# A French Scenario for Fast Reactor Deployment over the XXI$^{st}$ Century

S. Massara, P. Tetart
**Electricité de France (EDF R&D)**
L. Boucher
**Commissariat à l'Energie Atomique (CEA)**

**ARWIF2005, Oak Ridge, USA, February 16-18, 2005**

# Summary

1. Introduction
2. Hypotheses: FR deployment scenario
3. Results
4. Sensitivity analysis
5. COSI (CEA) and TIRSTRAT(EDF) comparison
6. Conclusions

# Introduction

French Nuclear fleet: 63 GWe (58 reactors)

53 GWe in 1978 – 1990 + 10 GWe in 1990 – 2000

## Long term strategy

- Life span beyond 30 years
- Staggering the replacement over a longer period

**Beginning of the nuclear fleet renewal from ~ 2020**

# Introduction

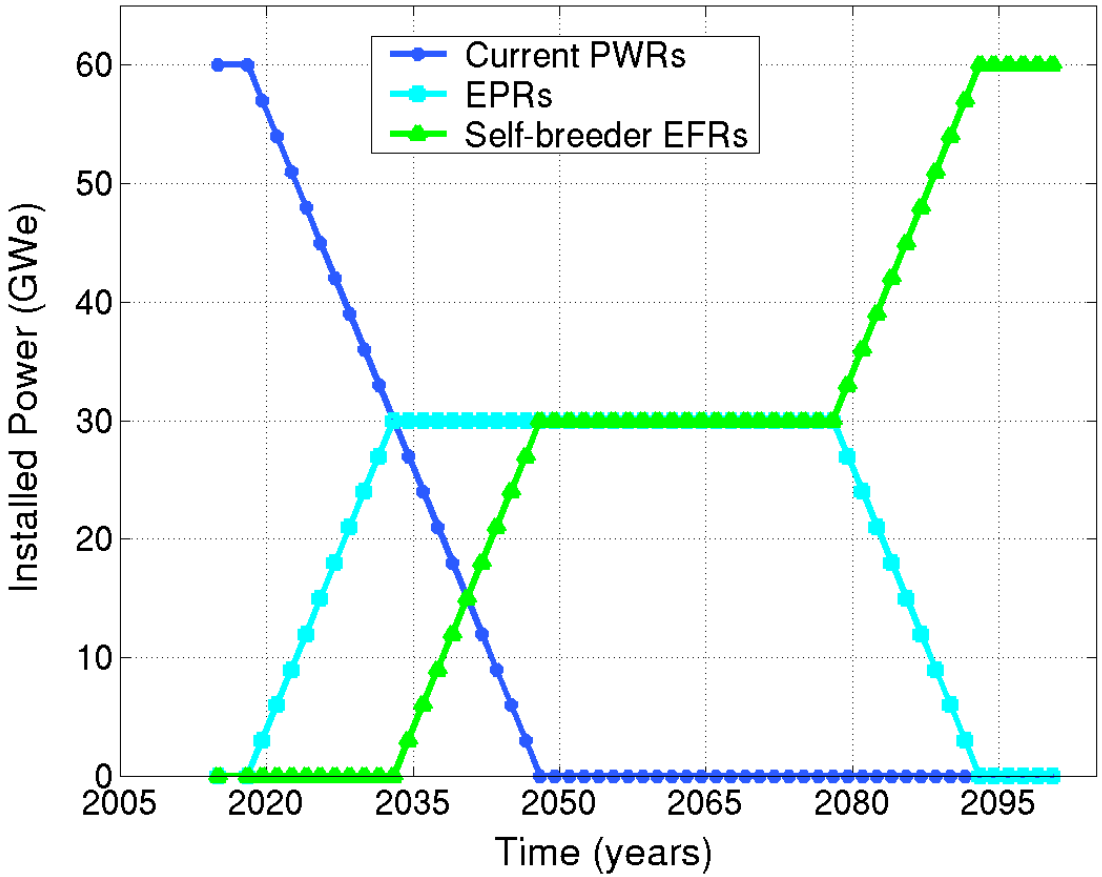
- Renewal of current facilities from ~ 2020
- European Pressurized Reactor (EPR) – 60 yrs lifetime
- Gen IV systems expected for ~ 2030 – 2040 (later ?)
- Sustainable nuclear energy → Self-breeder FRs
- Current facilities replacement in 2 steps:

