TWOFCS WORKSHOP 2021

Impact of disruption between options of plutonium multi-recycling: in PWRs and in SFRs

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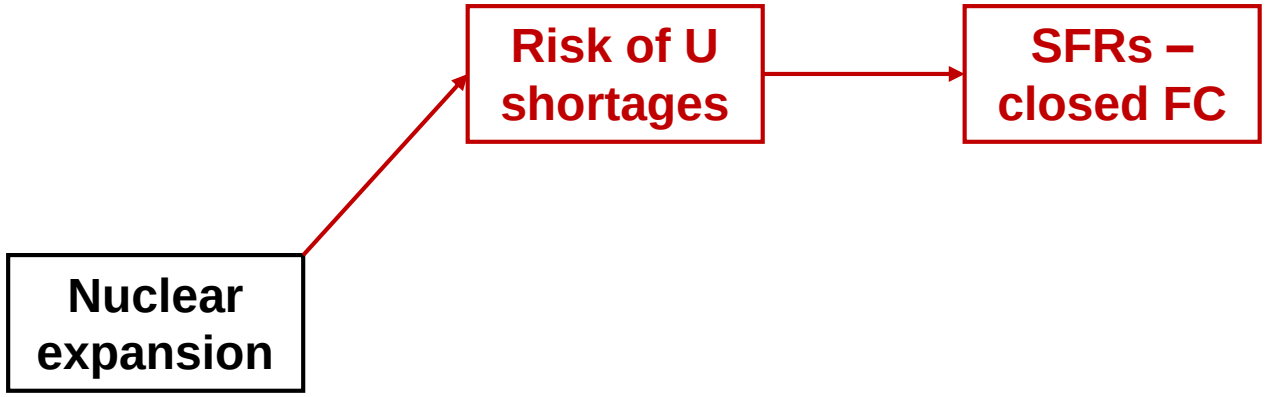
Subatech

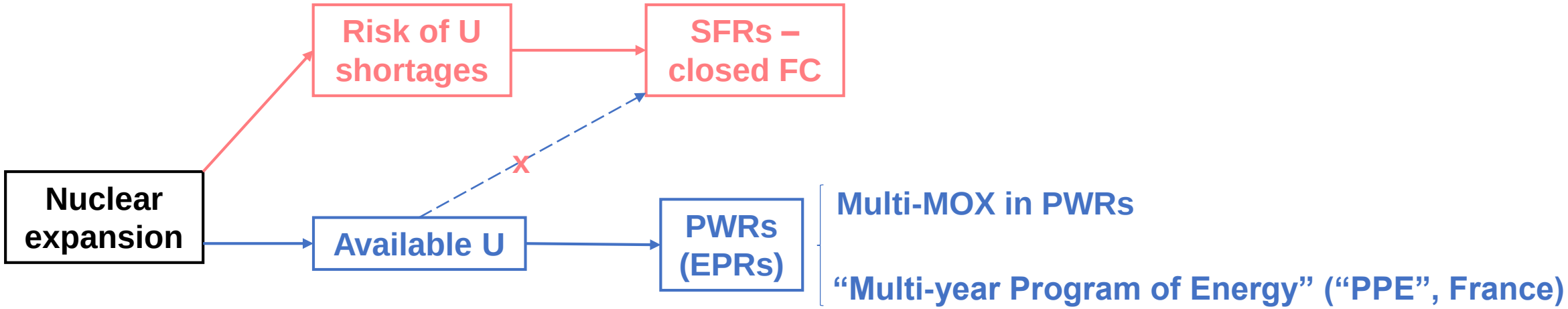
Outline

- Uncertainty of nuclear future: which technological orientation?
- Methodology: disruption & robustness assessments
- (Prior) Trajectories of interest: TRJ SFR & TRJ MIX
- Adaptations in case of disruption:
  - From TRJ MIX: SCN MIX2SFR
  - From TRJ SFR: SCN SFR2MOXEUS
- Conclusion

Uncertain Nuclear Future



Uncertain Nuclear Future



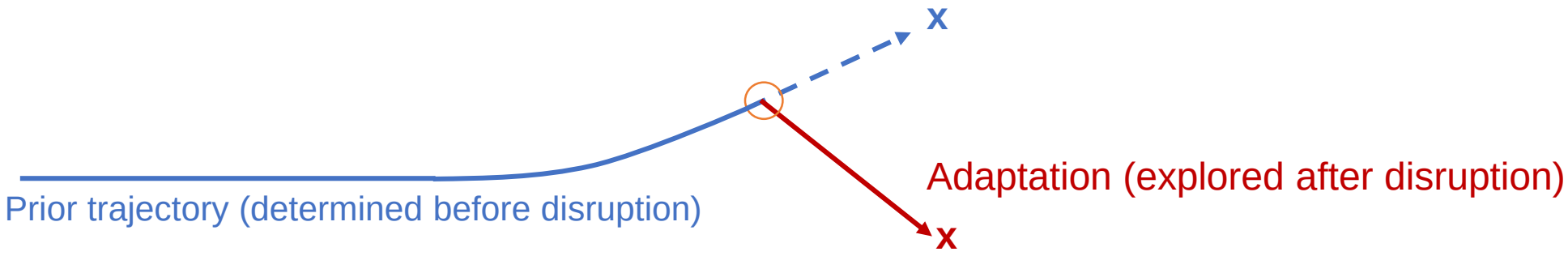
➔ Uncertain future: technological orientations of Pu multi-recycling → definitive decision?

➔ Given one implemented strategy (today) → possible to turn to the other direction (future)?

Uncertainty of future → Which system to be studied & which criterion for the assessment?

Methodology

- Strategy robustness (previous study[1]):
  - × Stick to a given future
  - ✓ Adapt to changes
- Disruption of objective/criterion & adaptation



- Application of the method: French fuel cycle & (inspired from) national strategies
- Simulator: CLASS (Core Library for Advanced Scenario Simulation)

