Estimation of the vitrified canister production for a PWR fleet with the CLASS code

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Introduction

Fuel cycle strategy analysis ➞ Fuel cycle impact quantification

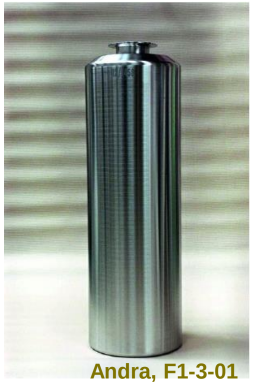
- **One output of interest: waste production**
  ➞ Effects: deep geological waste repository, …
  - CLASS used for actinide inventory quantification *(mass & isotopy)*
  - *But o*ther important physical quantities
  - Vitrified canisters (CSD-V)

➞ New developments in CLASS

Core Library for Advanced Scenario Simulation

Simplified vitrification model

- **Reprocessed HM mass**
- **Criteria**
  - Decay heat at production time
  - Cumulative α dose over 10 000y
  - FPA oxide mass content
- **Number of CSD-V produced**



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Outline

1. Global approach validation
2. Data base construction
3. Simplified vitrification modelling
4. Scenario definition
5. Scenario analysis

Global approach validation

Strong variations of decay heat with FP isotopic composition

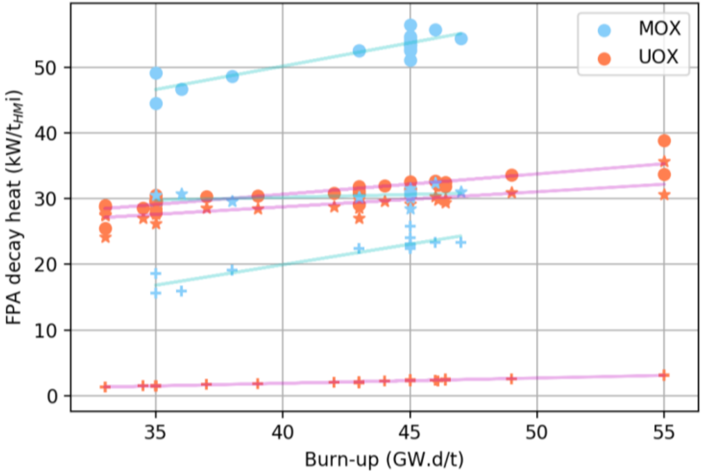
FP calculation in CLASS

- « *Usual* » method: ANN predictions per isotopes
  - Some XS missing for precise FP calculation
    - Mean deviation for MOX fuels ~10%
  - <u>Increase of simulation time</u>

- **Global approach**
  - CESAR calculations: different UOX & MOX compositions
  - Mass: linear functions of burn-up
  - Decay heat: functions of burn-up <u>if TC>3 years</u>
  - ➞ Function of fuel type, compositions, burn-up & TC

➞ Direct prediction of the quantities of interest in CLASS

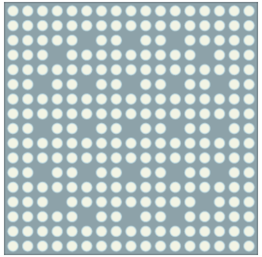
TC = 90 days



* Fission products
\+ Actinides
● FPA

Data base construction

2 data base family: depletion simulations ➞



- **Sampling *(LHS)***
  - UOX/ERU: 200 initial compositions ➞ VU + ^{235}U enrichment
  - MOX/MIX: 500 initial compositions ➞ VPu +Pu content + ^{235}U enrichment
  - Discharge burn-up ➞ [0;55] GW.d/t
  - Cooling time ➞ [3;100] y

- **Post-irradiation data calculation**
  - Decay heat at production
  - Cumulative α dose over 10 000y
  - FPA oxide mass content

