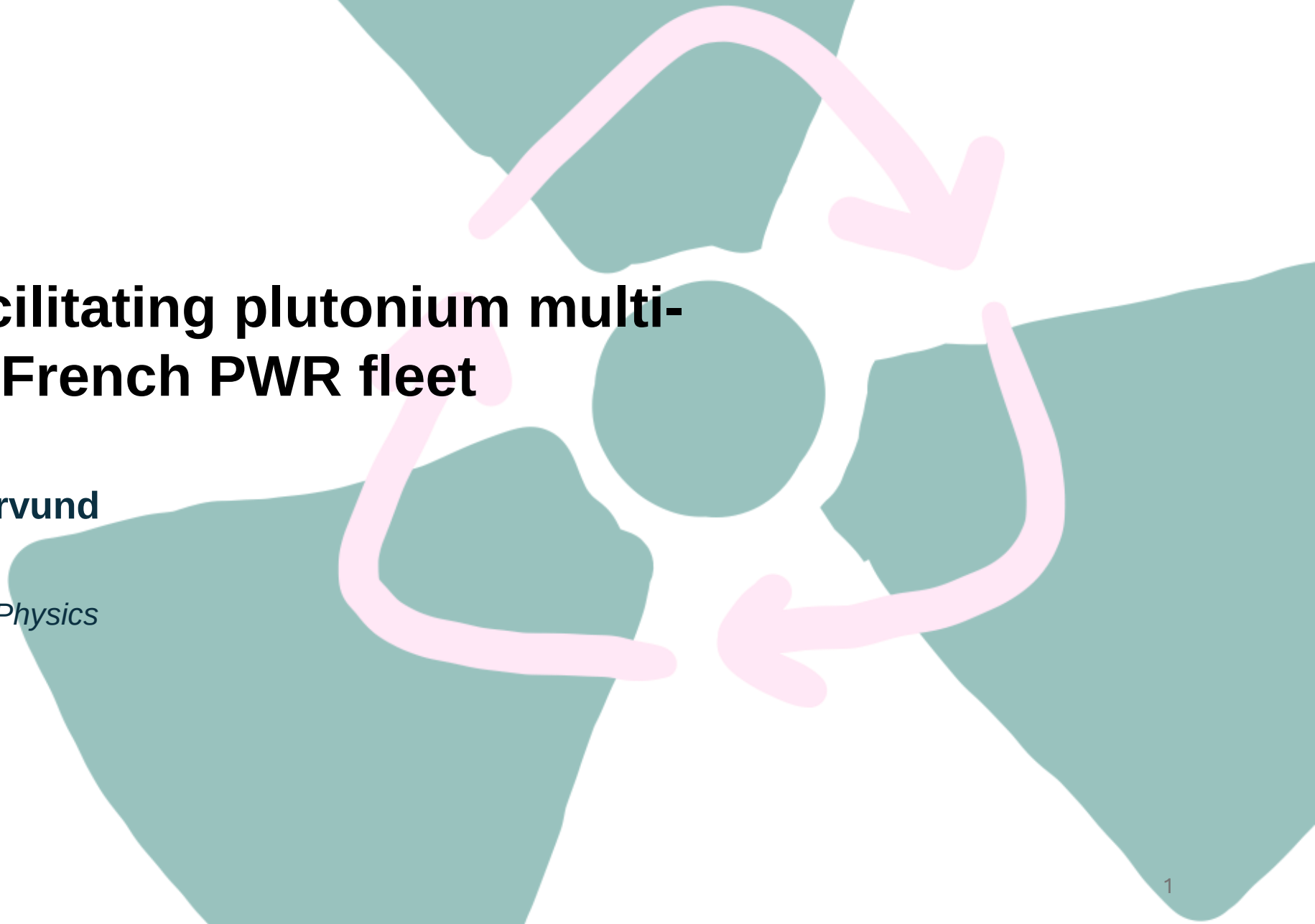
UNIVERSITY OF OSLO

Multi-MOX: Fascilitating plutonium multi-recycling in the French PWR fleet

Gulla Louise Serville Torvund

PhD student, University of Oslo

15th Nordic meeting on Nuclear Physics



IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

NUKLEÆRSENTERET

UNIVERSITY OF OSLO

Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

UNIVERSITY
OF OSLO

Master's thesis

Multi-recycling of plutonium in PWRs with the MMOX strategy

A proposal for a more sustainable nuclear fuel multi-recycling strategy in the French nuclear fleet, aiming for stabilization of the plutonium inventory.

Gulla Louise Serville Torvund

Physics
60 ECTS study points

Department of Physics
Faculty of Mathematics and Natural Sciences

Spring 2024

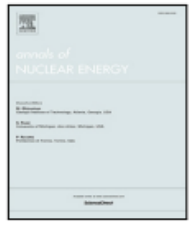
Master's thesis (spring '24)

Annals of Nuclear Energy 223 (2025) 111641

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene



Multi-MOX: Facilitating plutonium multi-recycling in the French PWR fleet

Gulla Torvund [a,b,c,*], Marc Ernoult [b], Fanny Courtin [d], Xavier Doligez [e], Dorthea Gjestvang [a,c], Sunniva Siem [a,c], Nicolas Thiollière [d]

[a] Department of Physics, University of Oslo, N-0316 Oslo, Norway
[b] Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France
[c] Norwegian Nuclear Research Centre, Norway
[d] Subatech, IMT Atlantique, CNRS/IN2P3, Université Nantes, 44307 Nantes Cedex 3, France
[e] CNRS/IN2P3, LPSC, 38026 Grenoble, France

ARTICLE INFO

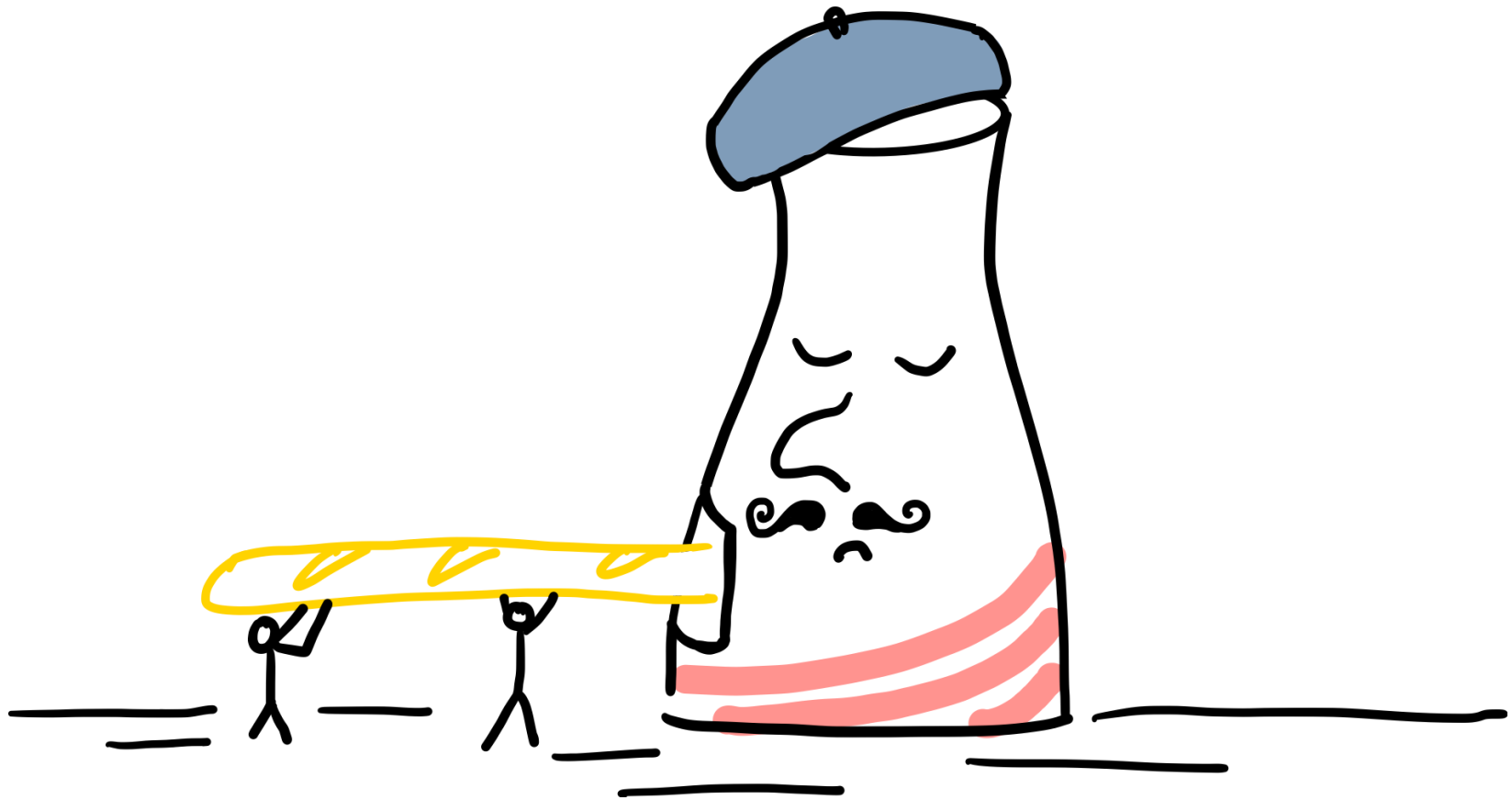
Keywords:
Fuel cycle
Plutonium recycling
Nuclear energy
MOX fuel
MMOX

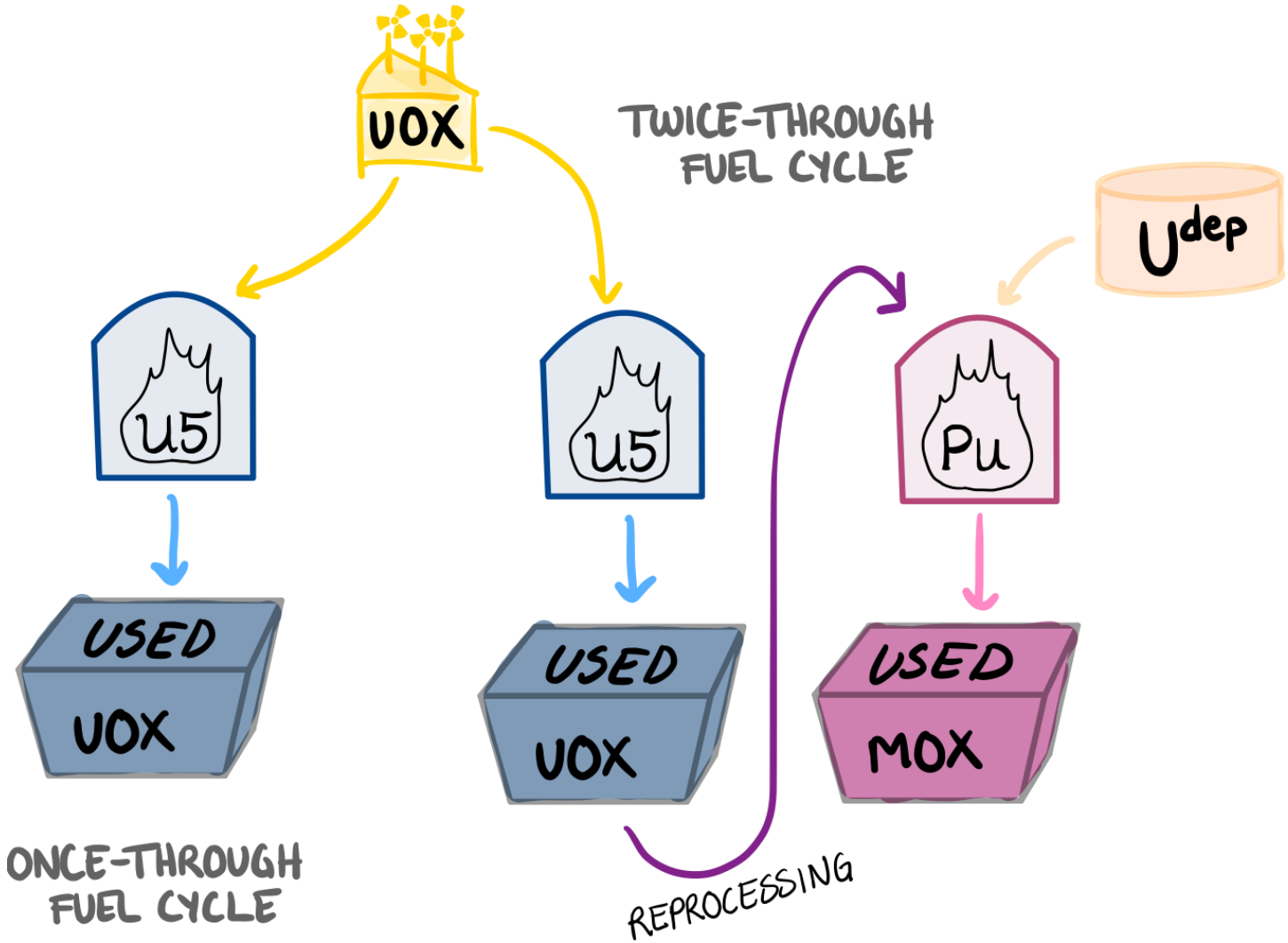
ABSTRACT

This study examines the Multi-MOX (MMOX) strategy for plutonium multi-recycling in PWRs using the CLASS fuel cycle simulation tool with assembly-level calculations. MMOX facilitates the multi-recycling of used nuclear fuel by mixing reprocessed plutonium from various sources to create viable fresh nuclear fuel. The strategy significantly curtails the growth of the plutonium inventory, but does not stabilize it entirely in the long term. Although lower fuel burnup reduces plutonium build-up, it increases the production of minor actinides. Comparing MMOX with non-recycling and mono-recycling scenarios, we find that it reduces plutonium inventory by 35% and 19%, respectively. Despite a higher level of minor actinide production, MMOX decreases overall transuranic element production. Additionally, MMOX reduces the need for interim spent fuel storage by a factor of ten compared to non-recycling and by two-thirds compared to mono-recycling, while substantially lowering the age of stockpiled used nuclear fuel.

