Presentation of COSAC
&
some studies conducted with COSAC

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COSAC
Development history

- **COSAC = acronym for "COde de Scénarios pour l'Aval du Cycle" (in English: code for back-end fuel cycle scenarios)**
- **Issued from an internal R&D program in AREVA that started in the late 1990's**

- **First release of the Kernel (calculation module) was issued in 1999**
- **Second release of the Kernel was in 2001: some functionalities added (e.g. radiotoxicity and decay heat calculations)**

- **First release of the GUI was issued in 2005: GUI dedicated to only input data**
- **Second release of the GUI was issued in 2007: both input and output data are handled by the GUI**

- **Last release of the Kernel + GUI was issued in 2015: improvements of some functionalities (more details later in this presentation)**

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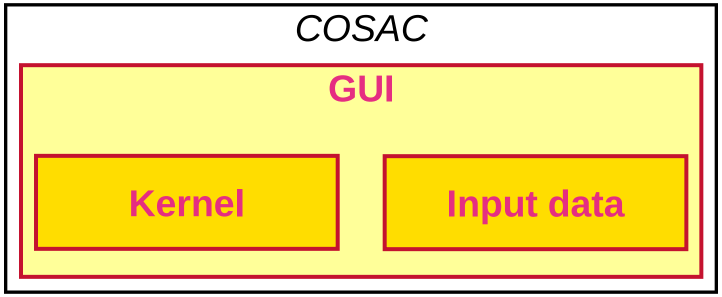
COSAC *at a glance*

- **COSAC made of 3 components:**
  - **Calculation module (Kernel)**
  - **Graphical User Interface (GUI)**
  - **Input data for physics & parameters of the scenario**



- **The calculation module is fully surrounded by the Graphical User Interface**
  - **to introduce the initial data (input)**
  - **and to display the results and analyze the scenario (output)**
- **The software language of the Kernel is C++ (about 25,000 lines)**
- **No physics written in the software: processes such as depletion (in a reactor) or radioactive decay (in a storage center) are brought into the code by input data**
- **No need to call external codes: COSAC runs alone from the input data provided by the user**
- **Quickness: a typical run lasts between a few seconds and a few minutes**

COSAC
Physics

- **Physics is brought to COSAC as input data (in the form of matrices and functions)**
- **Advantage: it allows to simulate almost all types of reactors**
- **4 kinds of matrices:**
  - **Irradiation matrices: to simulate the in-flux evolution of the fuel**
  - **Decay matrices: to simulate the out-of-flux evolution of the fuel**
  - **Decay power matrices: to convert masses into decay power (takes into account isotopic composition)**
  - **Radiotoxicity matrices: to convert masses into radiotoxicity (takes into account isotopic composition)**
- **Equivalency functions: to adjust the Pu content to the isotopic composition in a MOX fuel**
- **Flows of nuclear materials between two installations are supposed to be made instantaneously**

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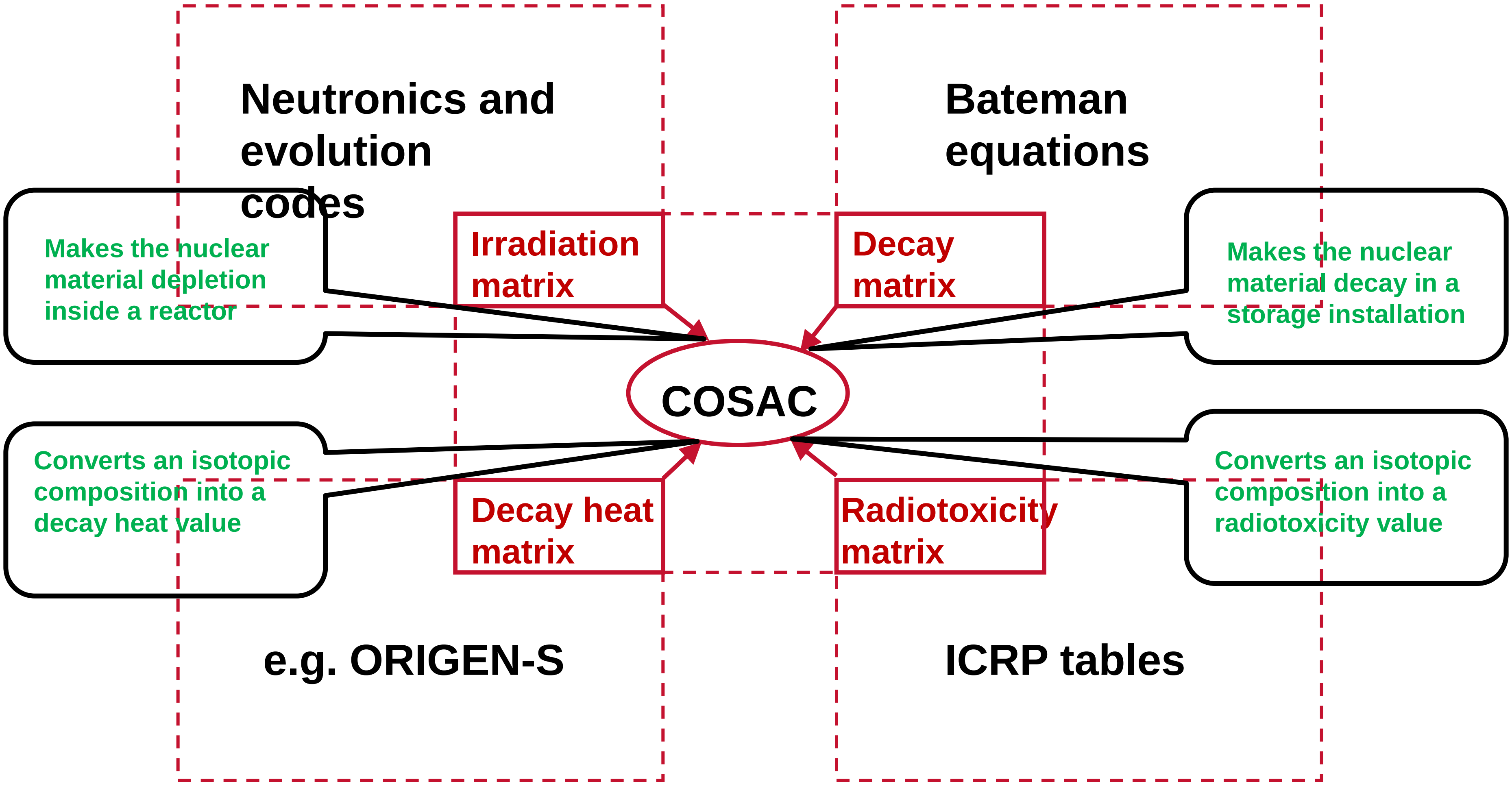
COSAC
Functional architecture