➞ Generation of 6 predictors *(Artificial Neural Networks)*

Data base construction

2 data base family: depletion simulations ➞

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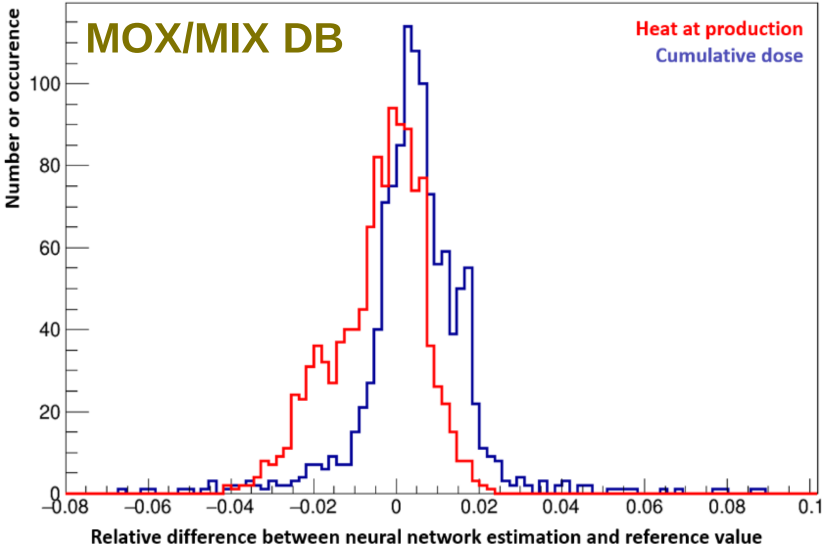
- **Predictor accuracy verification**
  - Independent data bases
  - Standard deviation on CSD-V production **<1.5%**



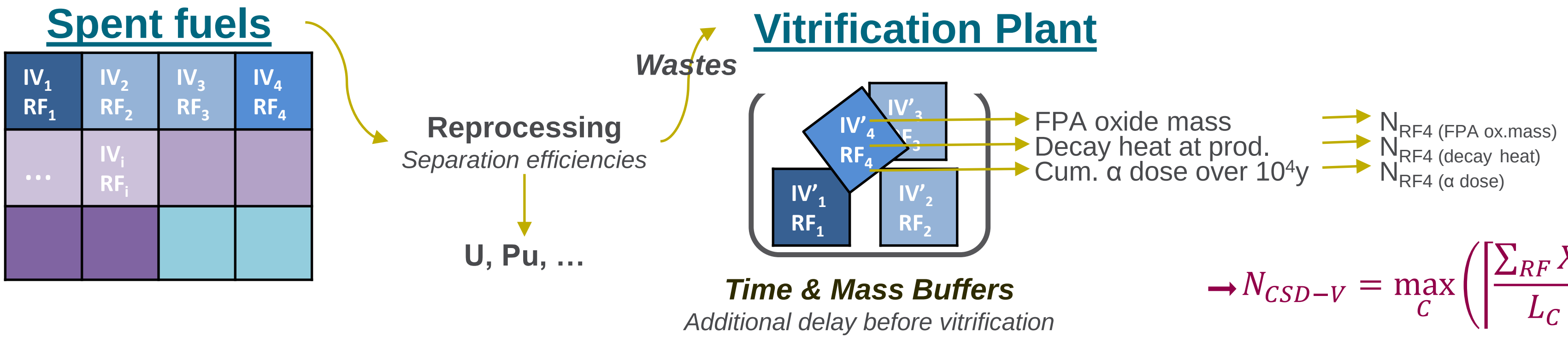
Simplified vitrification modelling

ReactorFuel

- **Fuel fabrication ➞ Waste vitrification**
  - Fuel & reactor type
  - Initial fuel composition
  - Discharge burn-up
  - Updated cooling time before vitrification

Vitrification Plant

- **CSD-V characteristics**
  - Container mass
  - Conversion factor *(HM mass ➞ oxide mass)*
  - Buffers
  - Limit values for the 3 criteria L_C
- **For each RF ➞ ANN predictions** X_C

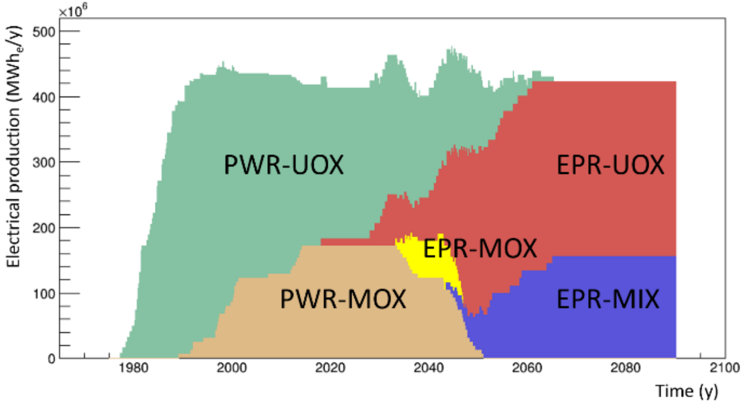


$$\rightarrow N_{CSD-V} = \max_{C}\left(\left\lceil \frac{\sum_{RF} X_C}{L_C} \right\rceil\right)$$

