Optimization of an electro-nuclear scenario

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Background

PhD (2020)

G-SCOP, Grenoble
Combinatorial Optimization, Markov Processes

Postdocs (2020-2023)

LICIT-ECO7, Gustave Eiffel University, Bron
Operational Research for mobility and network design

Since 2023

DISP, Lyon 2 University
Robustness and resilience of systems

General context

Robustness and resilience

- disruptions (small, large...)
- how to react to them ?
- recover an operating state

Fields of interest

- mobility
- energy
- links between both

2 projects

Mobility

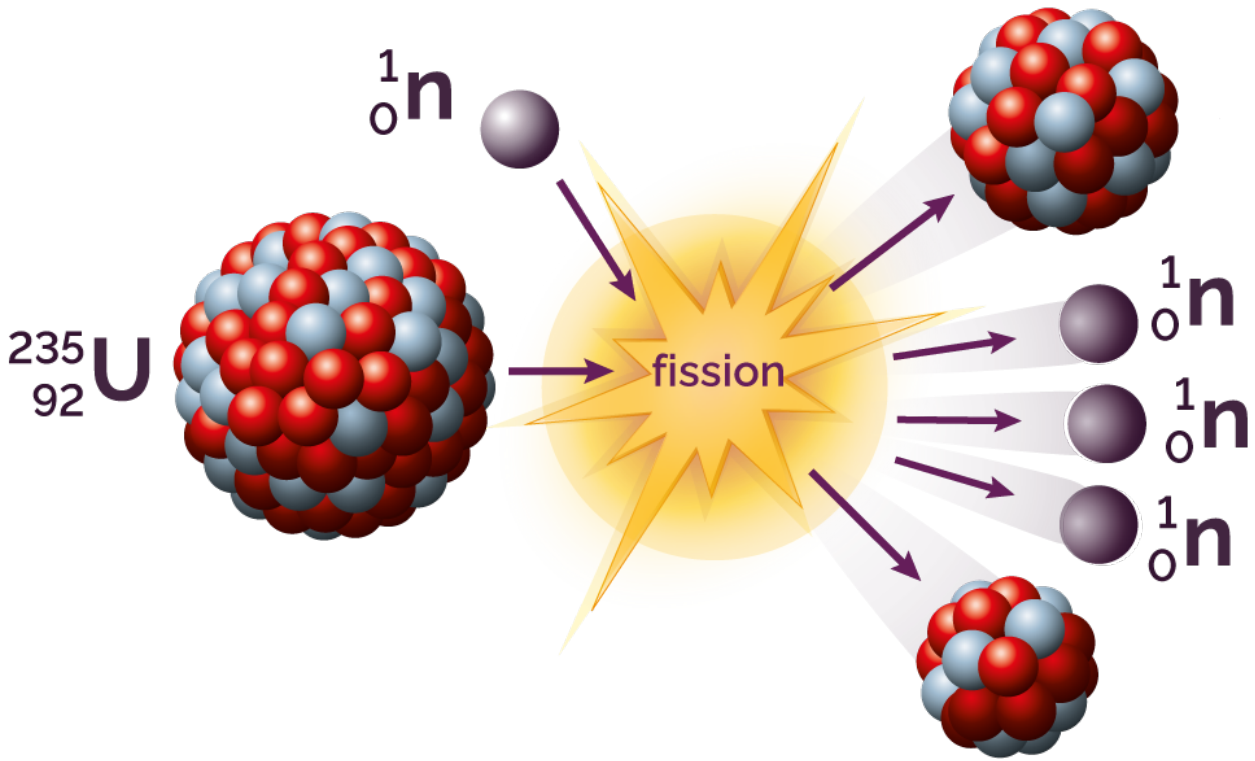
- Lability project
- robustness, resilience of Île-De-France region after COVID
- mobility and telework
- multidisciplinary team

Energy

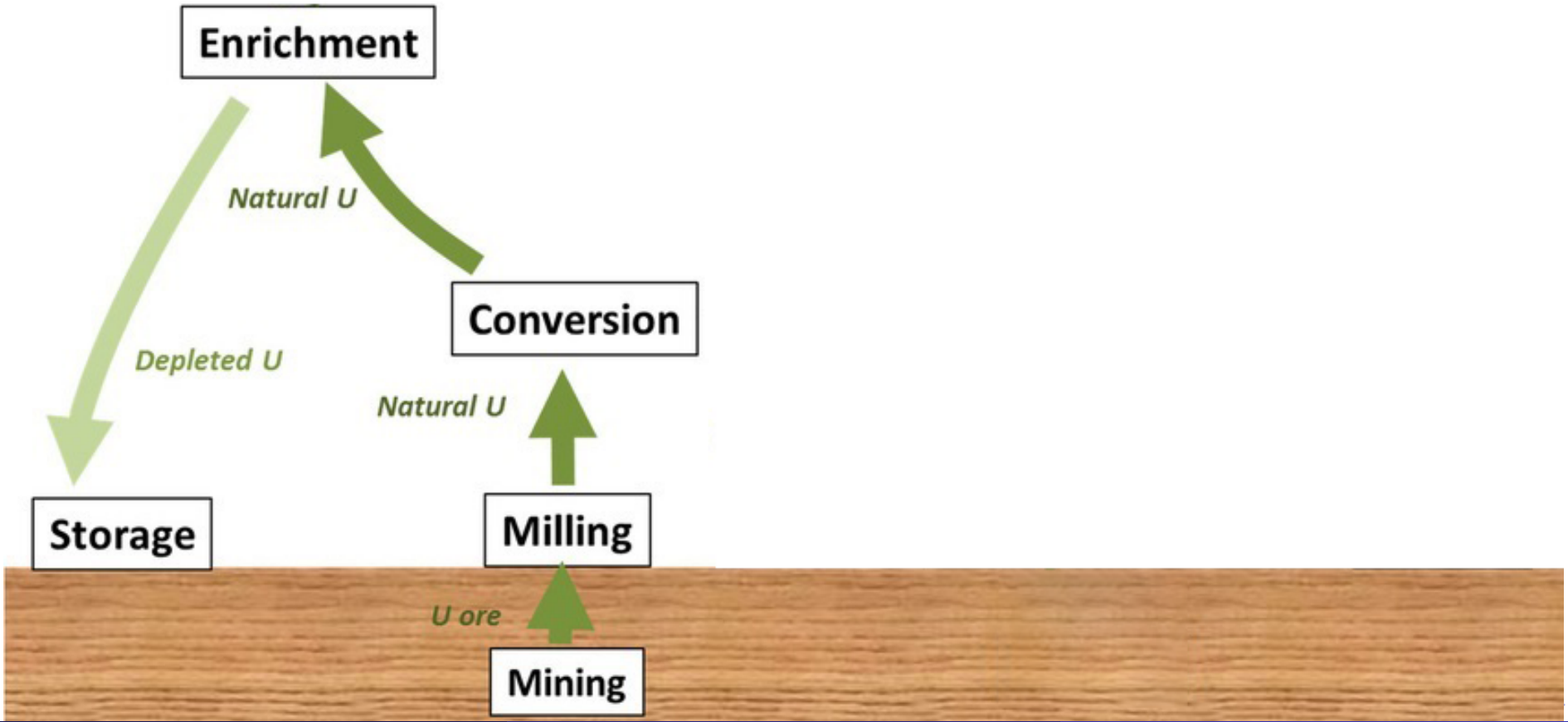
- electronuclear scenarios
- master thesis internship funded by GIEIF
- cooperation with CEA
- PhD thesis starting in sept. 2024