100% PWRs → 50% EPRs + 50% FRs → 100% FRs

***Will Pu inventory be sufficient for self-breeder EFR-type deployment ?***

# FR deployment scenario

## 60 GWe – 400 TWhe/yr nuclear fleet between 2015 et 2100




**2020 - 2035**

**30 GWe PWRs → EPRs**

**(2025 MOX stopped)**

**2035 - 2050**

**30 GWe PWRs → FRs**

**self-breeder EFRs**

**2080 - 2095**

**30 GWe EPRs → FRs**

**self-breeder EFRs**

**Estimated Pu stockpile in 2015: ~ 300 t**

# Hypotheses

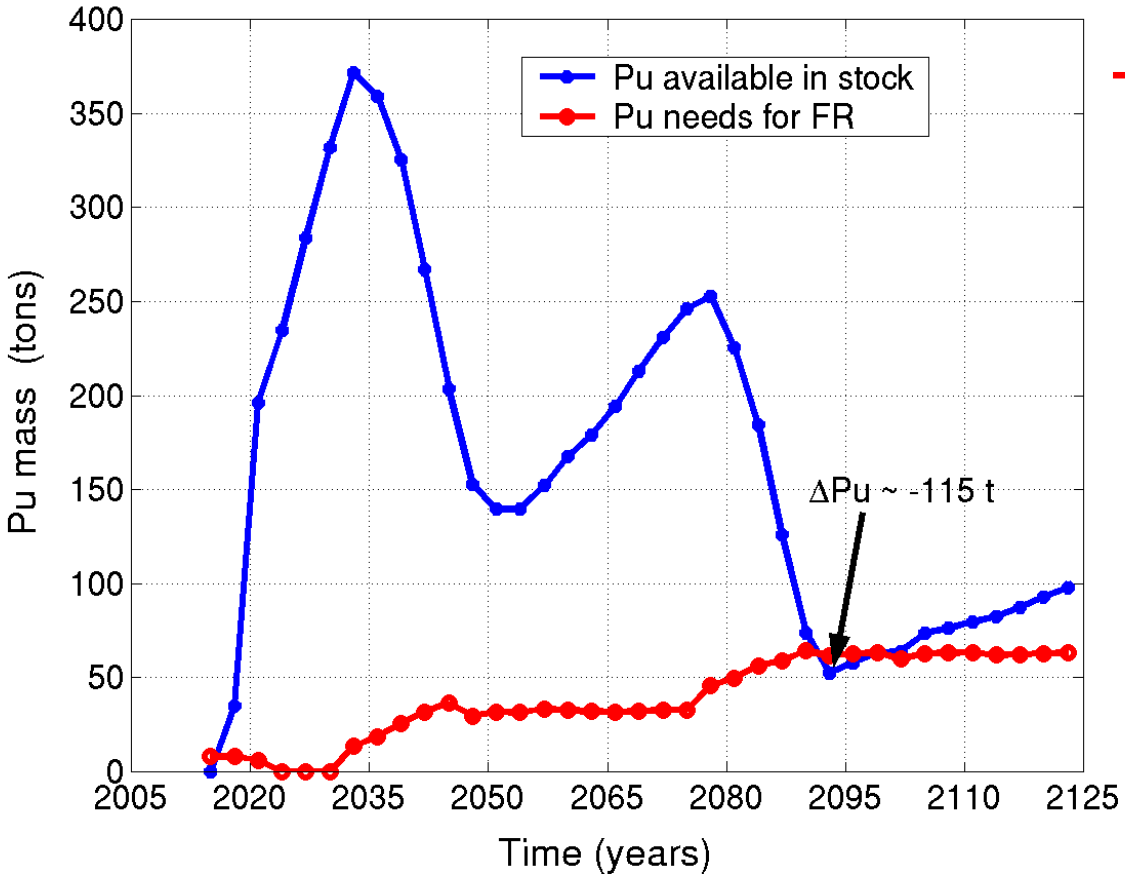
- Fuel cycle simulation codes: COSI and TIRSTRAT
- Cooling + ageing time: 5 + 2 yrs
- Pu losses rate (fabr. and reproc.): 0.1% wt.
- 50 yrs mean lifetime for PWR, 60 yrs for EPR and EFR
- EPR and EFR electrical output: 1450 MWe
- Average discharge Burn-Up (GWd/tHM):