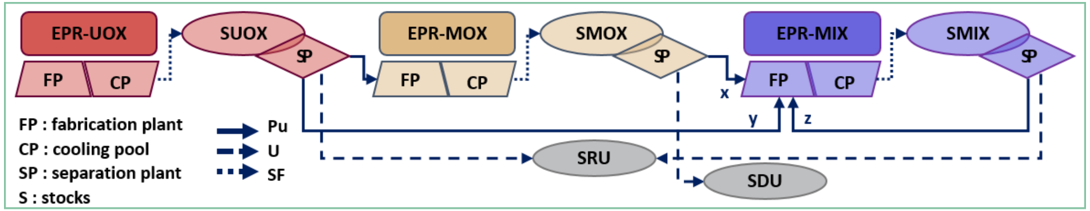
Scenario definition

Pu mono-recycling fleet ➞ Pu multi-recycling fleet

G. Martin *et al.*, French scenarios toward fast plutonium multi-recycling in PWR, ICAPP 2018



- **EPR**
  - 1530 MW_e, 51.8 GW.d/t, 129 t_{HM}
- **Fuels**
  - MIX: Pu content 8%, ^{235}Ue <5%
  - MOX: Pu content <12%
  - UOX: ^{235}Ue <5%
- **Cycle**
  - T_{Fab} 2y
  - Minimal T_C 5y
- **Vitrification**
  - CSD-V mass 410 kg
  - Conversion factor 1.2
  - Limits
    - FPA oxide mass 18.5%
    - Decay heat 3 kW/CSD-V
    - α dose 2.5 10^{19} α des/g of glass



Scenario definition

Pu mono-recycling fleet ➞ Pu multi-recycling fleet

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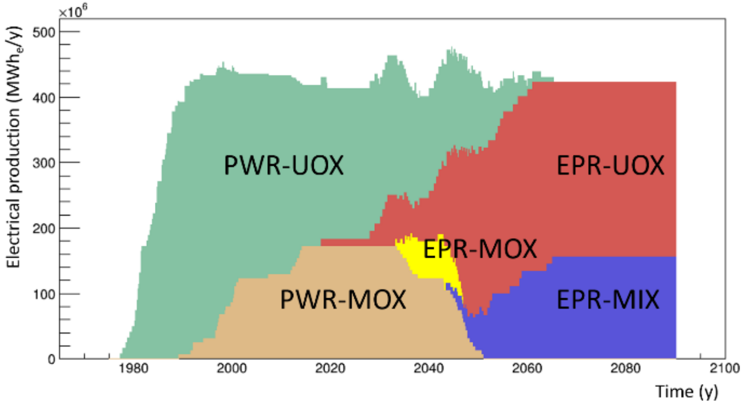
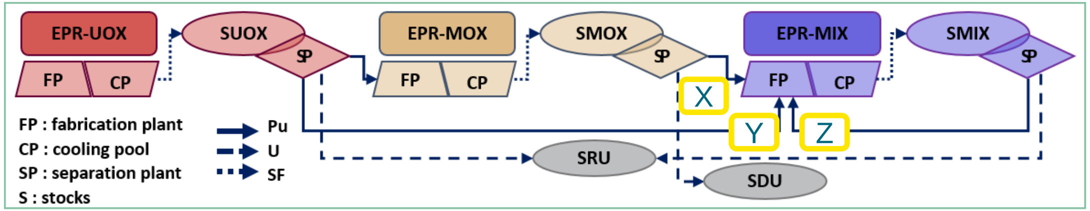
- **Parameters**

UOX SF repro. for MOX fab.	LIFO / FIFO
UOX, MOX, MIX SF repro. for MIX fab.	LIFO / FIFO
Stock priority sorting for MIX fab.	Without priority / X > Y > Z *(6 possibilities)*
Vitrification buffer	None / 2y / 5y / 200t / 1000t

