



# Minor actinide recycling in sodium fast reactor : status in 2008 of Phénix experimental program

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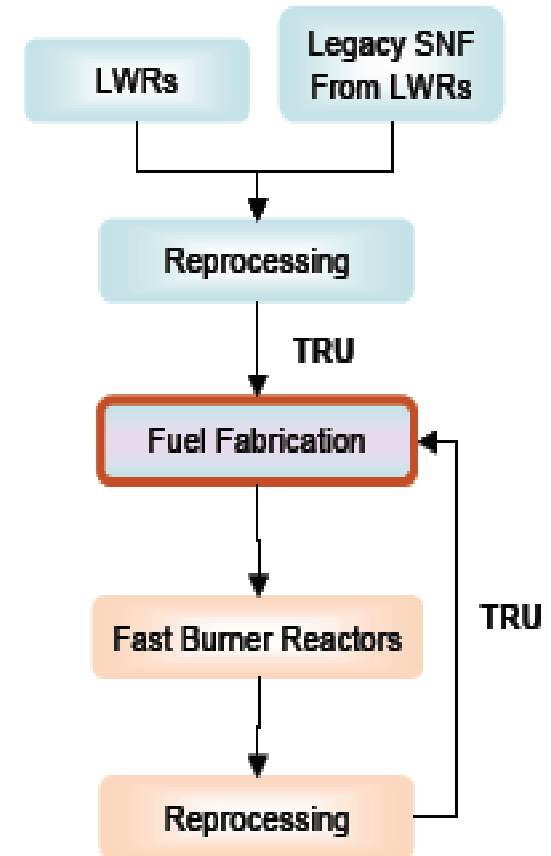


# The specificities of MA bearing fuels for recycling in SFR



Transmutation fuel development is considerably more challenging than conventional fuels :

- Multiple elements in the fuel
  - U, Pu, Np, Am, Cm
- Varying thermodynamic properties
  - e.g. High vapor pressure of Am
- Impurities from separation process
  - e.g. High lanthanide carryover
- High burnup requirements
- High helium production during irradiation
- Remote fabrication & quality control
- **Fuel must be qualified for a variable range of composition**
  - Age and burnup of LWR SNF
  - Changes through multiple passes in FR
  - Variable conversion ratio for FR



# Homogeneous recycling mode in SFR : acquired knowledge

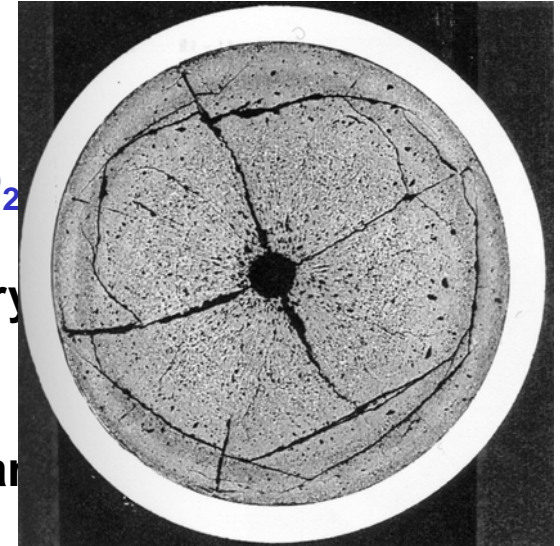


- **SUPERFACT homogeneous in Phénix, 1986 to 1988**

- $U_{0.74}Pu_{0.24}Am_{0.02}O_2$  and  $U_{0.74}Pu_{0.24}Np_{0.02}O_2$
- 382 efpd,  $P_{LIN} = 380$  to  $325$  W/cm
- Burn up = 6.7 at%

- **Fuel restructuration is similar than for  $UPuO_2$**

- **U, Pu, Am and Np radial distributions are very similar**  
→ **No actinide specific redistributions**
- **Transmutation ratio at the reactor middle plane**  
 **$\approx 28\%$  for  $^{241}Am$  and  $\approx 30\%$  for  $^{237}Np$**