COSAC depletion process
Building an irradiation matrix

$$E_i = \begin{pmatrix} E_{i1} \\ . \\ . \\ . \\ E_{in} \end{pmatrix} \xrightarrow{\text{Under flux evolution code}} S_i = \begin{pmatrix} S_{i1} \\ . \\ . \\ . \\ S_{im} \end{pmatrix}$$

$(E_{i1},\ldots, E_{in})$ = fresh fuel isotopia

$(S_{i1},\ldots, S_{im})$ = spent fuel isotopia from $(E_{i1},\ldots, E_{in})$

n vectors

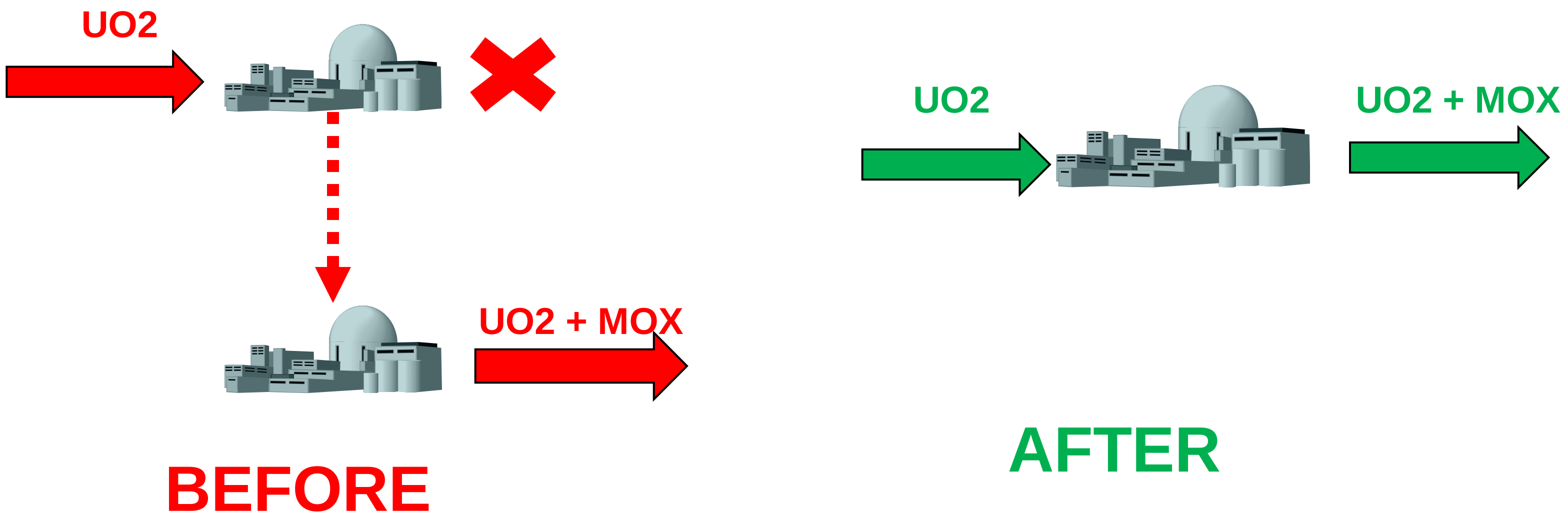
$$\underbrace{\begin{pmatrix} E_{11} \\ . \\ . \\ . \\ E_{1n} \end{pmatrix} \begin{pmatrix} E_{i1} \\ . \\ . \\ . \\ E_{in} \end{pmatrix} \begin{pmatrix} E_{n1} \\ . \\ . \\ . \\ E_{nn} \end{pmatrix}}_{\text{n vectors}} \xrightarrow{\text{Under flux evolution code}} \begin{pmatrix} S_{11} \\ . \\ . \\ . \\ S_{1m} \end{pmatrix} \begin{pmatrix} S_{i1} \\ . \\ . \\ . \\ S_{im} \end{pmatrix} \begin{pmatrix} S_{n1} \\ . \\ . \\ . \\ S_{nm} \end{pmatrix}$$

m isotopes

$$\text{Spent fuel} \left\{ \left[\underline{S} \right] = \underbrace{\left[\underline{\underline{M}}_{irr} \right]}_{\text{Irradiation matrix}} \cdot \left[\underline{E} \right] \right\} \text{Fresh fuel}$$

COSAC modelling
Recent improvements (1/4)

- **Possibility to change the fuel management inside a reactor without changing the reactor itself**



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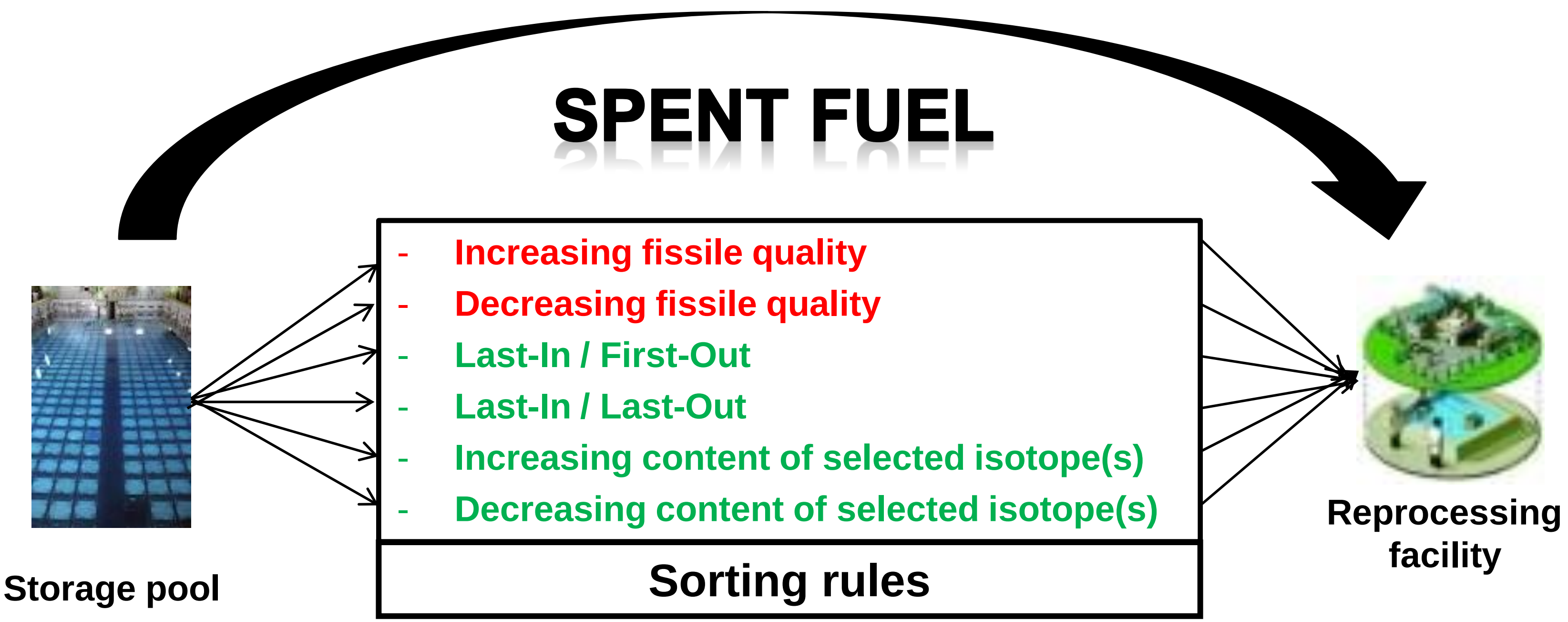
COSAC modelling
Recent improvements (2/4)