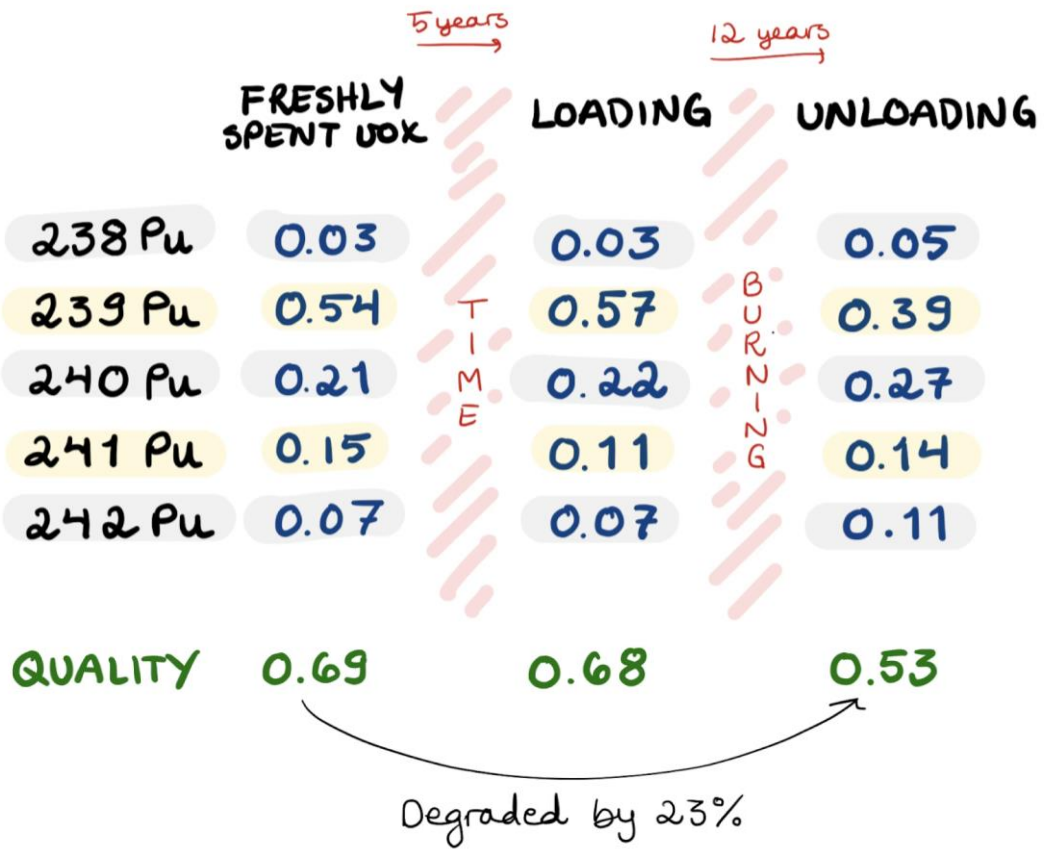
Annals of Nuclear Energy (spring ‘25)

Torvund, G., Ernoult, M., Courtin, F., Doligez, X., Gjestvang, D., Siem, S., & Thiollière, N. (2025). Multi-MOX: Facilitating plutonium multi-recycling in the French PWR fleet. *Annals of Nuclear Energy*, *223*, 111641.




UOX
TWICE-THROUGH
FUEL CYCLE
Udep
U5
U5
Pu
USED
UOX
USED
UOX
USED
MOX
ONCE-THROUGH
FUEL CYCLE
REPROCESSING

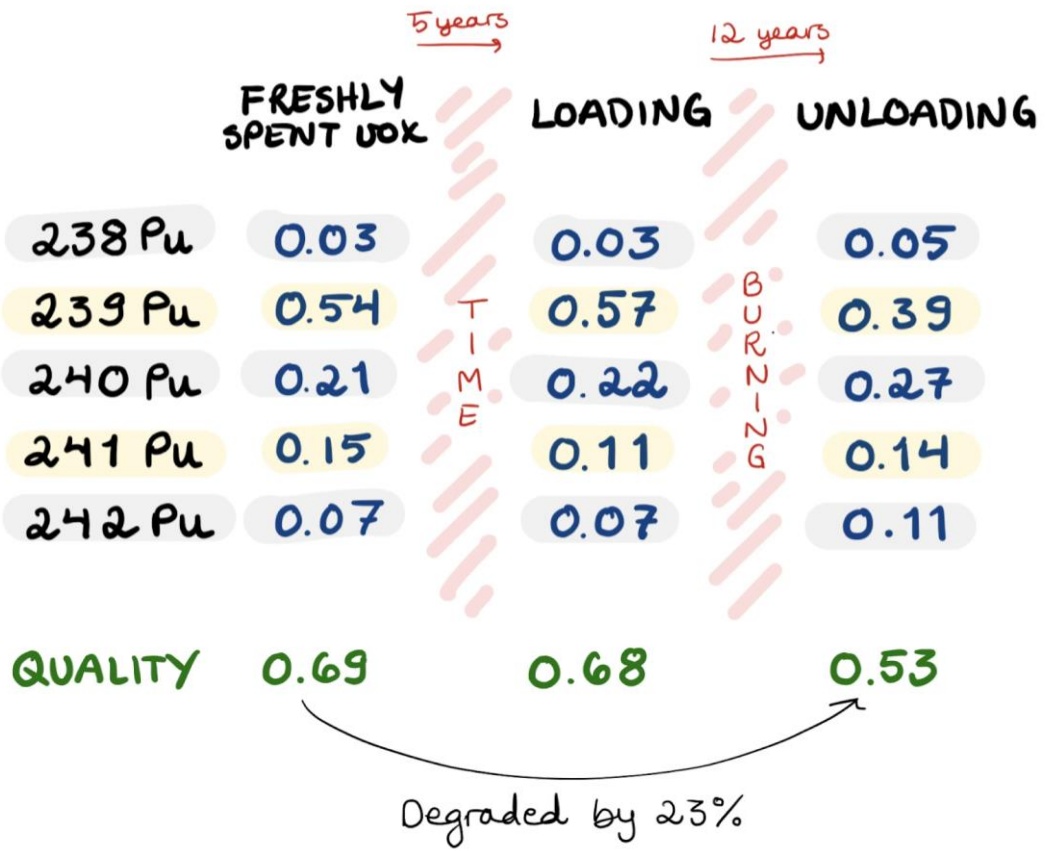
Two problems with Pu multi-recycling:

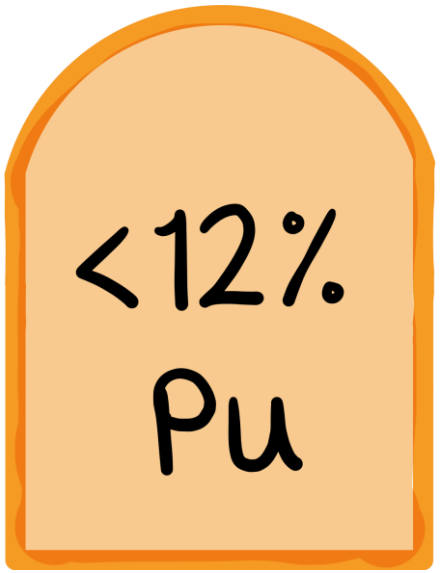


1) degrading Pu quality

[1]S. Aniel, J. Bergeron and A. Puill. *Evaluation of the maximum content of a MOX-fueled pressurized water reactor versus isotopic composition with respect to the void coefficient*. Tech. rep. Gif-sur-Yvette: Commissariat a l'Energie Atomique (CEA), 1997, pp. 181–193.

Two problems with Pu multi-recycling:

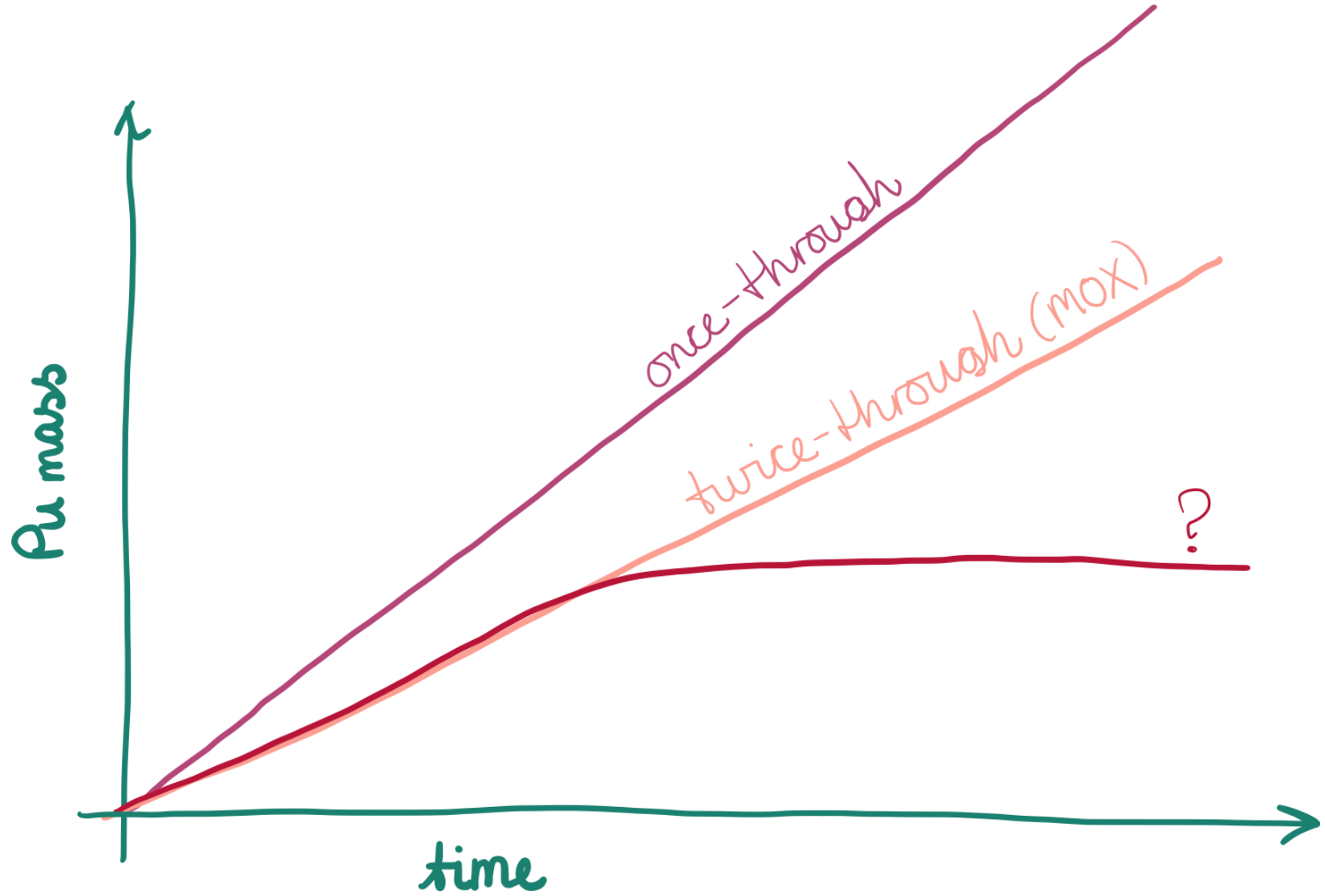




1) degrading Pu quality

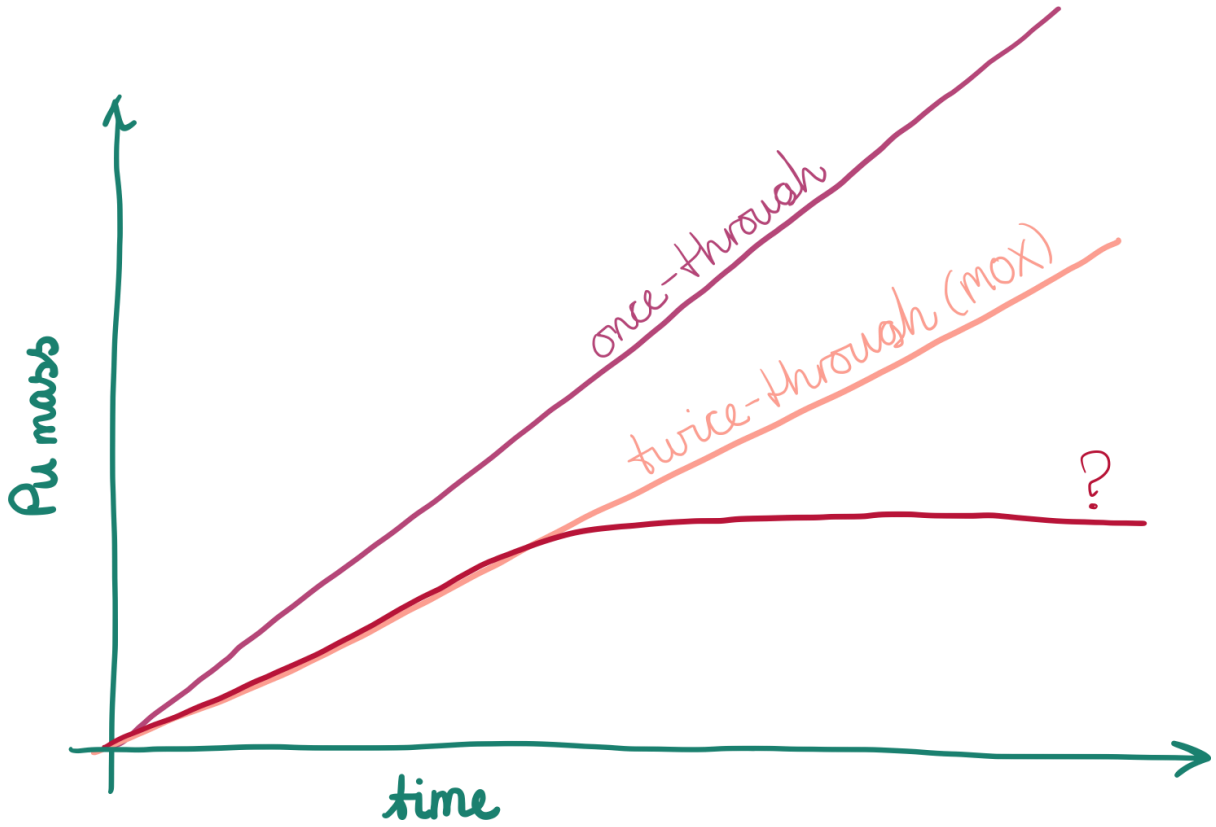
2) safety limit on Pu in reactors[1]

[1]S. Aniel, J. Bergeron and A. Puill. *Evaluation of the maximum content of a MOX-fueled pressurized water reactor versus isotopic composition with respect to the void coefficient*. Tech. rep. Gif-sur-Yvette: Commissariat a l'Energie Atomique (CEA), 1997, pp. 181–193.


Pu mass
time
once-through
twice-through (MOX)
?