⇒ **For low linear power, no real influence of the low MA amount, up to a BU equal to 6.7 at%, except for the He release of the Am fuel**  
**(4 times greater than standard  $UPuO_2$  pins release)**

# Fabrication of MA bearing fuels : development of fabrication process



- Synthesis of MA compound powders
- A promising process : the oxalic co-precipitation, calcination, then direct pelletizing or dilution in  $UO_2$



**Pu**

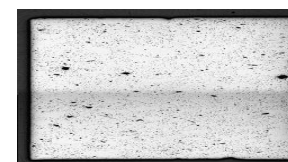
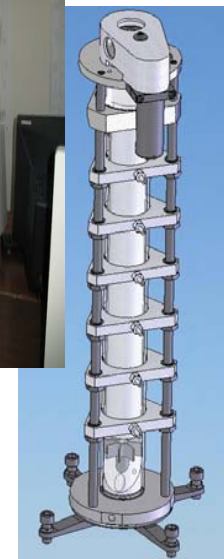


**U and Pu**



**U, Pu, Np, Am,..Cm**

- Characteristics of the powders : physico-chemistry, flowability, sintering properties,...
- Technology:
  - continuous precipitation apparatus: vortex effect, pulsed column, ...
  - modeling
- COPIX (UPu) $O_2$  irradiation test in Phenix, 2008-2009

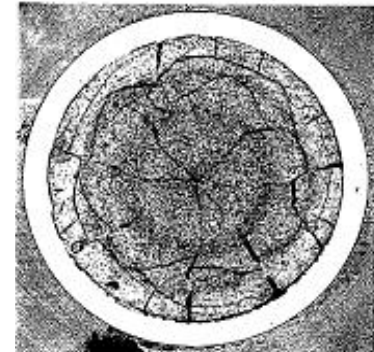


# Heterogeneous recycling mode in SFR : acquired knowledge



- Dilution of MA in  $UO_2$  matrix, MA : 10-20 %, periphery of the core : “blanket”
- SUPERFACT heterogeneous in Phénix :
  - $U_{0.6}Am_{0.20}Np_{0.20}O_2$
  - 382 efpd,  $P_{lin} = 174$  to  $273$  W/cm
  - Burn up = 4.1 at%
- Limited fuel restructuring:
  - Fuel-clad interaction,
  - Cold fuel (no central hole),
  - High He retention for  $UAmNpO_2$

No central hole



He Production

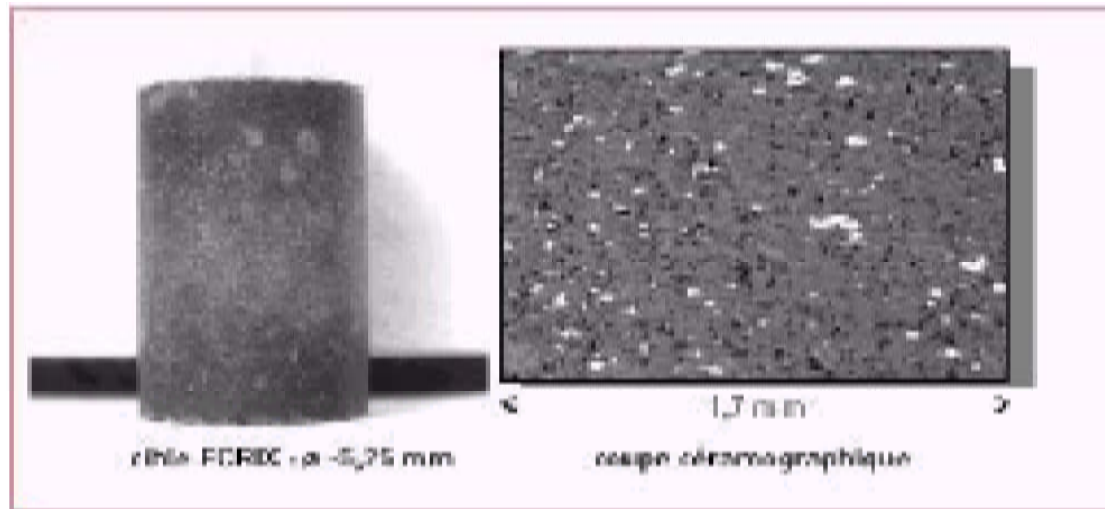
mm <sup>3</sup> /g fuel	Xe Kr	He
Standard $UPuO_2$ 6at%	1220	40
$UAmNpO_2$ , 4at%	764	2970

