Transition Analysis with Cyclus

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Introduction

- DOE start a campaign to assess US nuclear future on different criteria:
  - nuclear waste management,
  - resource utilization,
  - environmental impact...
- Evaluation and screening (E&S) phase evaluate 40 equilibrium scenarios called “Evaluation Group”

- EG23 & EG29 are part of the 4 “most promising” one

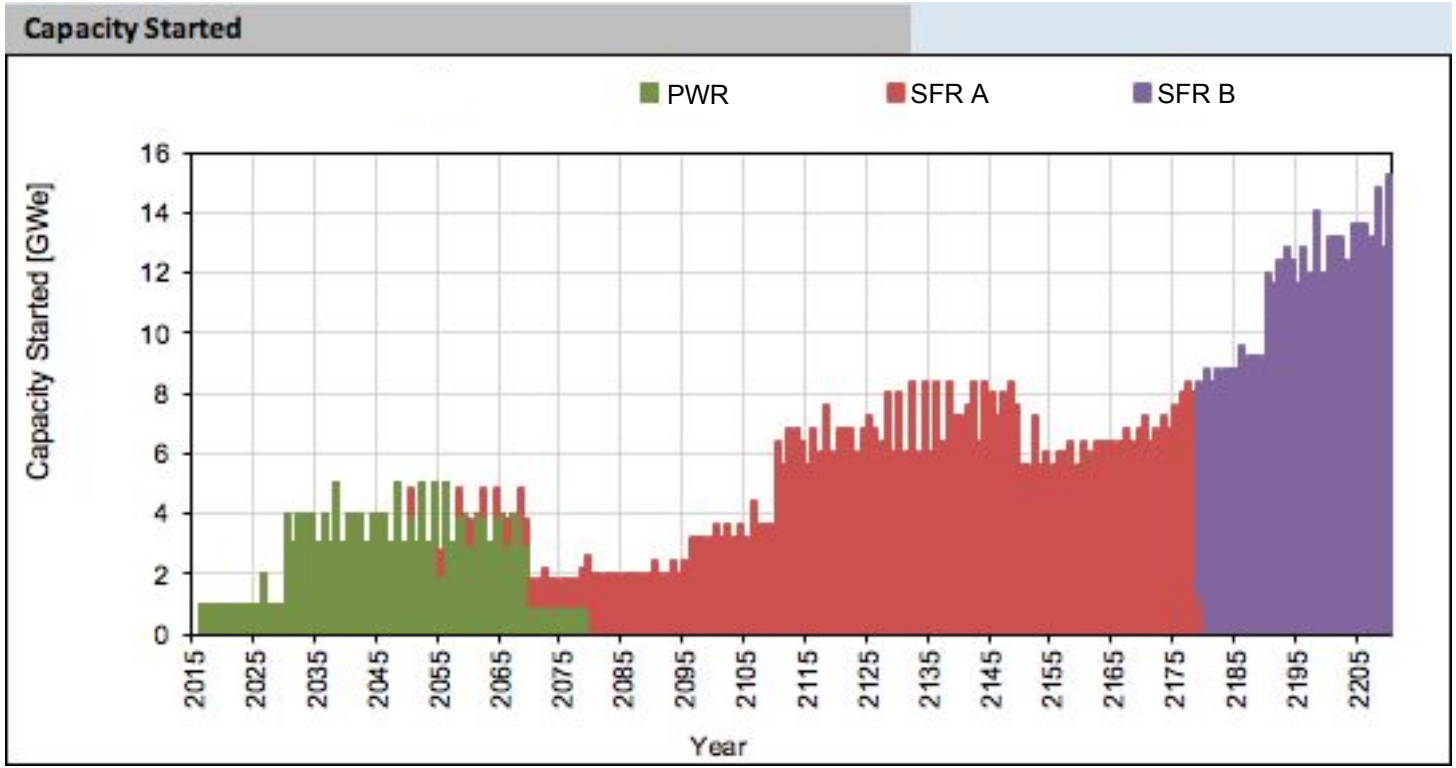
- EG23: 100% SFR
- EG29: 70/30 SFR/PWR fleet
  both using multi-MOX fuel, feeded with high quality Pu from SFR blanket

EG23 transition

- Transition from 100 PWR-UOX to 100% FBR-MOX
- 1% annual grows of nuclear electricity production

- In order to minimize plutonium accumulation:
  - Deployment of a second wave of PWR
  - 2 waves of SFR:
    - Start high breeding SFR deployment
    - Second wave of lower breeding ratio SFR