➞ 84 simulations

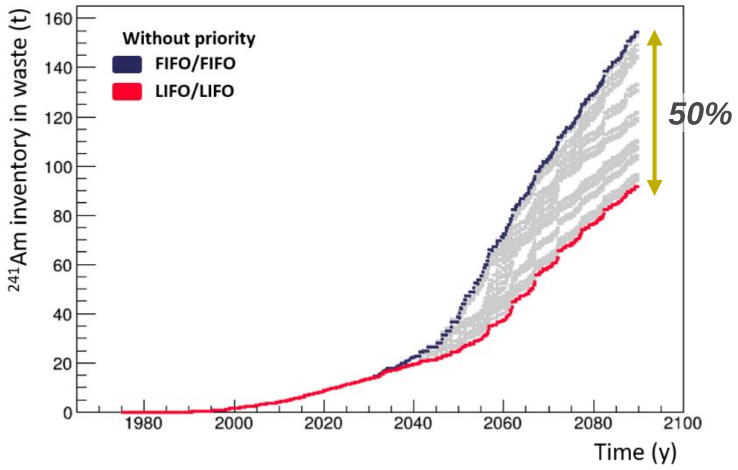


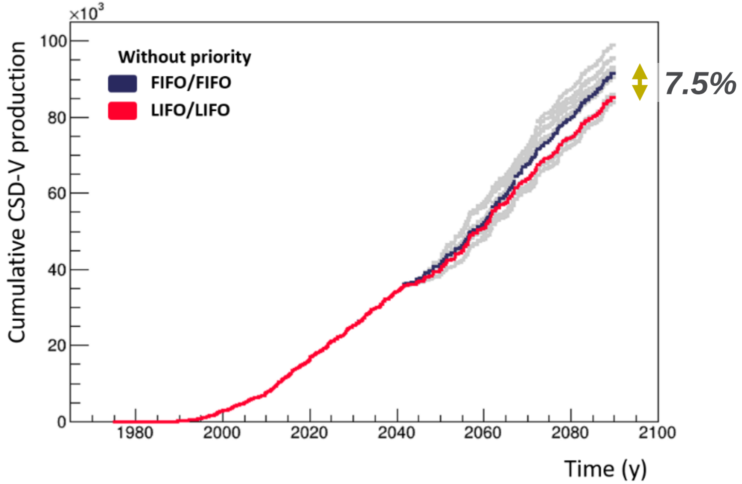


Waste inventory

^{241}Am optimisation ≠ CSD-V optimisation

- **FIFO / FIFO**
  - Maximal TC before reprocessing ➞ Maximal ^{241}Pu decay ➞ Maximal ^{241}Am (MA & Am) inventory
  - 'Old' SF treatment not a priority
  - ^{241}Am: high impact on α dose **BUT** not the main driver of CSD-V production