- **New sorting rules have been added to select which spent fuel to be first reprocessed**



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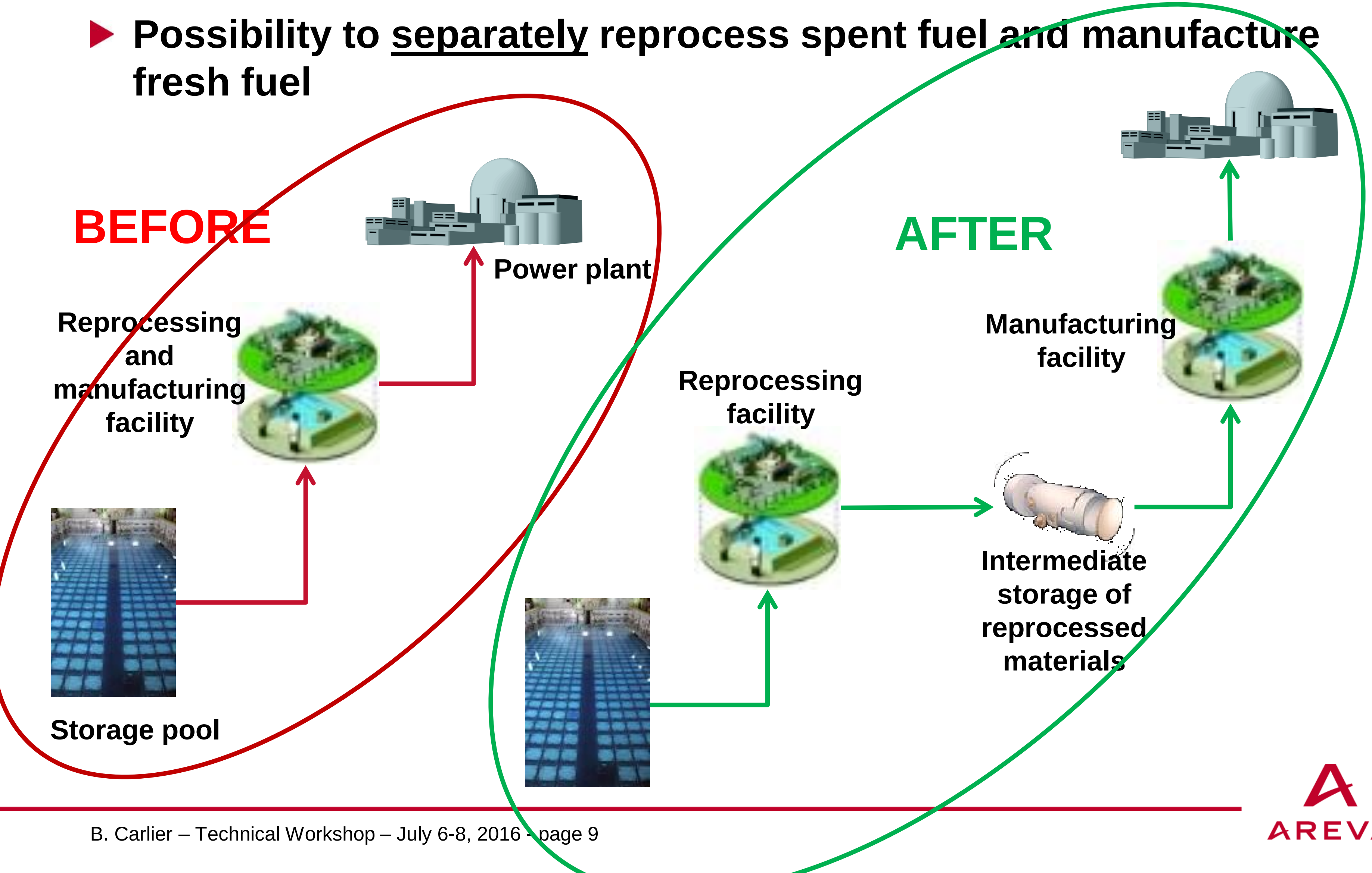
COSAC modelling
Recent improvements (3/4)

- **Possibility to <u>separately</u> reprocess spent fuel and manufacture fresh fuel**



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COSAC modelling
Recent improvements (4/4)

- **Evolution of the formula for the equivalency function:**

$t = \frac{E - e}{\alpha - e}$ (old formula) ➔ $t = \gamma . \frac{E - \beta}{\alpha - \beta}$ (new formula)

With: $\alpha = \sum_i \alpha_i . p_i$ ➔ $\alpha = \sum_i \alpha_i . p_i + \sum_{ij} \alpha_{ij} . p_i . p_j$

e = support enrichment ➔ $\beta = \sum_i \beta_i . u_i$

$0 \leq \gamma \leq 1$

- **More detailed displays of the out-of-run errors during a scenario calculation**
- **Minor bugs were fixed**