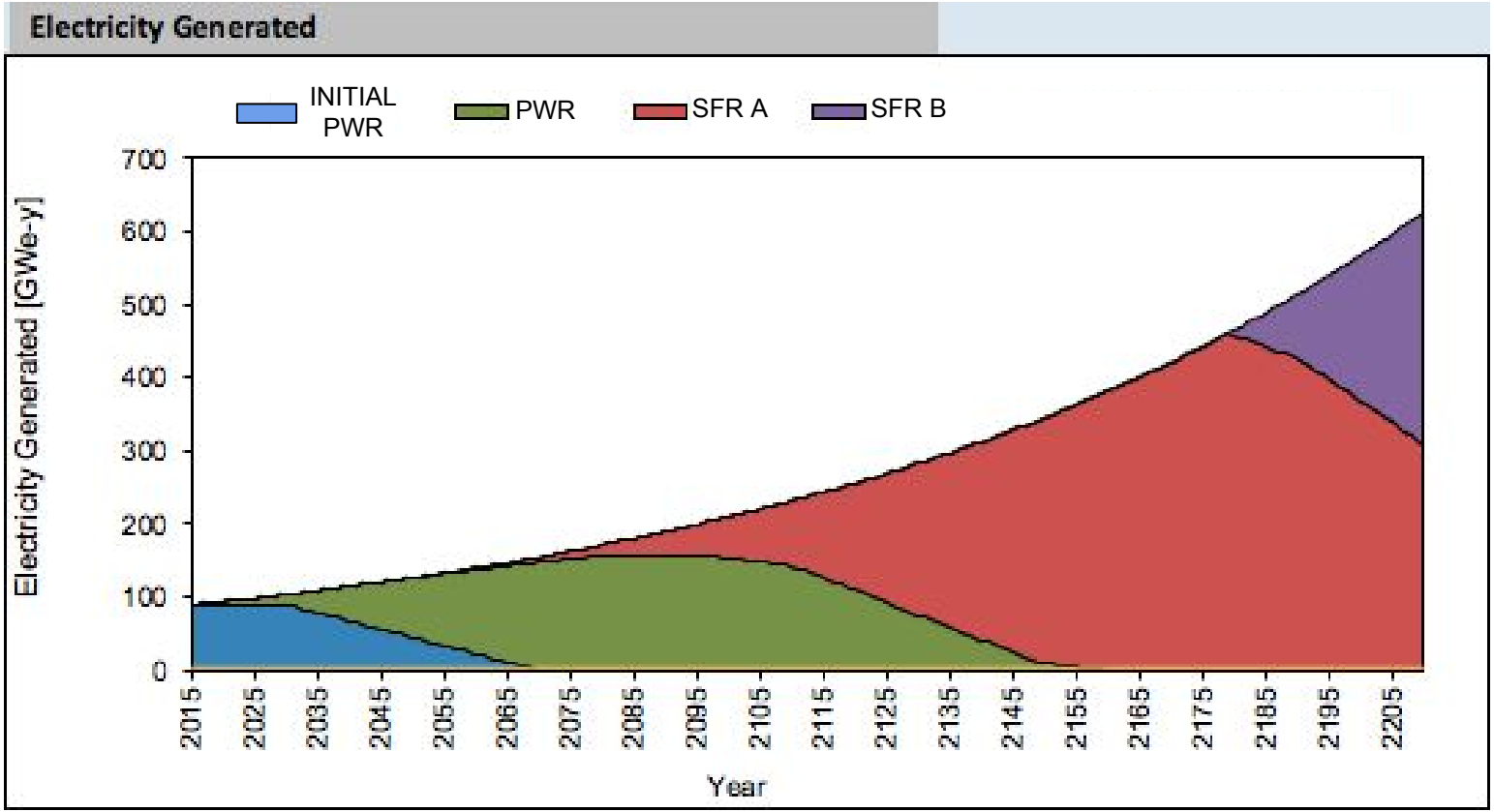
To EG23: deployment



PWR: UOX
SFR A: high breeding ratio
SFR B: low breeding ratio

B. Feng. Preliminary DYMOND results for example scenario with updated assumptions. 07/2015. 2, 3, 4

EG23: Electricity generated



EG23: Cycle Specifications

Core Specifications	LWR	SFR 1	SFR 2
Rated Power, [MWe]	1000	400	400
Thermal Efficiency	0.33	0.4	0.4
Capacity Factor	0.90	0.90	0.90
Burnup, [Gwd/tHM]	50	47.501	42.397
Number of batches	3	5.44	4.44
Cycle length, [month]	18	12	12
Core Inventory, [tHM]	3×29.565	37.62	34.40
Cyclus implementation			
Assembly size [kgHM]	29565	1383.09	1549.55
Assembly in the core	3	27	22
Assembly per batches	1	5	5
Cycle length, [month]	18	12	12
Core Inventory, [tHM]	3×29.565	27×1.383	22×1.549

Table 1: Reactor core properties.

Reactor		LWR [%w]	SFR fuel 1 [%w]	SFR fuel 2 [%w]
In recipe	235U	4.2	0	0
	238U	95.8	92.36	91.466
	Pu	0	7.64	8.534
Out recipe	235U	0.8	0	0
	238U/U	92.68	85.99	86.025
	Pu	1.2	9.02	9.596
	MA	0.11	0.13	0.107
	FP	5.21	4.86	4.272

Table 2: Fuel recipes

No detailed Isotopic monitoring

EG23: Fuel Loading/Cooling

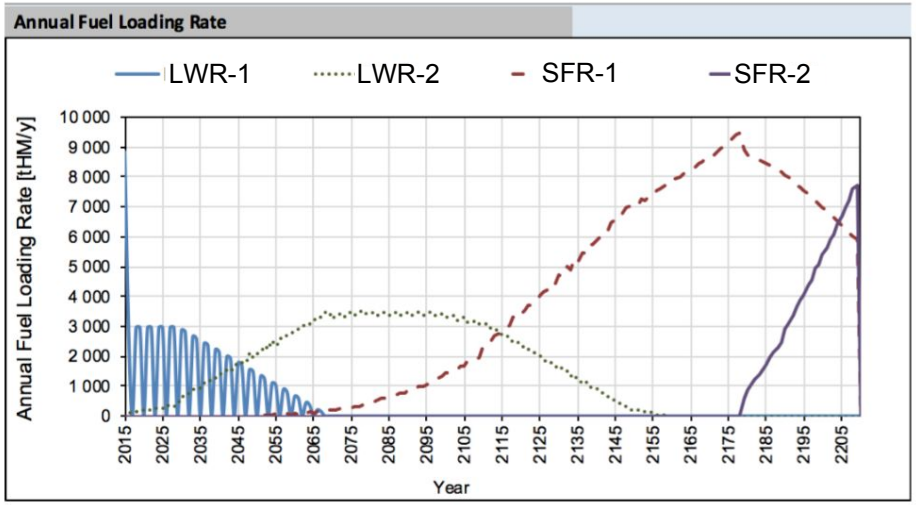


Figure 2: Fuel loading rate

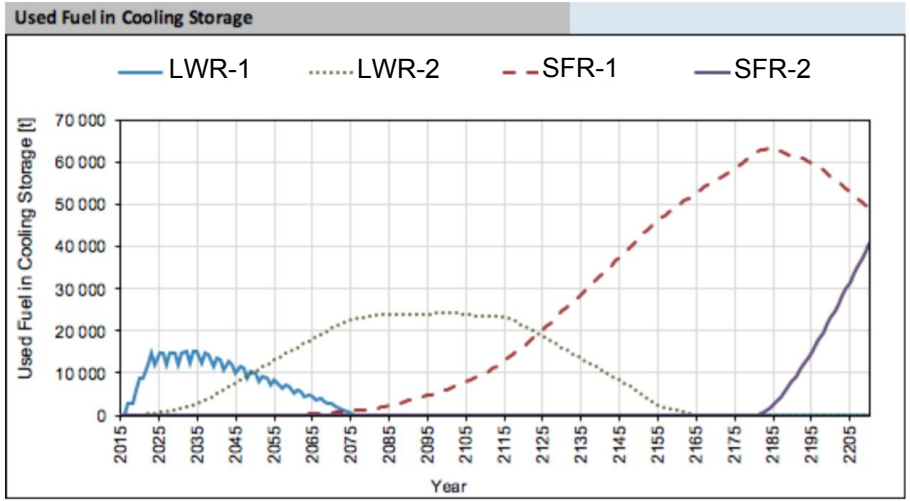
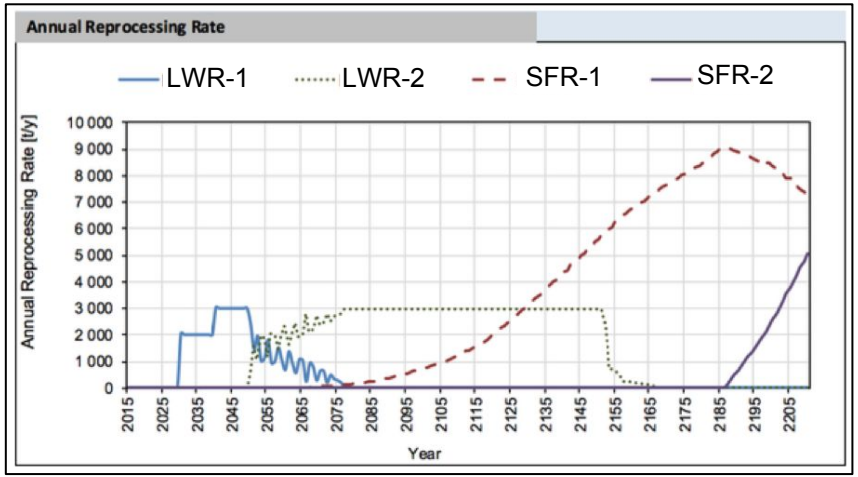