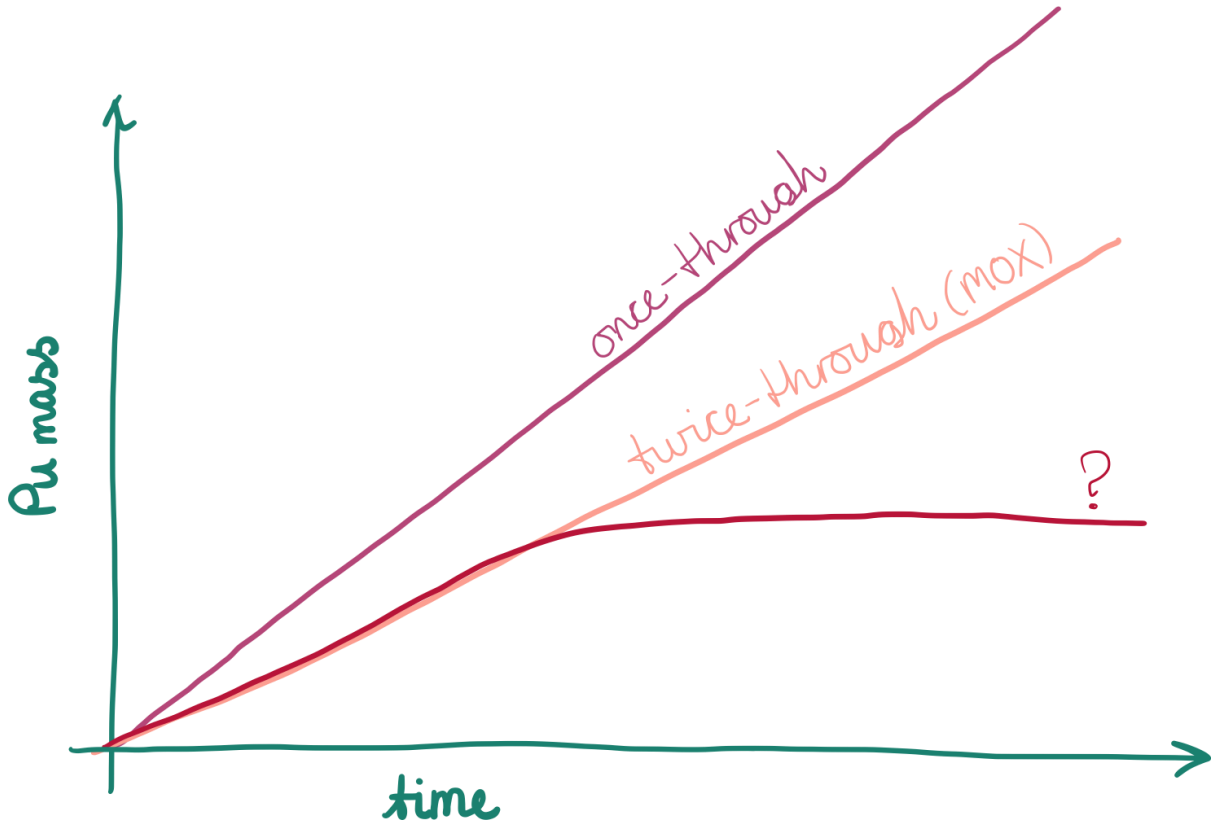
Fast reactors

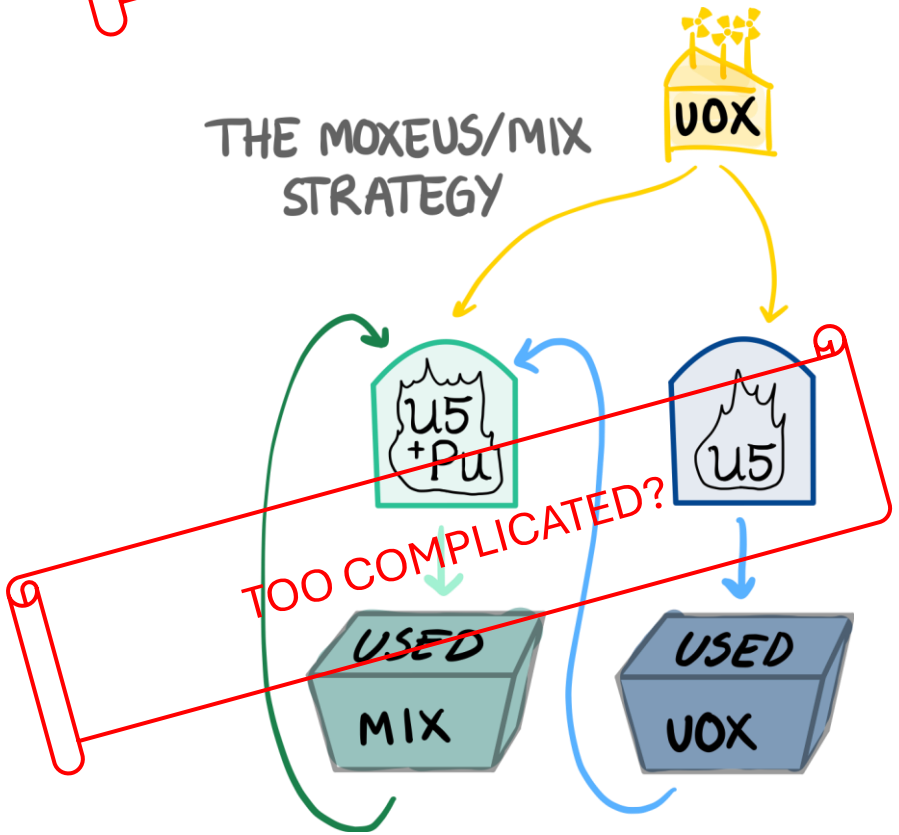
POSTPONED

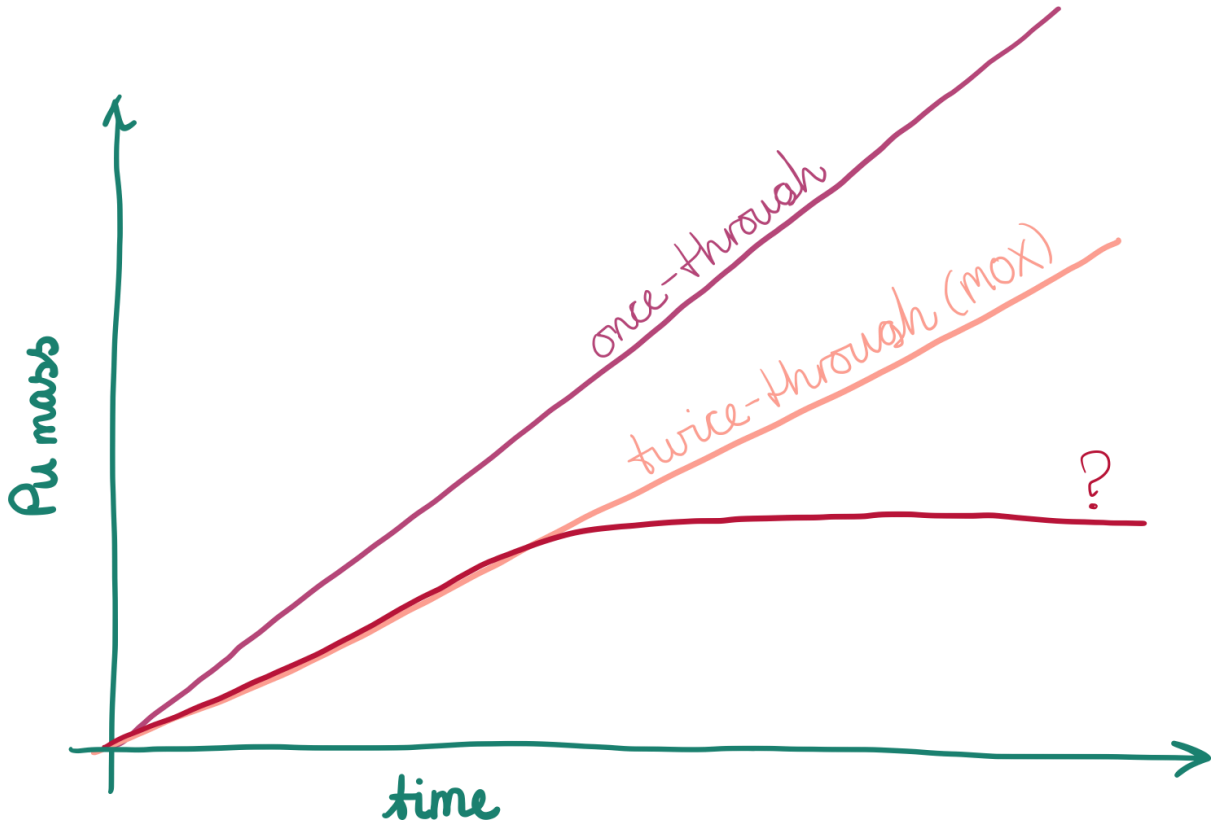


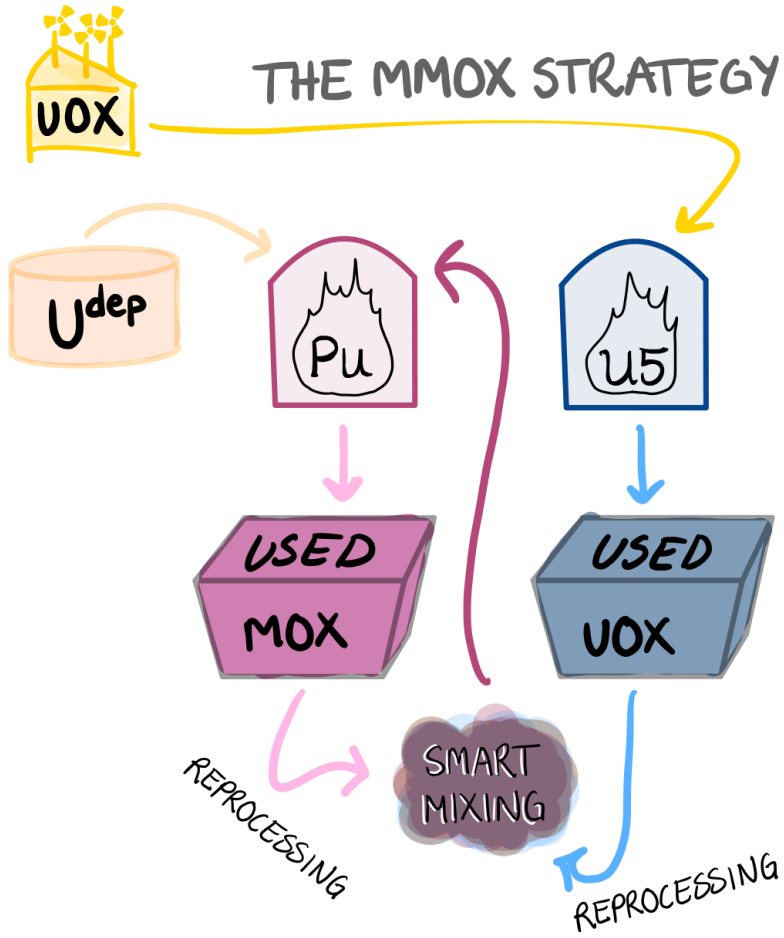
Fast reactors

POSTPONED






Pu mass
time
once-through
twice-through (MOX)
?

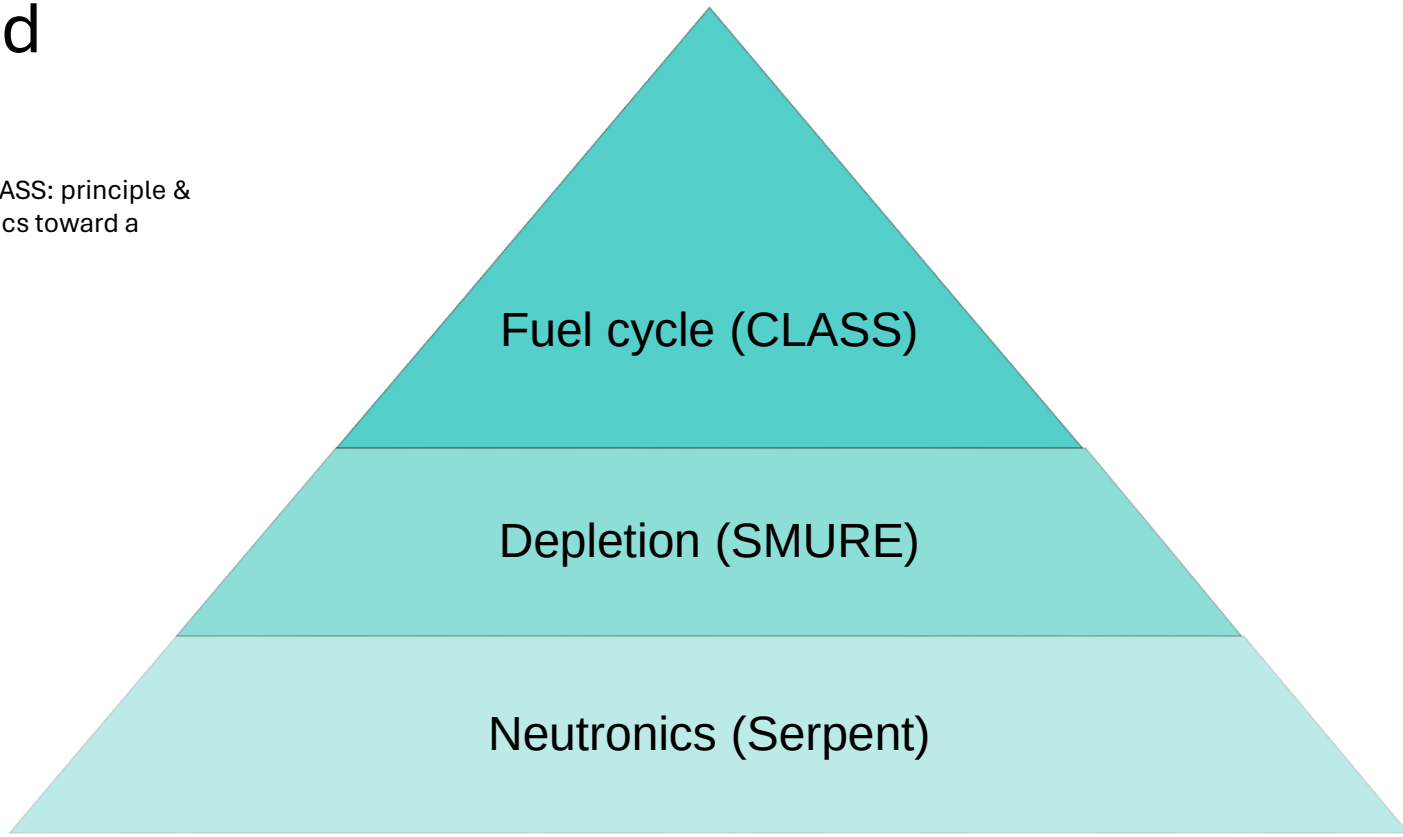

THE MMOX STRATEGY
UOX
Udep
Pu
U5
USED
MOX
USED
UOX
SMART
MIXING
REPROCESSING
REPROCESSING

What will happen to the plutonium inventory (and a bunch of other stuff) if we employ the Multi-MOX method?

CLASS

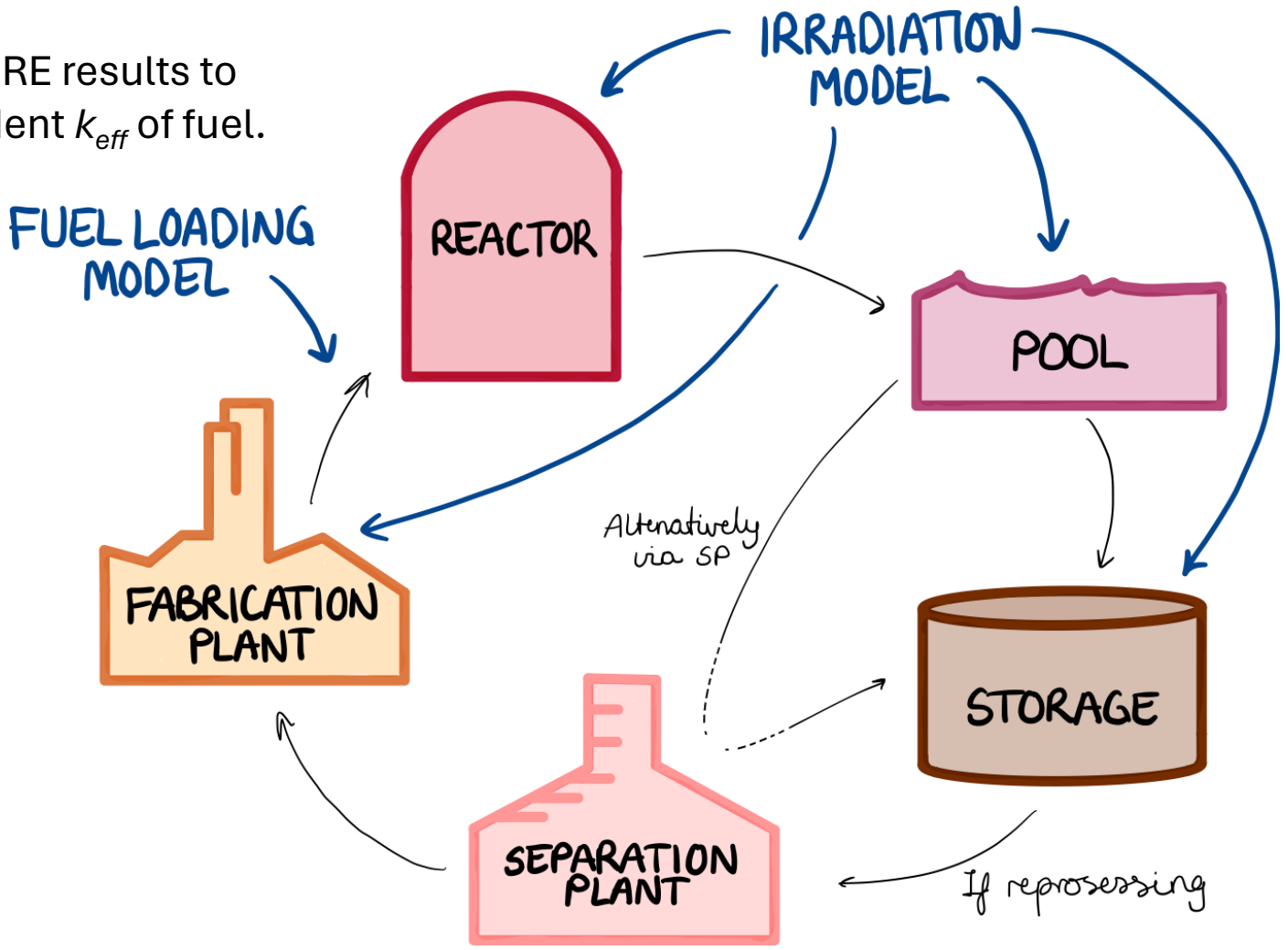
(**C**ore **L**ibrary for **A**dvanced **S**cenario **S**tudies)

