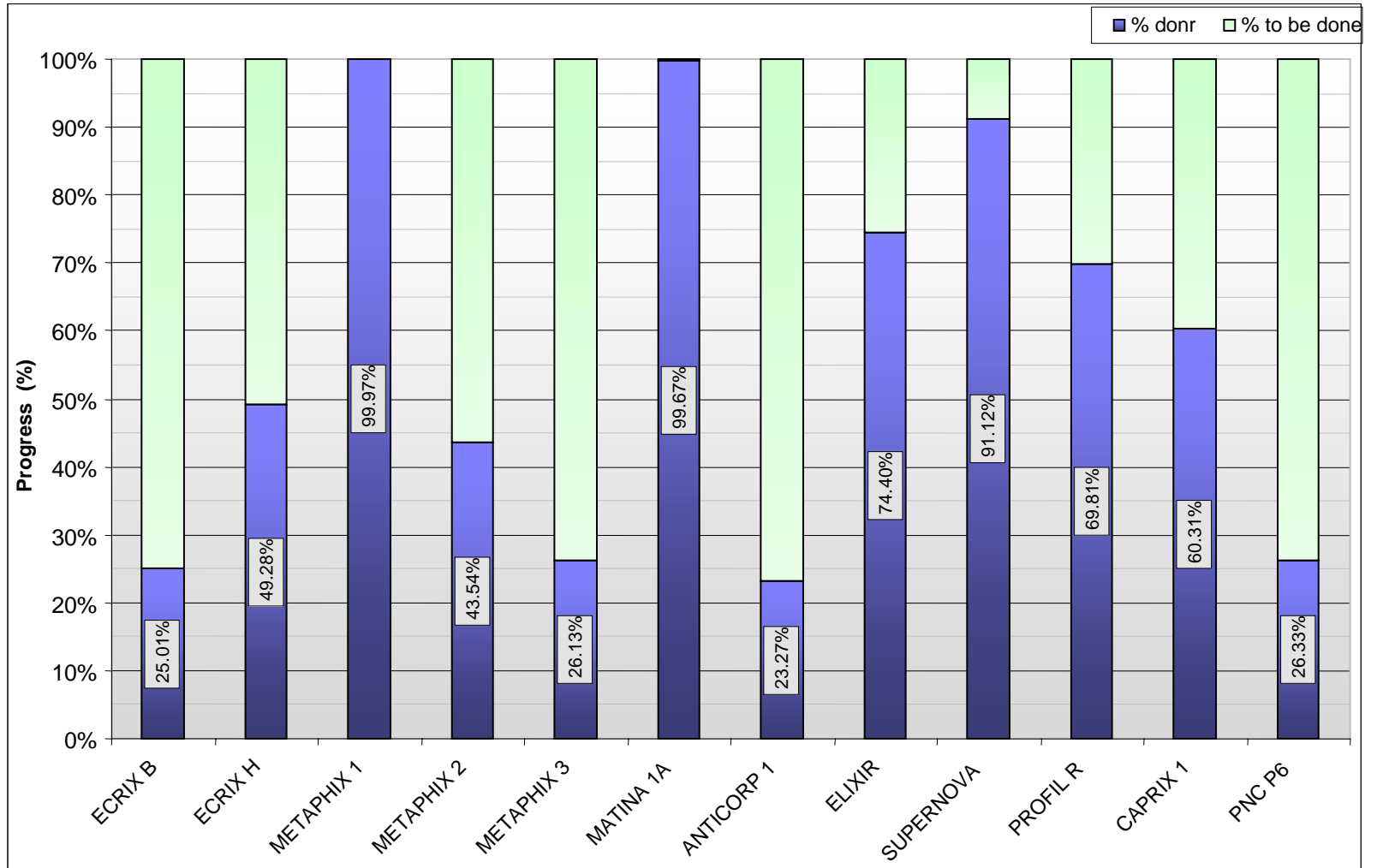
## Irradiation of high Pu content fuel

To assess:

- Thermal-mechanical behaviour of the pin
  - Radial Pu redistribution
  - Cladding Internal corrosion
  - Reprocessing
- 
- 2 pins: 45% Pu /(U+Pu) enrichment pellets with 17 driver fuel pins in a capsule
- 
- Target burn-up : 10 at%