Figure 3: Used Fuel in Cooling Storage

Reprocessing

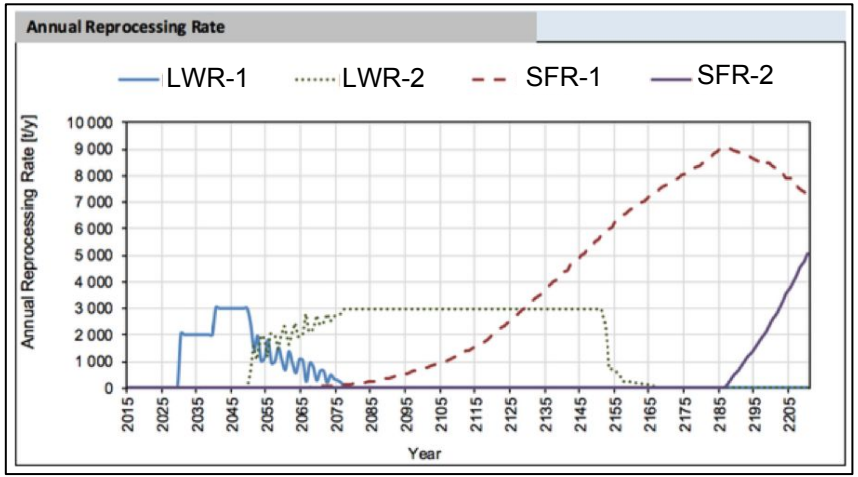


Separation Implementation	LWR	SFR 1/2
Throughput [tHM/month]	83.3333	5000
feed buffer [tHM]	107.537	5000
Pu output buffer [tHM]	Unlimited	5000
Pu separation efficiency	0.99	0.99
Recycled U buffer [tHM]	Unlimited	Unlimited
U separation efficiency	0.99	0.99
Waste buffer [tHM]	Unlimited	Unlimited

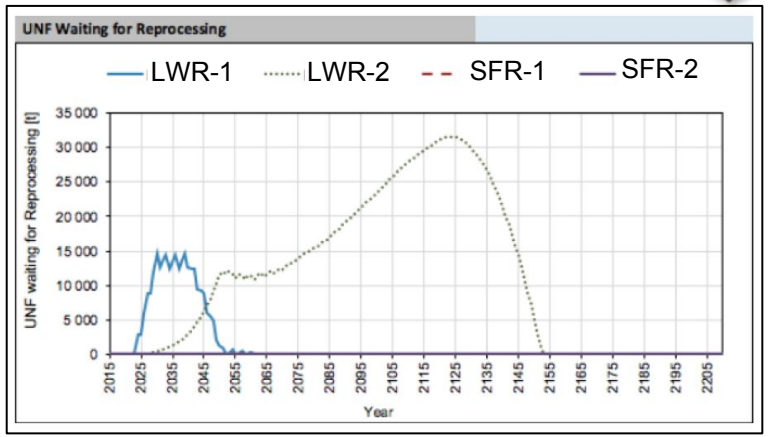
Table 4: Separation facilities core properties.

- Limited PWR-UOX reprocessing capacity
- Unlimited SFR-MOX reprocessing capacity

Reprocessing: Fuel cooled

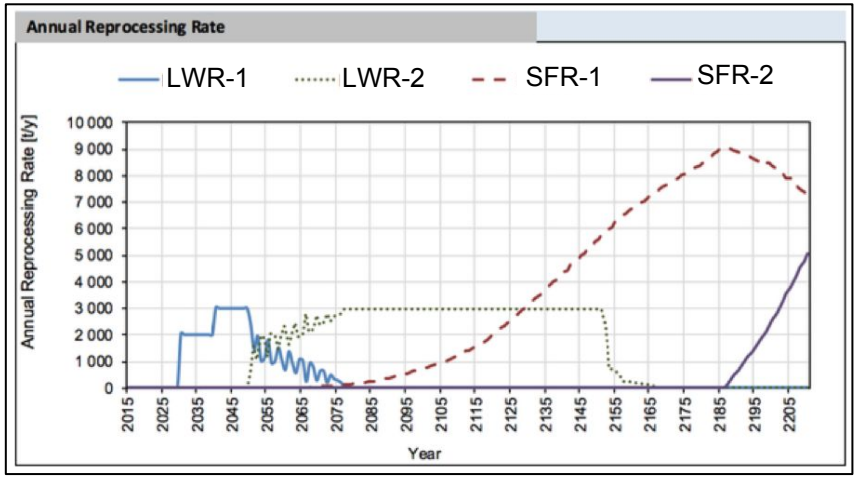


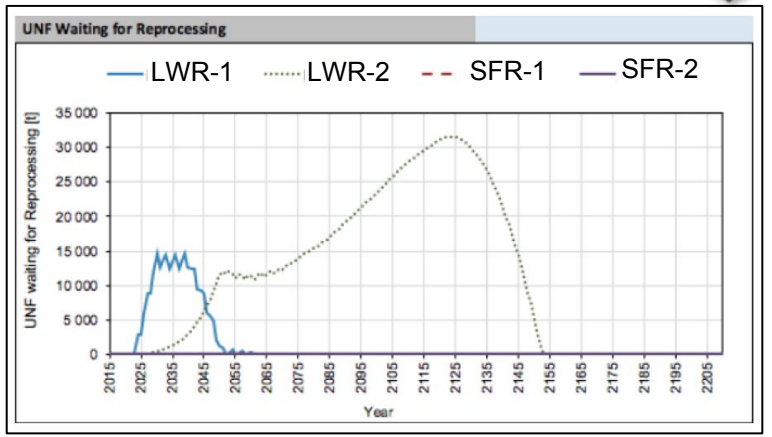
- Limited PWR-UOX reprocessing capacity
- Unlimited FBR-MOX reprocessing capacity

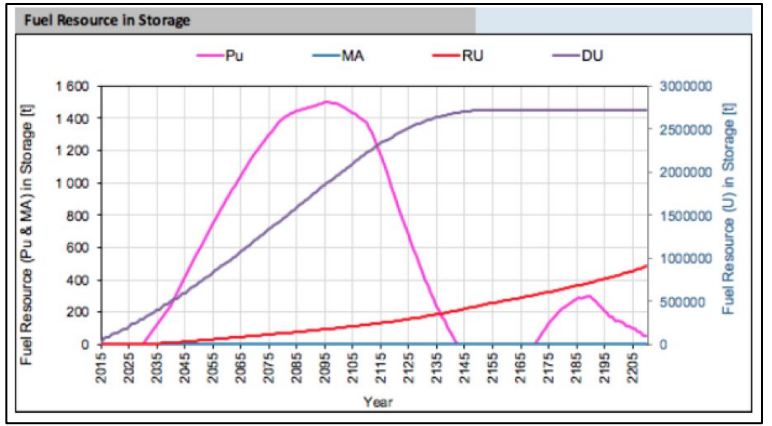


- MOX reprocessed when available
- Piling up of UOX-cooled-spent fuel

Reprocessing: Pu pilling







- Limited PWR-UOX reprocessing capacity
- Unlimited FBR-MOX reprocessing capacity

