Technical Workshop on Fuel Cycle Simulation

Functionality Isolation Test (FIT)

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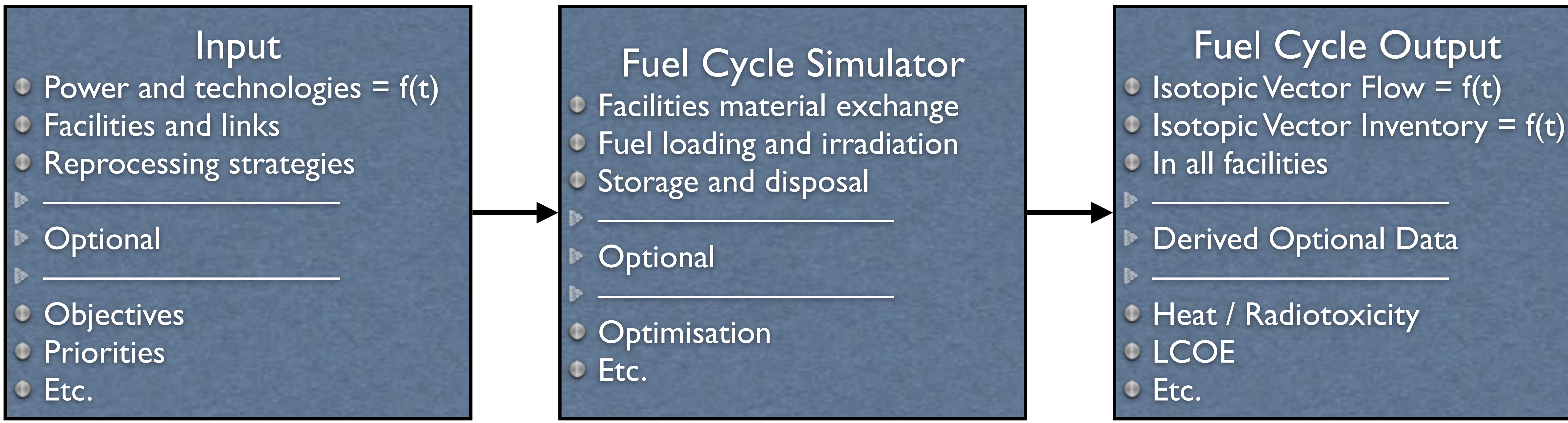
Fuel Cycle Simulators

- Since the 90's, a lot of different fuel cycle tools have been developed
  - Institutions : Industrial, Engineering, Academic
  - Complexity : From the simple spread sheet to the complex simulation framework
  - Capabilities and Flexibility : One specific problem to any problems



- Dynamic fuel cycle simulators are used for several applications :
  - Part of the technical evaluation of innovative systems deployment
  - Identification of drivers / parameters interactions in fuel cycle fleet physics
  - Production of data for further assessments (economy, safety, non-proliferation, etc.)

Improving the confidence in fuel cycle simulators output

Uncertainty assessment / propagation

Uncertainties
- G. Krivtchik PhD : Nuclear data impact
- A. Somaini PhD : Systems simplifications
- Scenario simplifications

Operational data
- F. Courtin PhD : Global Sensitivity Analysis

Scenario usage
- Problem formulation
- Problem resolution / methodology

Link between scenario and decision

Sociology : Role of scenarios
- Interviews with users
- Focus Groups with actors
- Round Table with decision maker

Comparison with experimental data

Reactor Data
- Possible to validate PWR UOx models
- Complex to assess PWR MOx models
- No available data for innovating reactors