  UOX PWR and EPR: 60, MOX PWR: 45, EFR: 136
- FR: **SELF-BREEDER EFR CD9/91 (BG = 0)**

  In-core inventory: 6.5 tons equivalent $^{239}$Pu (avg. 9.4 tons Pu)

# Results

# 60 GWe self-breeder EFRs fleet




Theoretical Pu inventory for 60 GWe: ~ 865 tons

Total Pu production by PWRs over all their lifetime : ~ 750 tons

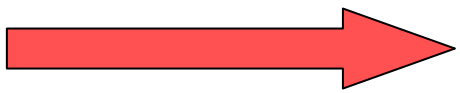
**~115 Pu tons (84 tons equivalent $^{239}$Pu) lack for a 60 GWe self-breeder EFRs fleet**

# Total Pu inventory

## 60 GWe EFRs

| Plant | Pu mass (tons) |
|---|---|
| Reactors | 388 |
| Cycle facilities | 128 |
| Stocks | 349 |
| *Total* | *865* |

**…but 115 Pu tons lack**



## 51 GWe EFRs

| Plant | Pu mass (tons) |
|---|---|
| Reactors | 333 |
| Cycle facilities | 108 |
| Stocks | 309 |
| *Total* | *750* |

**Pu inventory is sufficient for a 51 GWe EFRs fleet (BG = 0 & Cooling time = 5 years)**

# Sensitivity analysis

- EFR's cooling time reduction
- EFR's Breeding Gain > 0

# EFR's cooling time 5 to 3 years

- Lower Pu inventory (lower extra-core inventory)
- Higher Pu availability (lower $\beta^-$ from $^{241}Pu \rightarrow {}^{241}Am$)

| Spent fuel Cooling time ($t_c$) | 5 years (Reference) | 3 years |
|---|---|---|
| Maximum EFRs BG=0 Deployable Power (GWe) | 51 | 57 |
| Pu lack for 60 GWe EFRs BG=0 Fleet (tons) | 115 | 42 |

Requirements for 60 GWe fleet:

- BG=0, $t_c$~2 yrs
- BG~0.03, $t_c$=3 yrs

**Industrial feasibility of cooling time reduction ?**

# EFR Breeding Gain > 0

Spent fuel cooling time: 5 yrs

1. Breeder EFRs fleet
2. Mixed breeder and self-breeder EFRs fleet

| $t_c$ (years) | EFR's Installed Power (GWe) | BG | $t_D$ (years) |
|---|---|---|---|
| 2 | 60 | 0 | ∞ |
| 3 | 60 | 0.03 | 284 |
| 5 | 60 | 0.06 | 159 |
| 5 | 15 | 0.2 | 51 |
| | 45 | 0 | ∞ |

**If $t_c$ > 2 yrs → BG > 0 (Breeder EFRs) for 60 GWe**

# Results comparison

COSI (CEA) and TIRSTRAT (EDF) are both based on APOLLO2 and ERANOS cell codes

| Fuel cycle code | COSI | TIRSTRAT |
|---|---|---|
| Maximum EFRs BG=0 Deployable Power (GWe) | 51 | 50 |
| Pu (Equivalent $^{239}$Pu) lack for 60 GWe EFRs BG=0 Fleet (tons) | 115 (84) | 144 (105) |

**Very good agreement between the two codes**

# Conclusions

1. Reference scenario : lack of 115 Pu tons for 60 GWe EFRs
   BG = 0 fleet → 51 GWe fleet
2. 60 GWe EFRs fleet is possible if EFRs' cooling time and BG are modified (high sensitivity):

- increased BG is sufficient (~ 0.06) with 5 yrs cooling time
- reduced cooling time is sufficient (~ 2 yrs) with BG=0
- if cooling time > 2 yrs → BG > 0 (Breeder EFRs)

3. Very good agreement between CEA and EDF code

**Pu is a key resource**

**for nuclear energy sustainability**