# ECRIX : test of Am heterogeneous recycling mode in Phénix

## - ECRIX irradiation

- in Phénix, from March 2003 to March 2006
- AmO<sub>1.6</sub> micro dispersed into MgO
- Am = 0.7 g.cm<sup>-3</sup> (2.75 g of Am in 200 mm height column)
- Objective Fission rate > 30 at% (90% transmutation rate)
- non destructive PIE results indicate a satisfactory behavior of the target

- Results of on going complete PIE will allow to increase the performance of magnesia targets : Am amount, and transmutation rate





## - MATINA 2-3 irradiation

- in Phénix from July 2006, for 360 efpd (fast fluence:  $12 \cdot 10^{26} \text{ m}^{-2}$ )
- inert matrices  $\text{MgO}$ ,  $\text{ZrYO}_2$
- $\text{MgO} + \text{UO}_2$  macro  $100 \mu\text{m}$  or micro  $1 \mu\text{m}$  particles (damage)
- irradiation temperatures:  $1000^\circ\text{C}$  and  $1400^\circ\text{C}$

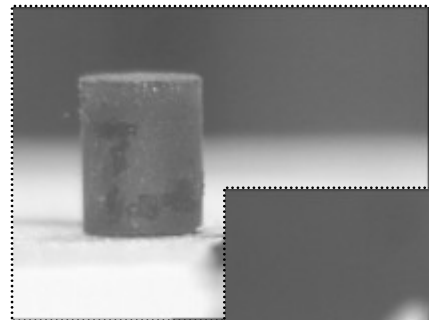
## - CAMIX-COCHIX irradiation

- fabricated at ITU-Karlsruhe
- in Phénix from April 2007, for 240 efpd (fast fluence:  $1.9 \cdot 10^{26} \text{ m}^{-2}$ )
- $\text{AmZrYO}_2$  solid solution,  $2200^\circ\text{C}$
- $\text{MgO} + \text{AmZrYO}_2$  with  $\text{AmZrYO}_2$   $100 \mu\text{m}$  and  $50 \mu\text{m}$  particles,  
 $1400^\circ\text{C}$
- Objective Fission rate  $> 23 \text{ at}\%$

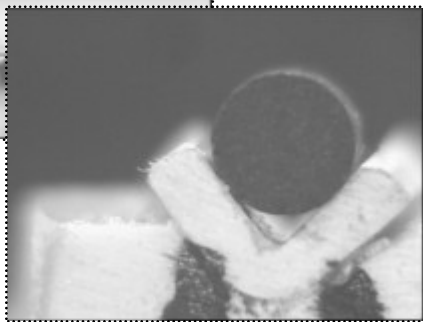
# FUTURIX FTA CERCER Experiment in Phénix



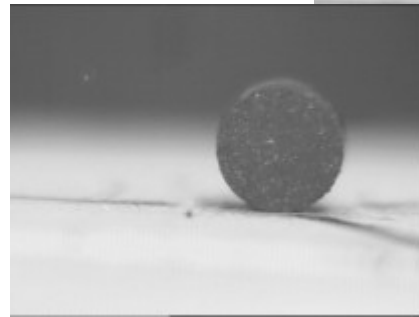
Studies on dedicated fuels containing high Minor Actinide concentration compound



**CEA-7**

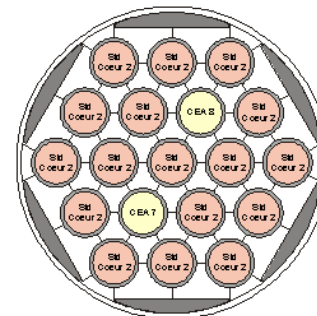
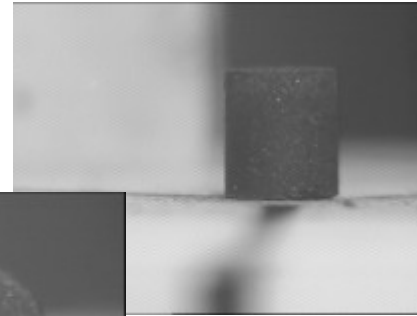