> Separated UOX-Pu accumulation
> Almost no separated SFR-Pu accumulation

EG23: Greedy vs "On-demand"

Case 1: Greedy reprocessing

Separation Implementation	LWR	SFR 1/2
Throughput [tHM/month]	83.3333	5000
feed buffer [tHM]	107.537	5000
Pu output buffer [tHM]	Unlimited	5000
Pu separation efficiency	0.99	0.99
Recycled U buffer [tHM]	Unlimited	Unlimited
U separation efficiency	0.99	0.99
Waste buffer [tHM]	Unlimited	Unlimited

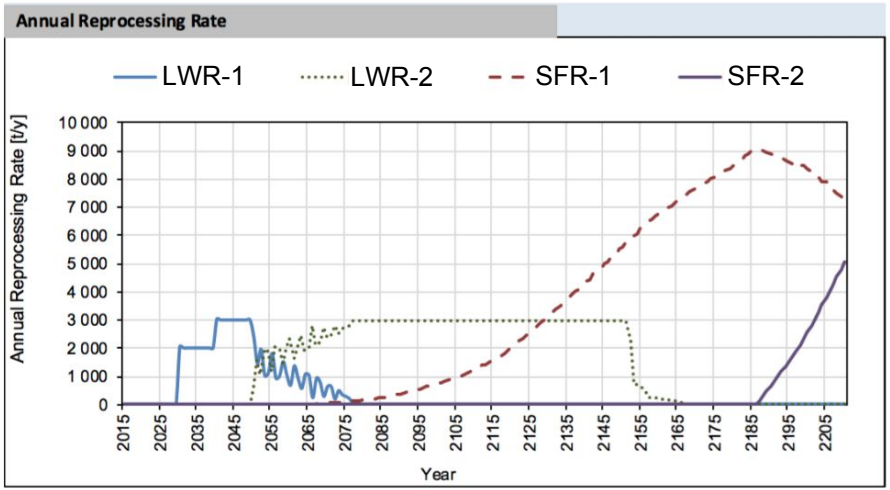
Table 4: Separation facilities core properties.

Case 2: on-demand reprocessing

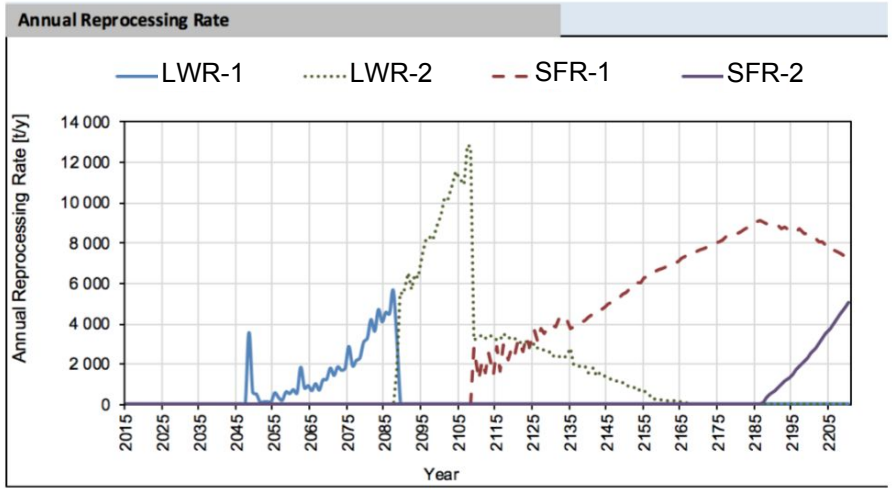
Separation Implementation	All Fuel
Throughput [tHM/month]	60
Feed buffer [tHM]	66
Pu output buffer [tHM]	6
Pu separation efficiency	0.99
Recycled U buffer [tHM]	Unlimited
U separation efficiency	0.99
Waste buffer [tHM]	Unlimited

- Preferences: UOX > MOX_A > MOX_B
- Deployment 1 facility for 10 SFR

EG23: Fuel Loading/Cooling



(a) Case 1.

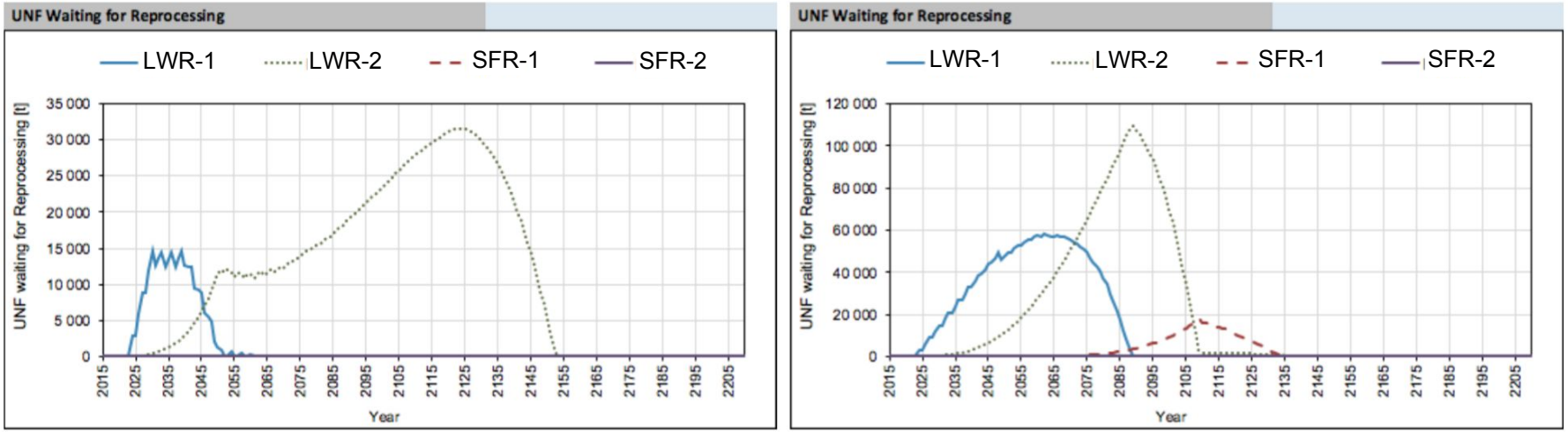


(b) Case 2.

Figure 5: Annual Reprocessing Rate.

