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 $\rightarrow$ definitive decision?
- Given one implemented strategy (today) $\rightarrow$ possible to turn to the other direction (future)?

Uncertainty of future $\rightarrow$ 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)

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\(^1\) 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
“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

![Graph showing average effective thermal power (GWth) over time](image)

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

![Graph showing MIX and SFR fraction in macro-PWR and the fleet](image)

- min. $t_{e,2SFR}$ (by optimization)
- vs TRJ SFR (year 2120)
### SCN MIX2SFR

#### Average Effective Thermal Power (GWth)

<table>
<thead>
<tr>
<th>$t_{ad}$</th>
<th>$t_{e,MIX}$</th>
<th>$t_{s,2SFR}$</th>
<th>$t_{e,2SFR}$</th>
<th>$BU_{UOX}$</th>
<th>$BU_{MIX}$</th>
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<tr>
<td>2065</td>
<td>$t_{ad}+1$</td>
<td>2077</td>
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<td><strong>2120</strong></td>
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<td>(Unit)</td>
<td>year</td>
<td>year</td>
<td>year</td>
<td>GWd/t</td>
<td>GWd/t</td>
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</table>

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

$\rightarrow$ Impact on the time when the replacement of fleet with SFRs finishes

$\text{vs } t_{e,2SFR} = 2120$ in TRJ SFR

- PWR UOX
- PWR MOX
- PWR MIX
- SFR
** 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 $\rightarrow$ 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. $P_{u_{idle,max}}$ (2140~2160)
- vs TRJ MIX (~ 250 tons)

![Average Effective Thermal Power (GWth)]

- PWR UOX
- PWR MOX
- SFR

![SFR fraction in the fleet (FrSFR; in %)]

- $Fr_{SFR}(t_{ad})$

![MOXEUS fraction in macro-PWR (FrMXE; in%)]

- $Fr_{MXE}$

Change towards the target values: $BU_{UOX}$ & $BU_{MXE}$

$t_{ad}$ $t_{e,2MXE}$ 2120 2140 Time (year)

- $Fr_{SFR}(t_{ad}) - 5\%$
**SCN SFR2MOXEUS**

**Average Effective Thermal Power (GWth)**

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

<table>
<thead>
<tr>
<th>$t_{ad}$</th>
<th>$Fr_{MXE_f}$</th>
<th>$t_{e,2MXE}$</th>
<th>$BU_{UOX}$</th>
<th>$BU_{MXE}$</th>
<th>$Pu_{idle,max}$</th>
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<tr>
<td>2085</td>
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<td>2096</td>
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<tr>
<td>(Unit)</td>
<td>%</td>
<td>year</td>
<td>GWd/t</td>
<td>GWd/t</td>
<td>ton</td>
</tr>
</tbody>
</table>

*Impact of SFR deploy. (<disrupt.) on the use of Pu (>disrupt.)*
SCN SFR2MOXEUS

- PWR UOX
- PWR MOX
- PWR MIX
- SFR

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 SFR FC
FC – adaptations
Nelder-Mead optimization

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