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

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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

Nuclear expansion → Risk of U shortages → SFRs – closed FC
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

Pu in the total cycle (ton)

Idle Pu in interim stocks (ton)
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

![Average Effective Thermal Power (GWth)](image)
**Prior: TRJ MIX**

"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

**Average Effective Thermal Power (GWth)**

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

**MIX fraction in macro-PWR (%)** vs **SFR fraction in the fleet (%)**

- min. $t_{e,2SFR}$ (by optimization)
- vs TRJ SFR (year 2120)
Prior strategy MIX + appropriate adaptations: robust if $t_{ad} \leq 2085$

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

| $t_{ad}$ | $t_{ad}+1$ | $t_{ad}+3$ | $t_{ad}+1$ | $BU_{UOX}$ | $BU_{MIX}$ |
|----------|------------|------------|------------|-------------|-------------|
| 2065     | 2077       | 2120       | 47.7       | 59.2        |
| 2085     | 2087       | 2120       | 31.8       | 42.1        |
| 2100     | 2118       | 2140       | 48.6       | 54.4        |

(Unit) year year year GWd/t GWd/t

(vs $t_{e,2SFR} = 2120$ in TRJ SFR)
** 100% fleet of SFRs (~46GWe after 2040) ~ 350t Pu
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- 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

- Stop putting new SFRs into service;
- Max. the use of Pu in PWRs?

- min. the peak of idle Pu: min. “\(P_{\text{idle,max}}\) (2140~2160)
- vs TRJ MIX (~ 250 tons)


SCN SFR2MOXEUS

Average Effective Thermal Power (GWth)

| $t_{ad}$ | FrMXEf | $t_{e,2MXE}$ | $BU_{UOX}$ | $BU_{MXE}$ | $Pu_{idle,max}$ |
|----------|--------|--------------|------------|------------|----------------|
| 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            |

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

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

( vs $Pu_{idle,max} = 250$ tons in TRJ MIX)
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 \(\rightarrow\) SCN MIX2SFR
  • Reconsideration of SFRs: min. finish time of deployment
  • Adaptively robust if \(\leq 2085\)

• Disruption TRJ SFR \(\rightarrow\) SCN SFR2MOXEUS
  • Max. the use of Pu by PWRs: min. the peak of idle Pu
  • Adaptively robust if \(\leq 2085\)

• Future work:
  • More output metrics, e.g. reactor lifespan \(\rightarrow\) indicator of industrial constraints
  • Optimization: one optimal strategy \(\rightarrow\) phase space of robust adaptations?
Backup
TRJ MIX FC
FC – adaptations
Nelder-Mead optimization

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