- Most of the UOX-fuel reprocessing around 2100
- No visible change for SFR-MOX fuel reprocessing

EG23: Waiting spent fuel

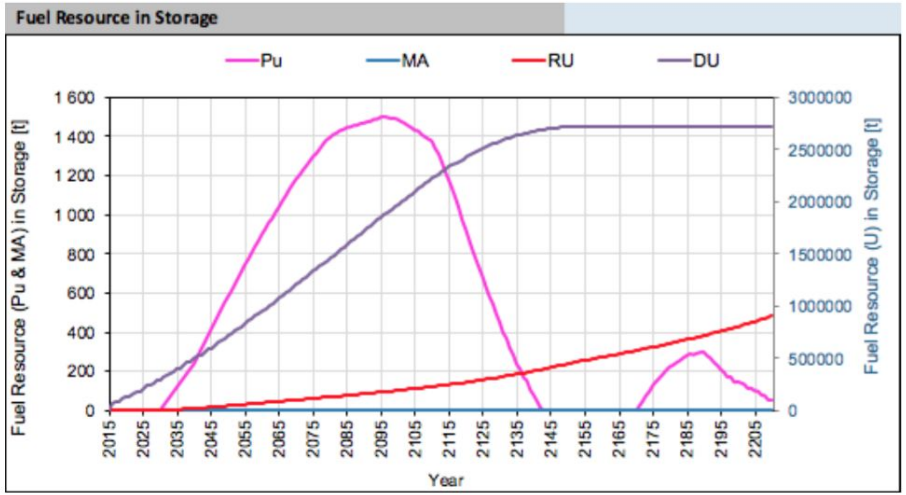


(a) Case 1.

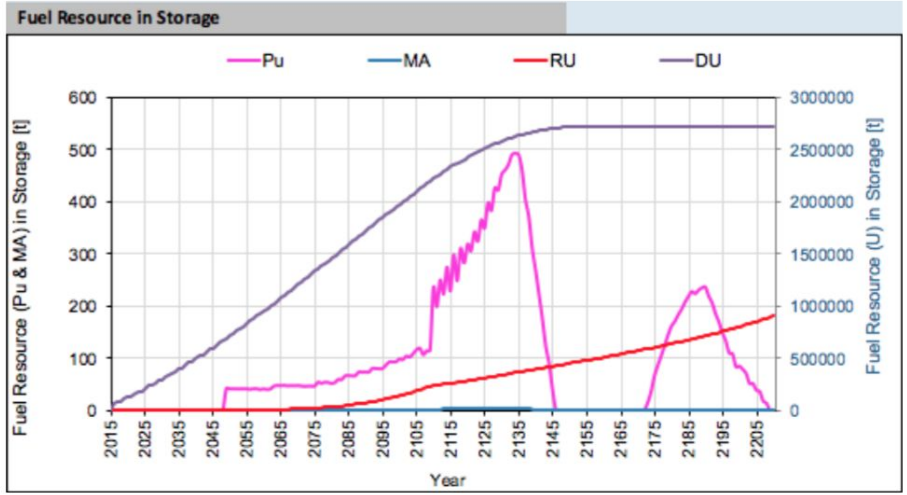
(b) Case 2.

Figure 4: Fuel waiting for Reprocessing.

Reprocessed material storage



(a) Case 1.



(b) Case 2.

Figure 6: Fuel in Storage.

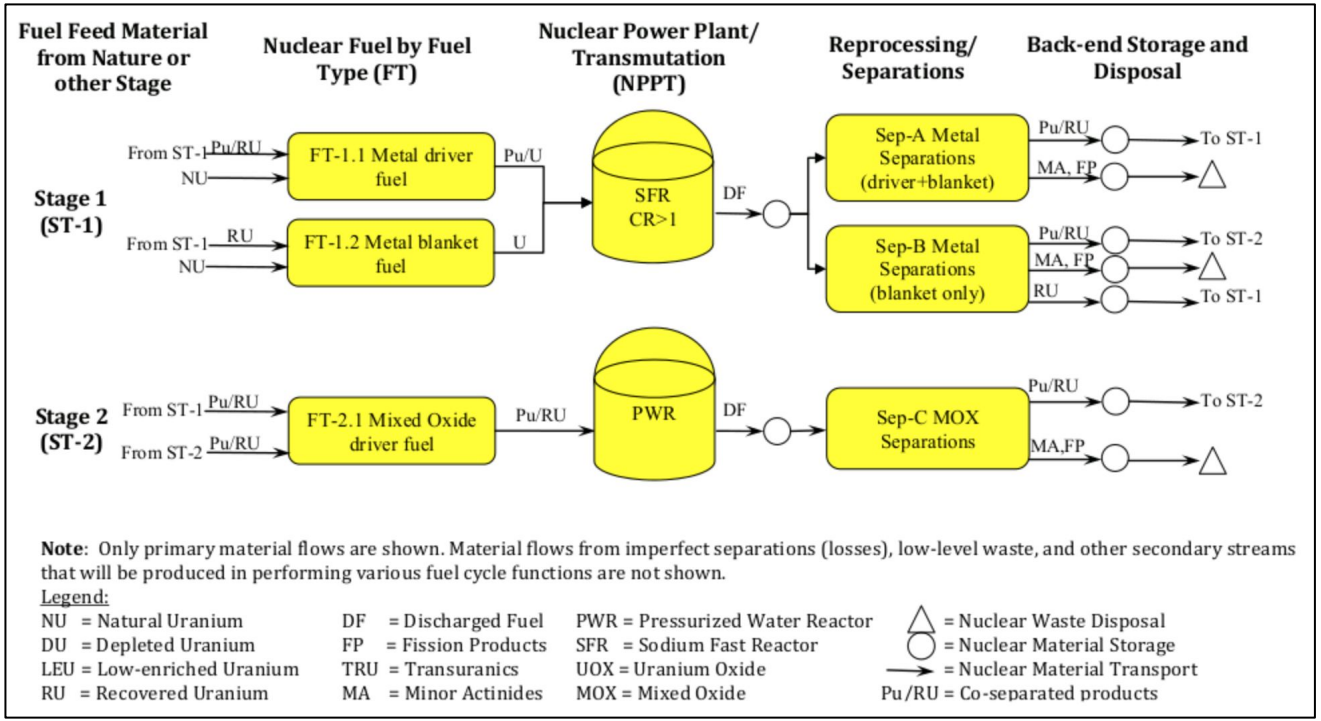
- Reduce the maximum plutonium accumulation by a factor 3.
- Follow closely the pu requirement for MOX fab (before 2100)
- Need to improve our separation capacity deployment...

EG23: conclusion

- Base case :
  - Large plutonium accumulation
  - Decay > ^{241}Am
  - Recipe problem...

- “On-demand”:
  - not perfect (still need some improvement)
  - “controled” separated pu accumulation
  - More stable plutonium composition
  - realistic ?

- PWR/SFR double strata scenario



From: "Nuclear Fuel Cycle Options Catalog," https://connect.sandia.gov/sites/NuclearFuelCycleOptionCatalog/SitePages/a/homepage.aspx.