Fleet Data
- Complex history with lack on input data
- Lack of output data

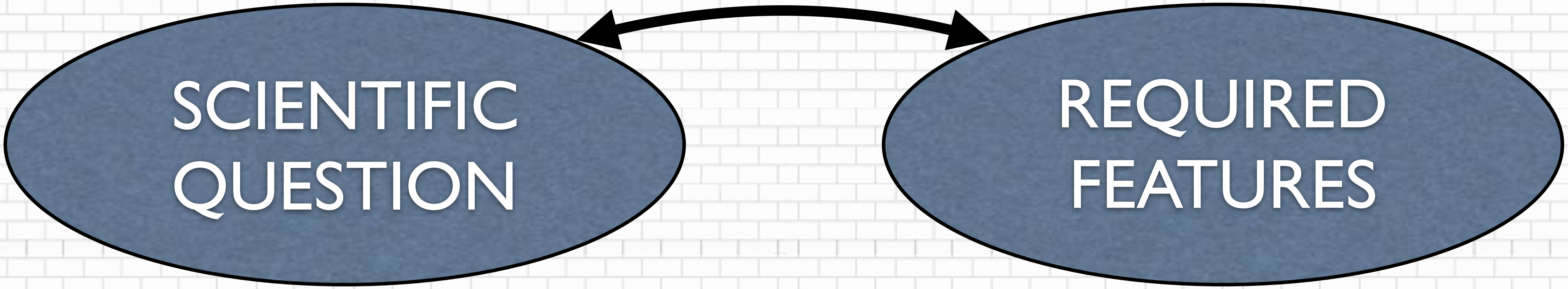
Code testing / comparison

Code comparison
- NEA benchmarks (2012)
- MIT Benchmark (2009)
- IAEA/INPRO Programme (2013)

Code testing methods
- Unit tests

Functionalities impact
- FIT Project

FIT (Functionality Isolation Test) Project description

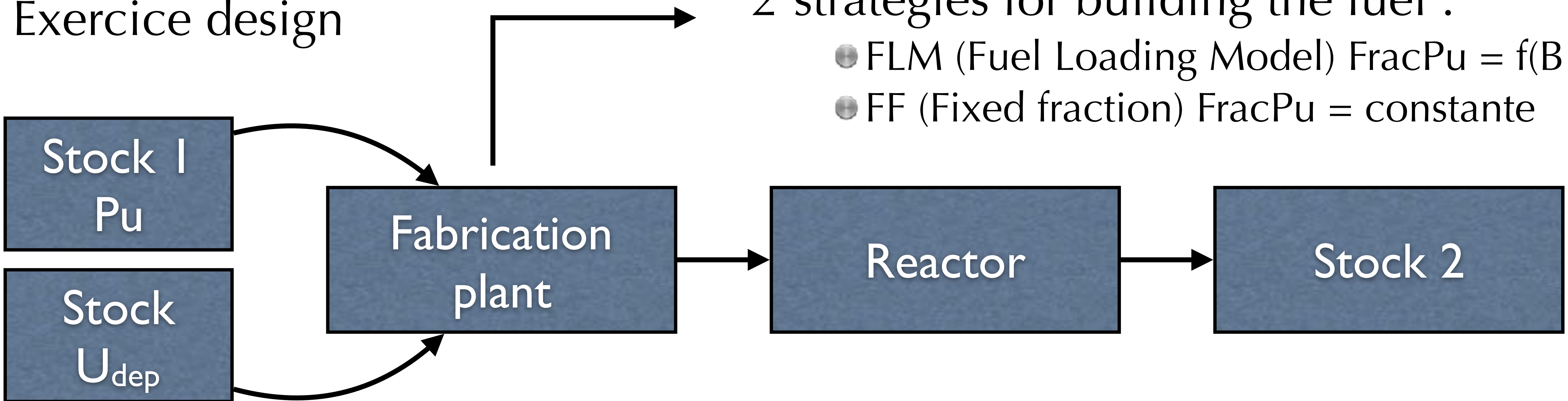


- The FIT effort is another brick in the wall of fuel cycle output confidence:
  - Focus on one single fuel cycle simulator functionality
  - Based on **<u>KISS</u>** (Keep It Simple Scientist!) principle

<u>Recipe</u>	VERSUS	<u>Update fuel composition</u>
Continuous reprocessing		Reprocessing when needed
No decay		Isotopic decay
Agent based reactors		Fleet based reactors
A single composition		Exact start-up composition
Average load factor		Load following
Constant fuel worth		Physics of mixed core

Testing Update fuel composition VS recipe

Exercice design



2 strategies for building the fuel :

- FLM (Fuel Loading Model) FracPu = f(BU)
- FF (Fixed fraction) FracPu = constante