Motivation

- Climate change
- Low carbon: 4g of CO_2/kWh



Introduction to the problem



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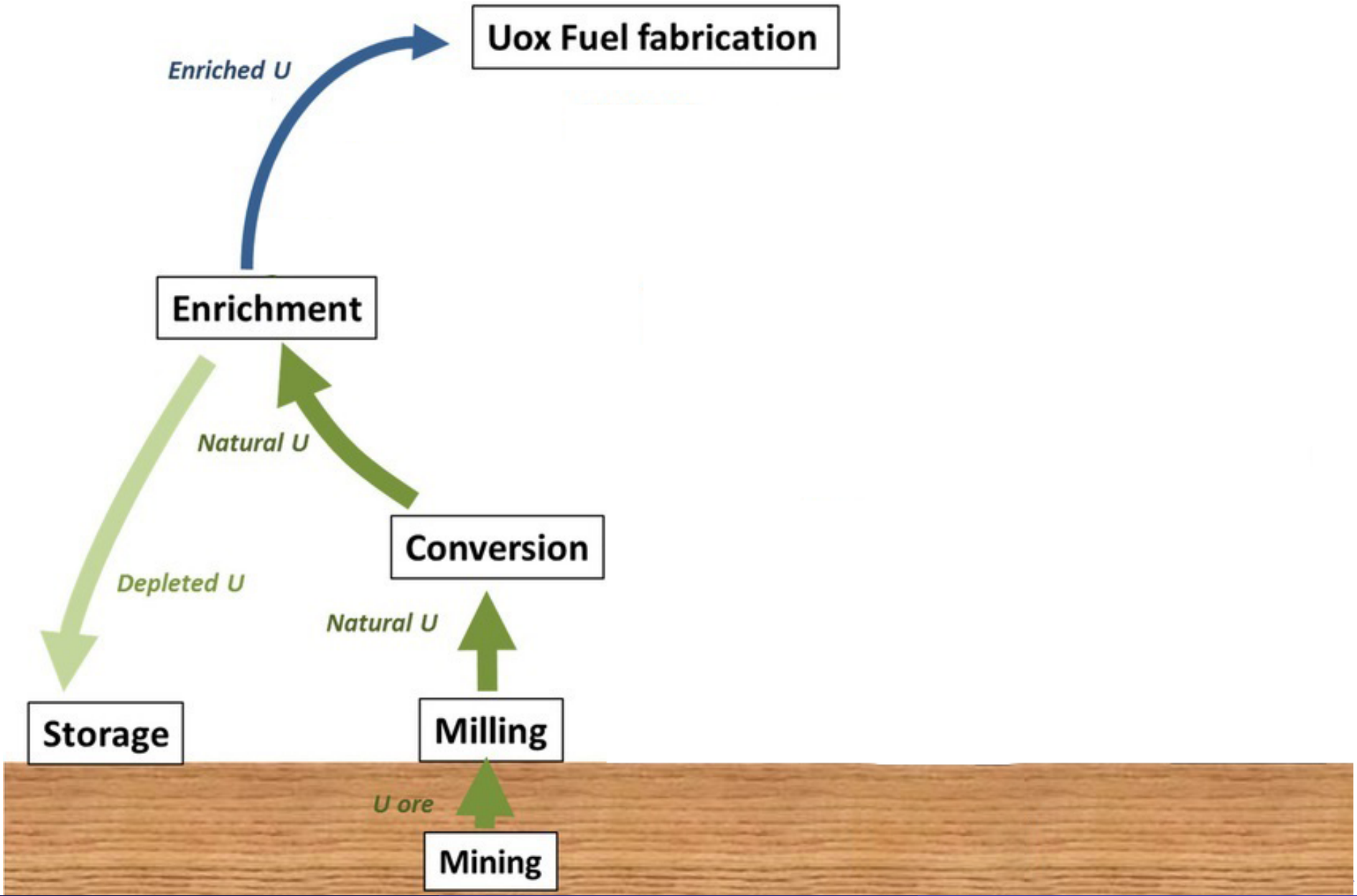

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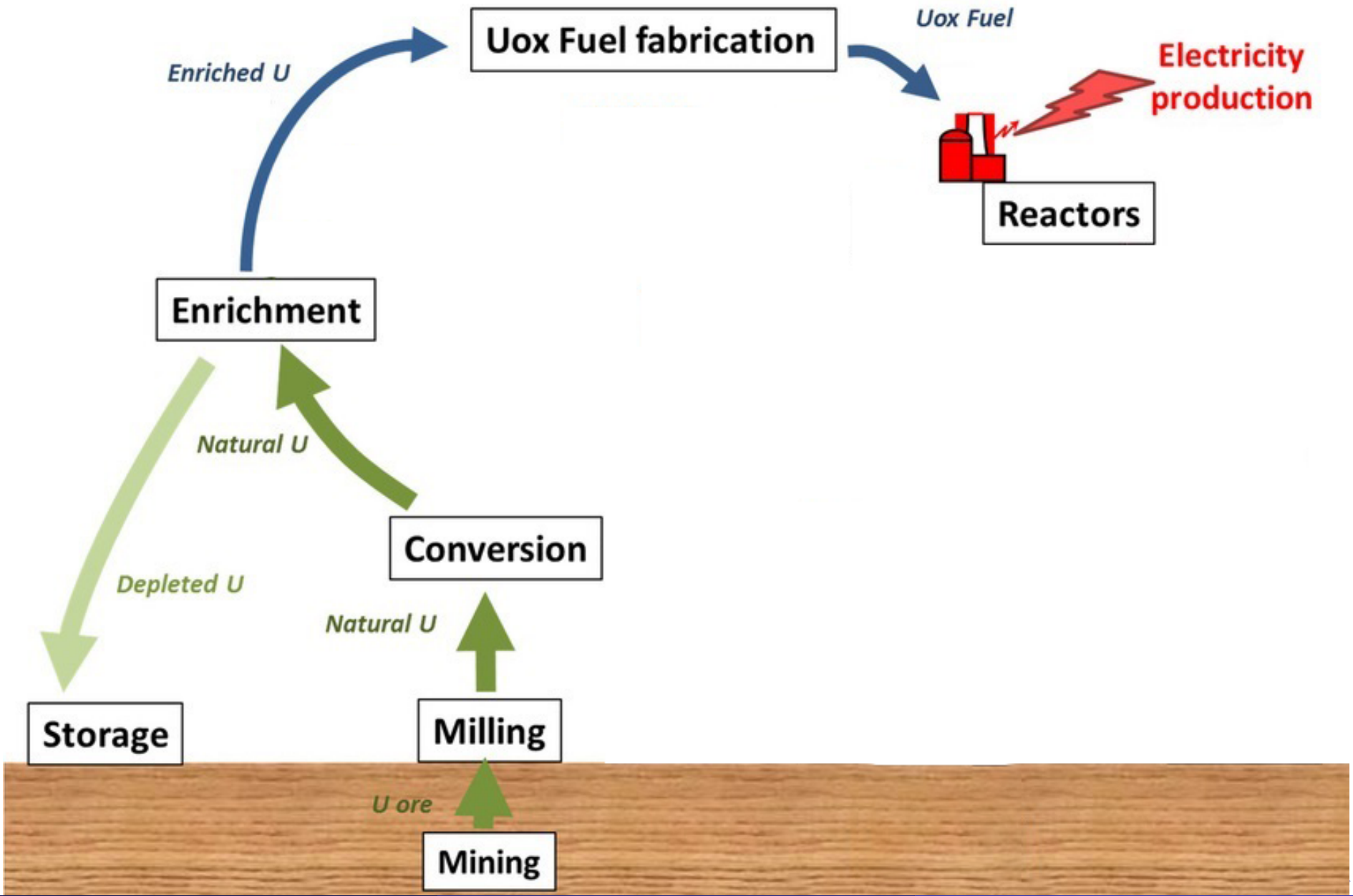