[1] Liang et al, Annals of Nuclear Energy, 2021

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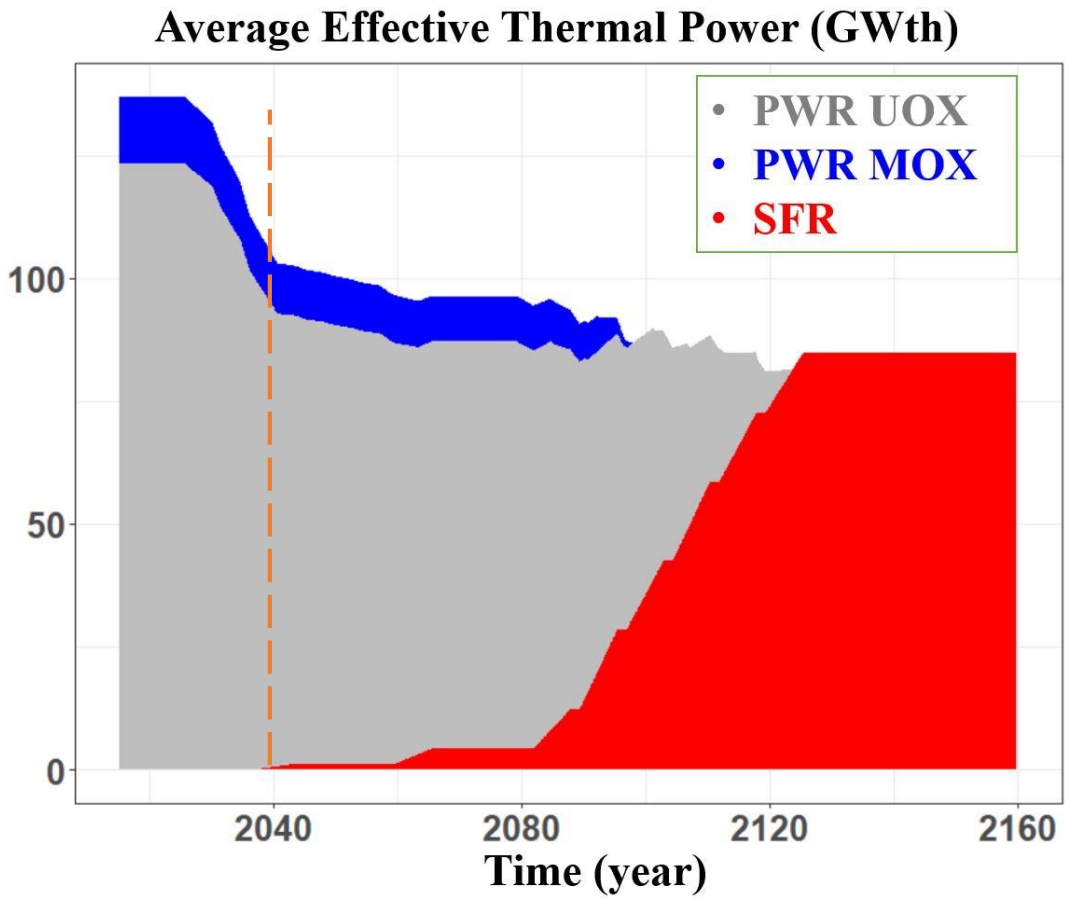
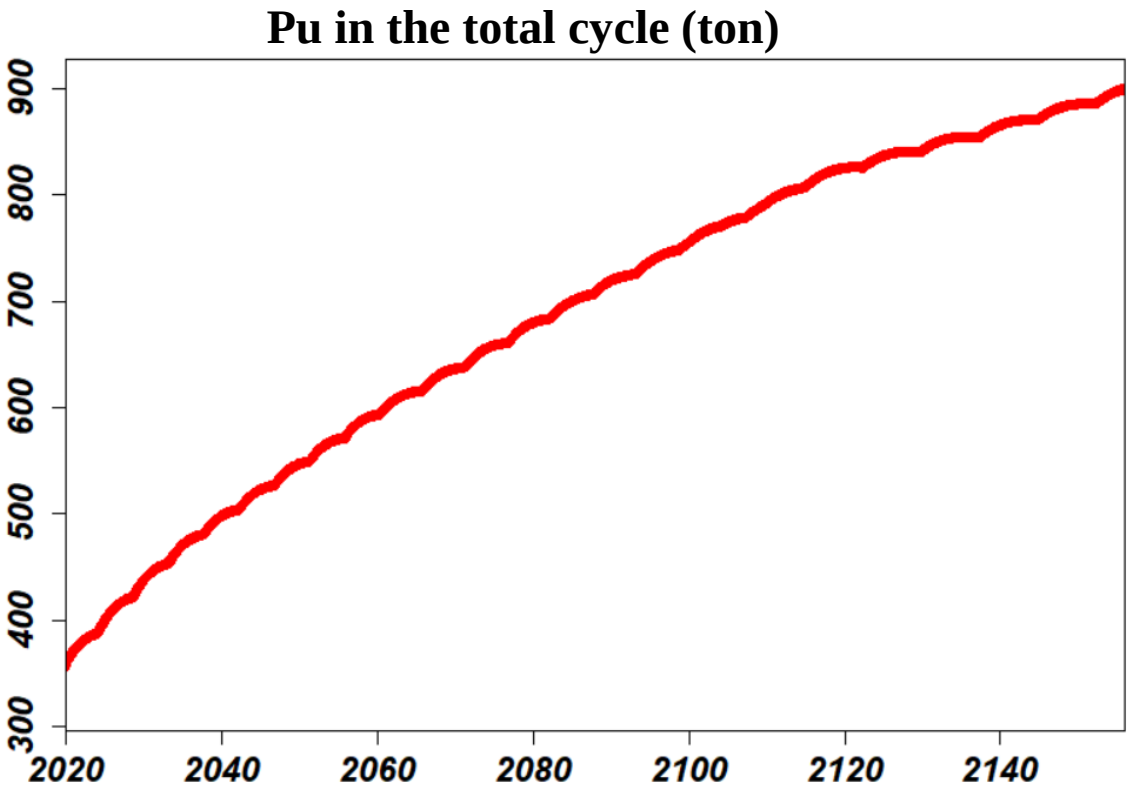
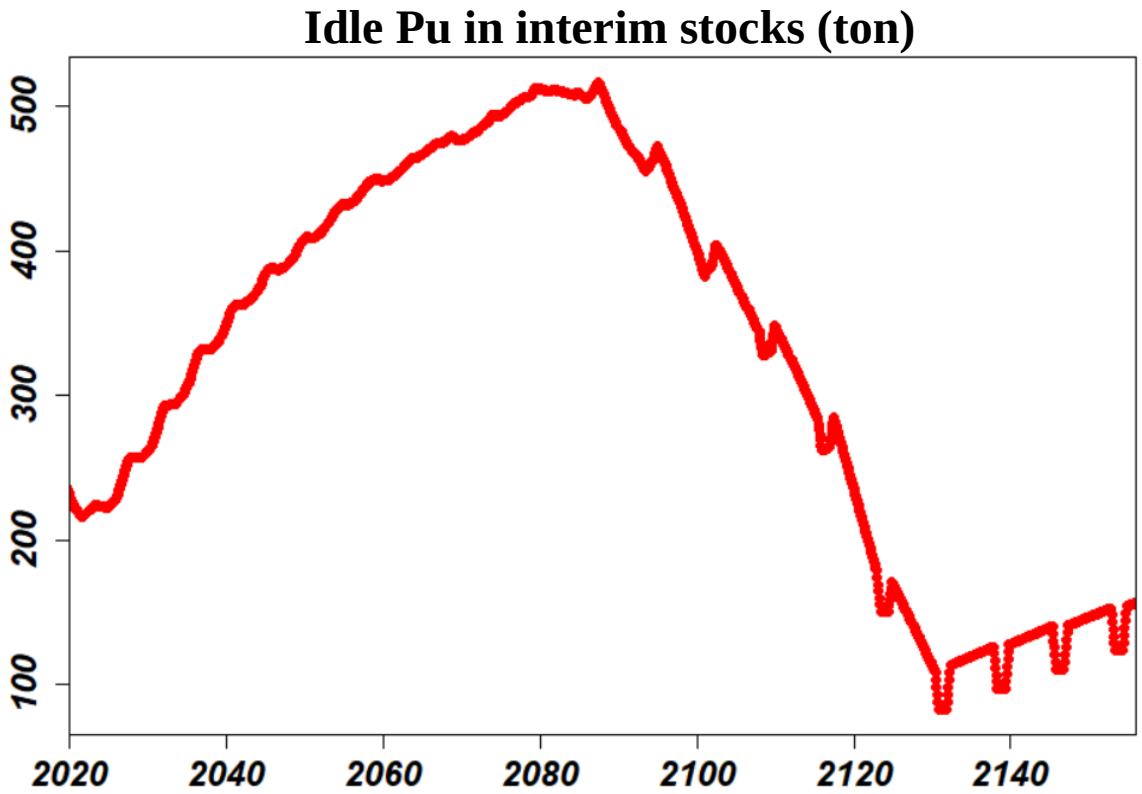
Prior: TRJ SFR