Parameters	SFR	PWR
Power	2500 MW_{th}	3000 MW_{th}
Capacity factor	0.9	0.9
Cycle length	1.264 y	1 y
Number of batch	5	3
Fuel residence time	6.32 y	3 y
Core HM mass	51953.4 kg	72000 kg
Annual HM loading	8218.1 kg	24000 kg

- 4 different compositions
  - Reference is tuned to get FLM = FF
  - Three test compositions

Weight %	Reference	Compo 1	Compo 2	Compo 3
Pu-238	1.98	3.12	2.87	4
Pu-239	62.25	51.59	46.99	38.53
Pu-240	22.50	24.32	33.91	24.56
Pu-241	8.00	11.75	4.54	15.9
Pu-242	5.00	8.04	10.92	12.78
Am-241	0.27	1.18	0.77	4.23

Results For The Reactor Loading

- FLM Results - PWR

CLASS - Neural Network				
Frac Pu	7	8.7	15.3	12
$K_{threshold}$	1.03	1.03	1.03	1.03
CYCLUS - Pu equivalent				
Frac Pu	7	7.9	10.9	9.4

- FLM Results - SFR

CLASS - Neural Network				
Frac Pu	16	14.5	18.1	14.7
$K_{threshold}$	1.03	1.03	1.03	1.03
CYCLUS - Pu equivalent				
Frac Pu	16	15.6	22.6	16.4

- FF impact on $K_{threshold}$

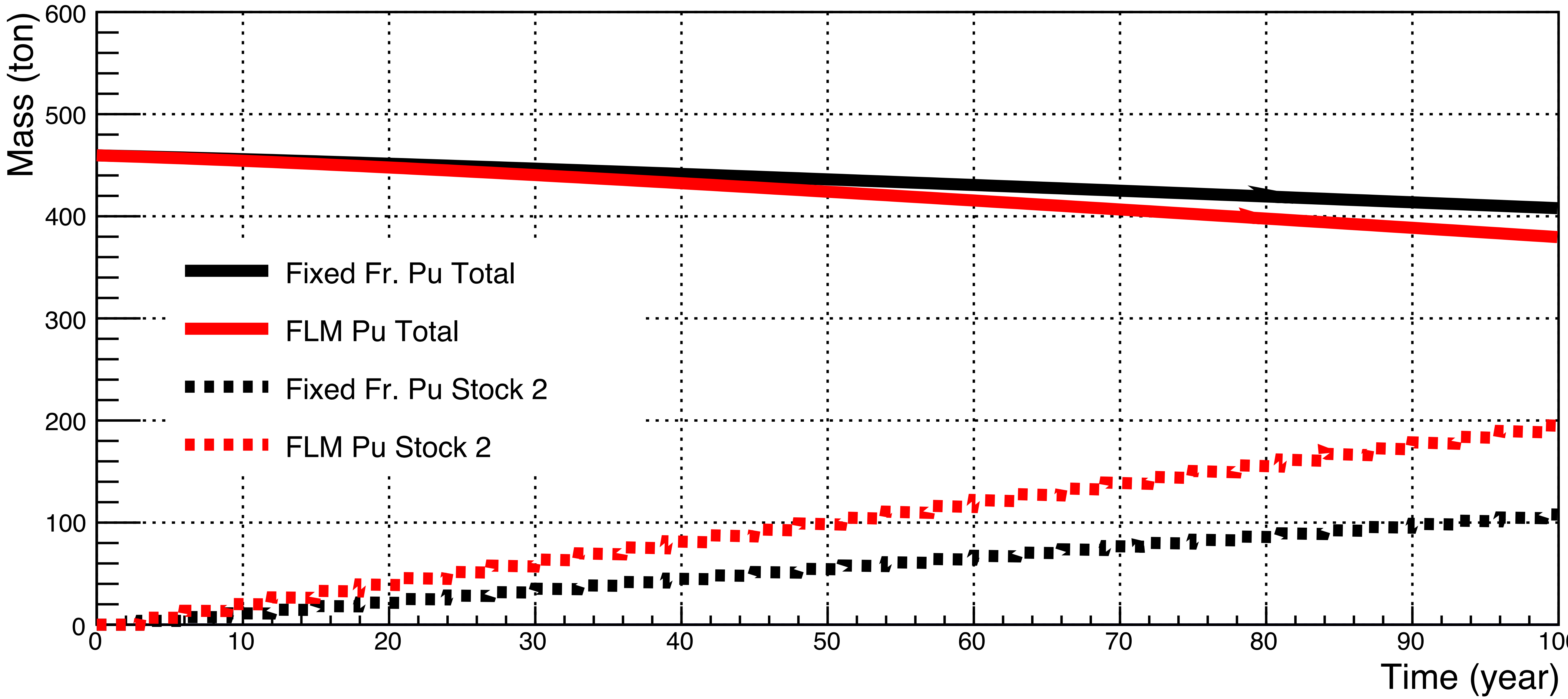
CLASS - Neural Network				
Frac Pu	7	7	7	7
$K_{threshold}$	1.03	1.005	0.959	0.97