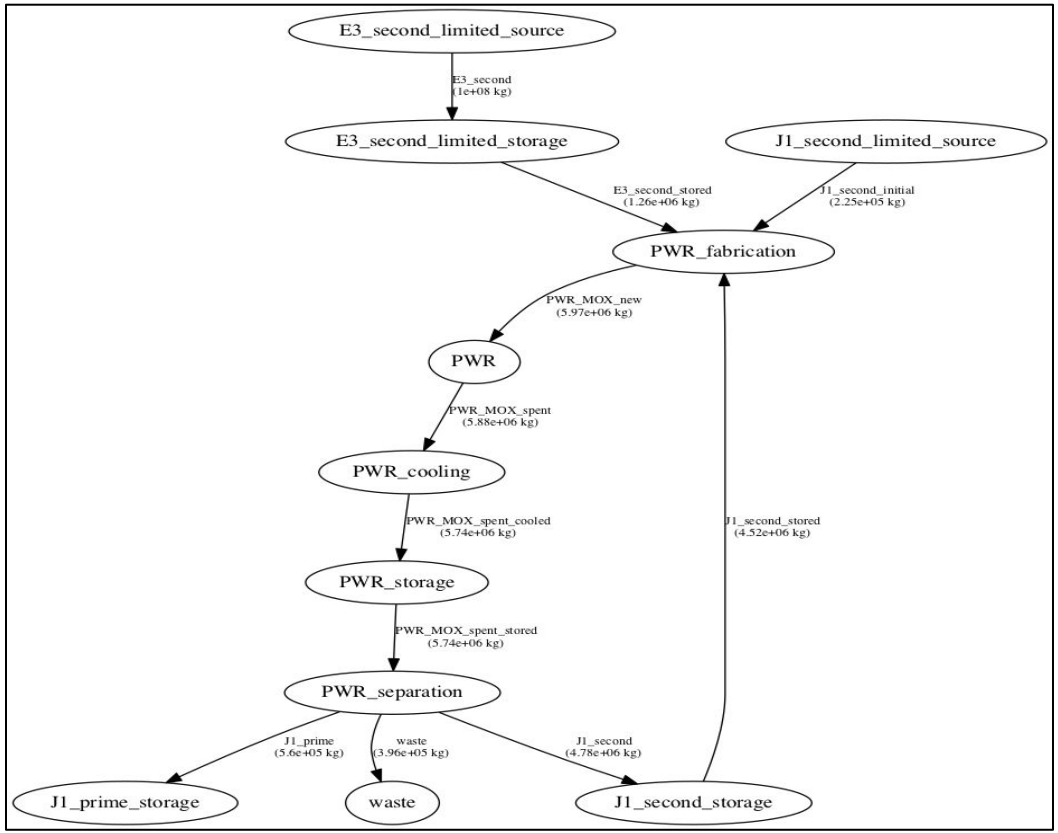
EG29: PWR

- Focus on the PWR stratum:
  - PWR - multi MOX with high quality plutonium feed

- Modeling choice on MOX plutonium enrichment
  - Fabrication model:
    - Fix mixing ratio
    - Plutonium equivalent like fuel fabrication
    - CLASS neural network

  - Decay,
  - Depletion vs recipe reactor

EG29: Cyclus flows



- E3 mimics FBR blanket plutonium stream
- J1 initial storage require to start cycle

Stream	^{234}U	^{235}U	^{236}U	^{238}U	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	F.P.
E3 [%]	0.002	0.203	0.083	81.082	0.0087	17.9764	0.6166	0.0216	0.0007	0	0
J1 [%]	0	0	0	93.632	0.1216	2.7058	1.8193	0.7402	0.6833	0.2978	0

- Case 1 - Fix mixing ratio fuel fabrication:
  E3: 0.105
  J1: 0.895
- Case 2 - pu-equivalent fuel fabrication:
  Initial reactivity = case1 fresh fuel compo
- Case 3 - neural network:
  50 GWd/t, 3 batches, $k_{inf} > 1.034$

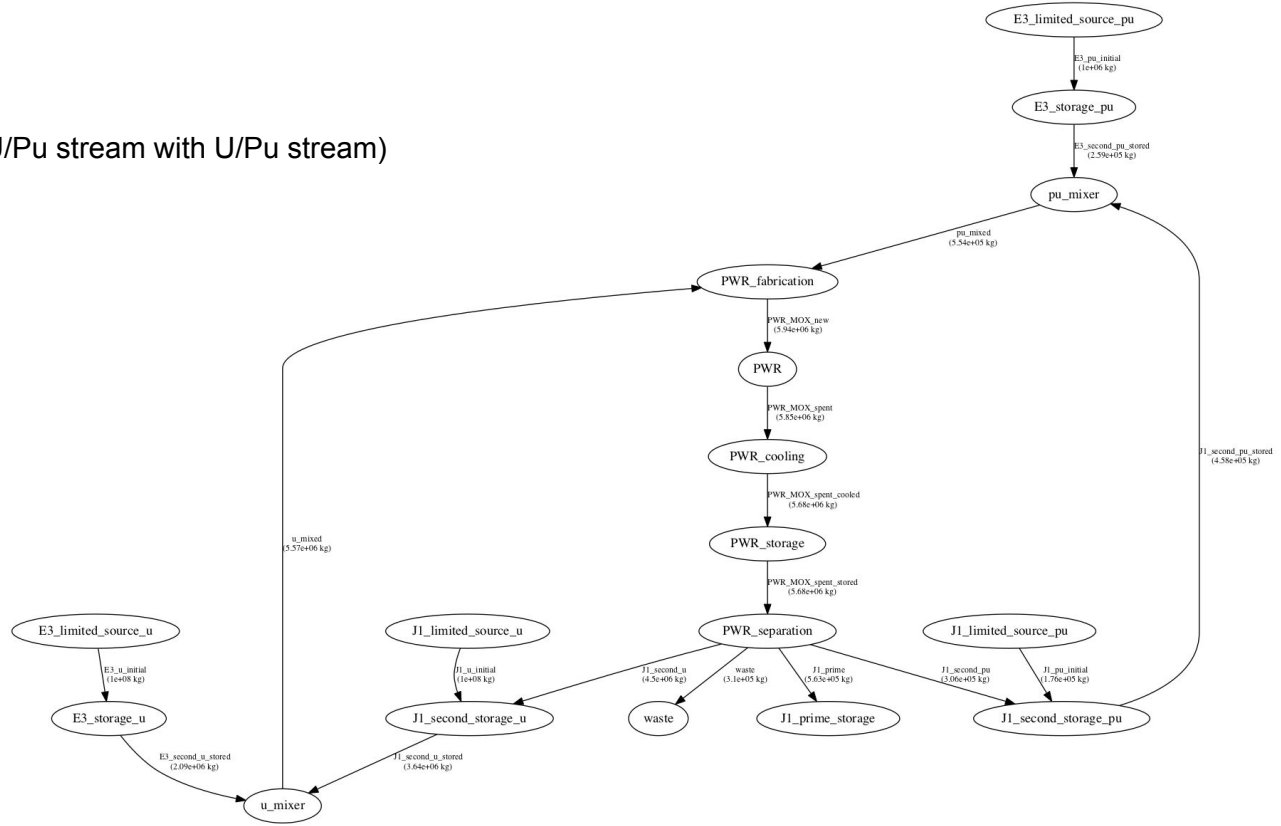
EG29: CLASS Models

CLASS model can mix:

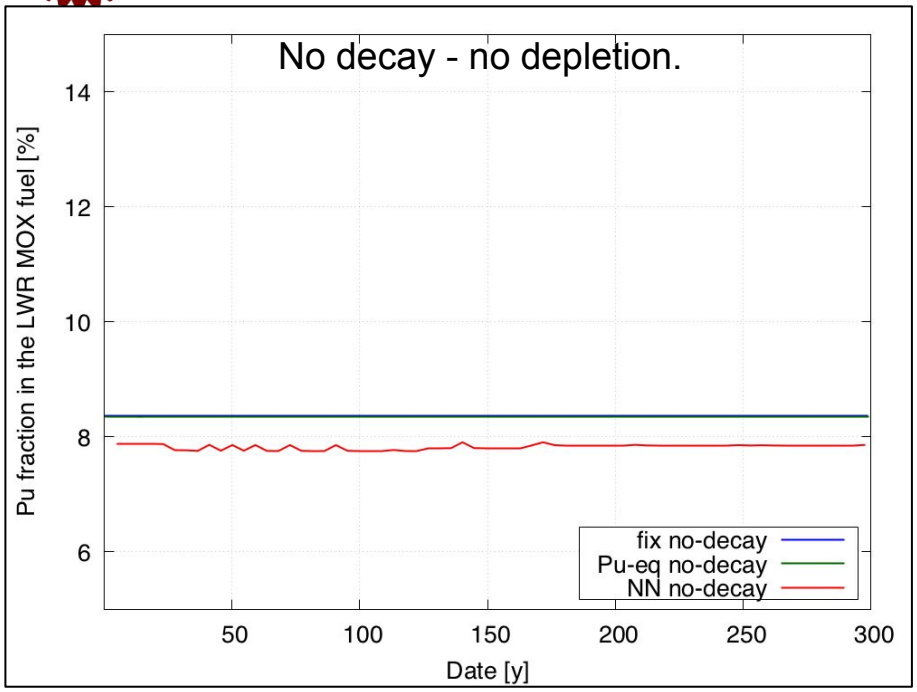
- pure U stream
- pure Pu stream

(sometime issue when trying to mix U/Pu stream with U/Pu stream)

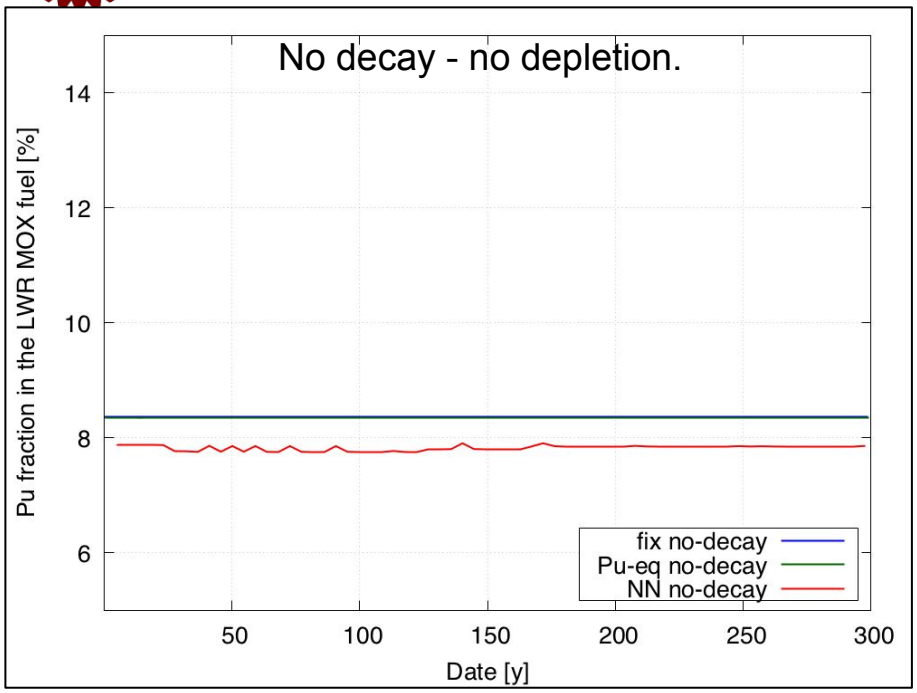
> separate both stream
> build pure U, Pu stream
(using fix mixing ratio)