- Former “reference” strategy (<2012): SFR deployment for 100% fleet



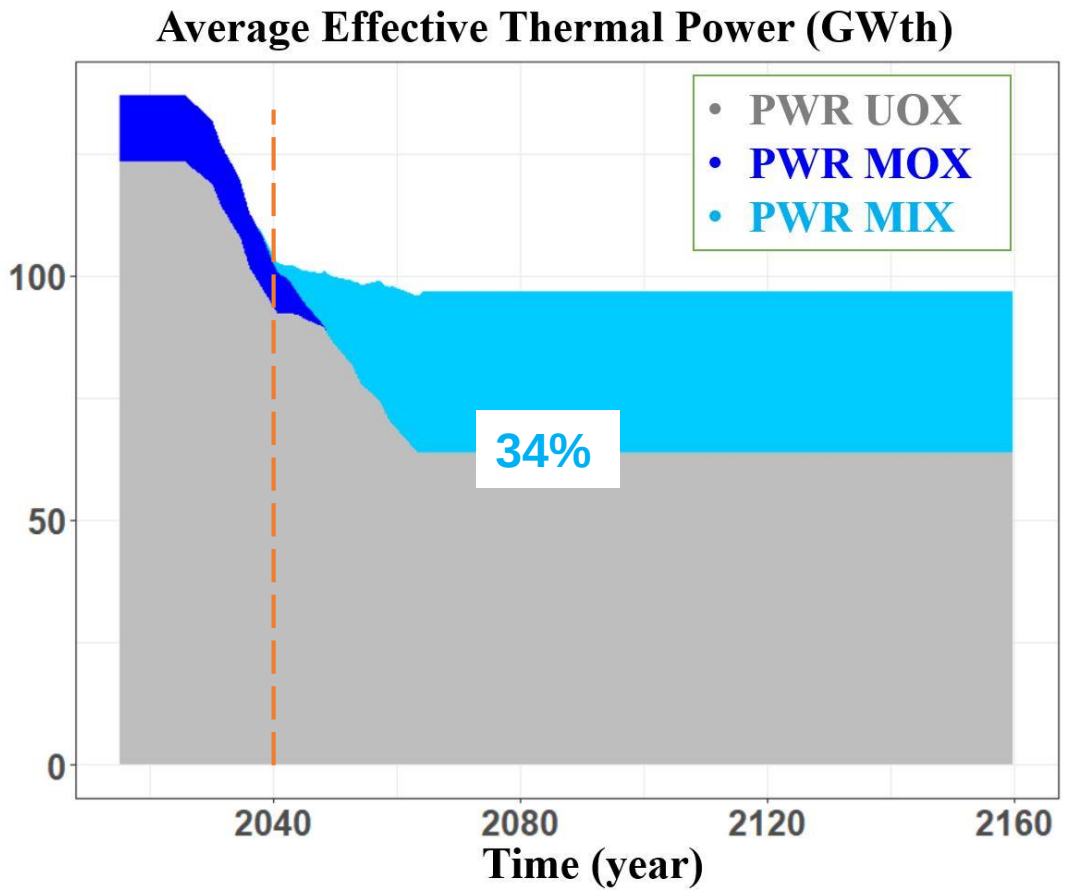
Prior: TRJ SFR





Prior: TRJ MIX

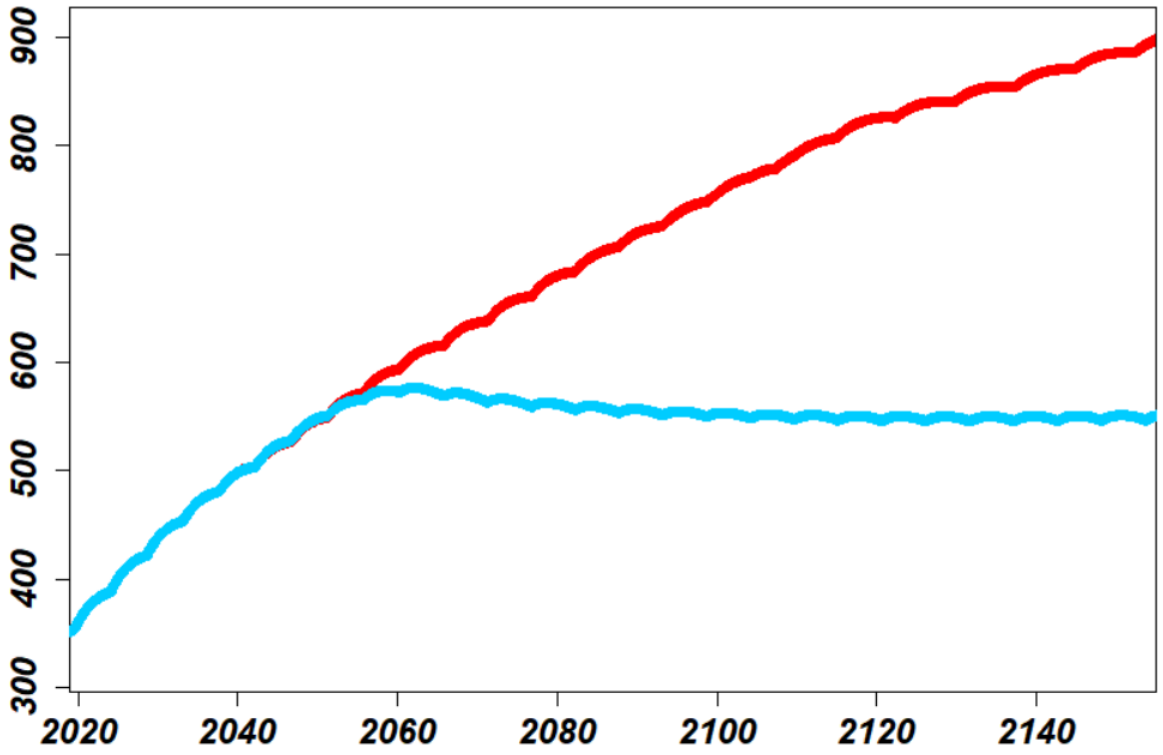
- New “reference”: Pu multi-recycling in PWRs (“Multi-year Program of Energy”)
- MIX design: homogeneous mix of multi-Pu oxides & enriched U oxides