- FF impact on $K_{threshold}$

CLASS - Neural Network				
Frac Pu	16	16	16	16
$K_{threshold}$	1.032	1.09	0.96	1.08

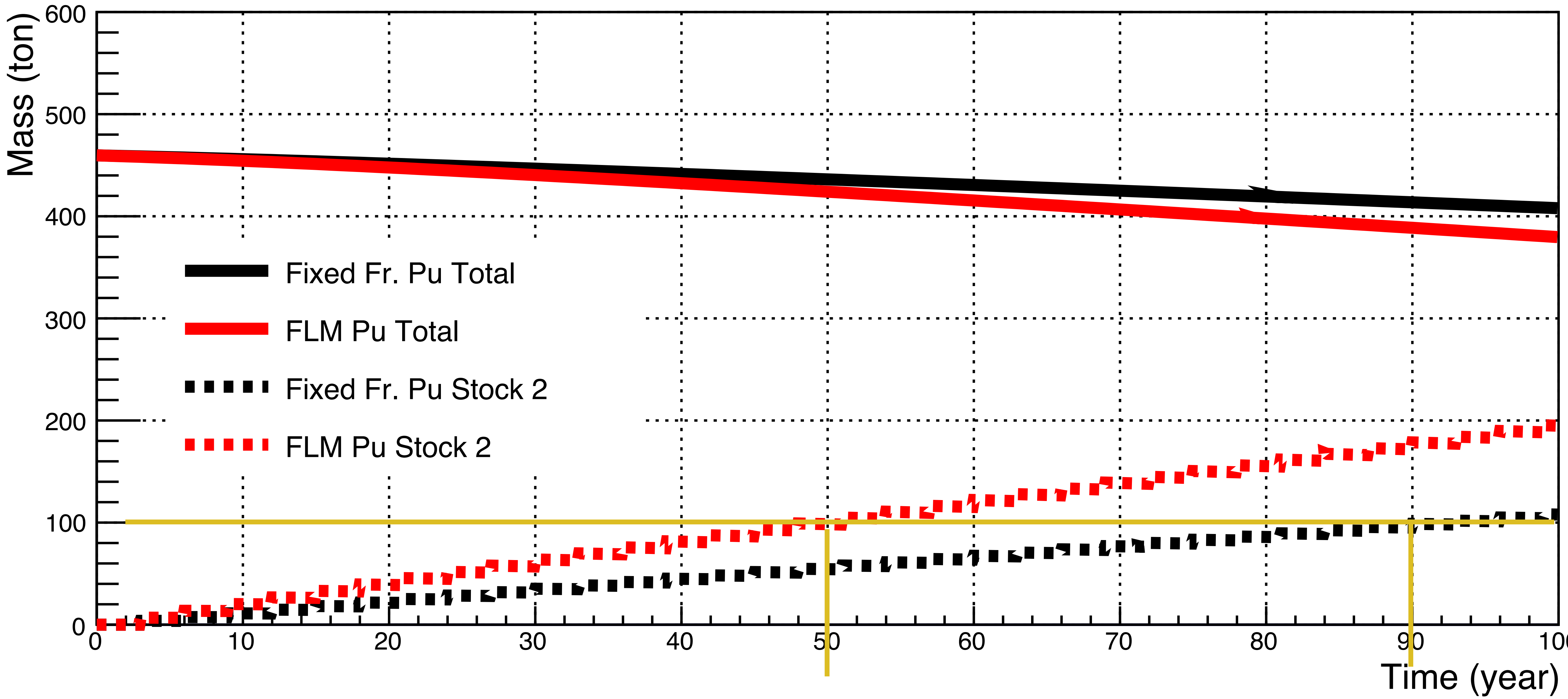
- What is the impact of reactor deviation on a fuel cycle calculation?
  - One Reactor for 100 years operation
  - No decay in the stock 1: Same Fuel @ BOC