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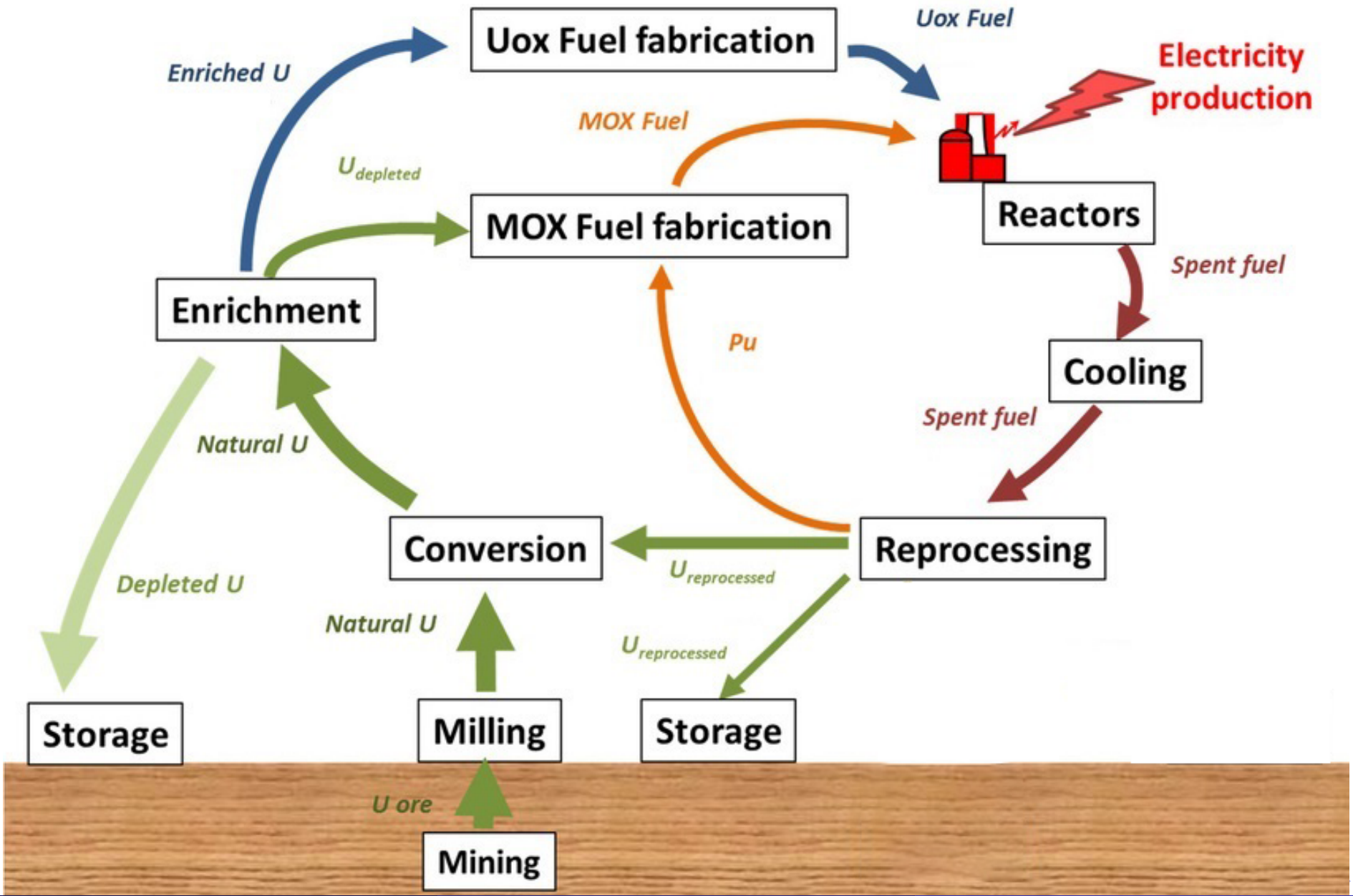