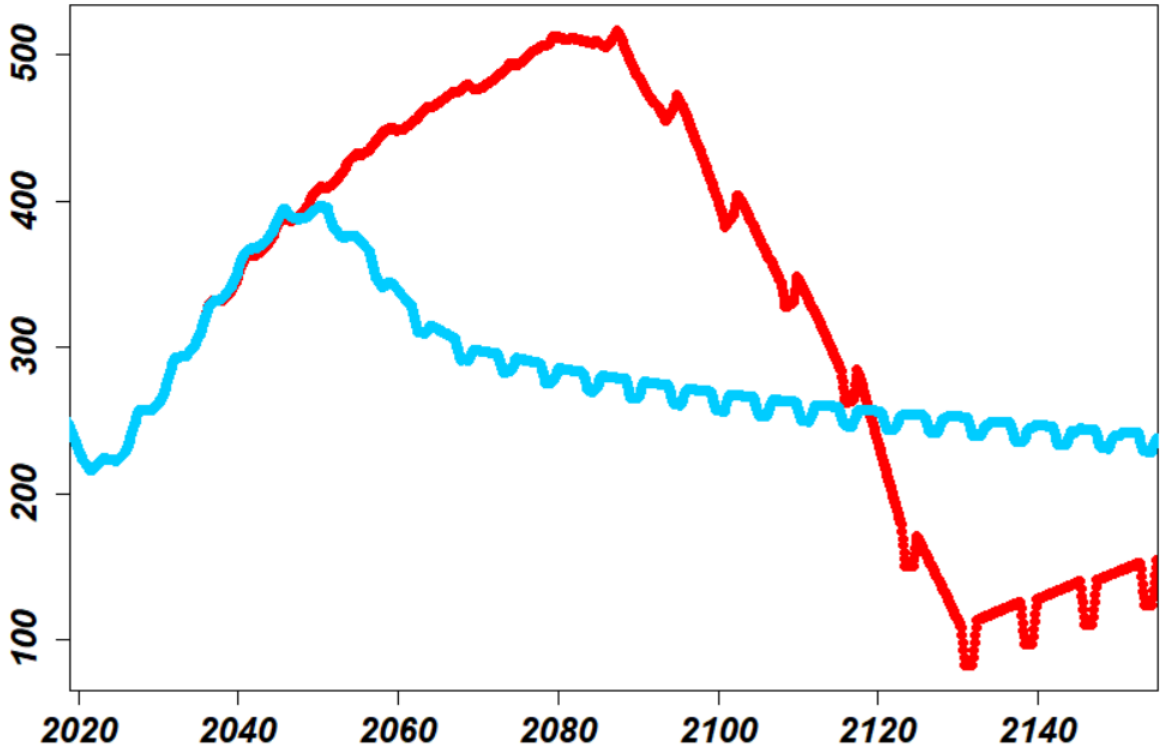
Prior: TRJ MIX

- TRJ MIX
- TRJ SFR

Pu in the total cycle (ton)



Idle Pu in interim stocks (ton)



"Contradiction": robustness of MIX-related strategy towards the future of SFR deployment?

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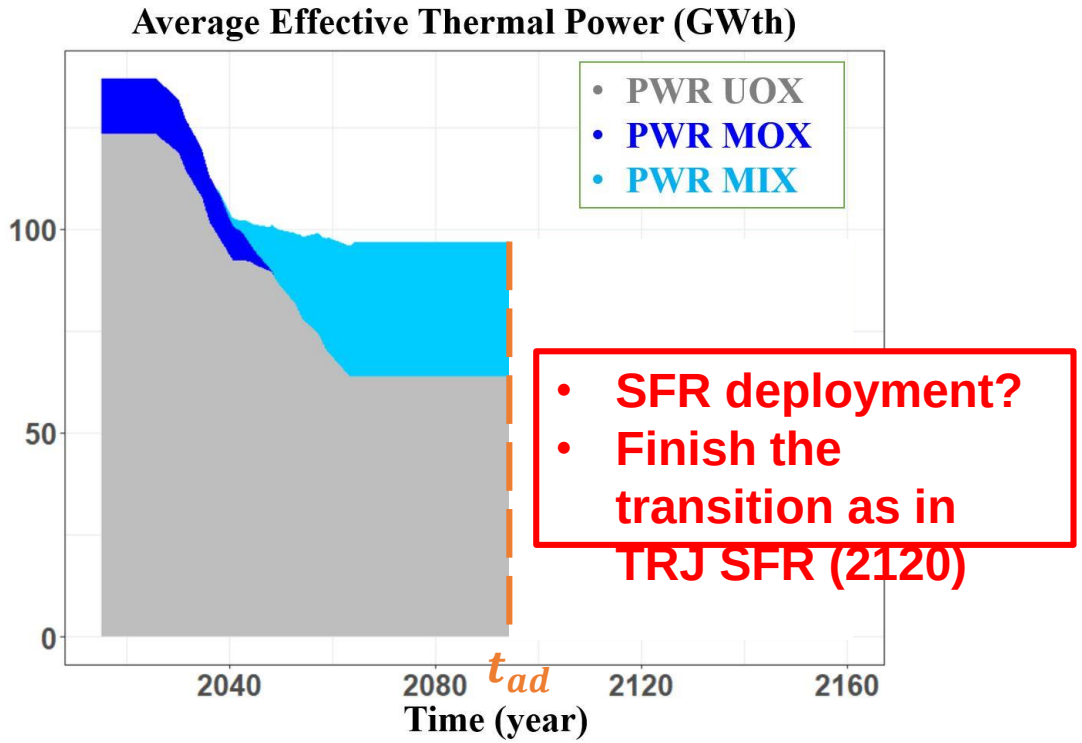
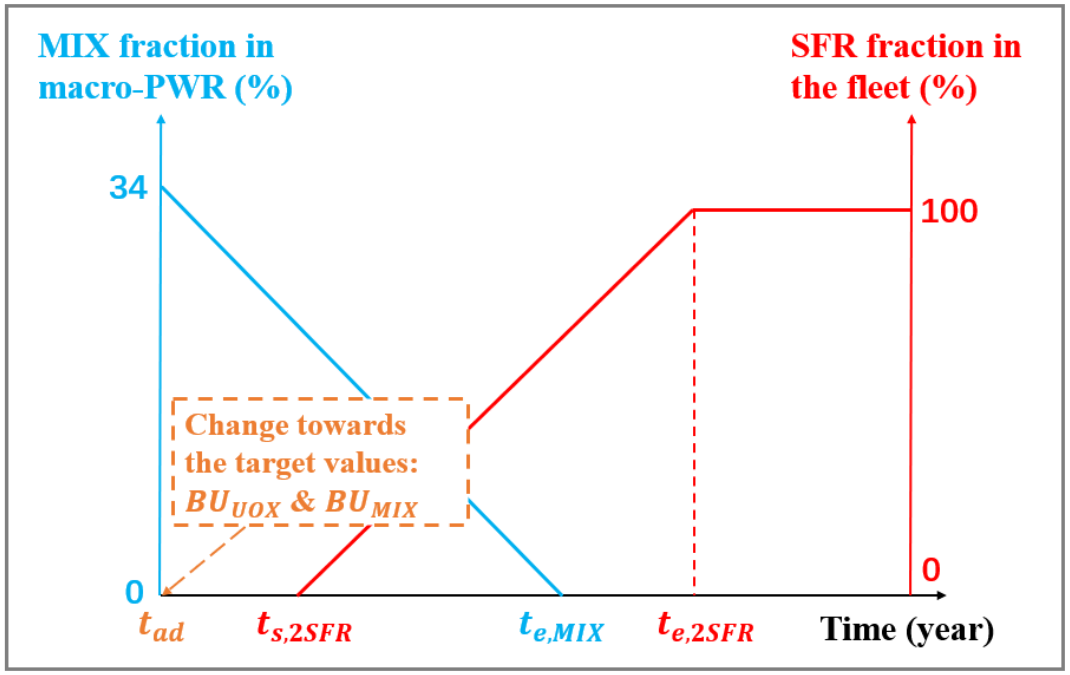
SCN MIX2SFR

- Disruption of TRJ MIX: re-estimation of U & reconsideration of SFR deployment
- Adaptation time (t_{ad}): 2065, 2085, 2100