$(Pu_{0,50}, Am_{0,50})O_{2-x} - MgO\ 80\%vol$

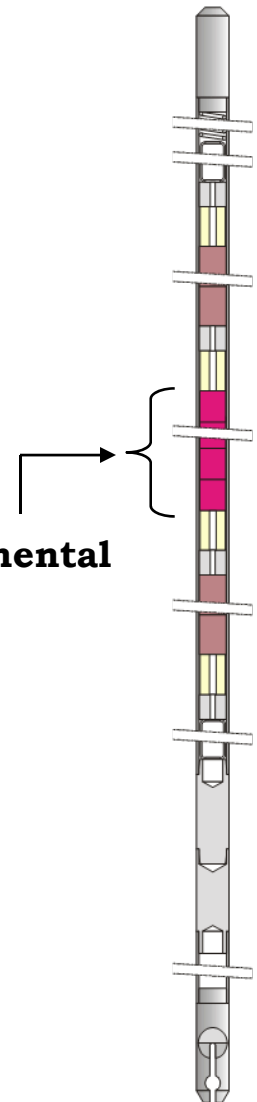


**CEA-8**

$(Pu_{0,20}, Am_{0,80})O_{2-x} - MgO\ 75\%vol$



**Two experimental pins CEA-7 and CEA-8 in a 19 pins capsule.**



**Experimental pelets**

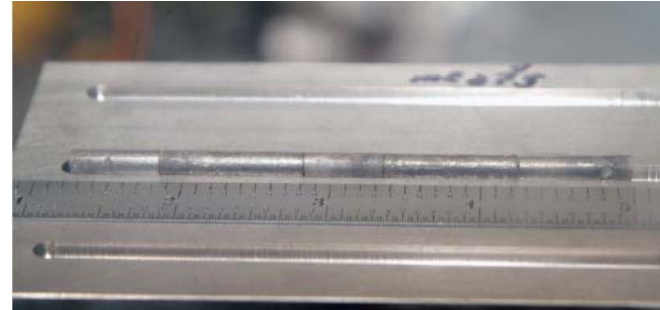
# FUTURIX FTA Metal Experiment in Phénix



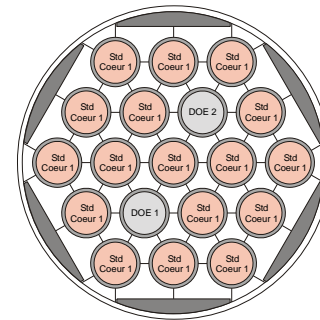
Studies on dedicated fuels containing high Minor Actinides concentration compound



**DOE-1 : 35U 29Pu 4Am 2Np 30Zr**

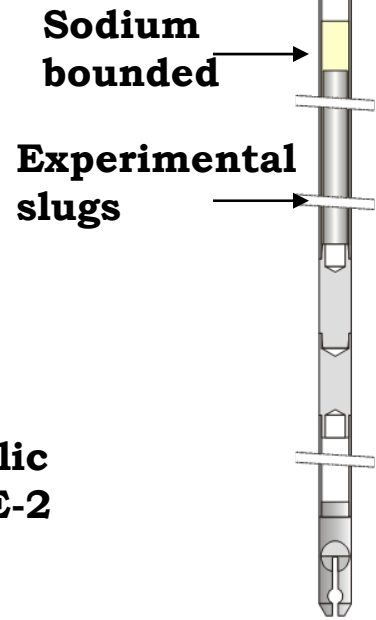


**DOE-2 : 48Pu 12Am 40Zr**



**The goal is to reach :**  
**DOE-1 :  $17.4 \cdot 10^{20}$  fiss.cm<sup>-3</sup>**  
**DOE-1 :  $20.5 \cdot 10^{20}$  fiss.cm<sup>-3</sup>**