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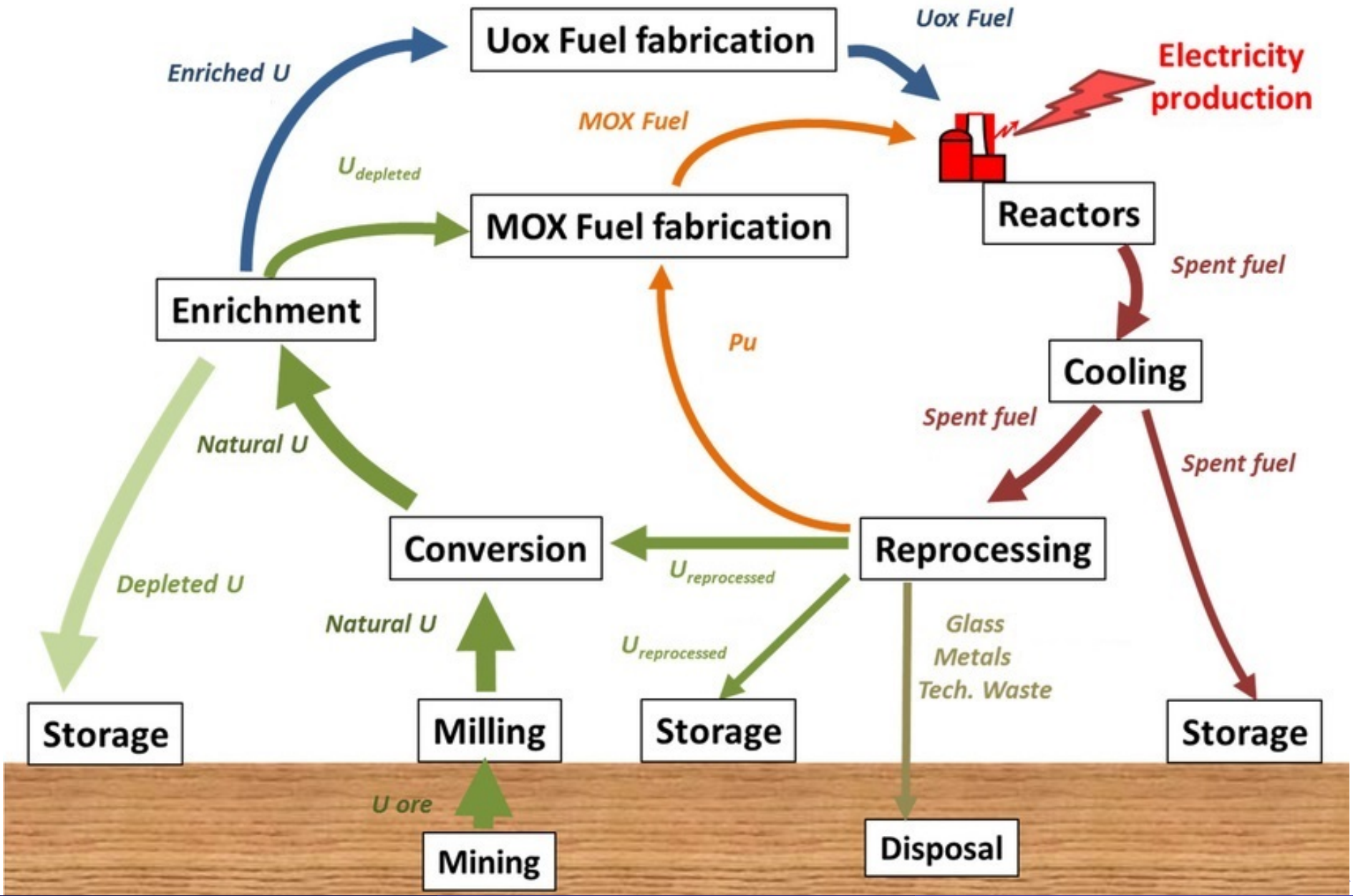

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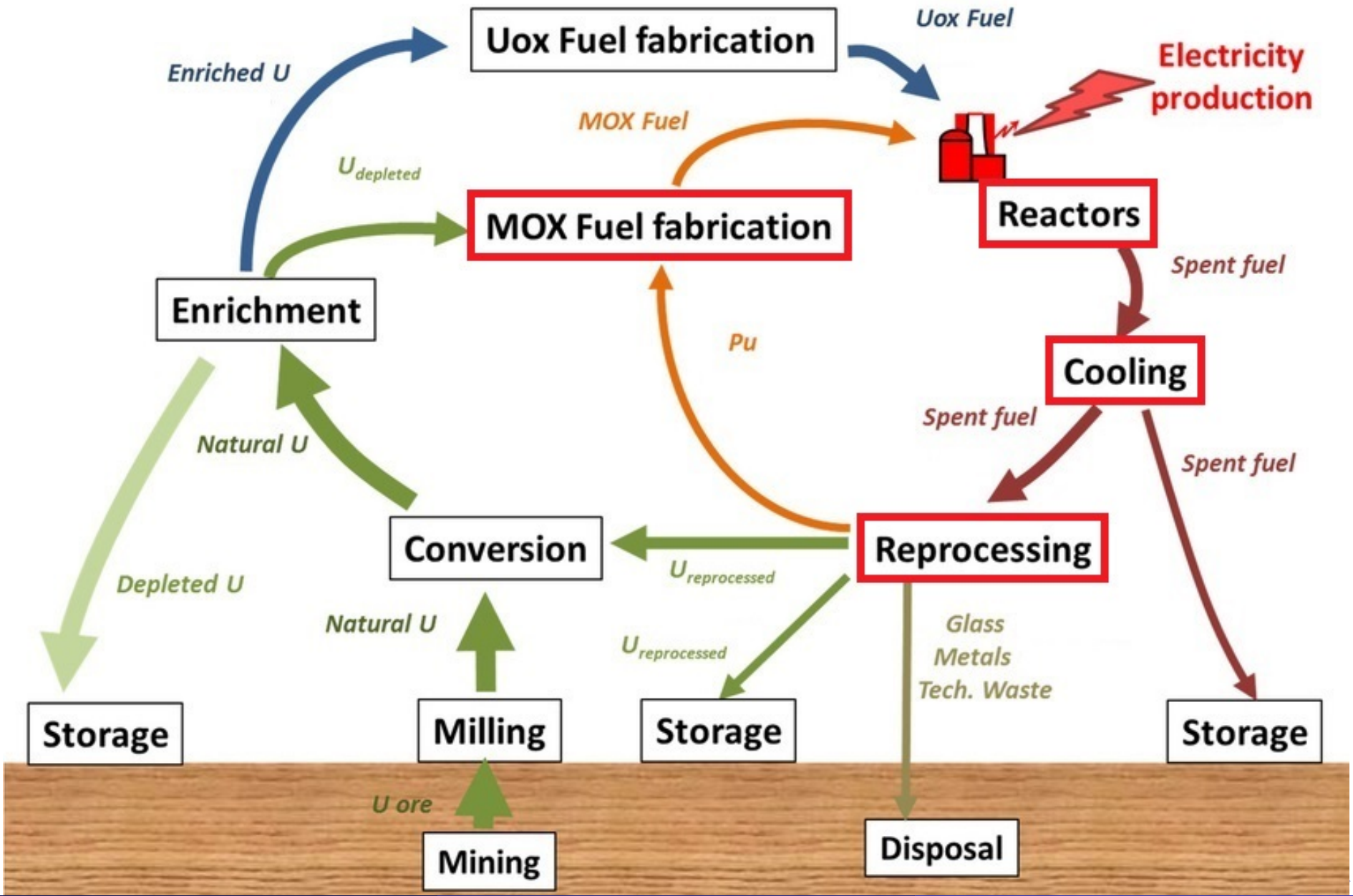
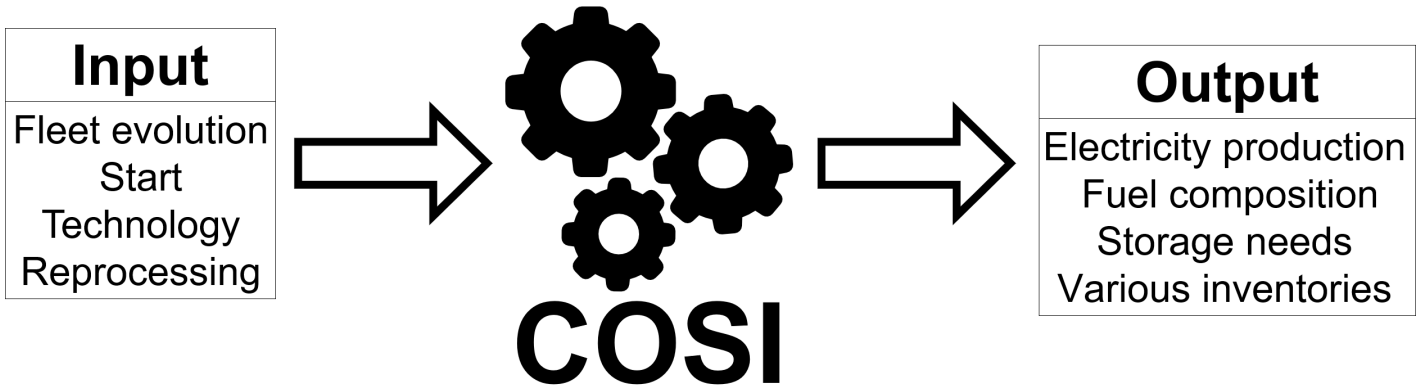