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COSAC
Overview of the GUI

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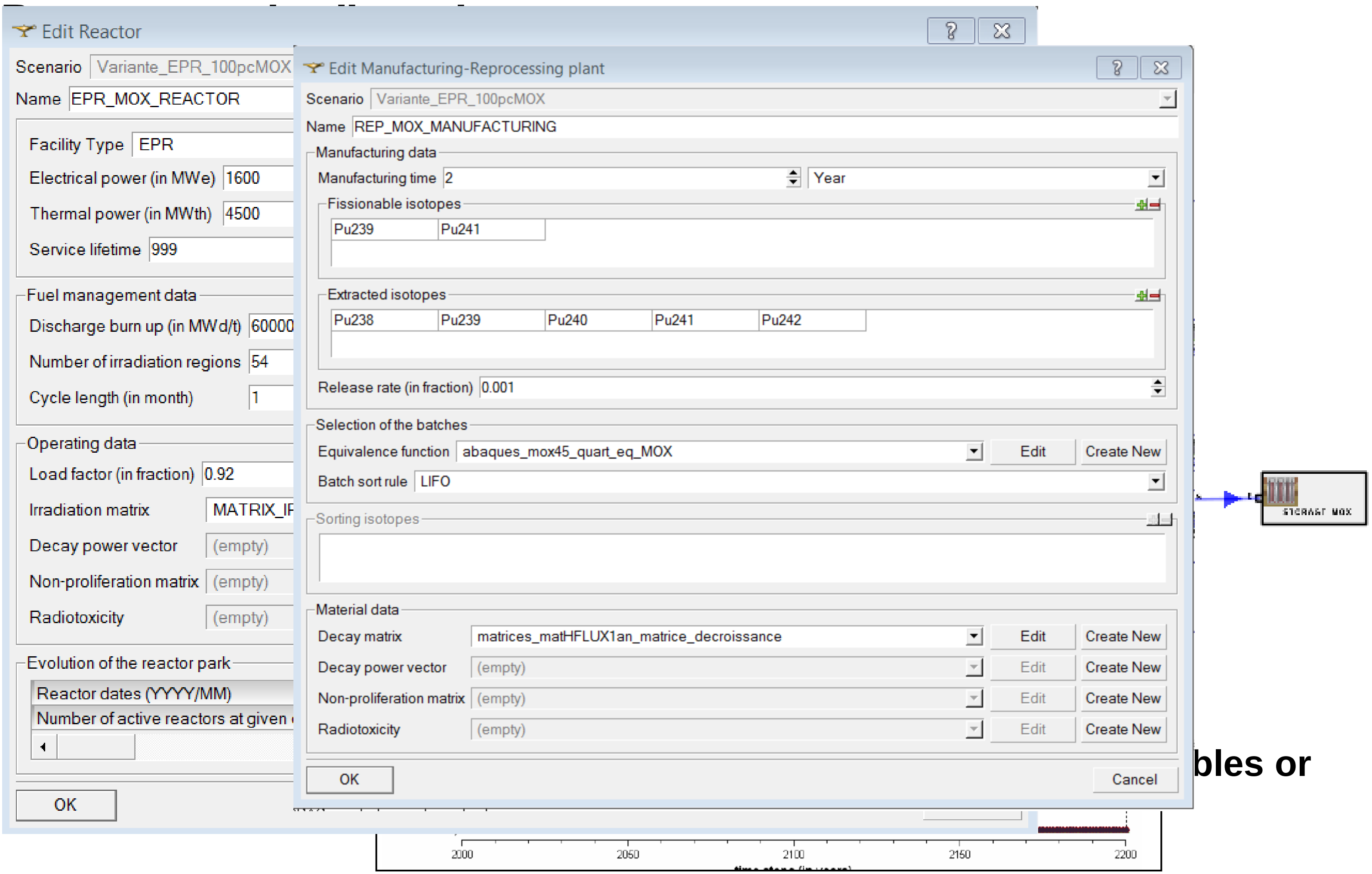

- “ … bles or

COSAC
Main outputs

- **At each time step (month or year), computation of:**
  - **Masses of nuclear materials inside the installations**
  - **Isotopic compositions of the nuclear materials**
  - **Material flows exchanged between the installations**
  - **Amount of energy produced**
  - **Amount of SWU (Separative Work Unit)**
  - **Decay heat and radiotoxicity calculations (if requested)**
  - **<u>No economics</u>**
- **Display of outputs for:**
  - **either a collection of installations or one installation**
  - **either a collection of isotopes (e.g. chemical element) or one isotope**

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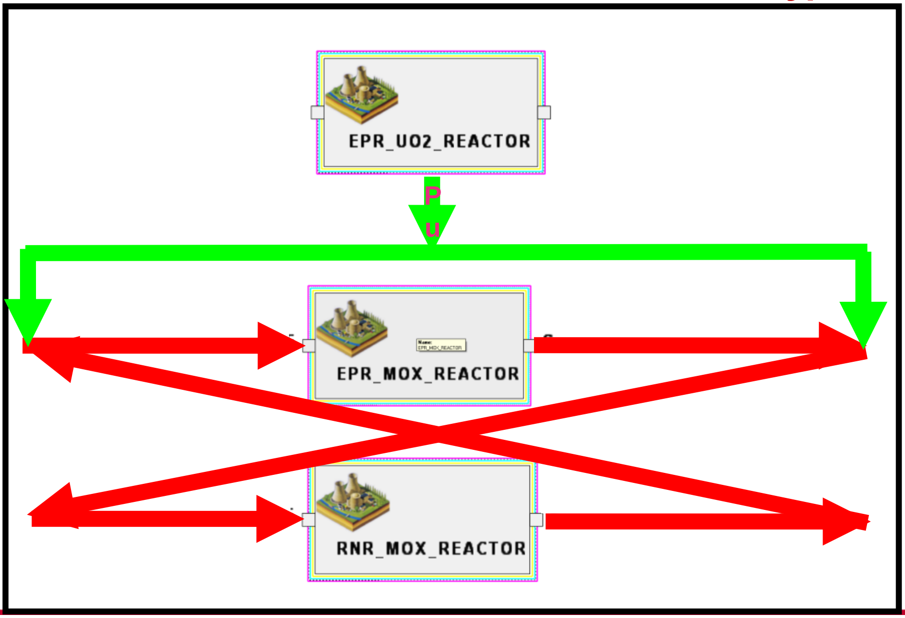
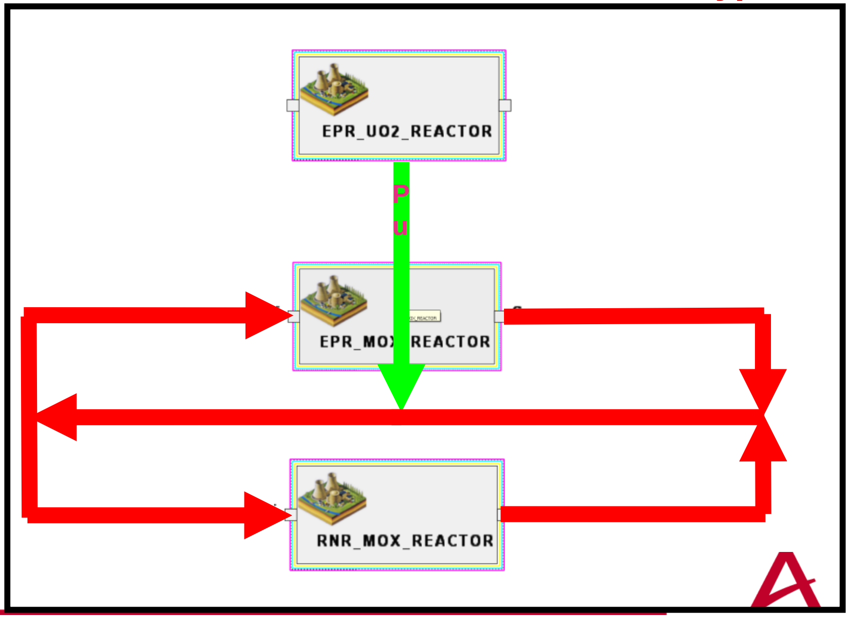
1st example of study with COSAC: symbiotic scenarios