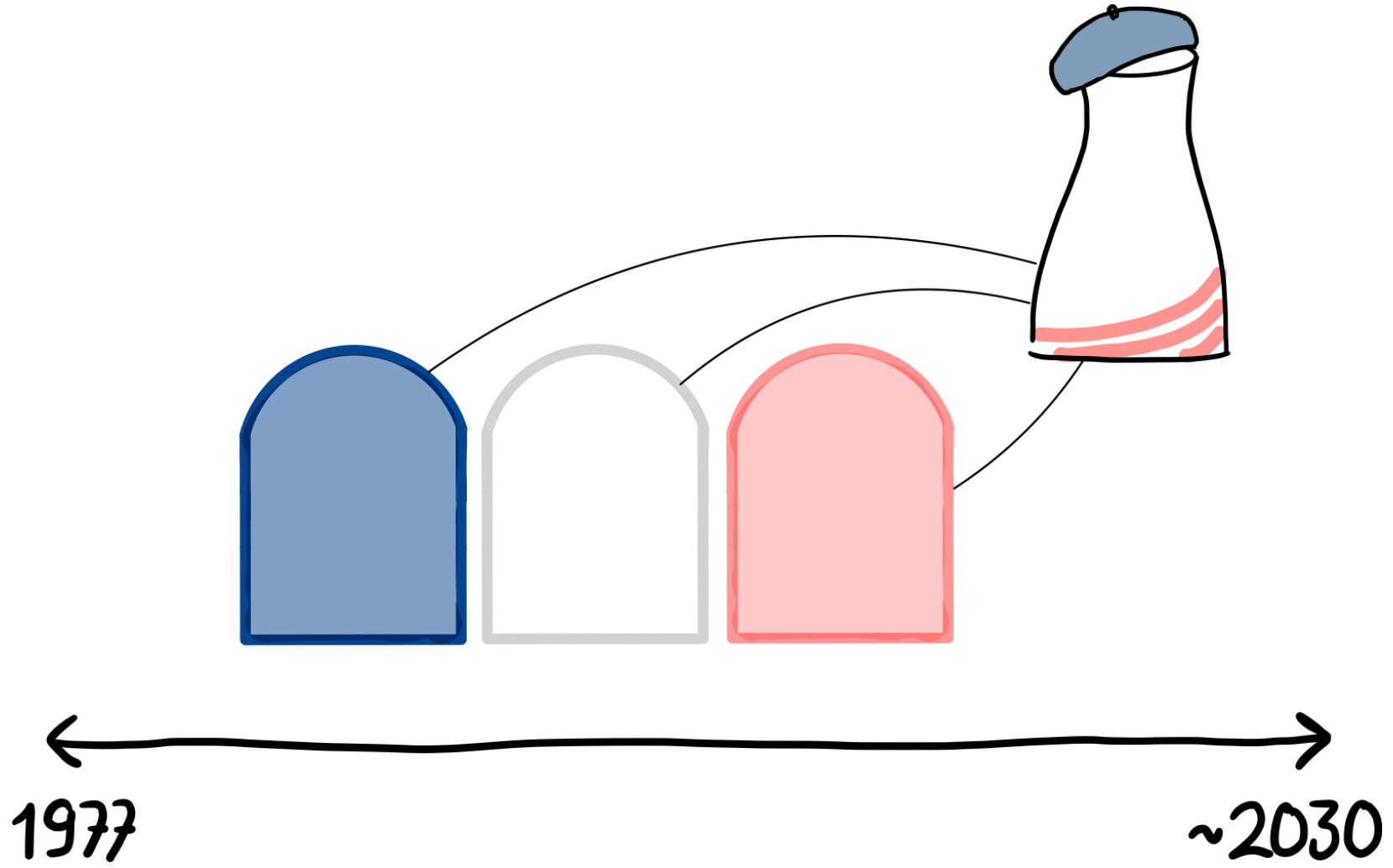
B. Mouginot et al. ‘Core library for advanced scenario simulation, CLASS: principle & application’. In: International Conference “The Role of Reactor Physics toward a Sustainable Future”(PHYSOR 2014). 2014, 12–p.

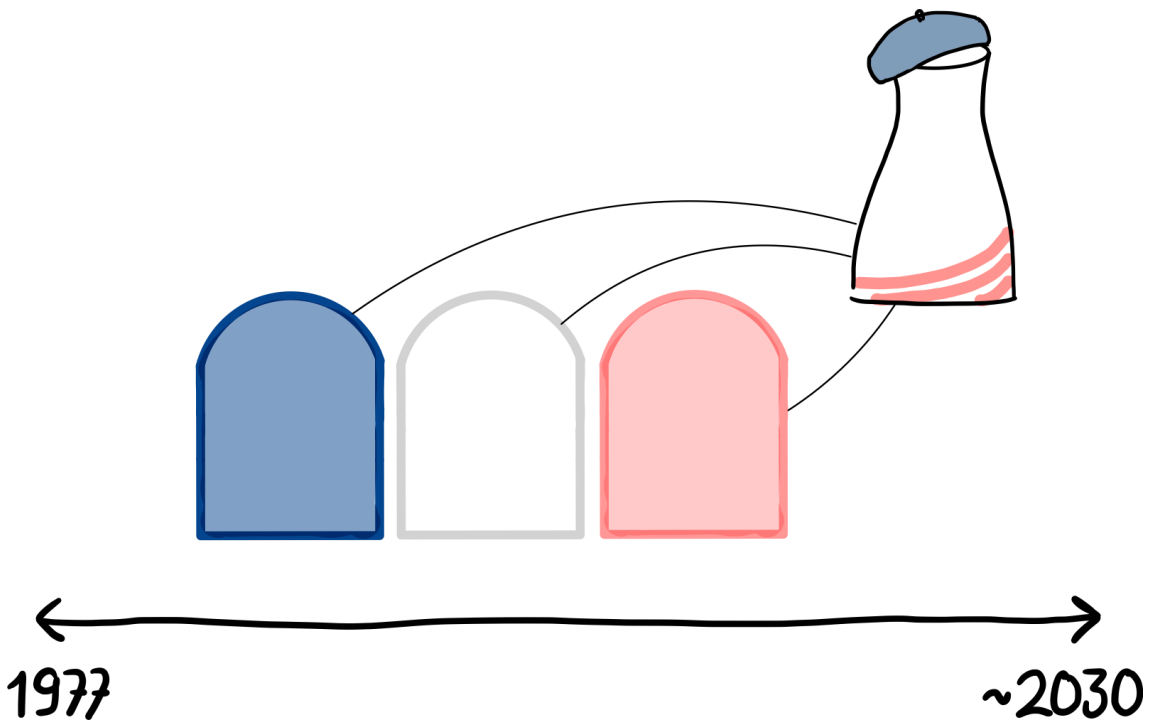


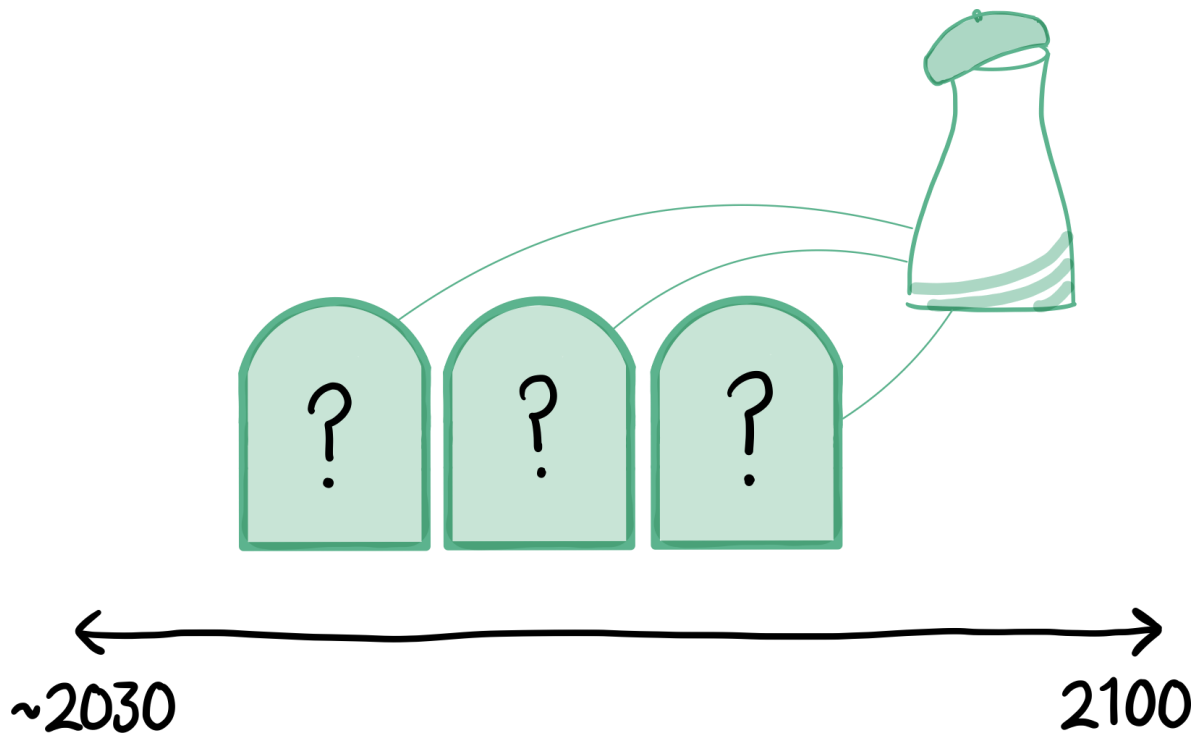
ANN trained on SMURE results predicts time-dependent cross sections. Irradiation model calculates neutron flux and depletion matrix.

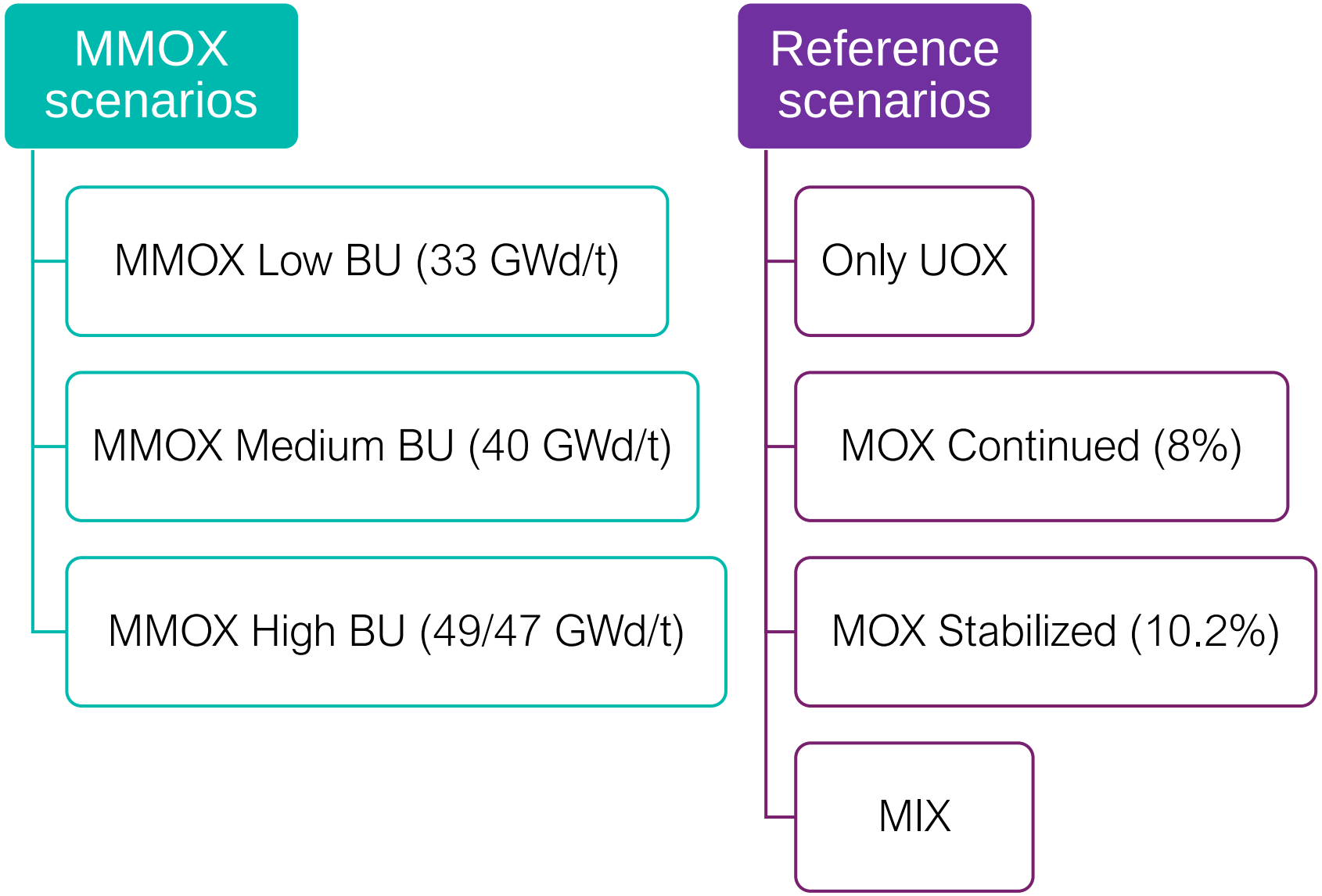
ANN trained on SMURE results to predict time-dependent k_{eff} of fuel.