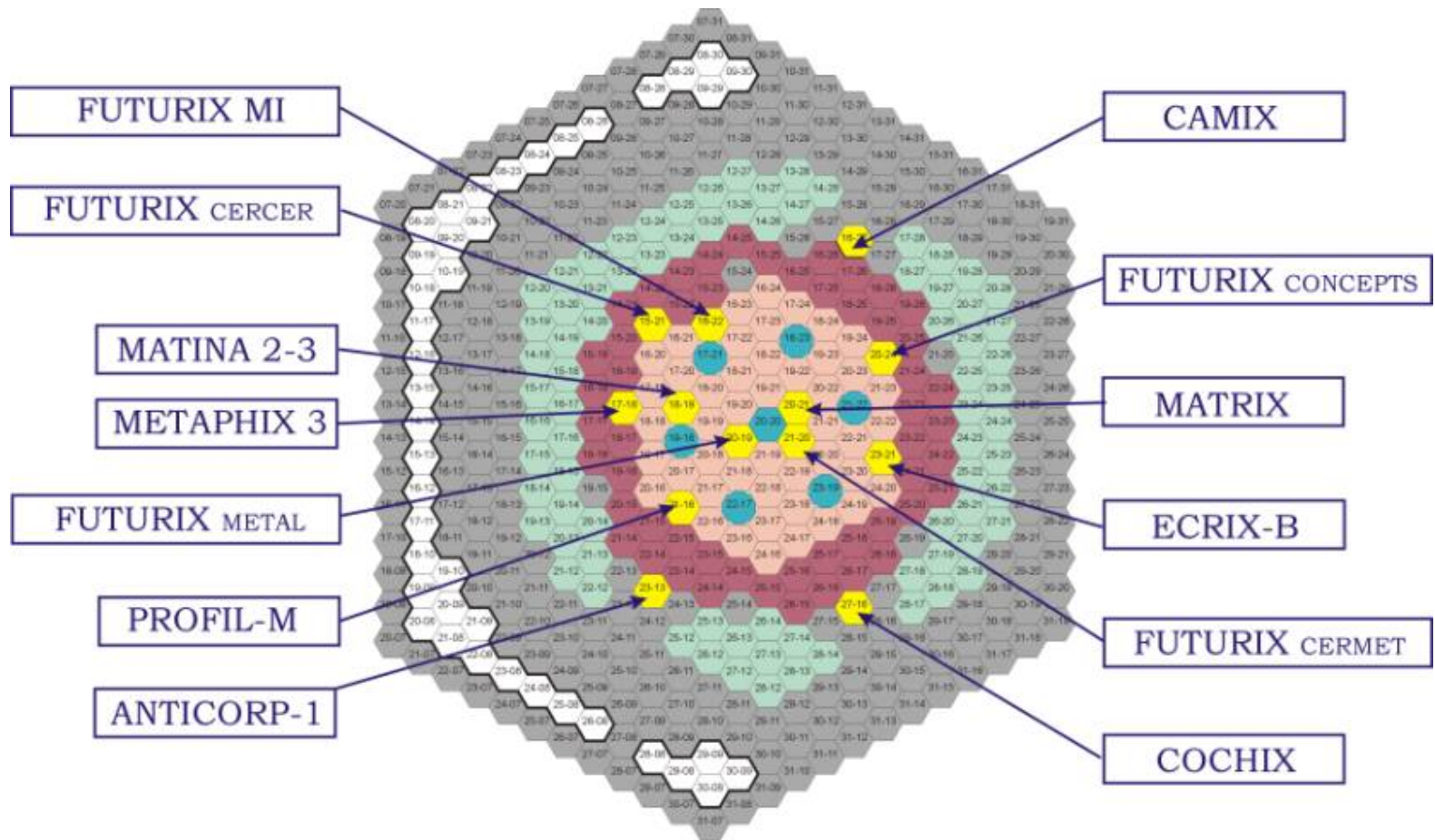
**Two experimental metallic fuel pins DOE-1 and DOE-2 in a 19 pins capsule.**