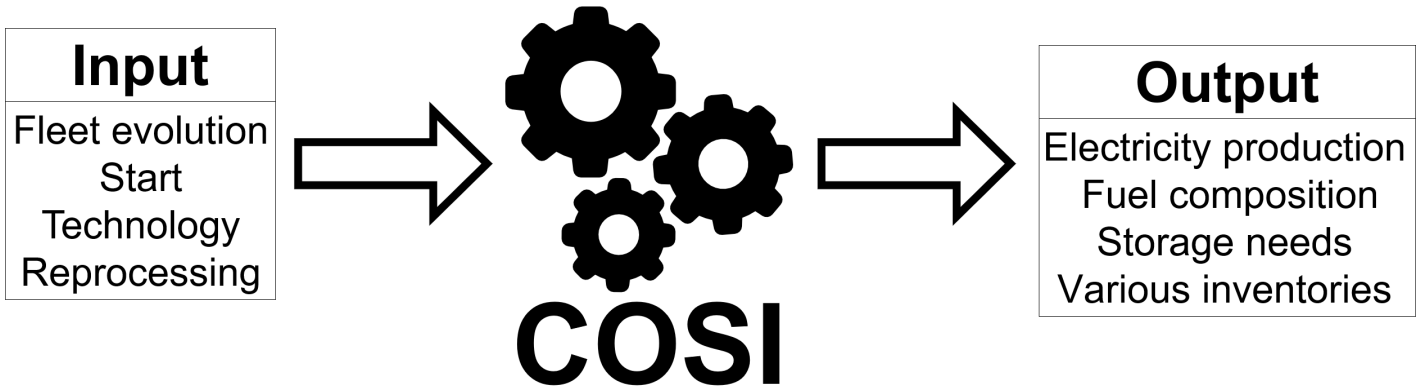
What is a scenario

- Managing the materials consumed and produced
- Simulate possible future scenarios of the fleet

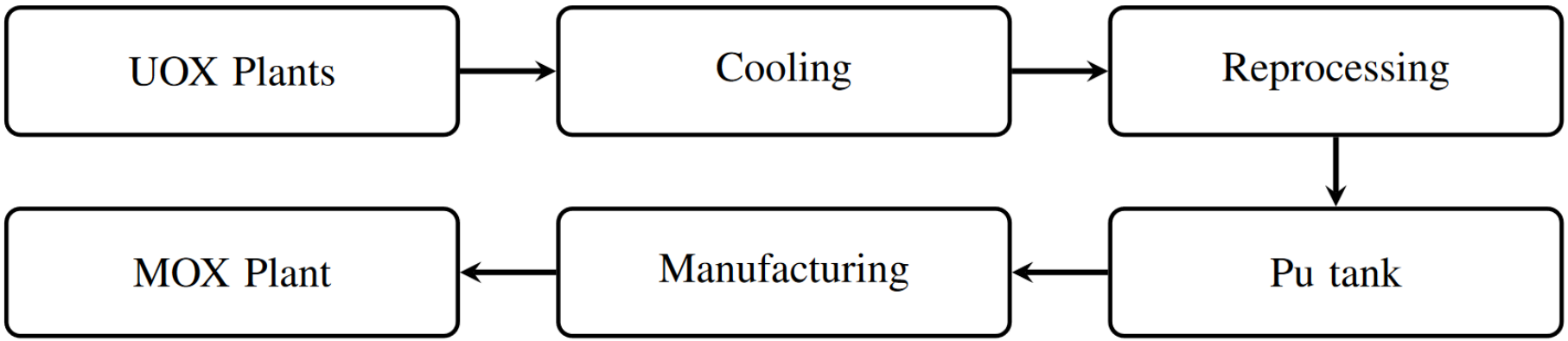


Optimization of scenario

- Long-term uncertainties
- Improve robustness
- Long and require advanced expertise
- Use mathematical Programming to find an optimal reprocessing strategy