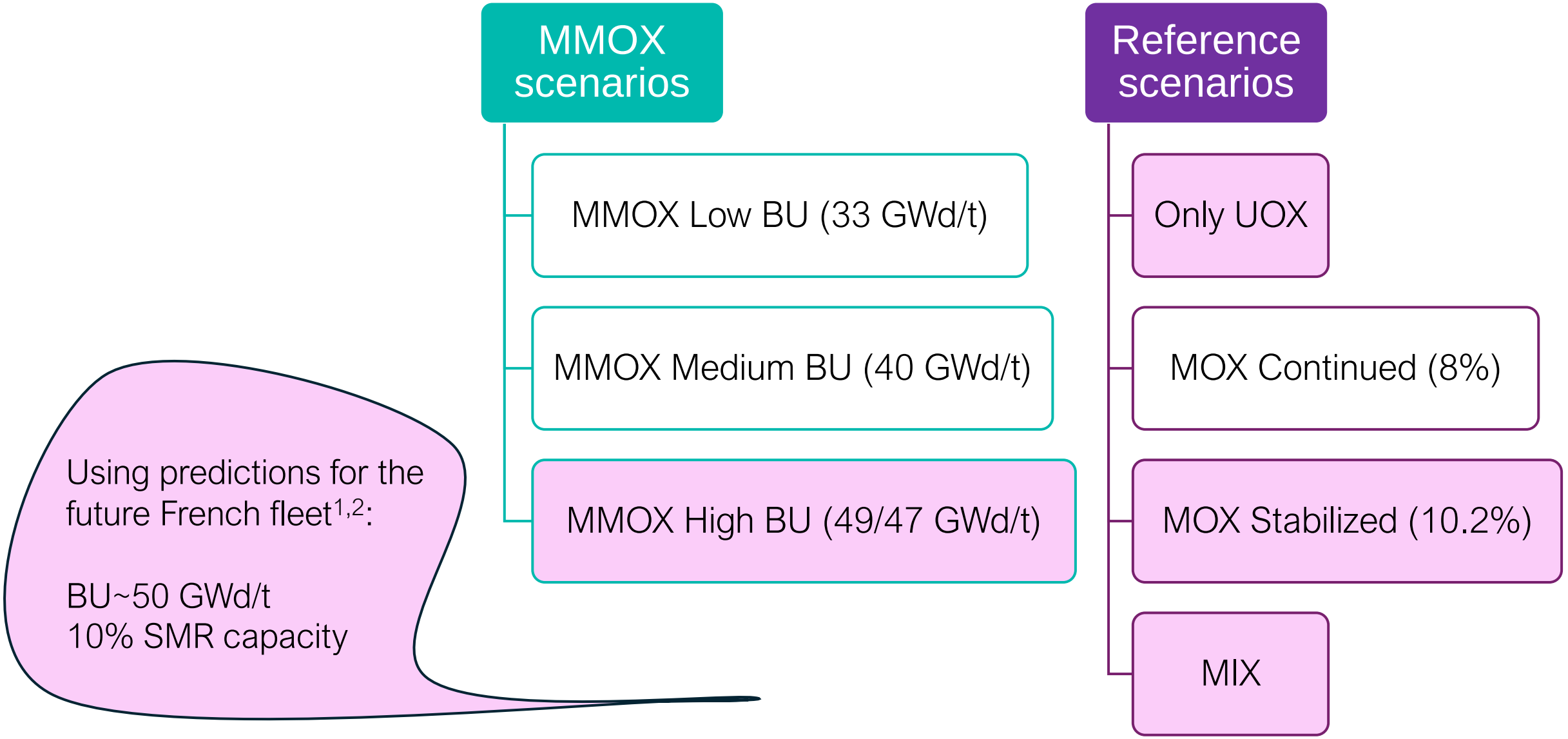



1977
~2030


1977
~2030

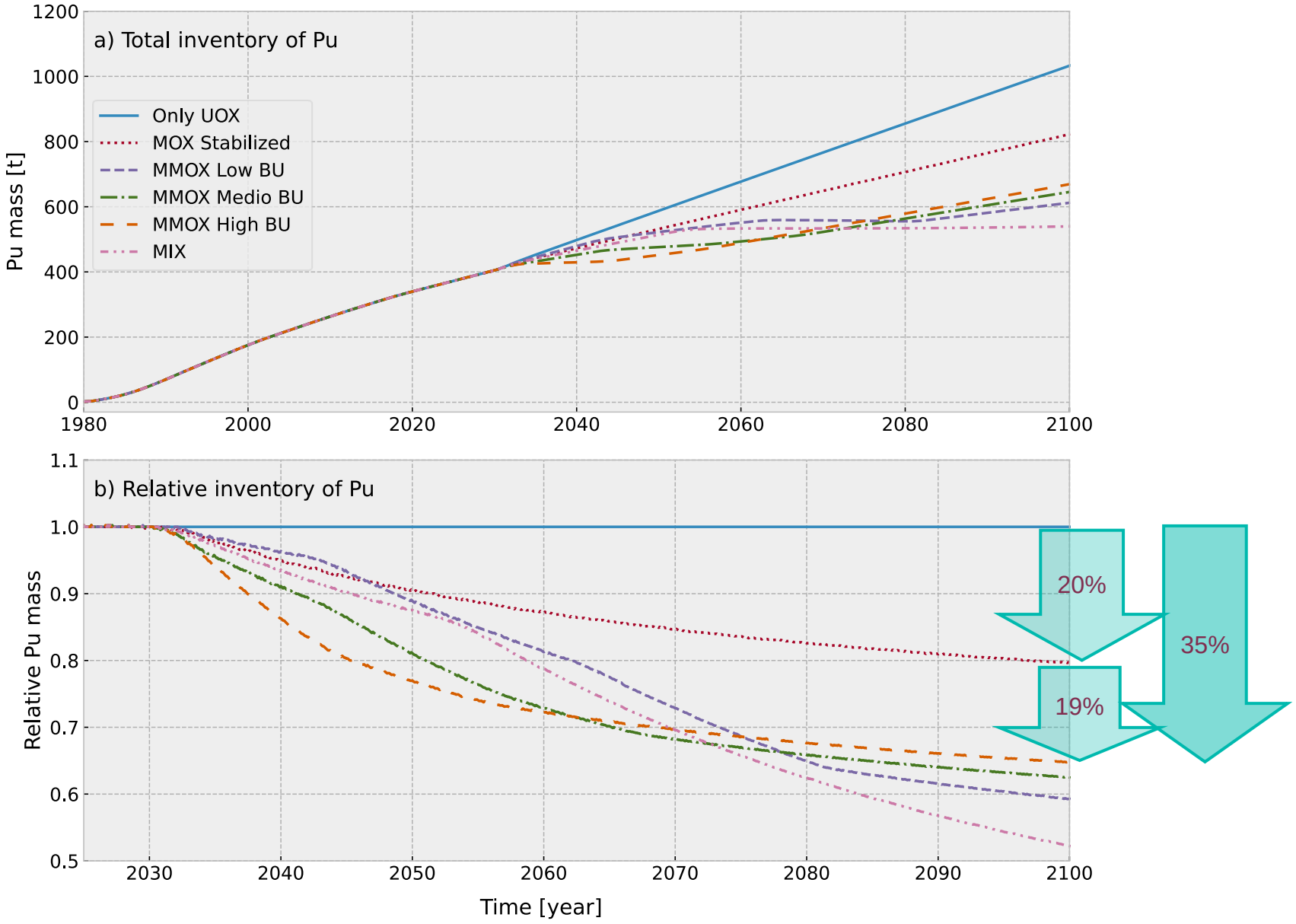

?
?
?
~2030
2100


MMOX scenarios
MMOX Low BU (33 GWd/t)
MMOX Medium BU (40 GWd/t)
MMOX High BU (49/47 GWd/t)
Reference scenarios
Only UOX
MOX Continued (8%)
MOX Stabilized (10.2%)
MIX

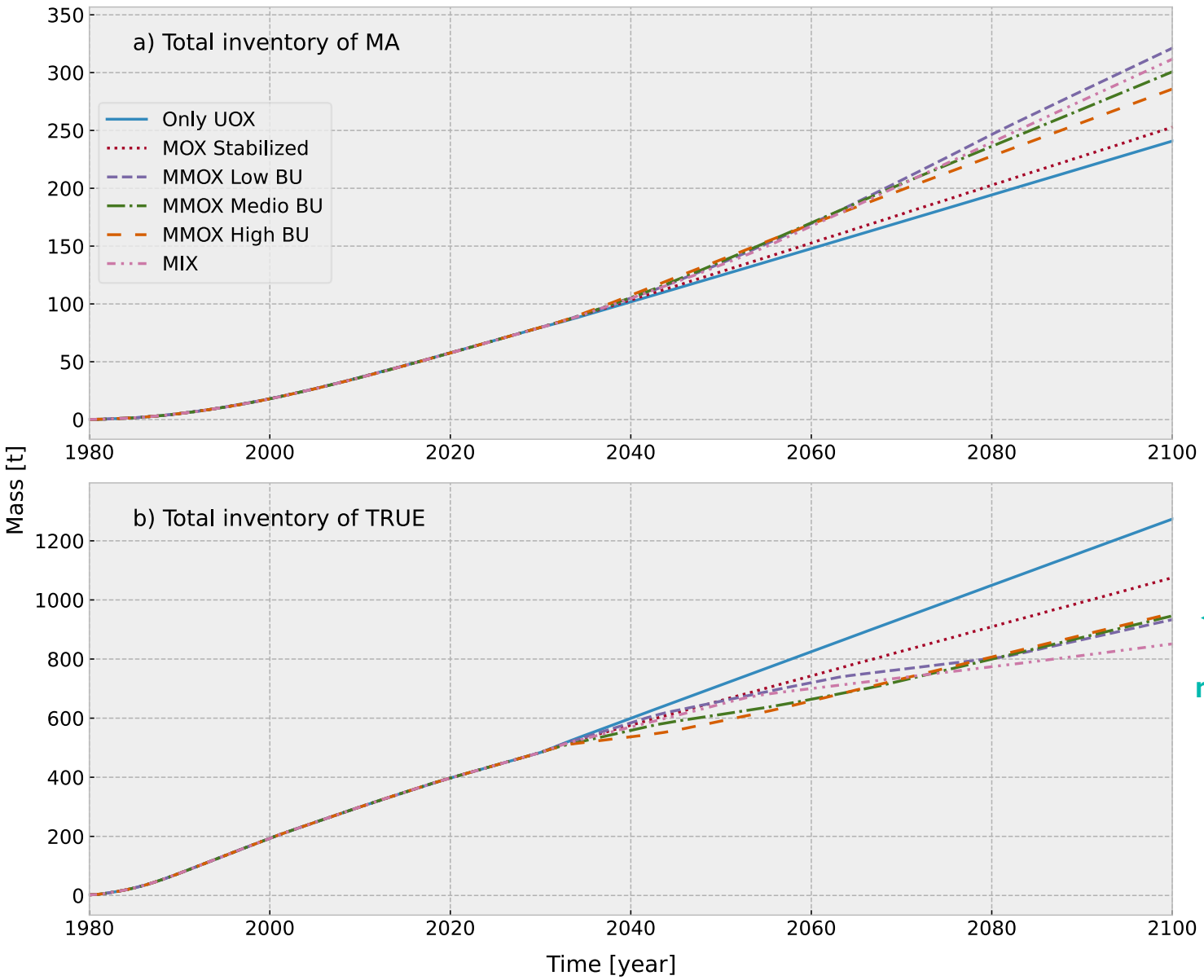


[1]F. Courtin et al. 'Pu multi-recycling scenarios towards a PWR fleet for a stabilization of spent fuel inventories in France'. In: *EPJ N-Nuclear Sciences & Technologies* 7 (2021), p. 23.
[2]RTE. *Energy Pathways to 2050 (Key results)*. Tech. rep. RTE for the French government, Oct. 2021.