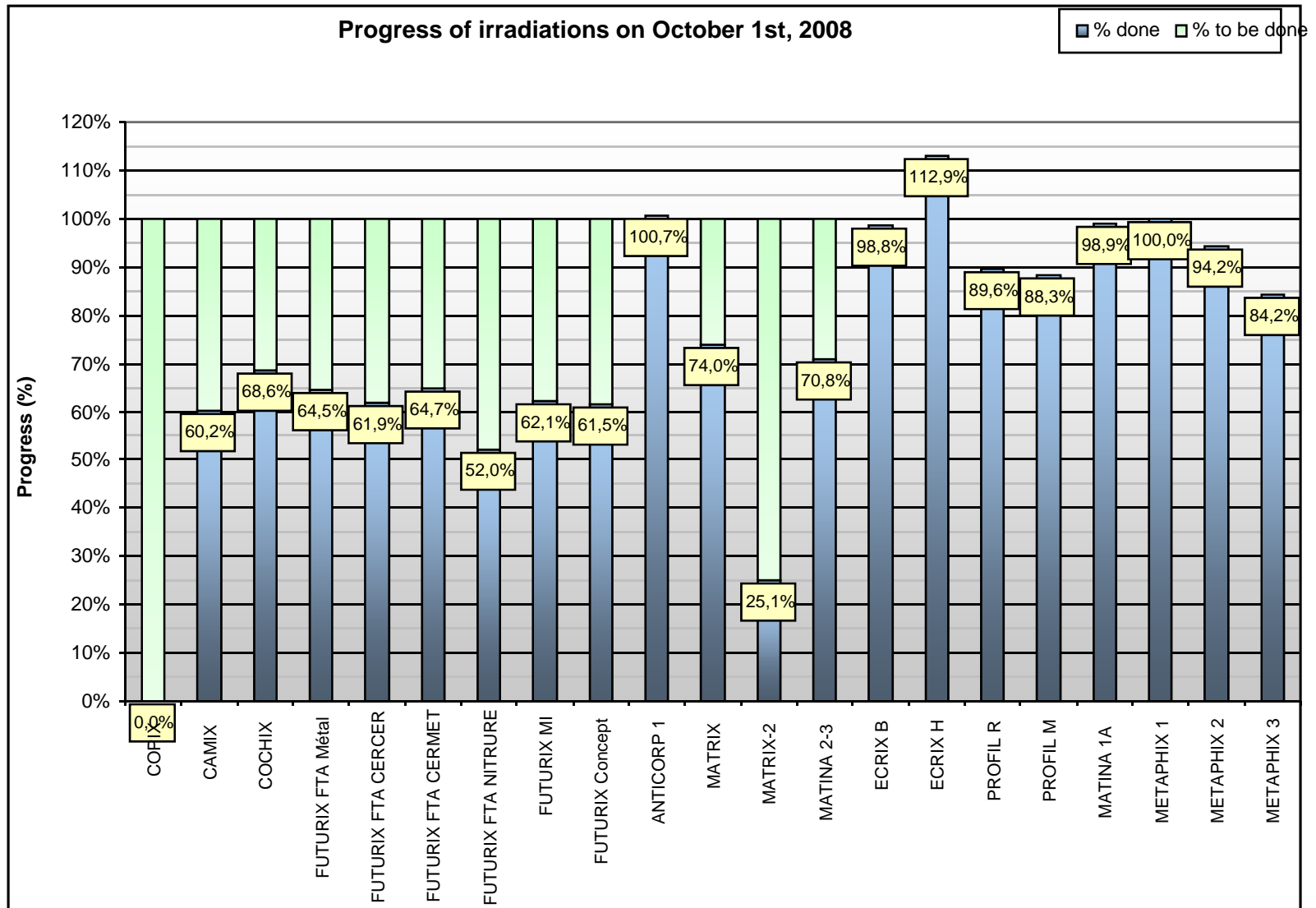
# The Phénix core on going transmutation experiments