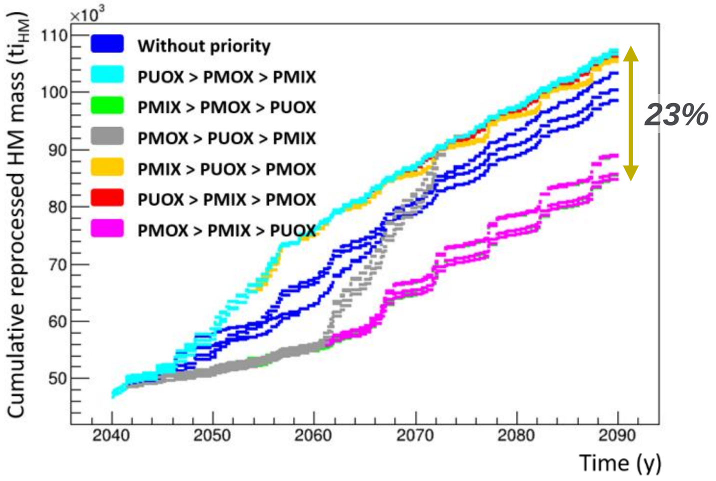


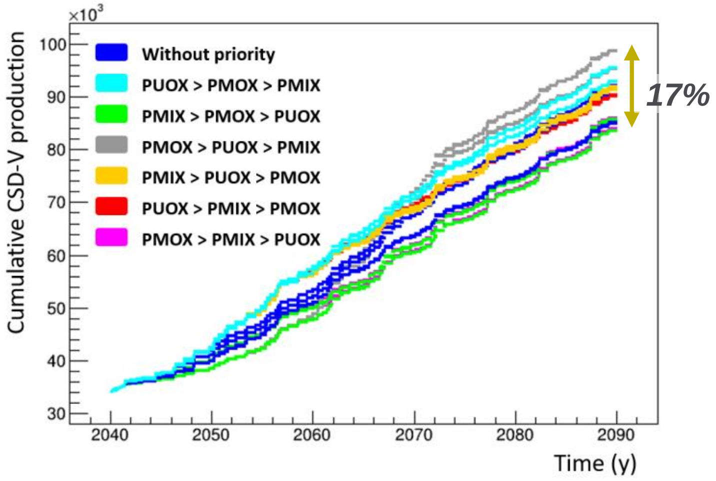


Reprocessed HM mass

Stock priority sorting for MIX fabrication & CSD-V production

- **UOX SF priority**
  - Less Pu in UOX SF ***and*** Pu content = 8% in MIX fuel ➞ higher reprocessed HM mass ➞ more CSD-V
  - Less MAs in UOX SF ➞ less alpha dose in the vitrified wastes ➞ less CSD-V / t_{HM}
  - Different variations: more reprocessed HM mass ***but*** less CSD-V per reprocessing



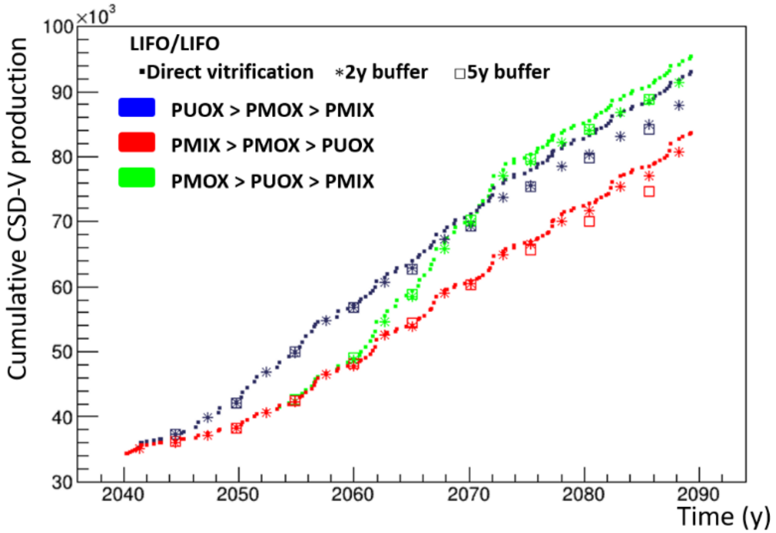


Buffer impacts

Double advantage due to buffers

- **Increase the cooling time before vitrification**
  - Decay heat decrease
  - No ^{241}Am inventory increase *(Pu already separated)*
- **Increase mixing possibilities**
  - Reduction of MIX & MOX α dose / t_{HM} reprocessed
  - Optimising the container load

	2-year buffer	5-year buffer
$P_{MOX} > P_{UOX} > P_{MIX}$	2.5%	2.3%
$P_{UOX} > P_{MOX} > P_{MIX}$	4.0%	4.7%
$P_{MIX} > P_{MOX} > P_{UOX}$	8.0%	10.8%



Conclusions

New CLASS feature : simplified vitrification modelling

- **CSD-V estimation**
  - Physical limit calculations thanks to predictors

    ➞ ANN trained on SMURE depletion data bases

    ➞ Models for PWRs UOX/ERU and MOX/MIX fuels

    ➞ Decay heat, cumulative alpha dose and FPA mass content
  - Physical analysis of limits reached during vitrification
  - Other outputs of interest: required reprocessing capacities

Application to plutonium multi-recycling scenarios

- **Variable reprocessing strategies**
  - Impact on required reprocessing capacities (~23%) ; smaller impact on CSD-V production (~17%)
- **^{241}Am mass in wastes ➞ not the main driver for the estimation of CSD-V production**
- **Variable vitrification parameters**
  - Buffer impact up to ~ -10% for CSD-V production (*but not systematic*)

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Thanks !

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Donnons toute sa valeur au nucléaire