Results:
Pu inventory

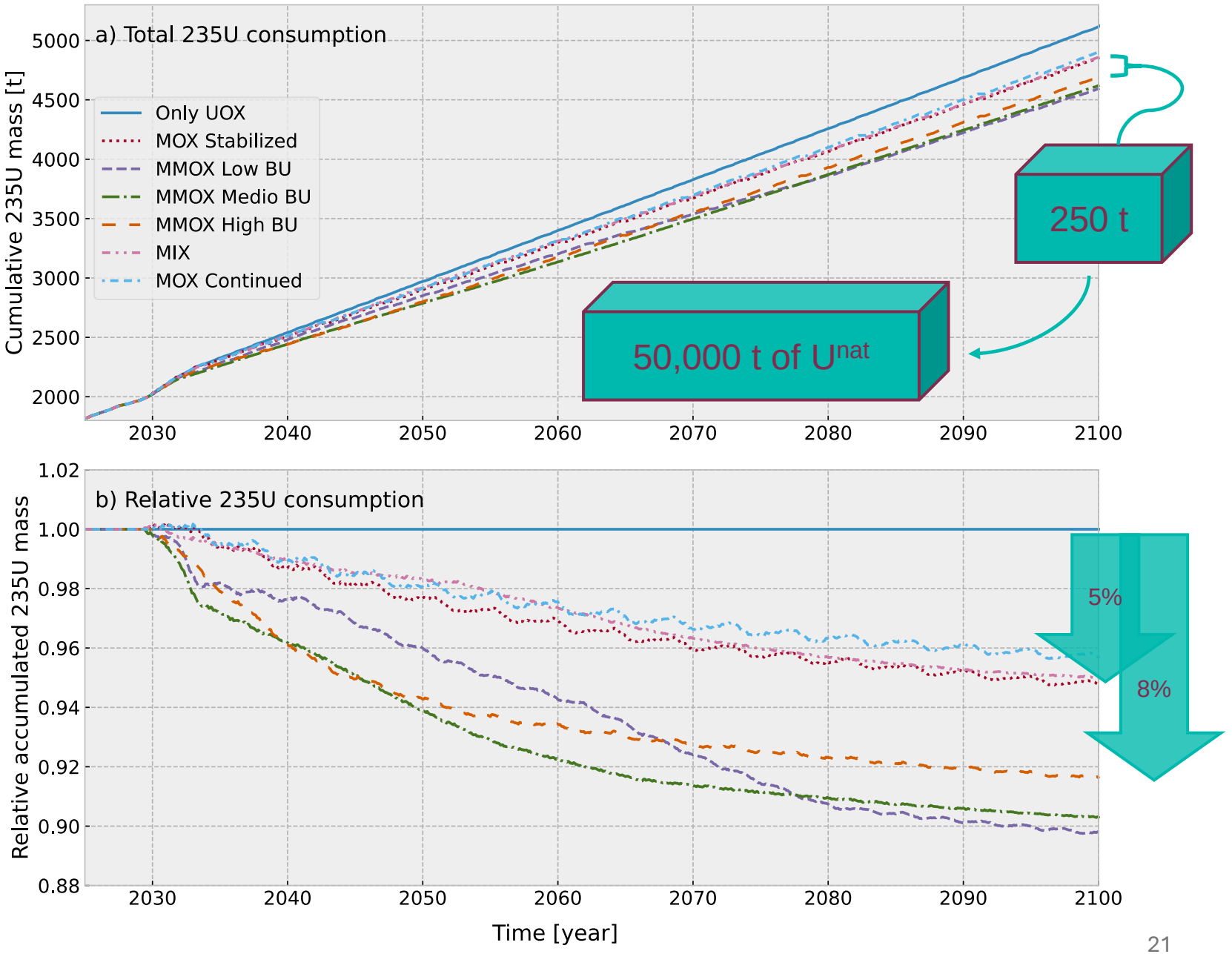


Results:
MA/TRUE inventory



same result regardless of BU

Results: Uranium consumption



Key takeaways: Multi-MOX

Novel method of multi-recycling plutonium in PWRs

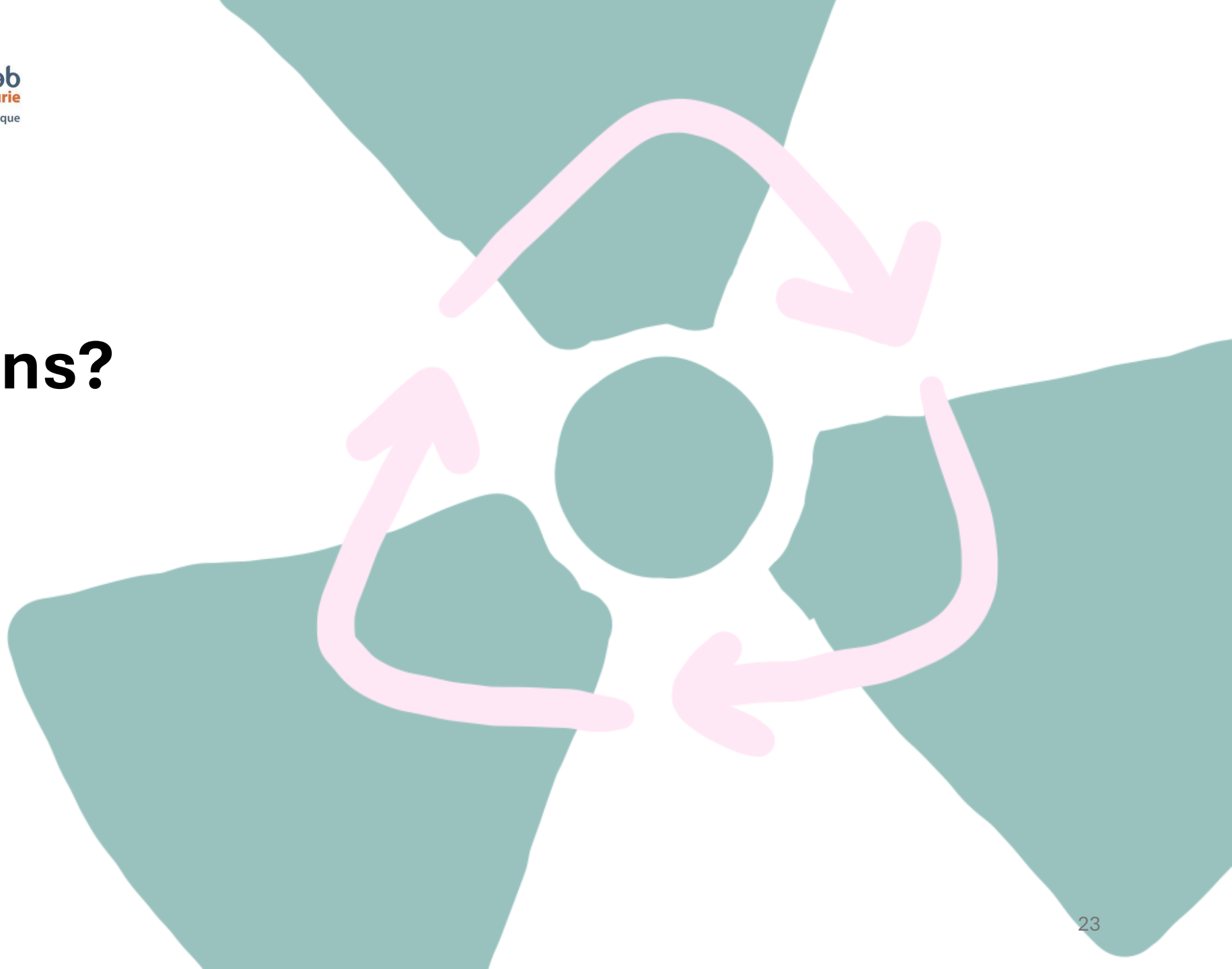
Easily implememted in a fuel cycle strategy already using MOX fuel

Significantly reduces the accumulation of plutonium in storage

UNIVERSITY OF OSLO

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

Questions?



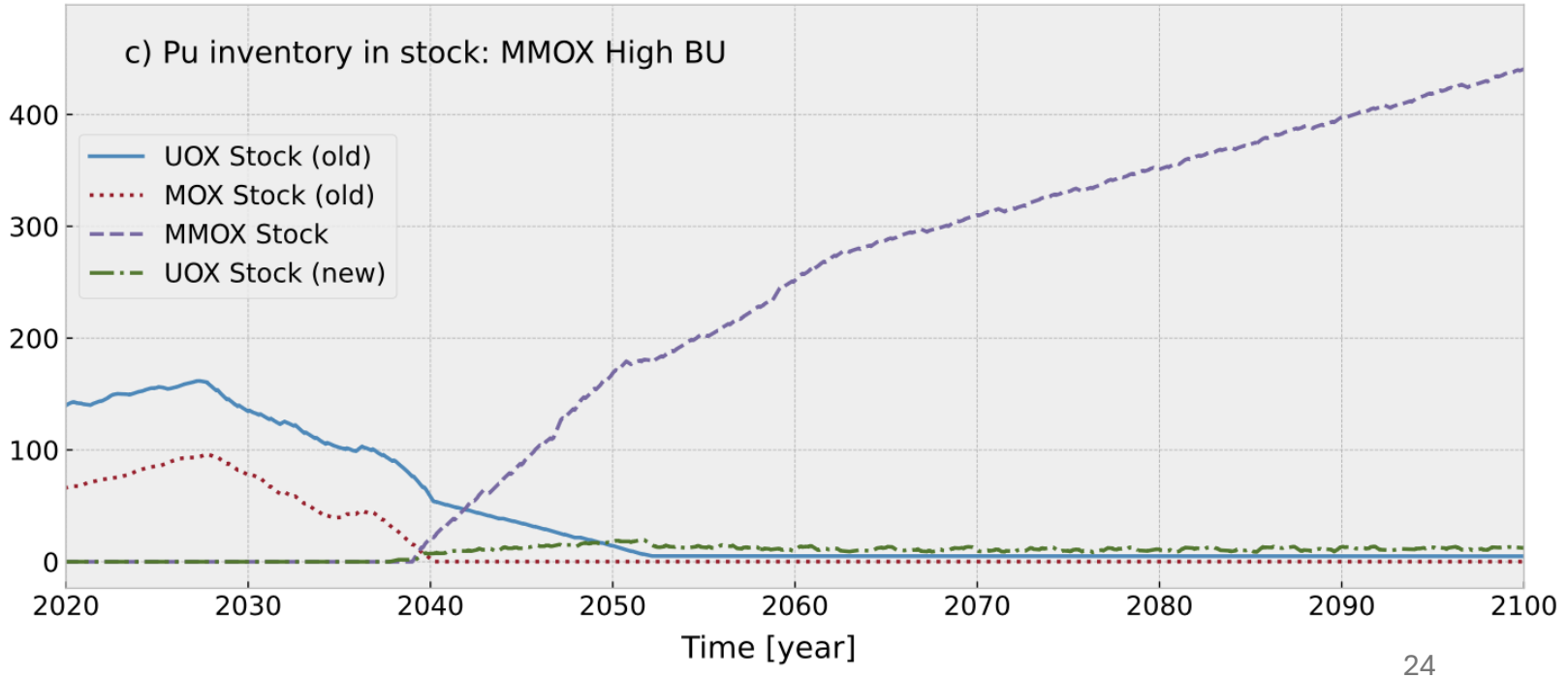
Gulla L. S. Torvund
gltorvun@uio.no

NUKLEÆRSENTERET

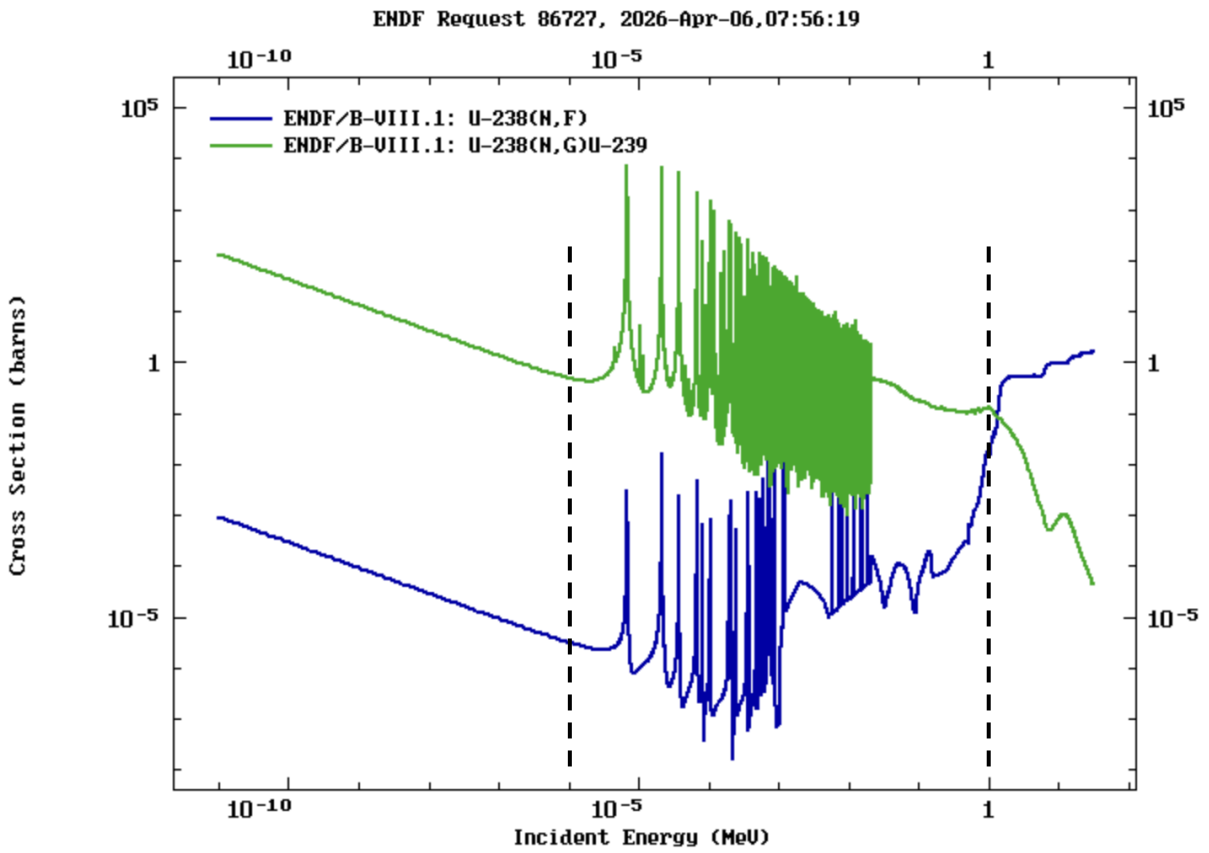
Table 13.4: This table lists the specifications of the *MMOX High BU* scenario. The three periods differ with varying MOX fraction in the total nuclear fleet and the used fuels that make up the MOX fabrication mix.