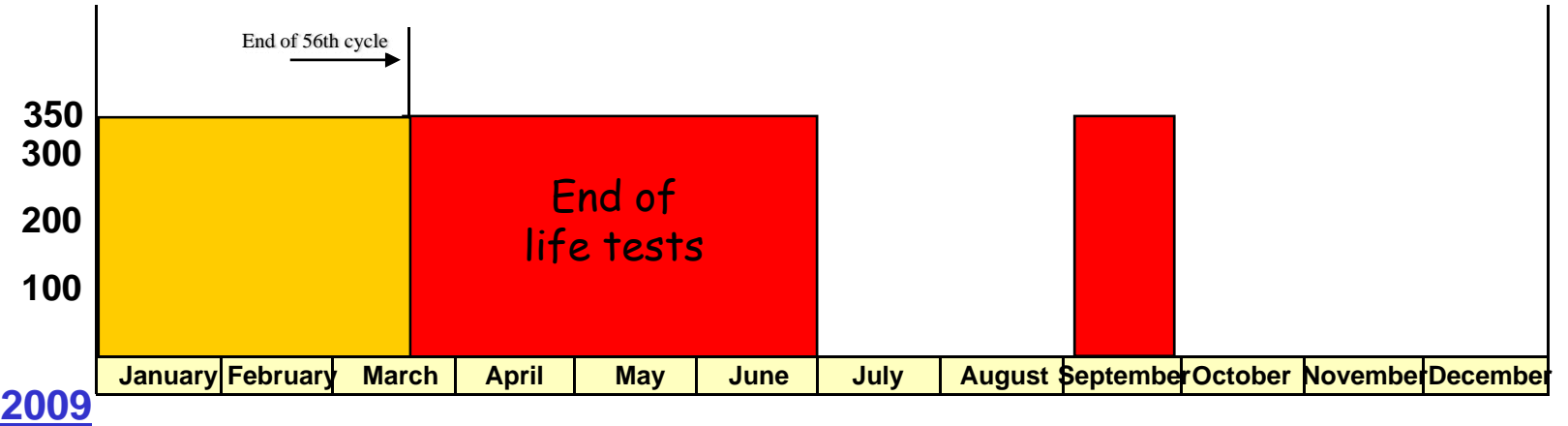
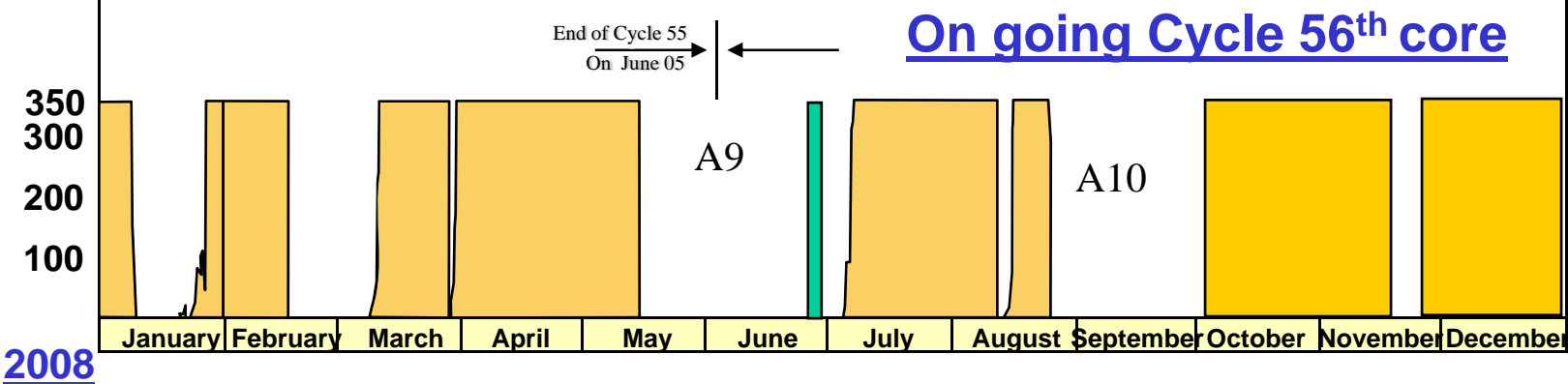
## On going Cycle 56<sup>th</sup> core