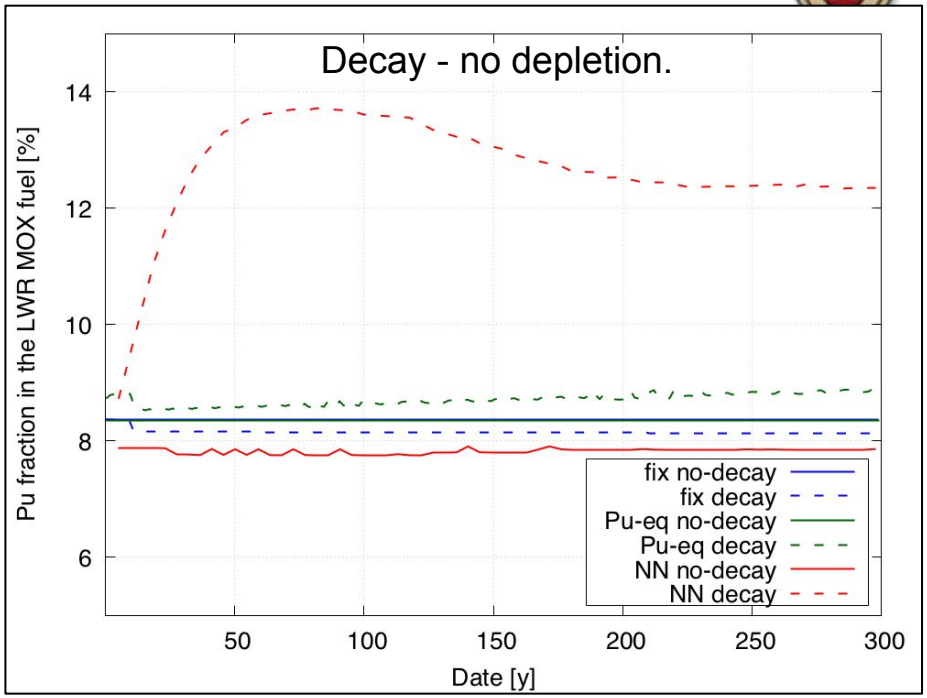


EG29: decay effect



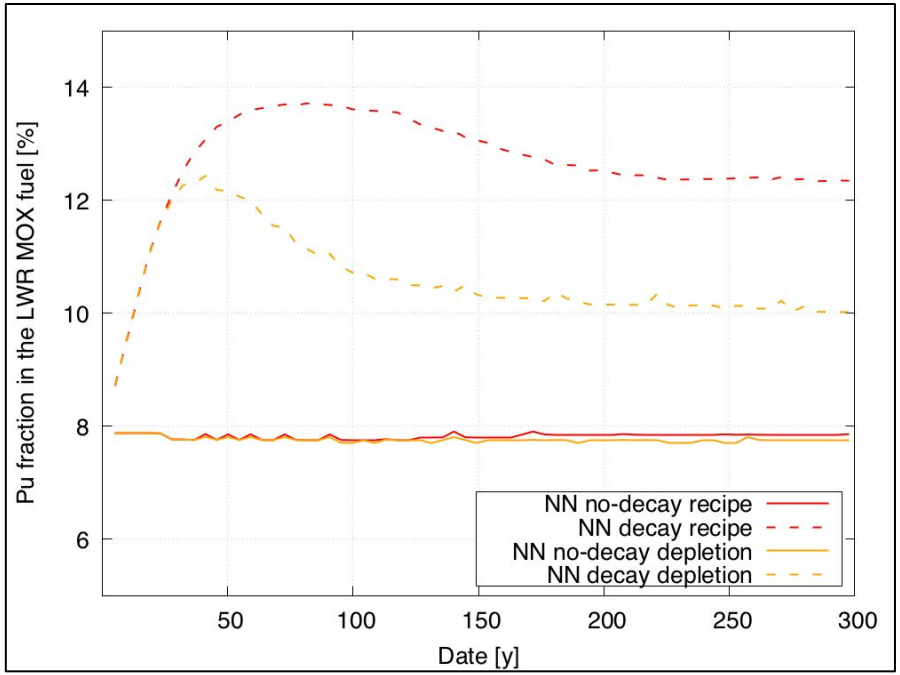
EG29: decay effect





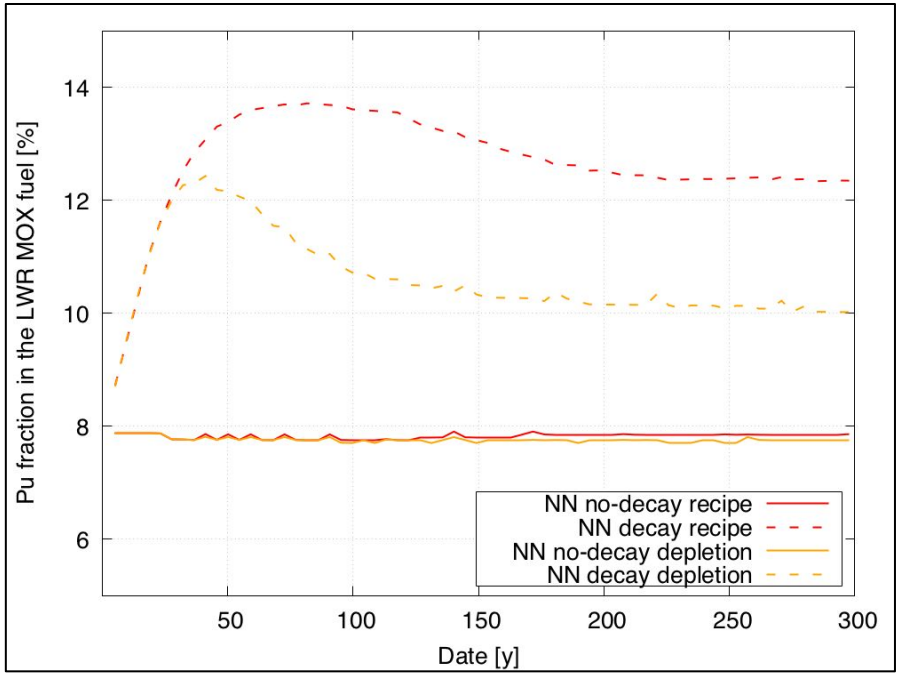
> Almost no effect of Pu-equivalent modeling
> Strong increase of the plutonium enrichment when using neural network model.

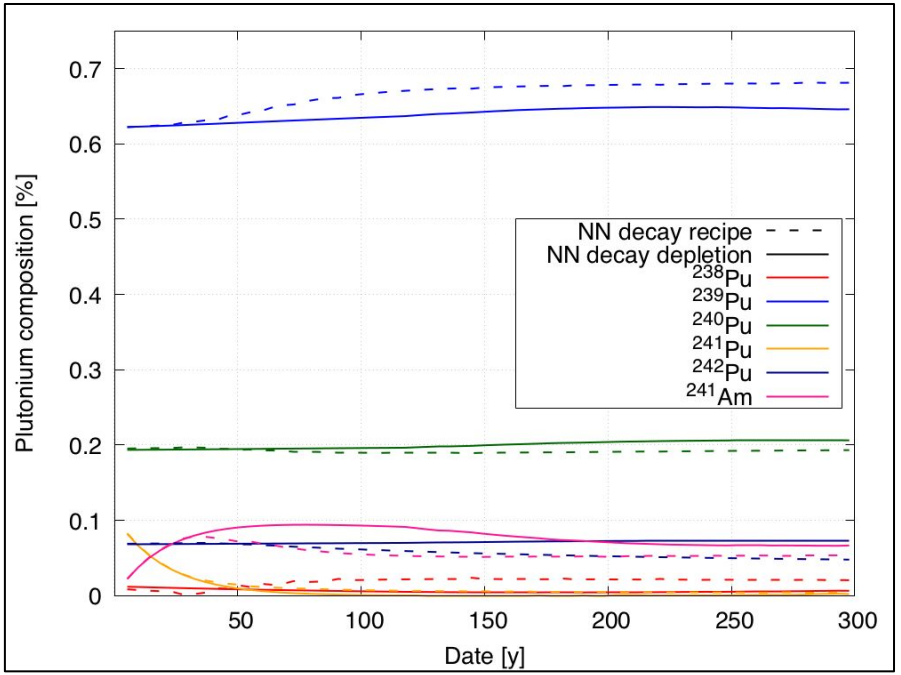
EG29: Depletion effect



> With depletion, reaching a “medium” Pu enrichment at equilibrium

EG29: Depletion effect





> With depletion, reaching a “medium” Pu enrichment at equilibrium
> Lower ^{241}Am content in the fresh fuel at equilibrium.

Conclusion

- EG23:
  - Continuous reprocessing:
    - Plutonium accumulation
    - Problem with recipe base
  - “On demand”:
    - Controlled plutonium accumulation (could be improved…)
    - Realistic ?

- EG29 PWR strata:
  - Strong impact of the decay (decay of ^{241}Pu)
  - Depletion compensate partially the decay of ^{241}Pu
  - Effect of the U/Pu mixing vs pure U + pure Pu
  - Effect of additionnal storage (on ^{241}Am production)
  - Same analysis on SFR stratum (and double strata)

- Cyclus:
  - Allows easy plug-in of new model and facilities
    CLASS NN fuel fabrication vs recipe reactors
  - Very good framework to isolate single modeling choice and measure their impacts