	1st period	2nd period	3rd period
Start (year)	2030	2042	2054
MMOX fraction	25%	16.5%	12.8%
MOX fabrication specifications			
Old used UOX	54.5%	18.2%	–
Used MOX	45.5%	–	–
New used UOX	–	36.4%	62.5%
Multi-recycled MOX	–	45.4%	37.5%

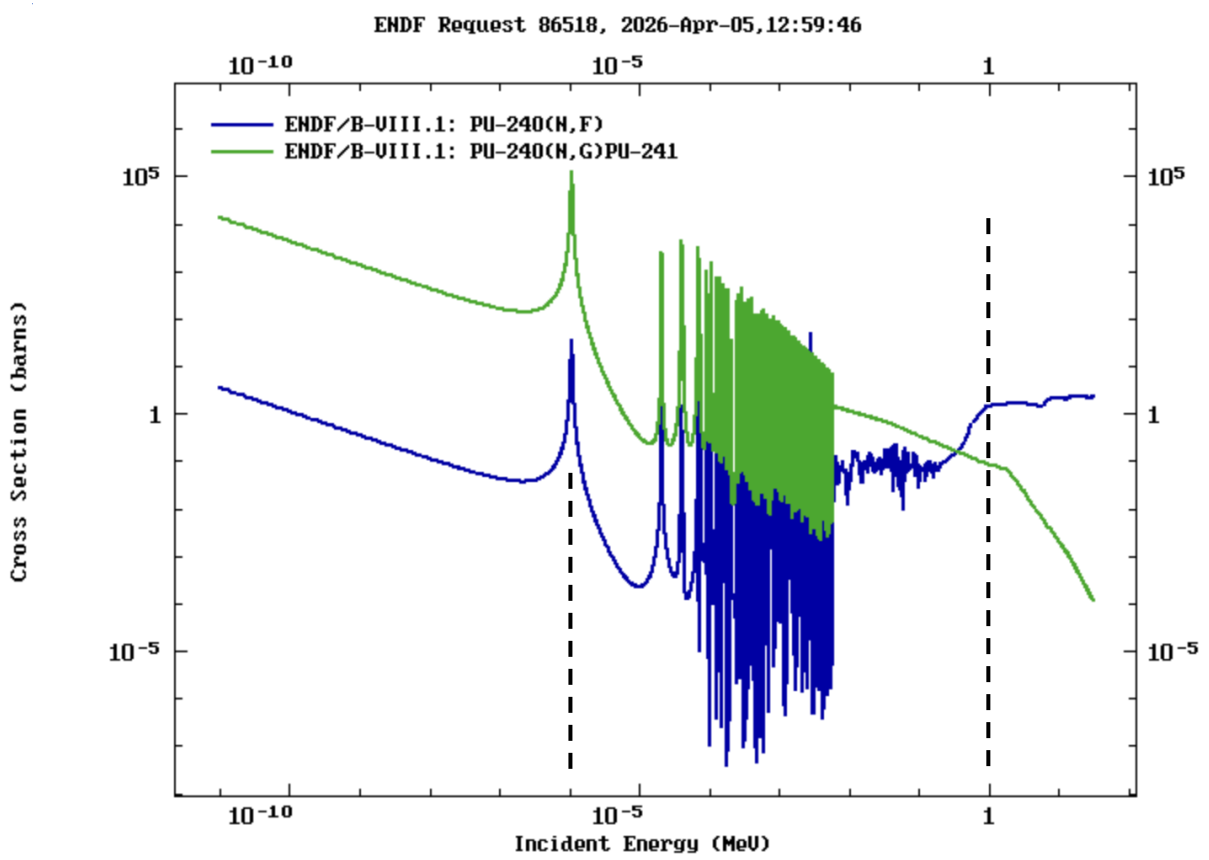
How did the MMOX mixing go?



Why does Pu-240 contribute to a positive void coefficient?

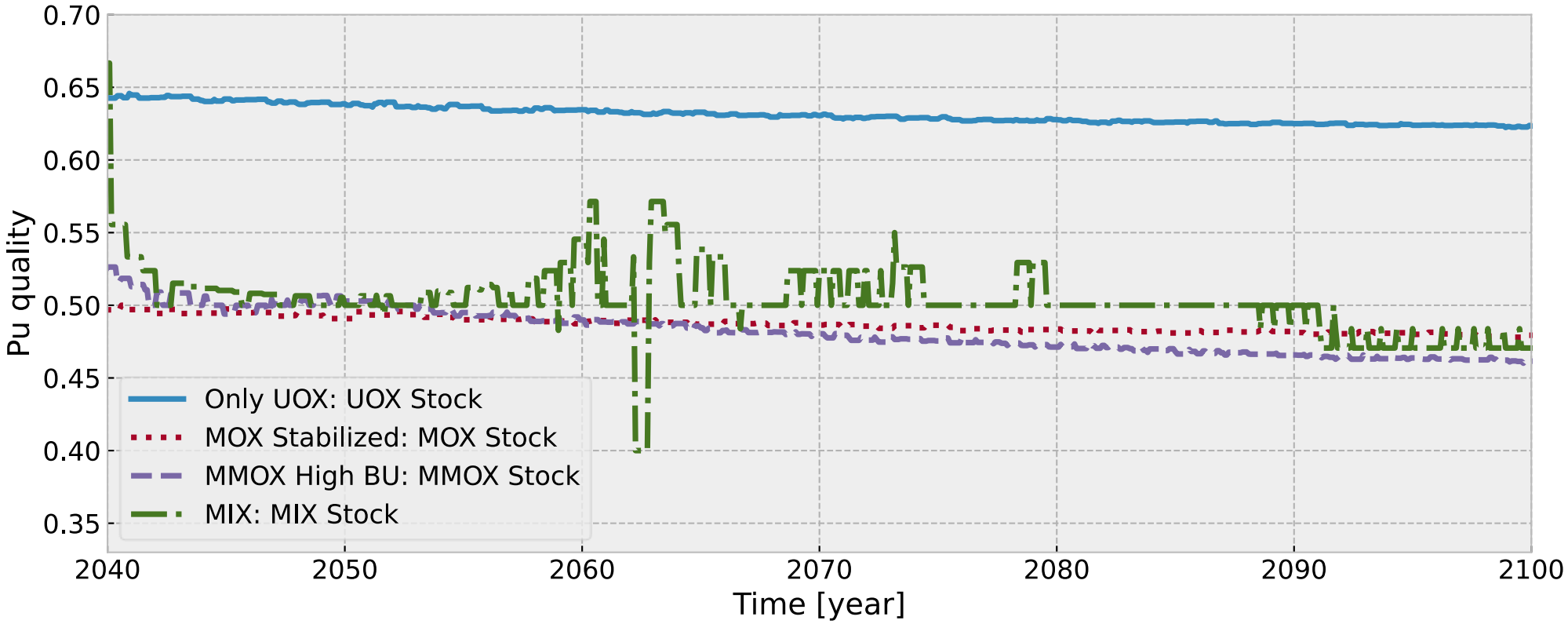


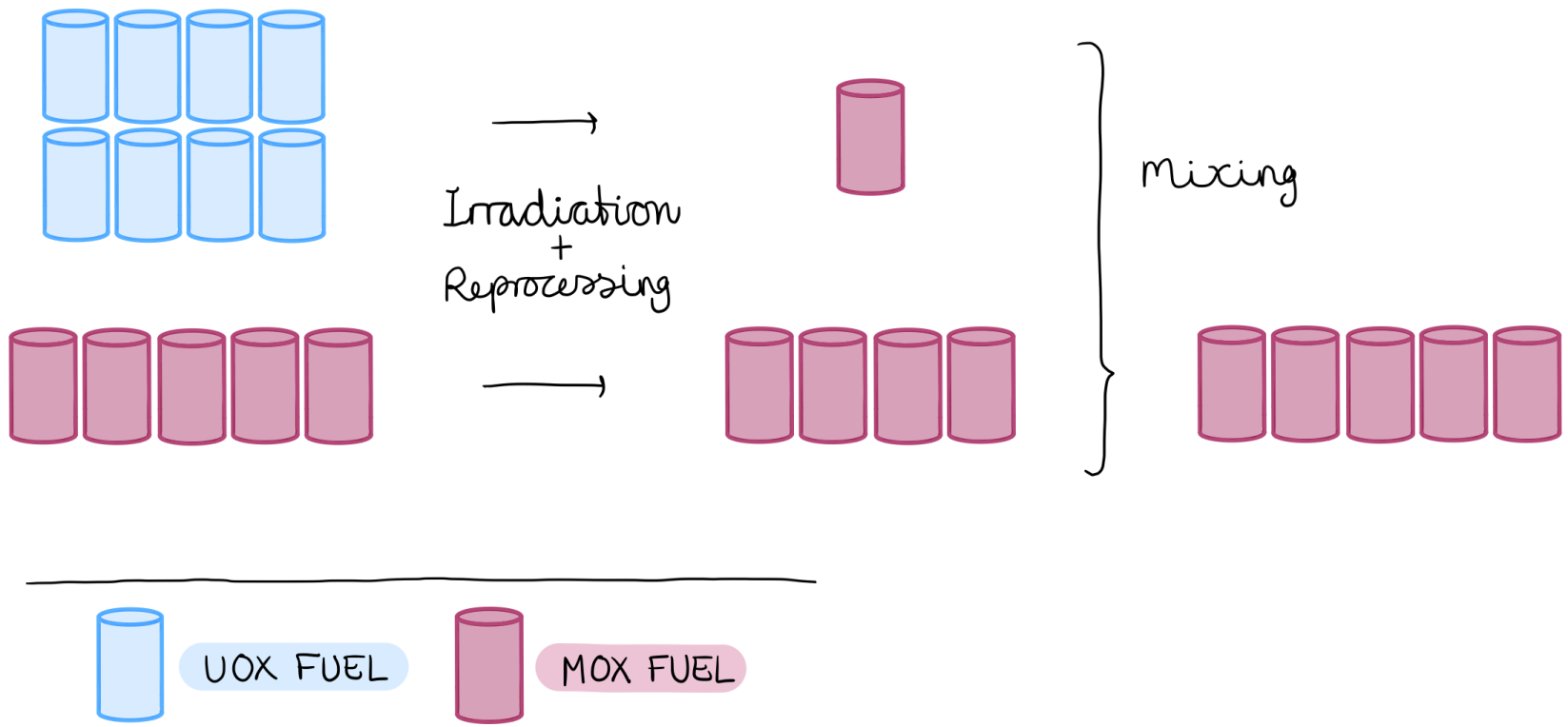
238-U



240-Pu

Results: Pu quality





~40% need to be MOX fueled