Results for PWR - MOx Compo 3 / CLASS



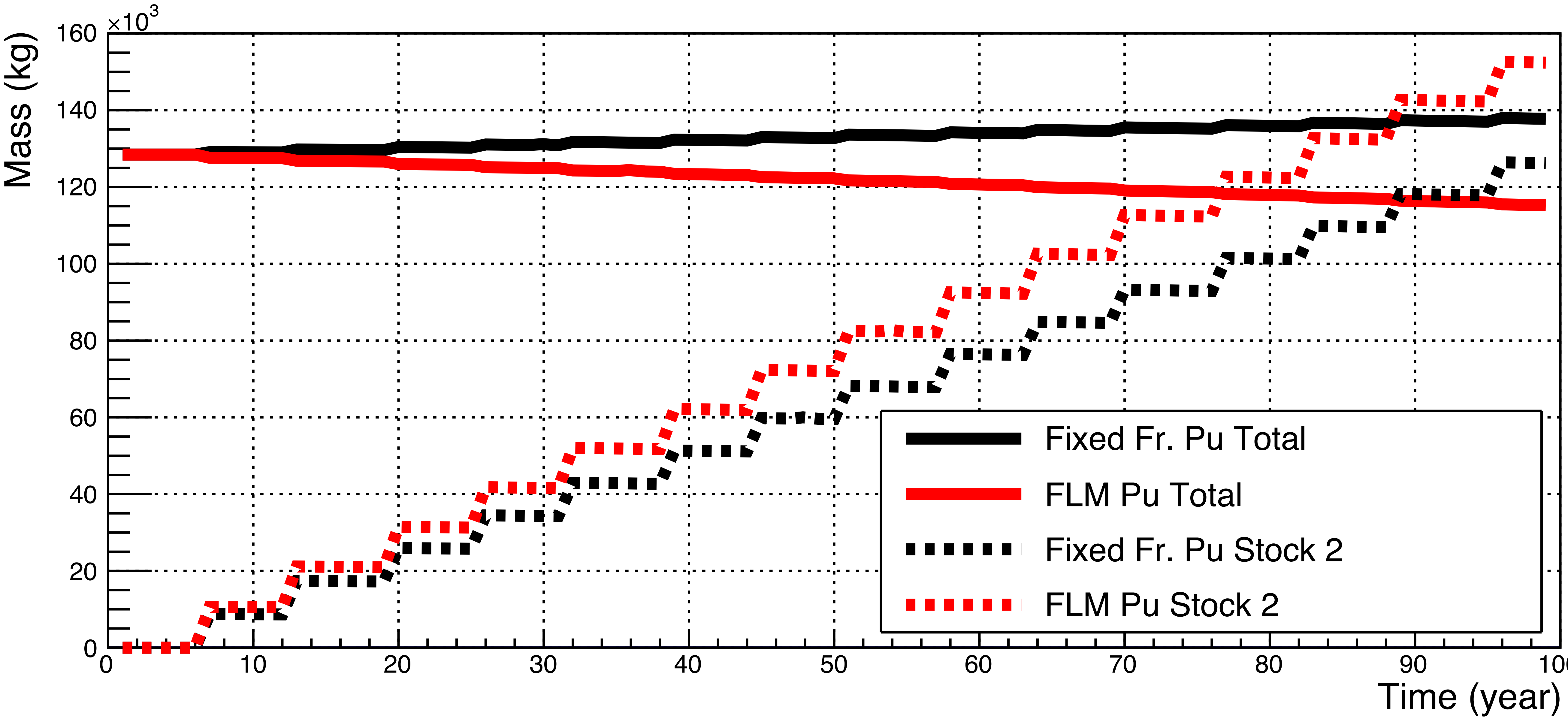
- The deviation between Total Plutonium FF and FLM is acceptable
  - Burn-up are similar so Pu balance are comparable
- The deviation between Stock 2 Plutonium FF and FLM is important
  - Pu fraction at B.O.C. are very different