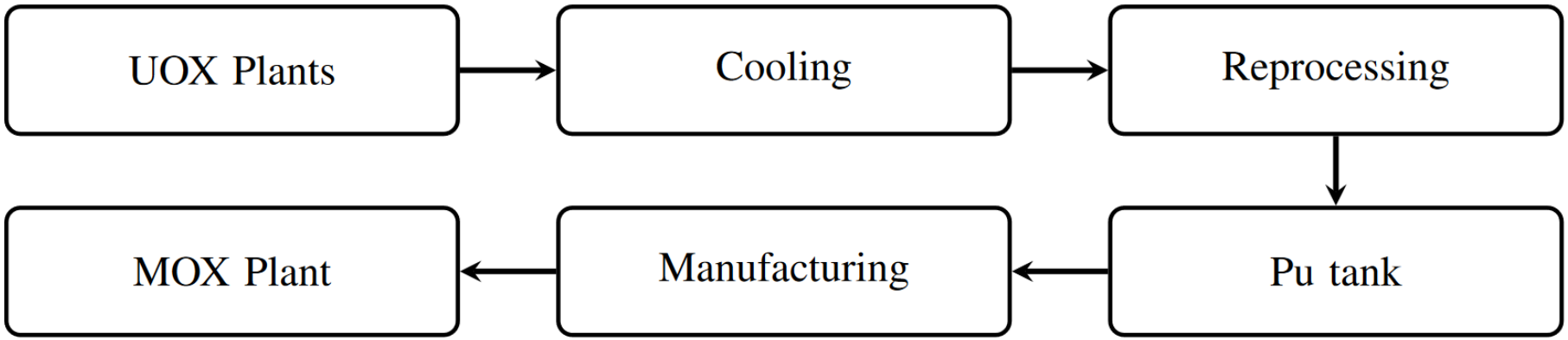


How nuclear fuel recycling works



Create a Mathematical model to simulate and optimize this nuclear waste recycle

How reprocessing works

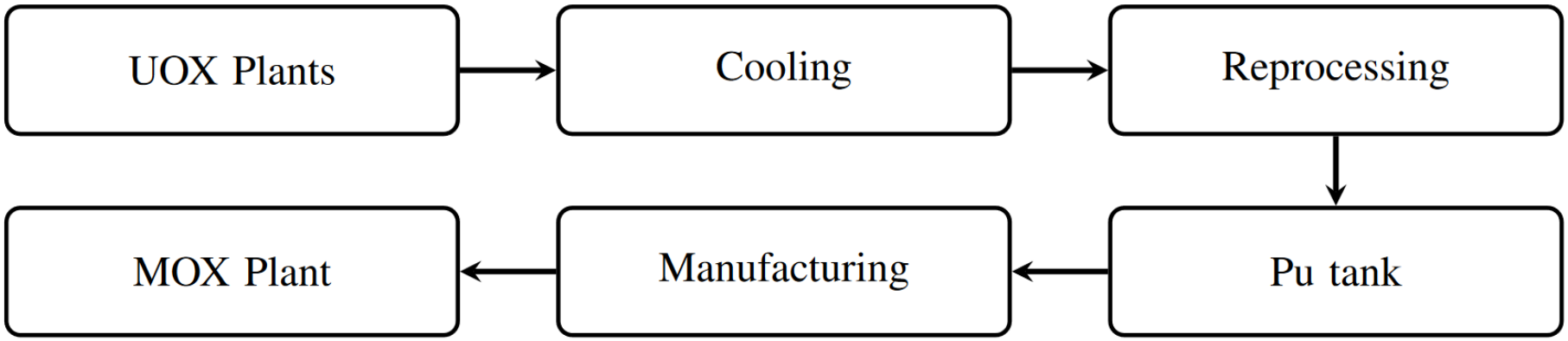


UOX Plants

- *n reactor*
- *fuel composed of 1% of Plutonium*
- *Pu241* $\rightarrow$ *Americium*

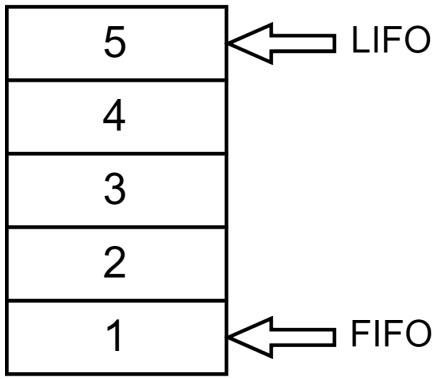
$$\overrightarrow{Pu} = \begin{Bmatrix} Pu238 \\ Pu239 \\ Pu240 \\ Pu241 \\ Pu242 \\ Am241 \end{Bmatrix}$$

How reprocessing works



Cooling

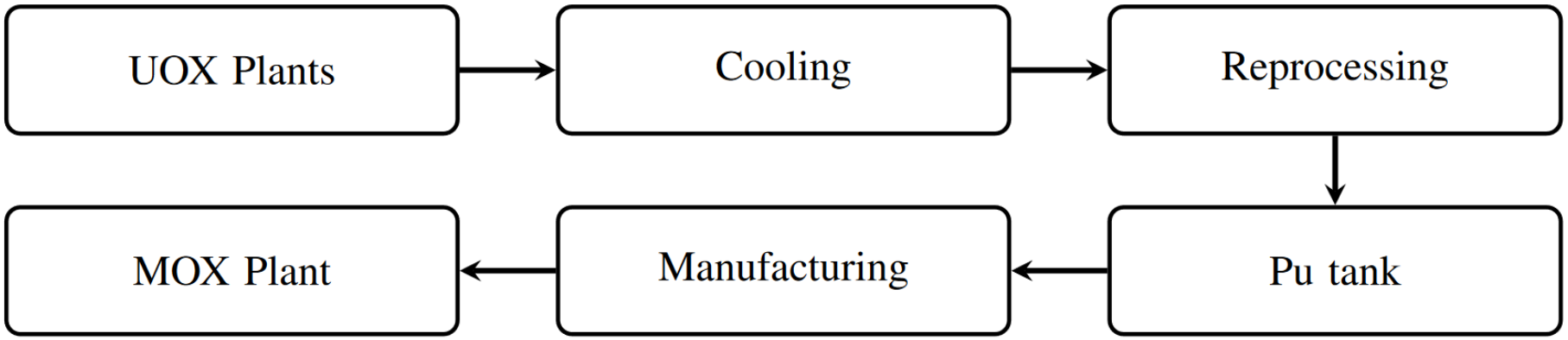
- *stored in an orderly way*
- *can only draw using a FIFO or LIFO strategy*



Reprocessing

- *operate once a year*
- *Plutonium is extracted and the Americium is removed*

How manufacturing works



Pu tank

- *homogeneous isotopic composition*
- *Capacity: 55t*

Manufacturing

- *supply the MOX Plant with MOX on a periodic basis.*
- $Q(\overrightarrow{Pu}) \geq 0.55$
- *Quality:* $Q(\overrightarrow{Pu})$ *= proportion of Pu239 + Pu241*