- Theoritical study done in 2009-2010
- Objective: to load the plutonium exiting the SFRs into the MOX PWRs, and vice-versa
- Basic principle: to improve the Pu quality exiting SFRs so that Pu can be recycled into MOX PWRs
- 2 schemes of Pu flow circulation were studied: « cross-scheme » and « mix-scheme »

Cross-scheme: the Pu exiting one type of reactors can't be reloaded in the same type



Mix-scheme: the Pu exiting one type of reactors can be reloaded in the same type



Symbiotic scenarios: « cross-scheme » analysis

Theoritical assumptions

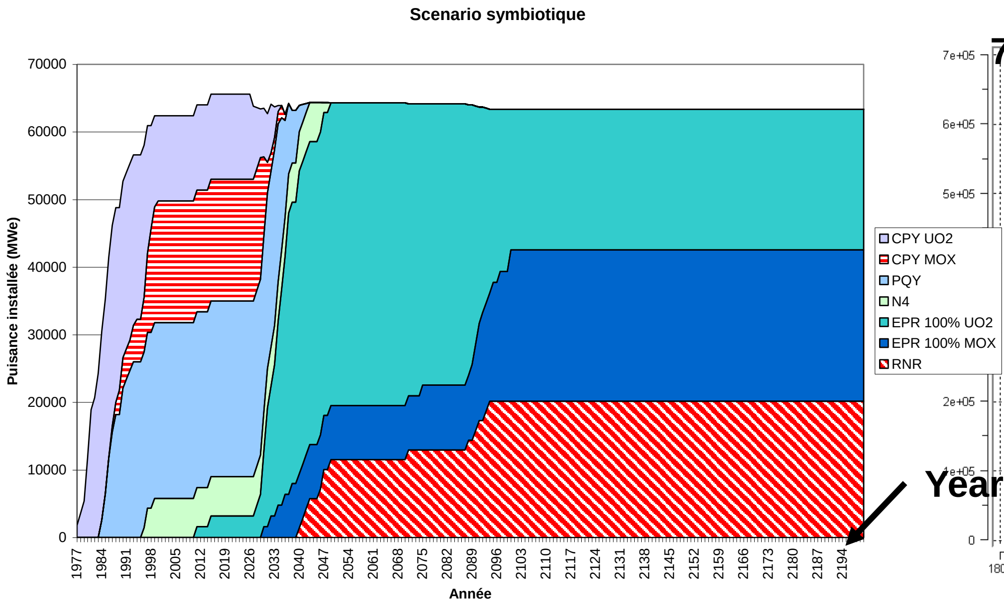
- infinite lifetime for the reactors
- no losses during reprocessing
- minimal cooling time (1 month)

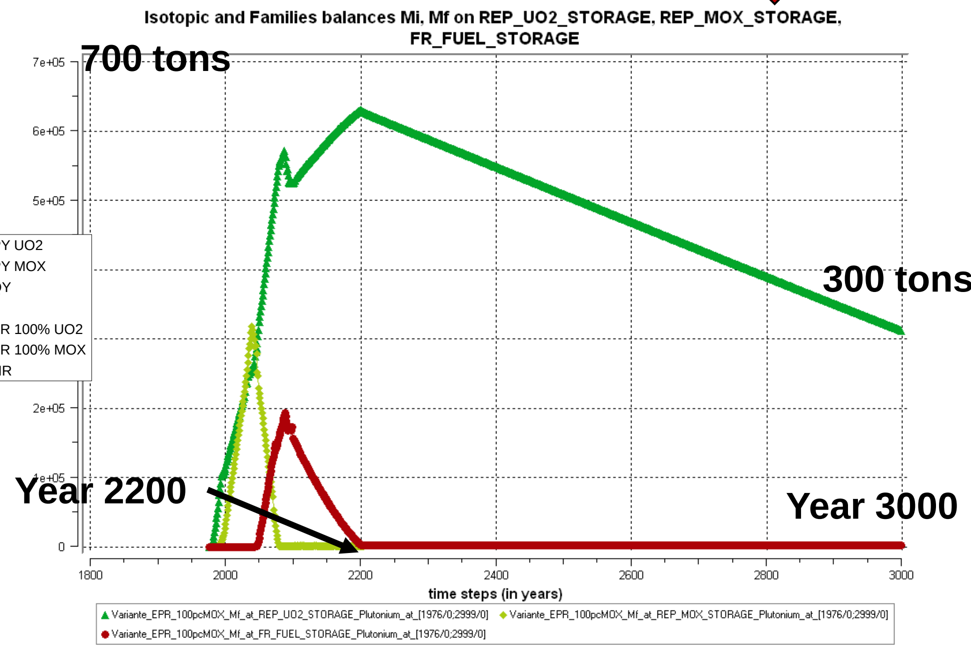
Equilibrium composition of the fleet:

1/3 UOX PWR – 1/3 MOX PWR – 1/3 MOX SFR

Pu inventories:

- in the spent PWR UOX stock
- in the spent PWR MOX stock
- in the spent SFR MOX stock





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Symbiotic scenarios: « mix-scheme » analysis

Theoritical assumptions

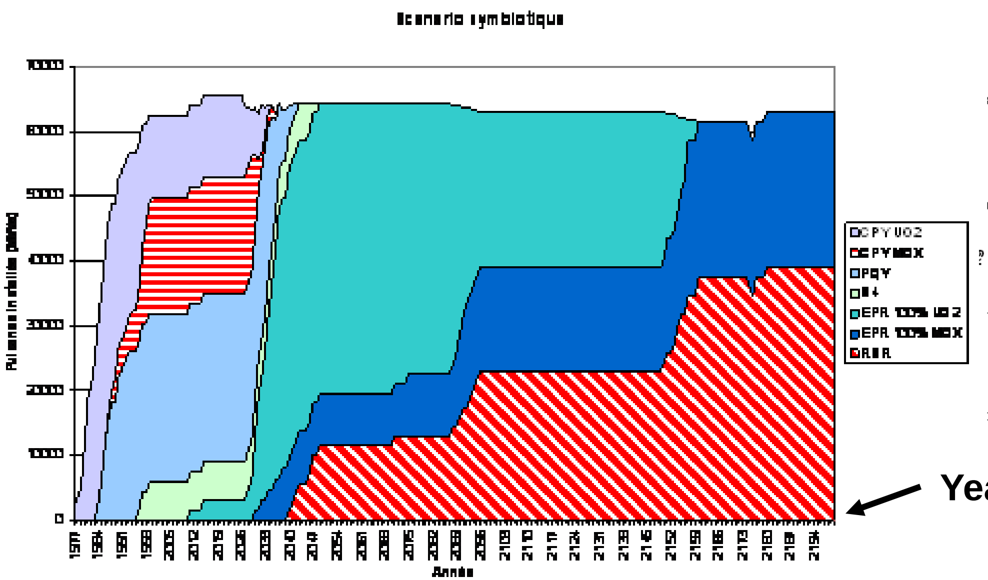
- infinite lifetime of the reactors
- no losses during reprocessing
- minimal cooling time (1 month)

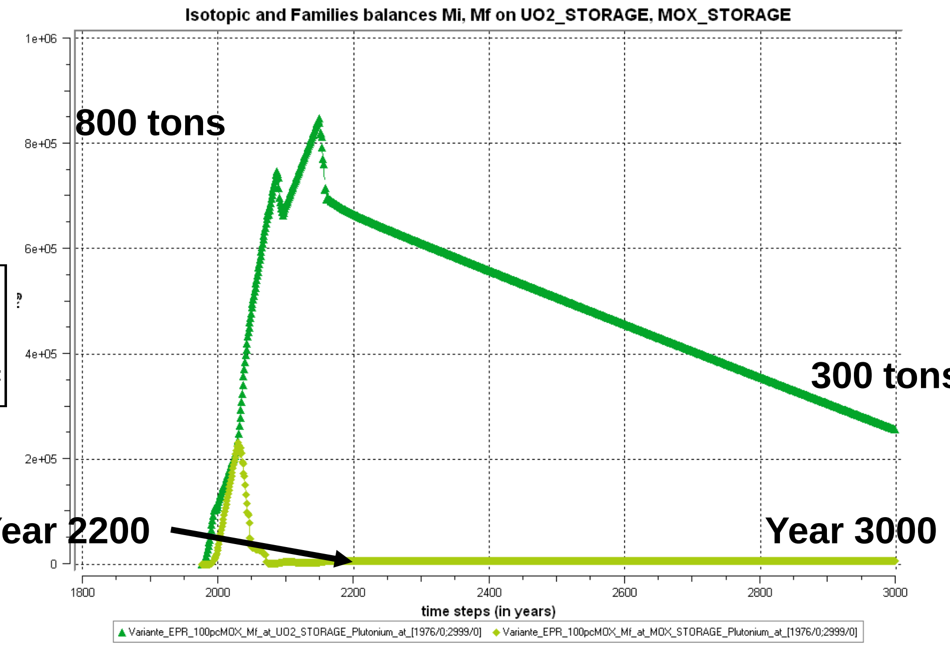
Equilibrium composition of the fleet:

40% MOX PWR – 60% MOX SFR

Pu inventories:

- in the spent PWR UOX stock
- in the spent MOX stock (either PWR MOX or SFR MOX)





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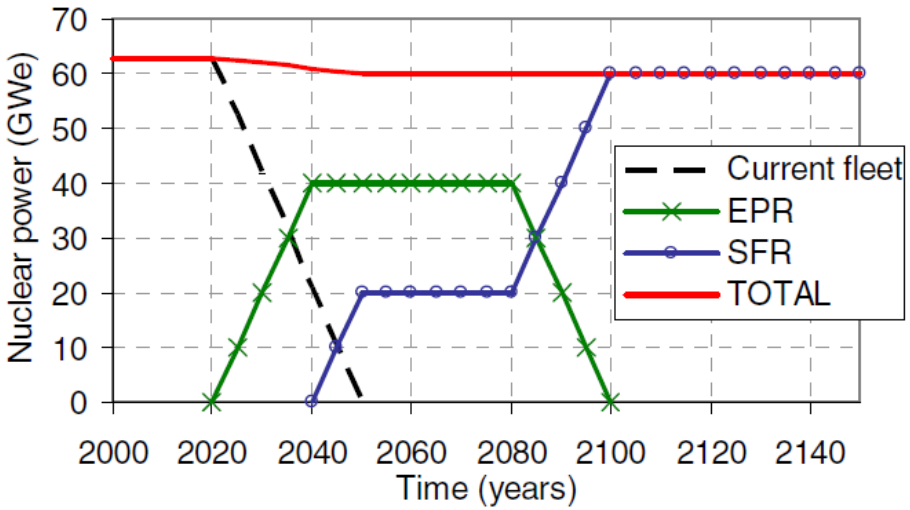
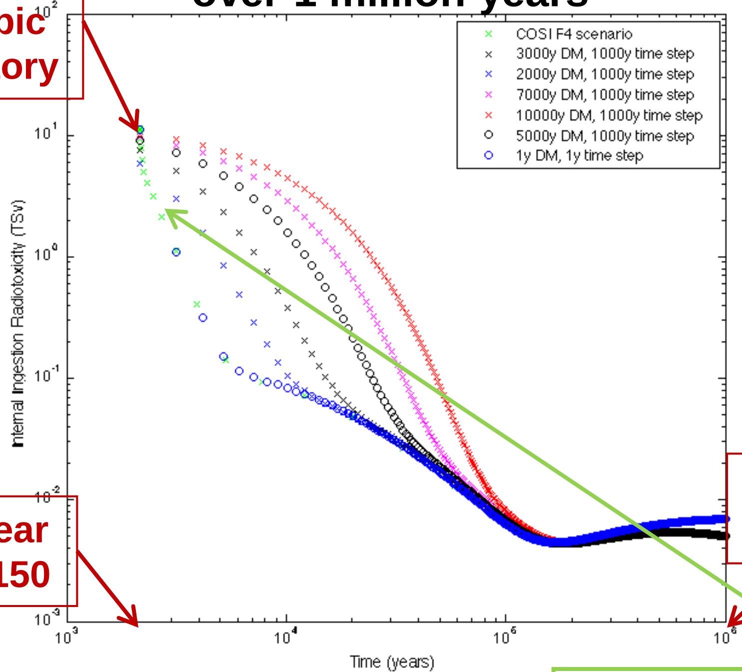
2nd example of study with COSAC: radiotoxicity and decay heat calculations