Results for PWR - MOx Compo 3 / CLASS



- Example of questions strongly impacted by the fuel loading method
  - We suppose we need 100 tons of Pu to start a new technology.
  - When will the deployment be possible?
  - Fixed Fraction answer : 90 years VS Fuel Loading Model answer : 50 years.

Results for SFR - MOx Compo 2 / CYCLUS



- The deviation between Total Plutonium FF and FLM is strong
  - SFR is sur-generator or burner
- The deviation between Stock 2 Plutonium FF and FLM is smaller / PWR
  - Impact for deployment strategy is smaller

Conclusions and Perspectives

- FIT Project has started since 2 years as a collaboration France - US
  - 2016 : Madison University and CNRS
  - 2018 : ANL, ORNL and INL integration
  - Lack of time for results integration
- FIT Project is opened to any fuel cycle simulation tool
  - Increase range of functionalities
  - Small investment, around 2 weeks per year
- 2018 - 2019 : Closing the first functionality tests
  - Run with all fuel cycle simulators involved
  - Formulation of conclusions for range of application of Fuel Loading Model
- Later : Test other functionalities
- Later : Build a dedicated framework for results presentation

BACKUP

Results from ORNL / ORION

- PWR Model used in ORION
  - One reference composition for cross sections librairies
  - Burnup-dependent cross section from SCALE code
  - Westinghouse 17 by 17 LOPAR fuel assembly
  - 27 burnup steps

wt%	ref	% diff	1	% diff	2	% diff	3	% diff
U234	0.002	-4.07	0.002	33.1	0.003	-4.35	0.005	-4.89
U235	0.117	0.0650	0.108	5.81	0.099	6.33	0.099	8.98
U236	0.023	-1.03	0.024	-2.50	0.026	-6.29	0.026	-6.32
U238	90.5	-0.400	89.8	0.193	89.8	0.051	89.8	0.076
NP237	0.016	-inf	0.015	-inf	0.019	-inf	0.019	-inf
PU236	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PU238	0.120	3.99	0.205	0.875	0.170	1.29	0.320	3.19
PU239	2.25	-0.55	2.17	-10.7	1.83	-5.43	1.76	-5.97
PU240	1.62	-6.97	1.45	0.622	1.63	5.60	1.35	-3.31
PU241	0.862	4.37	0.910	1.68	0.953	-1.49	0.863	4.15
PU242	0.436	5.00	0.549	19.6	0.700	12.7	0.814	21.3
AM241	0.059	5.98	0.078	2.16	0.0690	-8.99	0.116	-0.510
Am+Pu	5.48	-3.19	5.59	-4.95	5.61	-2.83	5.52	-3.21

Table 5: Discharge fuel composition for MOX LWR with percent differences from Cyclus results

$$\% \text{ diff} = \frac{\text{Cyclus result} - \text{ORION result}}{\text{Cyclus result}} * 100$$

- Change in plutonium stream quality does affect the ORION output depletion
- Important deviation could be observed between ORION and Cyclus