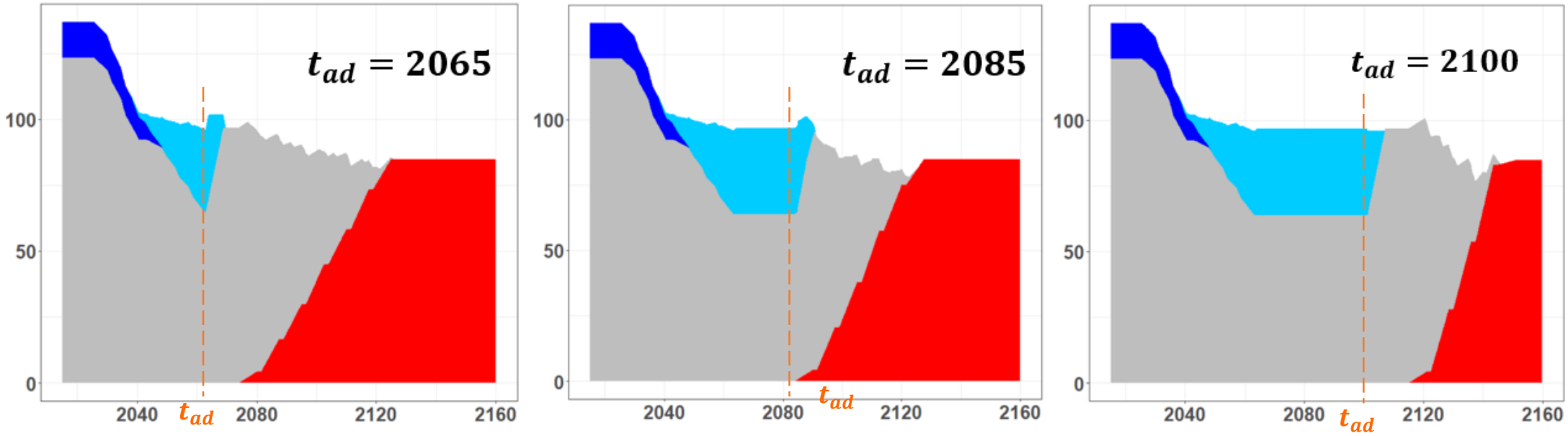
- SFR deployment?
- Finish the transition as in TRJ SFR (2120)



- min. $t_{e,2SFR}$ (by optimization)
- vs TRJ SFR (year 2120)

SCN MIX2SFR

Average Effective Thermal Power (GWth)



- PWR UOX
- PWR MOX
- PWR MIX
- SFR

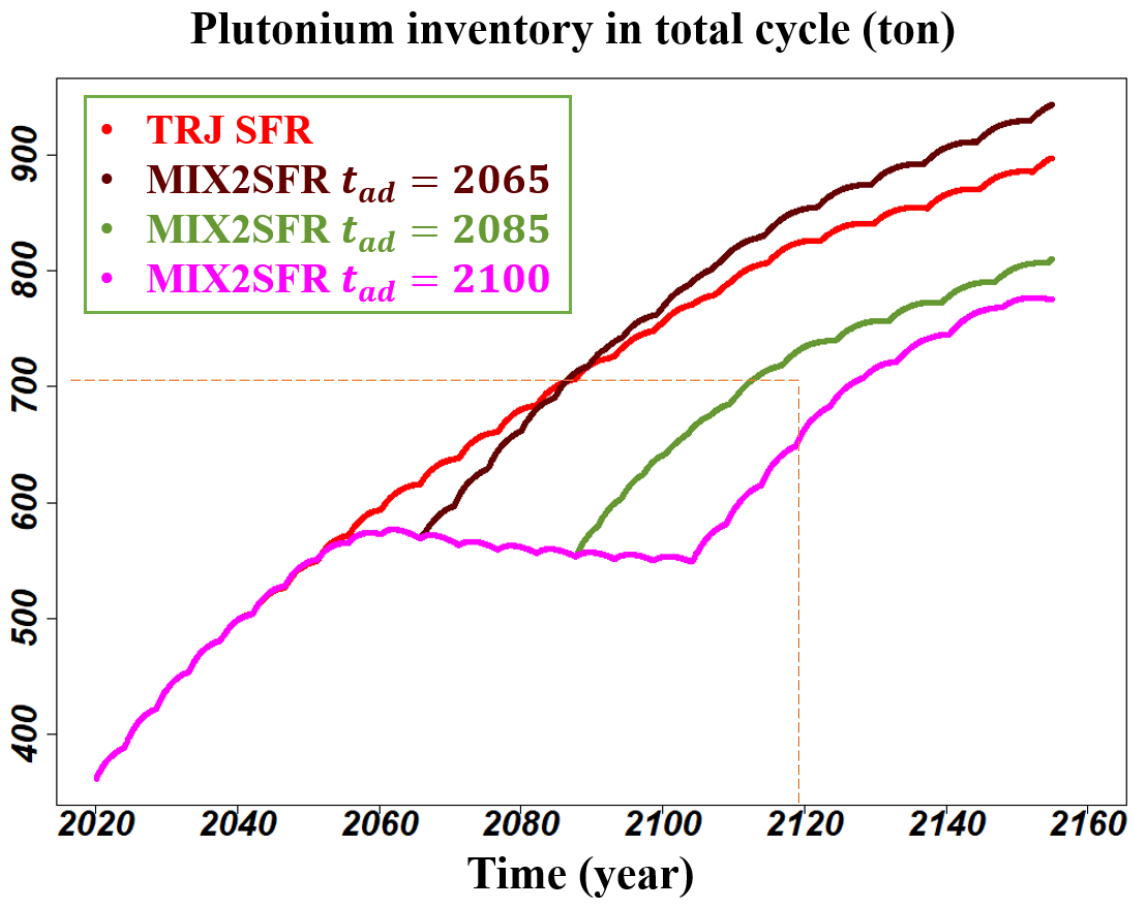
t_{ad}	$t_{e,MIX}$	$t_{s,2SFR}$	$t_{e,2SFR}$	BU_{UOX}	BU_{MIX}
2065	t_{ad}+1	2077	**2120**	47.7	59.2
2085	t_{ad}+3	2087	**2120**	31.8	42.1
2100	t_{ad}+1	2118	**2140**	48.6	54.4
(Unit)	year	year	year	GWd/t	GWd/t

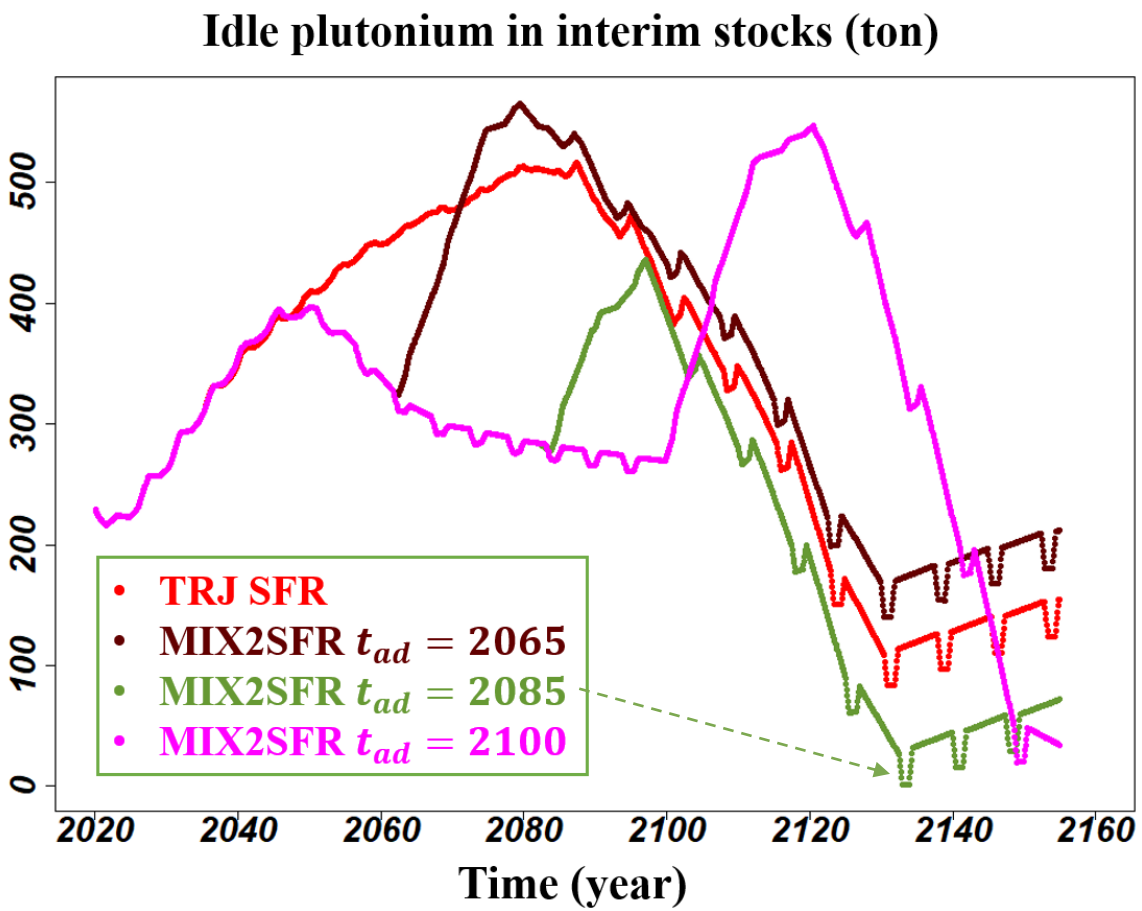
(vs $t_{e,2SFR} = 2120$ in TRJ SFR)