- **Internship during Summer 2011**
- **Expected goals:**
  - **Generate the appropriate data to enable decay heat and radiotoxicity calculations in COSAC**
  - **Benchmark the radiotoxicity and decay heat results with CEA results on a reference scenario**
  - **Optimize the choice of some parameters of the calculation to make the computation as accurate as possible**
- **Reference scenario (F4):**
  - **2000-2150: duration of the scenario**
  - **2150: initial isotopic inventory of spent fuel to decay**

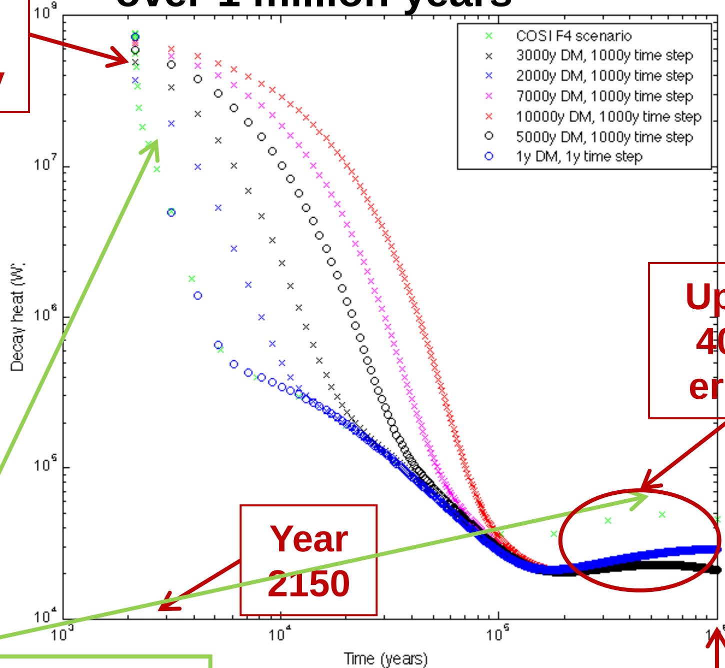


Optimizing radiotoxicity and decay heat calculations: choosing a Decay Matrix (DM) and a Time Step (TS)

Evolution of the Radiotoxicity over 1 million years



Evolution of the Decay Heat over 1 million years



CEA results (reference values)

- The choice of the duration for a Decay Matrix (DM) and the choice of a computational Time Step (TS) may affect the accuracy of the calculations.
- Six different durations for the DM were used to identify the most suitable one
- The same was done for the computational TS
- Conclusion: the TS used for the computation should always be equal to or greater than the duration of the DM

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Optimizing decay heat calculations: isotope study

Four fuel types at three different burnups were studied with the aim of identifying the shortest possible list of isotopes:

	Burnups studied					
Fuel	40 GWd/t	50 GWd/t	60 GWd/t	80 GWd/t	100 GWd/t	136 GWd/t
PWR UOX (U enrichment: 4.95%)	x	x	x			
PWR MOX (Pu content: 9%)	x	x	x			
SFR MOX (Pu content: 17%)				x	x	x
SFR MOX (Pu content: 23%)				x	x	x

Reference calculations were used for comparisons (ORIGEN for PWR-calculations and CESAR for SFR-calculations)

Accuracy target = 99% for mass inventory and heat decay

The obtained result was a list of 159 isotopes (instead of 109 used for the internship study)

3rd example of study with COSAC: introduction of PWRs with High Factor of Conversion (HFC PWRs)

- **Aims of the study**
  - **Introduction of some HFC PWRs in the French fleet before the arrival of SFRs**
  - **Several ways to manage the plutonium**
    - Mono-recycling of the plutonium coming from UOX PWRs into MOX PWRs
    - Multi-recycling of the plutonium either into HFC PWRs or into SFRs (or both)
    - Possibility to re-use the plutonium coming from HFC PWRs & SFRs into MOX PWRs (in case of excess of plutonium)
- **Two scenarios were studied**
  - **Scenario A: both HFC PWRs and SFRs are present at the equilibrium state**
  - **Scenario B: introduction of only one generation of HFC PWRs (limitation in time)**
- **Main assumptions**
    - Total installed power remains roughly steady: about 60 GWe (430 TWhe/year)
    - HFC PWR with a factor of conversion of 0.85: chosen as an intermediate value between triangular lattice design (value = 0.92) and rectangular lattice design (value = 0.8)
    - SFR: FC about 1 or FC = 1.2 (depending on the needs in plutonium)

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Scenario A:
looking for an equilibrium with all the technologies concomitant