# The Phénix core on going transmutation experiments



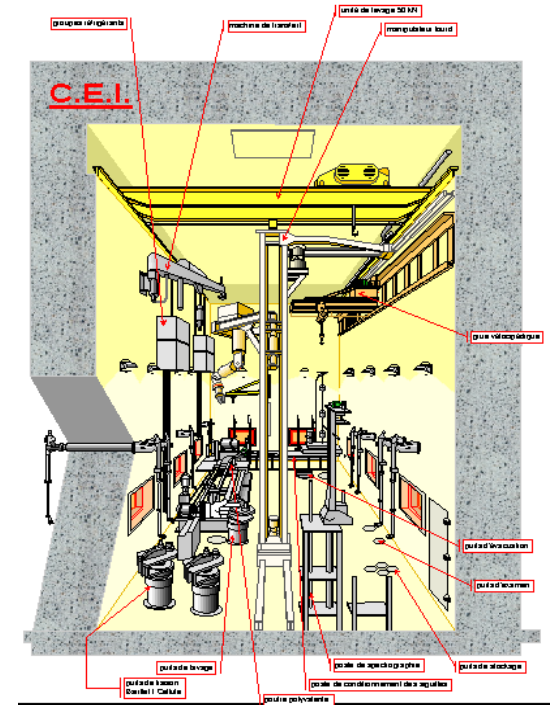
# Phénix schedule till final shutdown



# The Phénix Irradiated Element Cell



- Operational since 1974
- 14 m long, 6.5 m wide and 9 m high
- Concrete walls 1.20 m thick
- Atmosphere : nitrogen



## Purposes of the IEC :

- to examine the irradiated fuels in the Phénix reactor, for in-pile behavior studies (transmutation, waste management, support for future SFR)
- to dismantle core elements for re-processing of the fuel driver pins

# Objectives of Phénix end of life test program

- Tools validation in the fields of core physics, thermal-hydraulics, safety/operation



## 1- Subassemblies reactivity worth measurements

1A – Substitutions of S/A in core central position.

1B – Substitution of a control rod by a gas volume

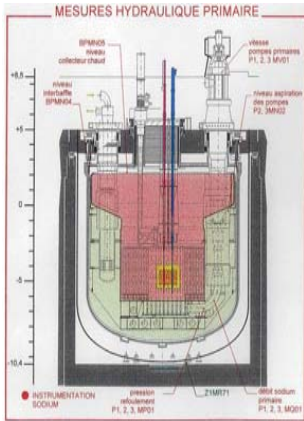
## 2- Control rod withdrawal

2A – Assymetrical control rod configuration (static)

2B – Control rod withdrawal (dynamic)

## 3- Decay heat measurement

## 4- Control rod worth measurements by different methods



- Safety demonstration: intrinsic safety features of sodium cooled FR, verification of calculation margins
- Investigation of scenarios for Phénix [negative reactivity transient](#) explanation
  - 1- Thermalhydraulics of Moderated carrier- Blanket S/A
  - 2- Core flowering
- [Test with on power and zero power reactor](#)

## After Phénix, the SFR perspectives

- The fast breeder reactors are fully in the frame of **sustainable development**, for preserving natural resources (breeding) and improving waste management (transmutation).
- Sodium Fast Reactors are on operation or under construction or projects in many countries, with a total operating experience of 385 years.
- The Phenix reactor has operating well, since its restart in 2003, and after demonstration of the breeding possibilities in the 1980's, it is demonstrating today the transmutation capabilities of these reactors.
- 2010-2020 : Future programs for irradiations , properties and design :
  - Irradiations in **Joyo** (MA 2 à 3%), and preparation of irradiations in **Monju** (~10% MA, including Curium)
  - Program for obtaining data needed for fuel design (optimized heterogeneous fuel for blanket assembly)
- **France in 2020 : a prototype of GEN IV reactor : ASTRID !!**  
**(Advanced Sodium Test Reactor for Industrial Demonstration)**



Phenix