Prior strategy MIX + appropriate adaptations: robust if $t_{ad} \leq 2085$

→ Impact on the time when the replacement of fleet with SFRs finishes

SCN MIX2SFR





** 100% fleet of SFRs (~46GWe after 2040) ~ 350t Pu

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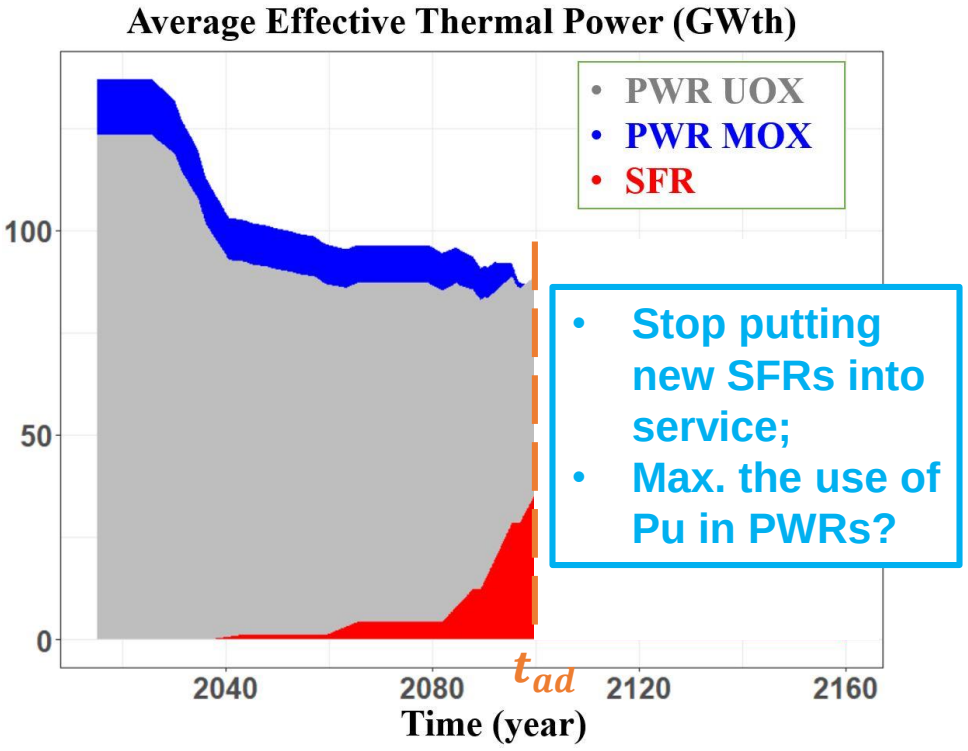
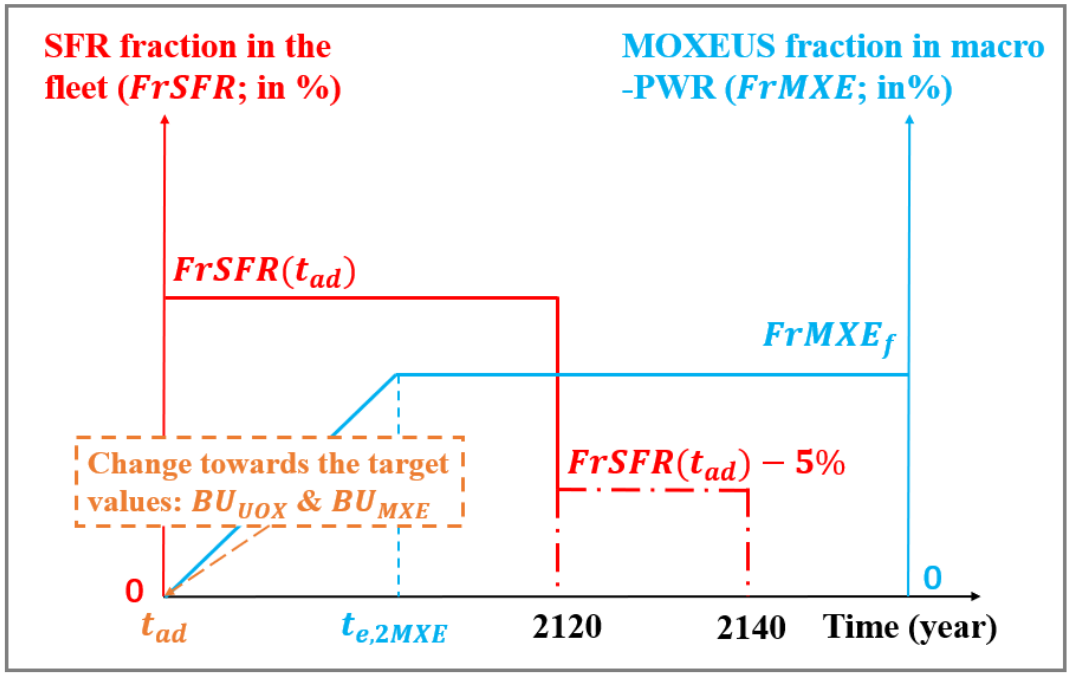
SCN SFR2MOXEUS

- Disruption of TRJ SFR: economic issues; max. the use of Pu by multi-MOX in PWRs
- MOXEUS (multi-MOX in PWRs): variable Pu content in the fresh fuel → flexible for diverse Pu quality

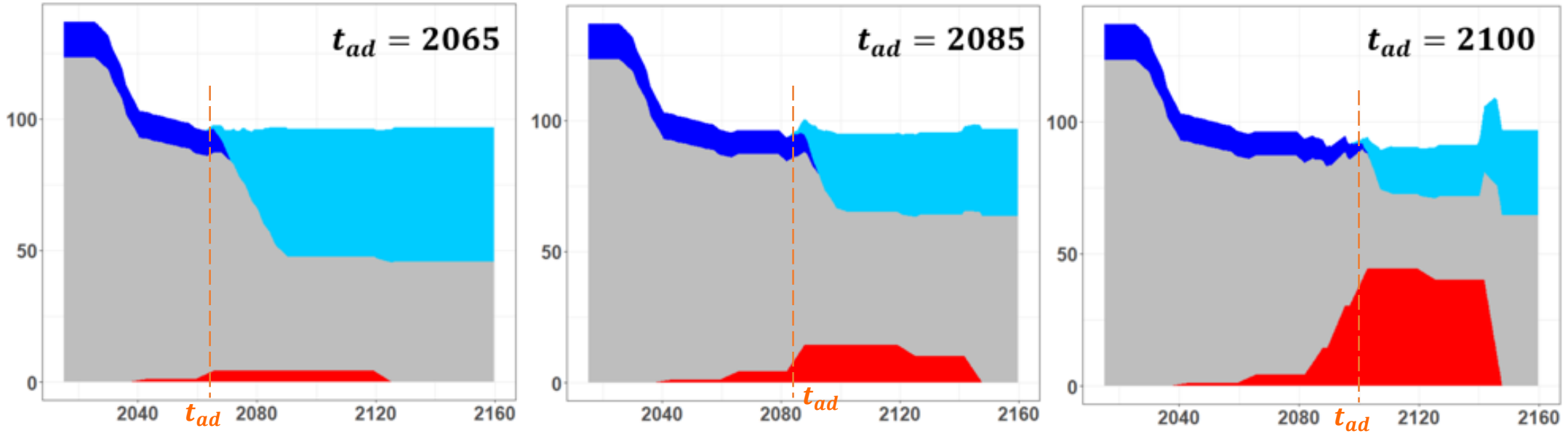




- min. the peak of idle Pu: min. "$Pu_{idle,max}$" (2140~2160)
- vs TRJ MIX (~ 250 tons)