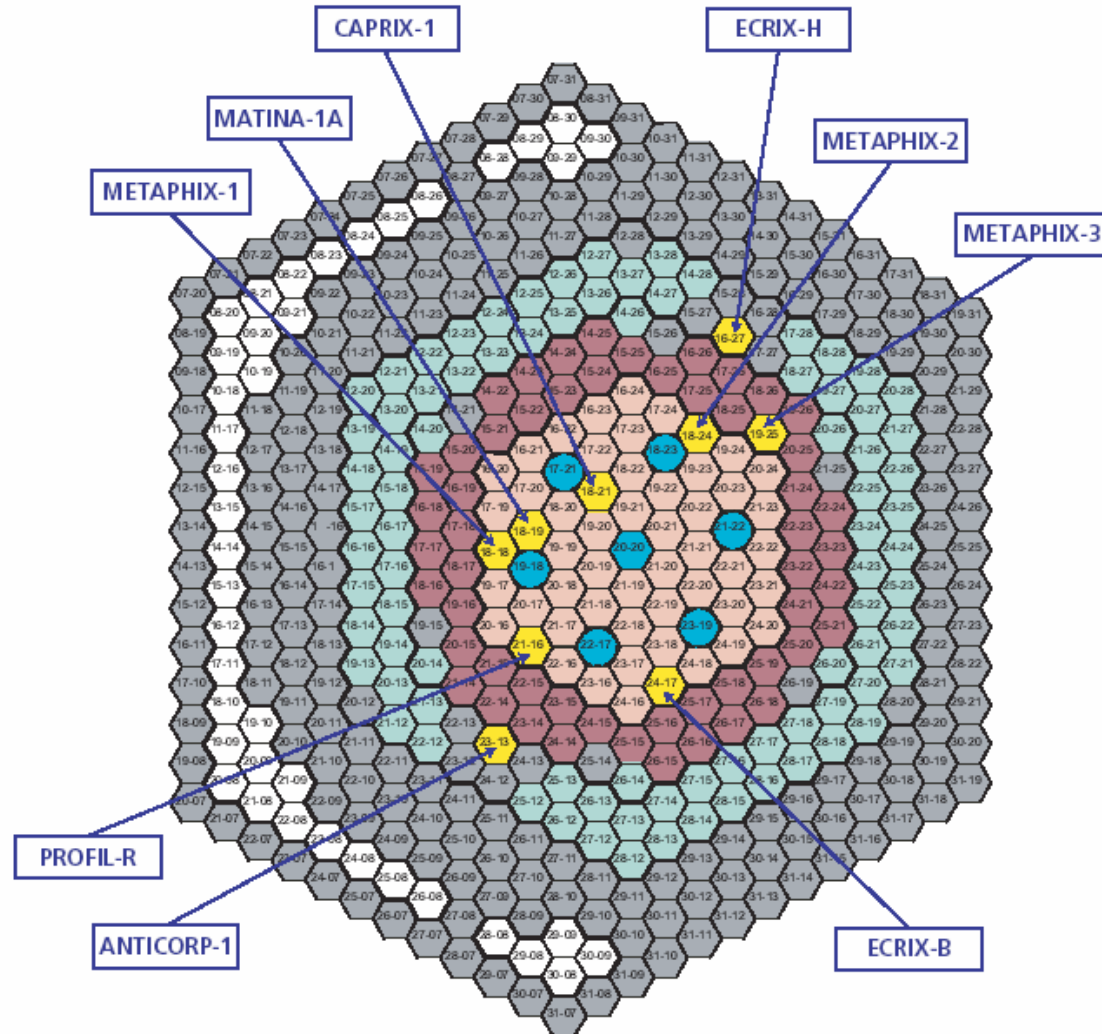
# Experiment progress in % of target



# CORE LOCATION OF IRRADIATION EXPERIMENTS



Emplacement des assemblages expérimentaux dans le cœur



# FUTURE EXPERIMENTS



## Optimisation of target for Americium transmutation

- ❑ CAMIX (Composé d'AMéricium dans PhénIX) :  
optimisation of actinide compound

COCHIX (Conception Optimisée vis-à-vis des miCrostructures dans PHénIX) :

testing of new microstructures (macromasses) dispersed in inert matrix

- ❑ MATINA 2-3  
testing of CERamics/CERamics targets with a MgO matrix and  
macrodispersed particles and of new materials

## Fuel for future systems

- ❑ FUTURIX/FTA (FUels for Transmutation of transURanien elements in PhénIX/Fortes Teneurs en Actinides

testing of Metal, nitride, CER/MET, CER/CER fuels with high TRU content

*Collaboration with US/DOE, ITU, CRIEPI*

## Materials for future systems

- ❑ MATRIX : irradiation of structural materials (metals, ceramics)



# CONCLUSIONS



- ❑ The unique fast breeder reactor in Europe PHENIX plant operated well into 2004
  - ❑ Availability factor 73% in 2004
  - ❑ Removal of 2 experiments MATINA 1A and METAPHIX



- ❑ Transmutation experimental programme in progress for:
  - ✓ Americium, Technetium 99, inert matrix for heterogeneous transmutation (ECRIX, ANTICORP, MATINA)
  - ✓ Homogeneous transmutation (METAPHIX )
  - ✓ Neutronic datas (PROFIL)which shall provide a validation of a wide range of concepts

- ❑ Irradiation of high PU content fuel (CAPRIX).
- ❑ Preparation of future experiments for the next cycles.