FIT case #1 : SFR

— Fixed Fraction

- - Fuel Loading Model

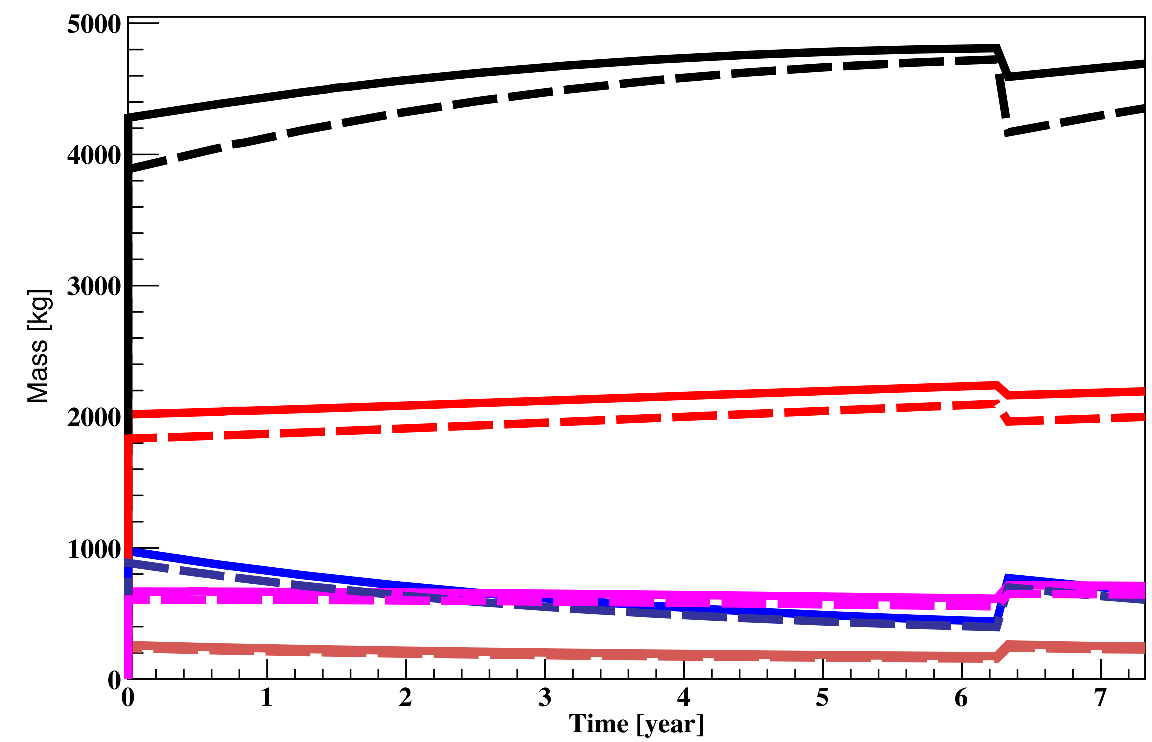
^{239}Pu

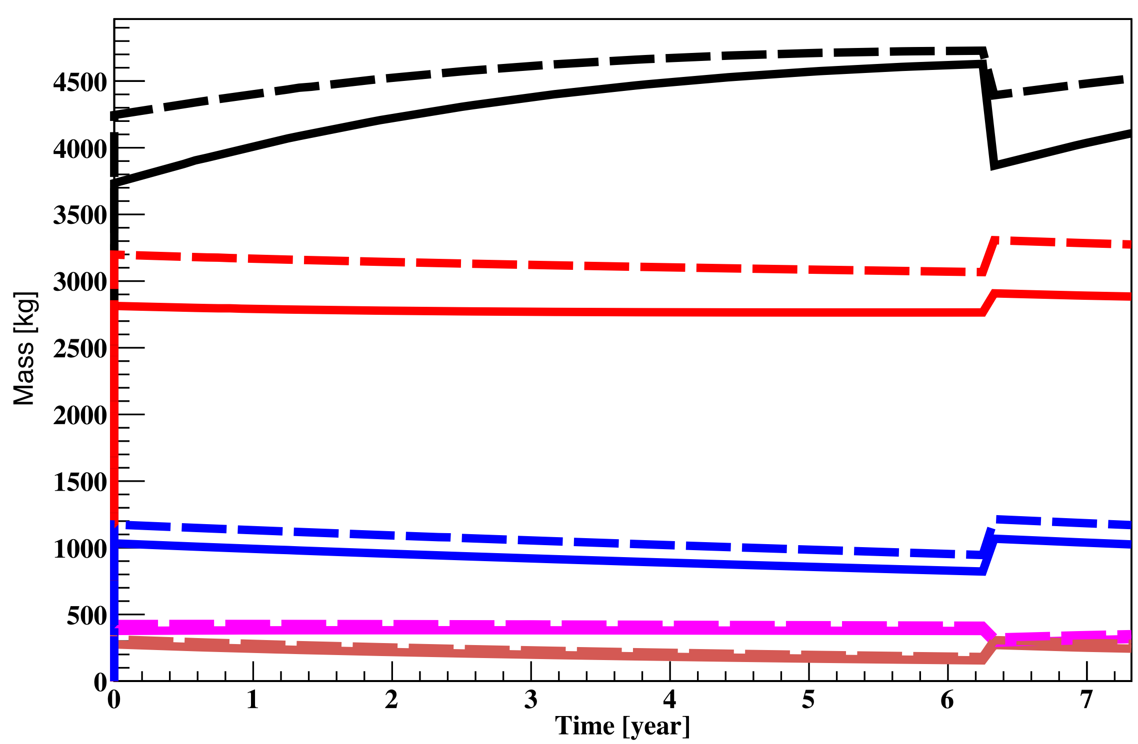
^{240}Pu