SCN SFR2MOXEUS

Average Effective Thermal Power (GWth)



- PWR UOX
- PWR MOX
- PWR MXE
- SFR

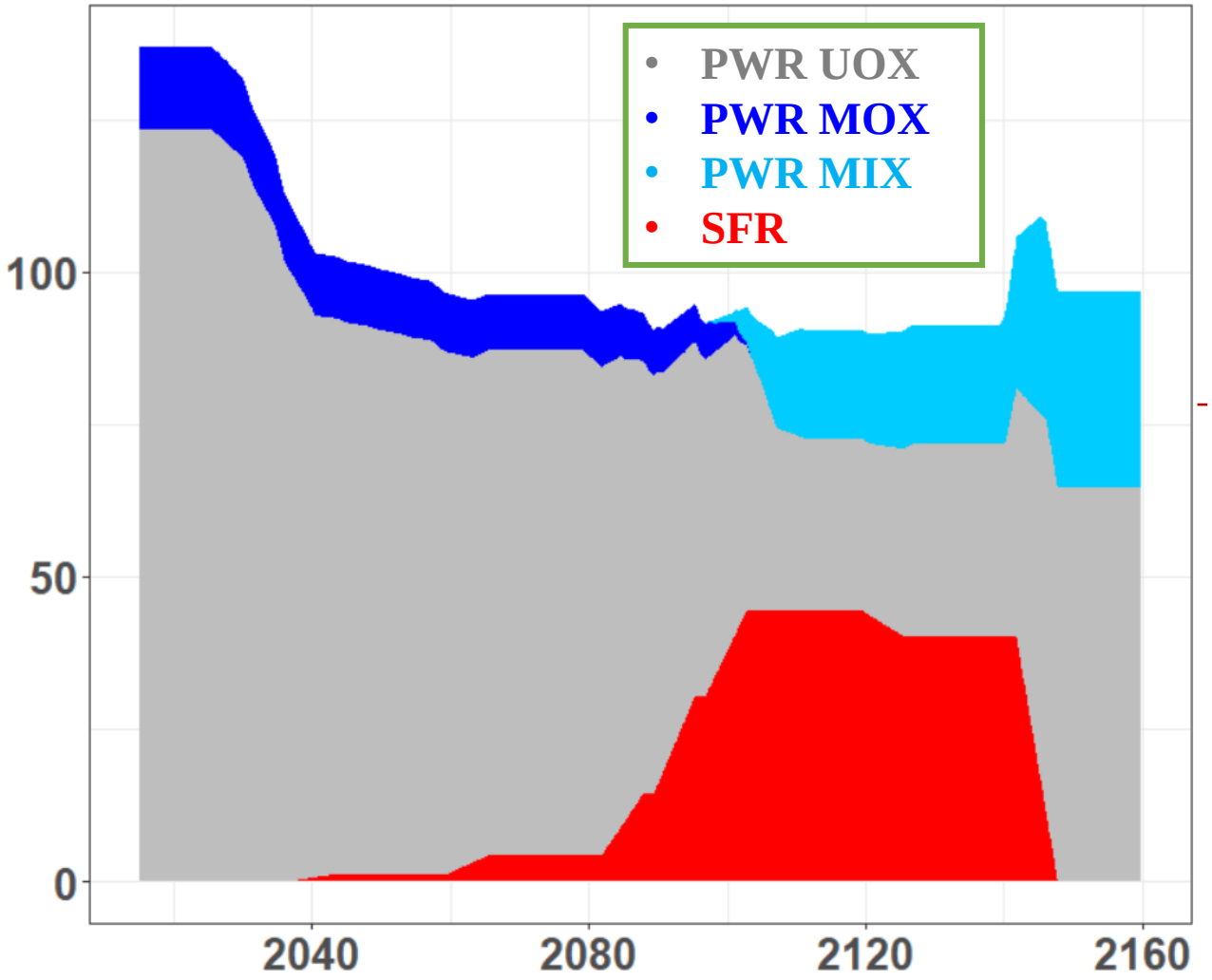
t_{ad}	$FrMXE_f$	$t_{e,2MXE}$	BU_{UOX}	BU_{MXE}	$Pu_{idle,max}$
2065	52.8	2087	40.2	37.5	**17**
2085	34.3	2096	40.1	36.8	**174**
2100	33.4	2105	38.9	40.0	**332**
(Unit)	%	year	GWd/t	GWd/t	ton

(vs $Pu_{idle,max} = 250$ tons in TRJ MIX)

Prior strategy SFR + appropriate adaptations: robust if $t_{ad} \leq 2085$

→ Impact of SFR deploy. (<disrupt.) on the use of Pu (>disrupt.)

SCN SFR2MOXEUS



Discharged from the last 2 irradiation cycles of SFRs (shut down in 2140)

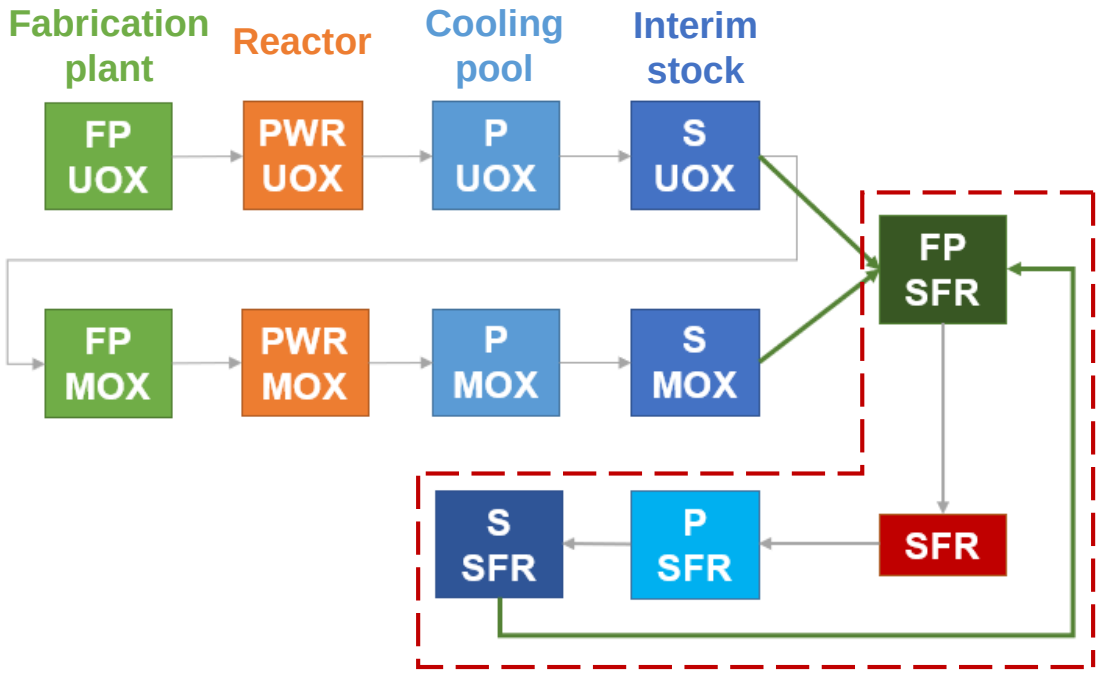
Conclusion & outlook

- Application of the methodology: robustness assessment
  - Capacity to adapt to future changes
- Disruption TRJ MIX → SCN MIX2SFR
  - Reconsideration of SFRs: min. finish time of deployment
  - Adaptively robust if ≤2085
- Disruption TRJ SFR → SCN SFR2MOXEUS
  - Max. the use of Pu by PWRs: min. the peak of idle Pu
  - Adaptively robust if ≤2085