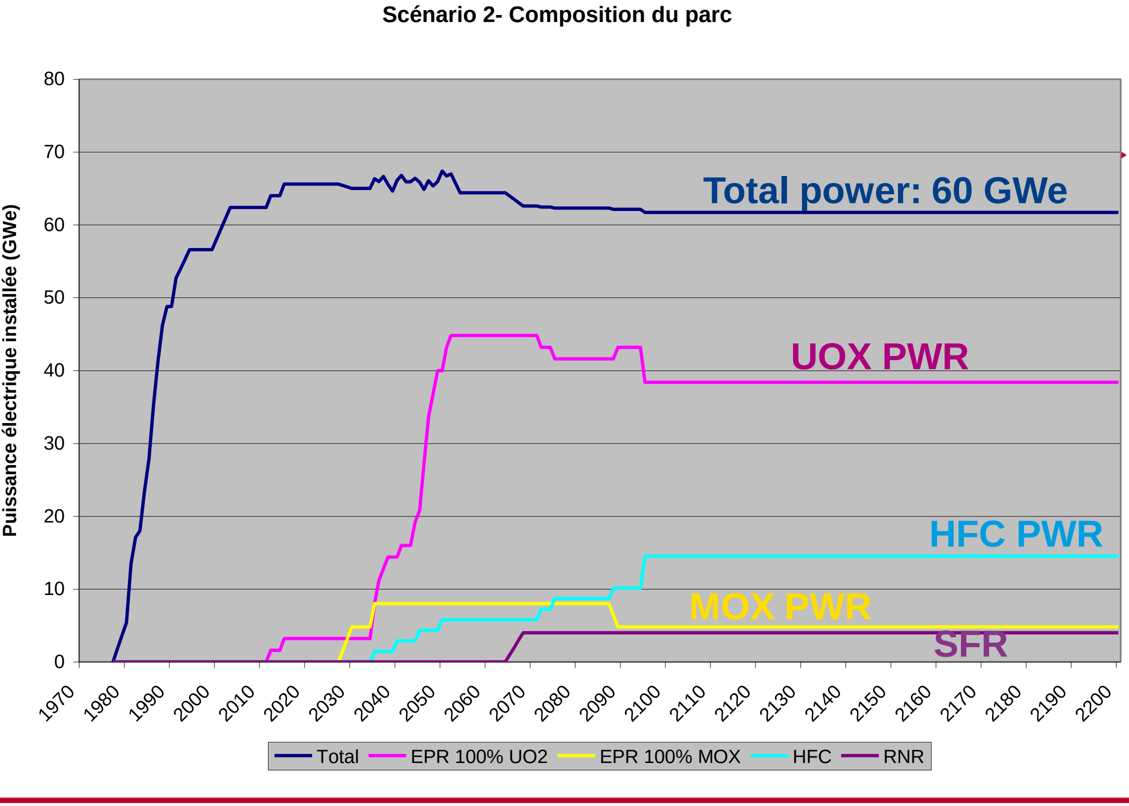
Assumption: once deployed, a technology remains present for the rest of the scenario

Composition of the fleet at the equilibrium (% of installed power)

➔ Equilibrium is reached after year 2100 ⟵

UOX PWR: 62% | **MOX PWR: 8%**

HFC PWR: 23.5% | **SFR: 6.5%** (FC = 1.2)



Schedule of technology deployment (from today to year 2200):

- **Deployment of UOX PWRs and MOX PWRs from year 2012 to replace the old PWRs Several generations**
- **Deployment of HFC PWRs from year 2035 Several générations**
- **Deployment of SFRs from year 2065 Several generations**

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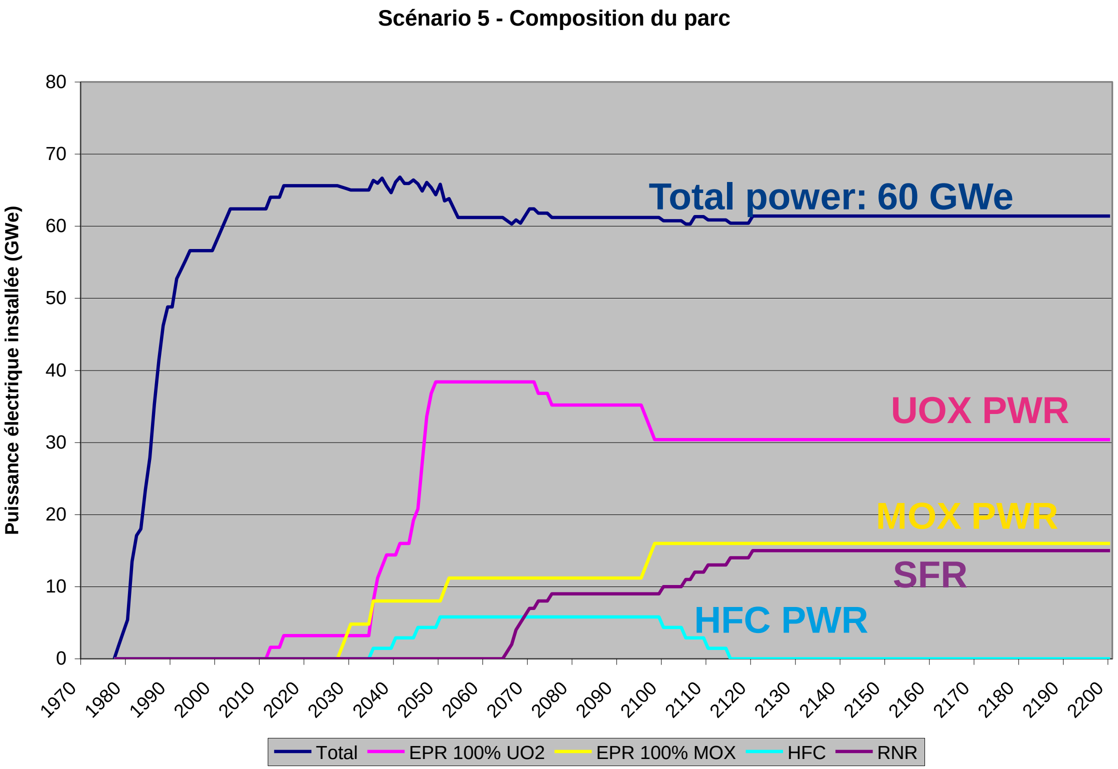
Scenario B:
HFC PWRs as a transition step towards SFRs

Assumption: as soon as available, SFR technology replaces HFC PWR technology

Composition of the fleet (% of installed power)

Step #1: t < 2060	**UOX PWR: 60%**	**MOX PWR: 30%**	**HFC PWR: 10%**
Step #2: t > 2115	**UOX PWR: 49.5 %**	**MOX PWR: 26.1 %**	**SFR: 24.4%** (FC = 1.04)



Schedule of technology deployment (from today to year 2200):

- **Deployment of UOX PWRs and MOX PWRs from year 2012 to replace the old PWRs**
  Several generations
- **Deployment of HFC PWRs from year 2035**
  Only one génération
- **Deployment of SFRs from year 2065**
  Several generations

THANK YOU

FOR YOUR ATTENTION!