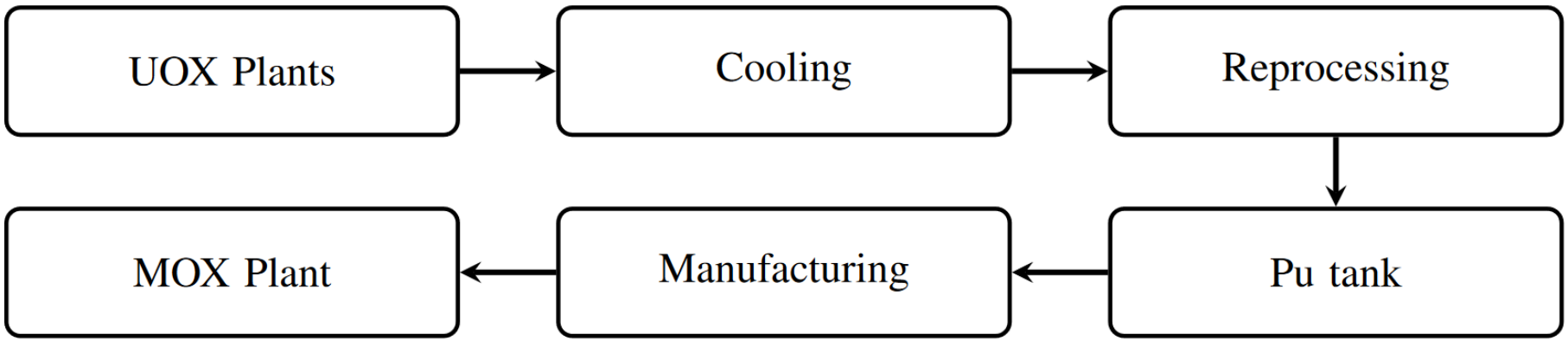
Model

Reality

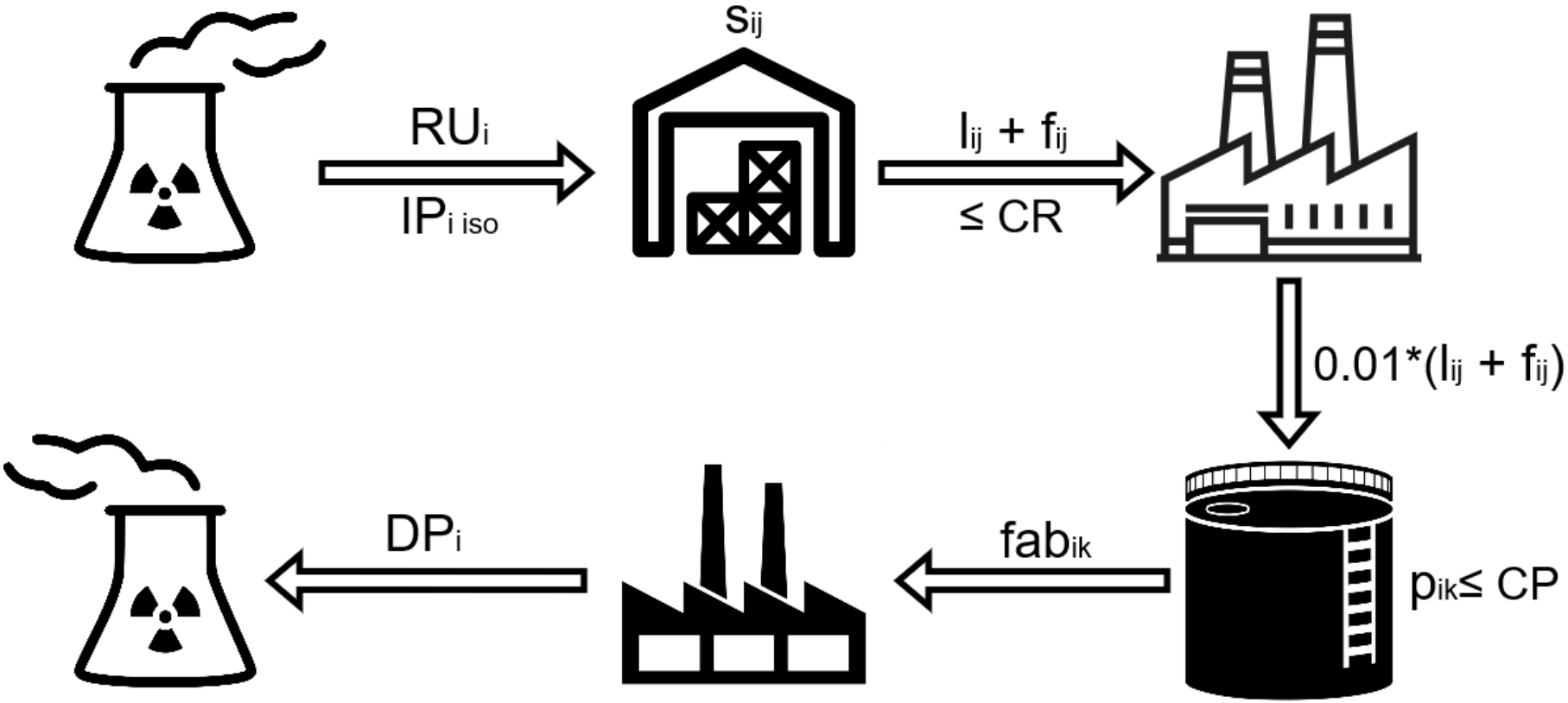
- *40 UOX Reactor*
- *Time step of one day*
- *Event happen on different days*
- *Plutonium requested each day depend on the quality*

Assumption

- *One UOX Reactor*
- *Time step of one year*
- *All events are synchronized every year*
- *Plutonium requested each year is constant*



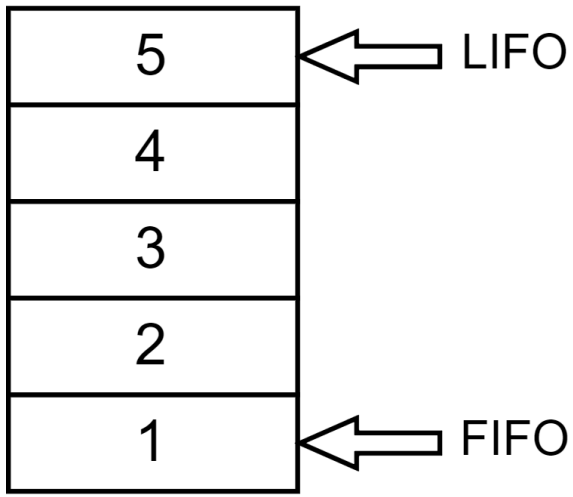
Model



Objective function

Enforce LIFO FIFO constraint

$min \sum_{i=0}^{T} \sum_{j=0}^{i} (i-j) \times I_{i,j} + j \times f_{i,j}$



Constraint

Managing the flow in the stock

$$s_{i,j} = s_{i-1,j} - l_{i,j} - f_{i,j} + RU_i \qquad \forall i \in \{1, t\}, j \in T$$

Contant of plutonium tank

- $\sum_{k=0}^{T} 0,01 \times (\delta^{i-k}) \times f_{k,i} + l_{k,i}) \times ip_{k,3} + \delta \times sp_{i-1,3} - fab_{i-1,3} = sp_{i,3}$
- $sp_{i-1,5} + (1 - \delta) \times sp_{i-1,3} - fab_{i-1,5} = sp_{i,5}$
- $\sum_{k=0}^{T} 0,01 \times (f_{k,i} + l_{k,i}) \times ip_{k,53} + sp_{i-1,53} - fab_{i-1,53} = sp_{i,53}$