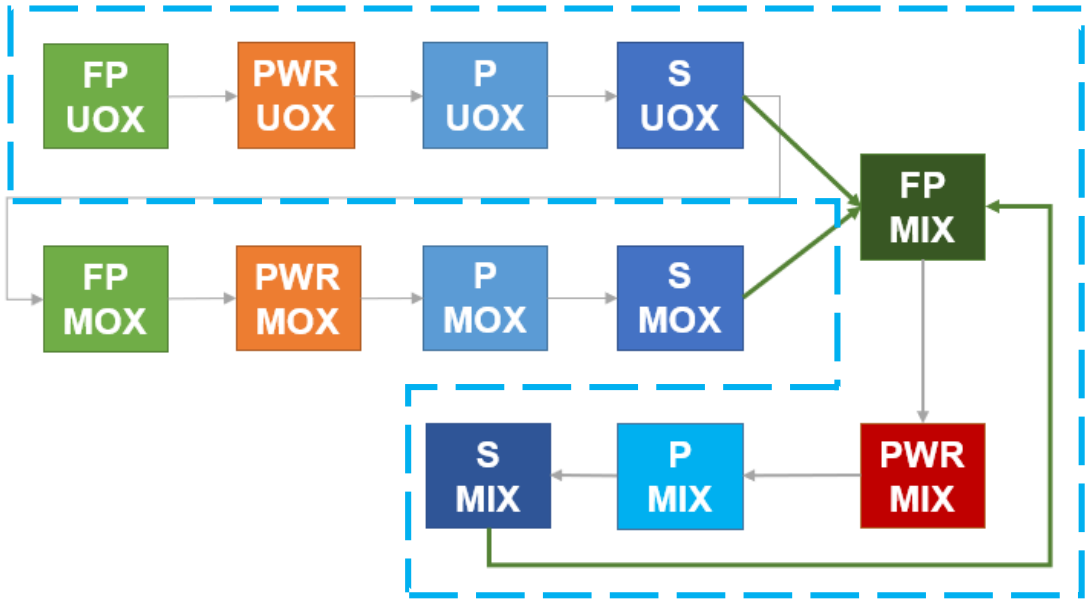
- Future work:
  - More output metrics, e.g. reactor lifespan → indicator of industrial constraints
  - Optimization: one optimal strategy → phase space of robust adaptations?

Backup

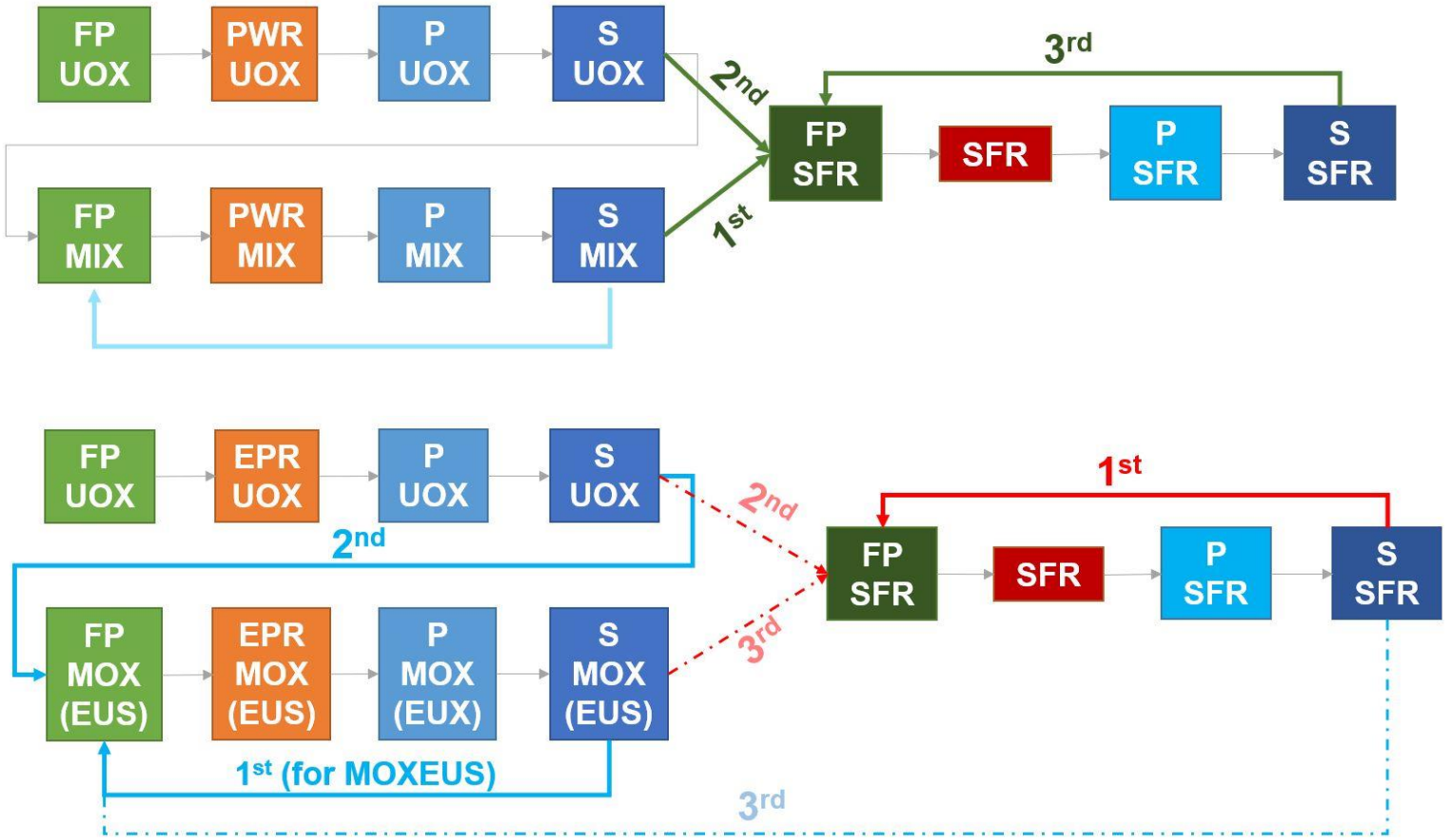
TRJ SFR FC


Fabrication plant
Reactor
Cooling pool
Interim stock
FP UOX
PWR UOX
P UOX
S UOX
FP MOX
PWR MOX
P MOX
S MOX
FP SFR
S SFR
P SFR
SFR

TRJ MIX FC


FP UOX
PWR UOX
P UOX
S UOX
FP MOX
PWR MOX
P MOX
S MOX
FP MIX
S MIX
P MIX
PWR MIX

FC – adaptations



Nelder-Mead optimization

- Simplex-based
- Reflection, expansion, contraction, shrinkage