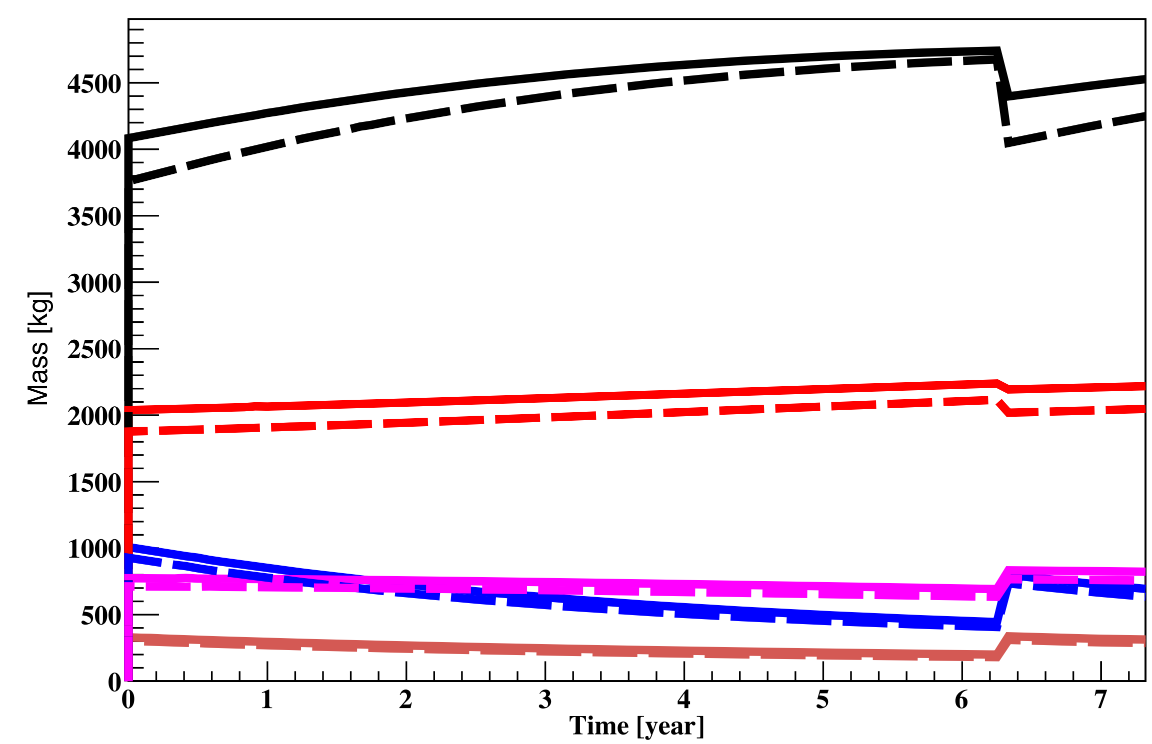
^{242}Pu

^{241}Pu

^{238}Pu







FIT case #2 : PWR

— Fixed Fraction

- - Fuel Loading Model

^{239}Pu

^{240}Pu

^{242}Pu

^{241}Pu

^{238}Pu