Plutonium take by the manufacture

- $\sum_{iso=0}^{6} fab_{i,iso} = DP_i \qquad \forall i \in T$
- $fab_{i,1} + fab_{i,3} \geq 0.55 \times \sum_{iso=0}^{6} fab_{i,iso} \qquad \forall i \in T$

Final Model

$$min \sum_{i=0}^{T} \sum_{j=0}^{i} (i-j) \times l_{i,j} + j \times f_{i,j}$$

$$s_{0,0} = RU_0$$

$$s_{0,j} = 0 \qquad \forall j \in \{1,t\}$$

$$f_{0,j} = 0 \qquad \forall j \in T$$

$$l_{0,j} = 0 \qquad \forall j \in T$$

$$p_{0,iso} = 0 \qquad \forall iso \in \{0,6\}$$

$$s_{i,j} = s_{i-1,j} - l_{i,j} - f_{i,j} + RU_i \qquad \forall i \in \{1,t\}, j \in T$$

$$s_{i,j}, f_{i,j}, l_{i,j}, yf_{i,j}, yl_{i,j} = 0 \qquad \forall i,j \in T, j > i$$

$$\sum_{k=0}^{T} 0,01 \times (\delta^{i-k}) \times f_{k,i} + l_{k,i}) \times ip_{k,3} + \delta \times sp_{i-1,3} - fab_{i-1,3} == sp_{i,3} \qquad \forall i \in \{1,t\}$$

$$sp_{i-1,5} + (1-\delta) \times sp_{i-1,3} - fab_{i-1,5} == sp_{i,5} \qquad \forall i \in \{1,t\}$$

$$\sum_{k=0}^{T} 0,01 \times (f_{k,i} + l_{k,i}) \times ip_{k,53} + sp_{i-1,53} - fab_{i-1,53} == sp_{i,53} \qquad \forall i \in \{1,t\}$$

$$\sum_{iso=0}^{6} p_{i,iso} \leq CP \qquad \forall i \in T$$

$$s_{i,iso} \times \sum_{j=0}^{6} (fab_{i,iso}) == fab_{i,iso} \times \sum_{j=0}^{6} (s_{i,iso}) \qquad \forall i \in T$$

$$fab_{i,iso} \leq p_{i,iso} \qquad \forall i \in T, iso \in \{0,6\}$$

$$\sum_{iso=0}^{6} fab_{i,iso} = DP_i \qquad \forall i \in T$$

$$fab_{i,1} + fab_{i,3} \geq 0.55 \times \sum_{iso=0}^{6} fab_{i,iso} \qquad \forall i \in T$$

$$s_{i,j}, f_{i,j}, l_{i,j} = 0 \qquad \forall i,j \in T, j > i$$

$$s_{i,j}, f_{i,j}, l_{i,j}, p_{i,iso}, fab_{i,iso} \in [0, CP]$$

New feature

- Multi reactor
- Time step desynchronization

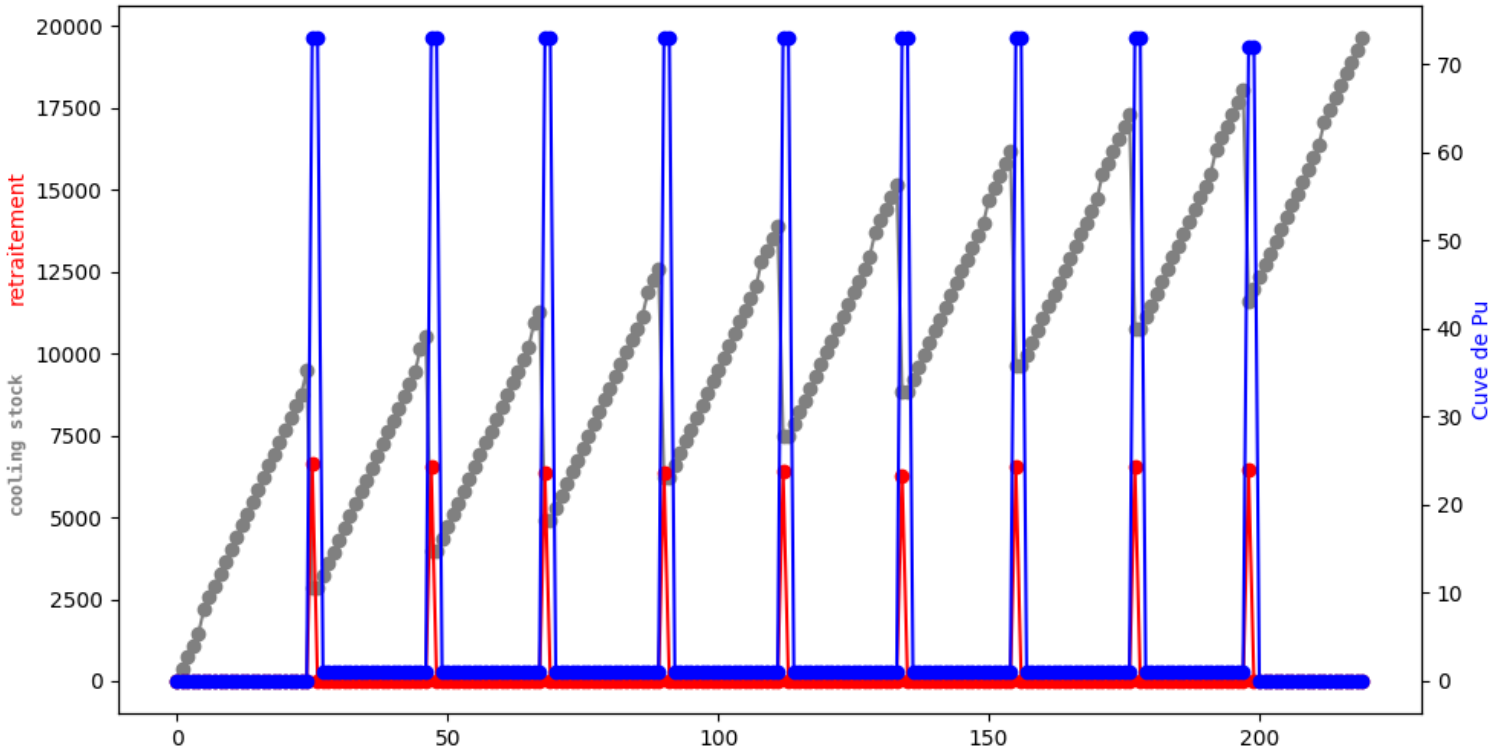


Figure: Tonnes of material for 10 years in a Multi reactor model

Conclusion

- Developed a mathematical program modeling a simple recycling case
- POC validate by a CEA engineers