The rationale of future nuclear fuel cycles in view of sustainability

Dates are purely indicative

TOWARDS INCREASING SUSTAINABILITY

Once-through cycle

Pu-mono-recycling
- Twice-Through Cycle
- LWR reactors
- Pu-recycling in MOX fuel

Pu multi-recycling
- Multi-Through Cycle
- Fast-Reactors (FR)
- Pu multi-recycling

Pu+MA multi-recycling
- Fast Reactors (FR)
- Pu multi-recycling
- MA burning

Main incentives
- 1st step towards U resource saving
- Efficient waste conditioning

Main incentives
- Major resource saving
- Energetic independence
- Economic stability

Main incentives
- Decrease of waste burden,
- Optimisation of the disposal
- Public acceptance
FROM LWRs RECYCLING TO FRs RECYCLING

SFR merits as regards to fuel cycle

No front end steps and no enrichment technology / Use depleted U; Use Pu included in MOX Spent Fuel

Multi-recycling of Pu / Possible recycling of Minor Actinides

Scenario can be flexible
Both systems can coexist during a transition phase

Pu stored in MOX Spent Fuel recycled in MOX SFR to start the SFRs deployment

Current technologies: a bridge between GEN II/III and GEN IV

THE PRINCIPLE OF THE FRENCH CLOSED FUEL CYCLE (rough amounts/year, 400 TWh/y)
FR REACTORS DEPLOYMENT: CURRENT SCENARIO STUDIES

EDF-AREVA-CEA joint studies

Stage 1: recycle used LWR-MOX
- a few FR needed (3 GWe)
- Used MOX-LWR amount stabilized

Stage 2: multi-recycle all fuels
- More FR needed (# ≥20 GWe)
- Pu amount stabilized

Stage 3:
- No natural uranium needs
- More FR needed (# >40 GWe)

Current fleet

Next Generation 3 LWR fleet

2025 ASTRID demonstrator

# 60 GWe

# 2050
SCENARIOS STUDIES: A PROGRESSIVE DEPLOYMENT OF FR, WITH STAGES OF INCREASING AMBITION

- # 63 GWe
- LWR
- FR
- Parc actuel
- Industrial demonstration
- 2050
### FUEL CHARACTERISTICS AND FINAL WASTE

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>UOX 45 GWj.t⁻¹</th>
<th>MOX 46 GWj.t⁻¹</th>
<th>SFR-MOX 92 GWj.t⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor Actinides</td>
<td>1,9 – 1,7 – 0,2</td>
<td>14,3 – 0,5 – 2,7</td>
<td>3,7 – 0,4 – 0,2</td>
</tr>
<tr>
<td>Fission Products</td>
<td>130</td>
<td>130</td>
<td>110</td>
</tr>
<tr>
<td>CSD-V (HLW)</td>
<td>2,2</td>
<td>5,3</td>
<td>1,8</td>
</tr>
</tbody>
</table>

**See C. Chabert – IAEA TM AFCWBM – 22 June 2016**
## RESULTS: EVALUATION OF HLW FOOTPRINT

<table>
<thead>
<tr>
<th></th>
<th>OPEN CYCLE PWR</th>
<th>MONO-RECYCLING PWR</th>
<th>BI-RECYCLING PWR-SFR (5%)</th>
<th>MULTIRECYCLING SFR</th>
<th>MULTIRECYCLING SFR Am Transmutation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TUNNEL FOOTPRINT HLW</strong> (m²/TWh) (*)</td>
<td>490</td>
<td>150</td>
<td>170</td>
<td>170</td>
<td>20</td>
</tr>
<tr>
<td><strong>POTENTIAL FOOTPRINT FOR NON RECYCLED SPENT FUEL</strong> (m²/TWh) (*)</td>
<td>0</td>
<td>180</td>
<td>120</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>GLOBAL EVALUATION OF THE FOOTPRINT HLW</strong> (m²/TWh) (*)</td>
<td>490</td>
<td>330</td>
<td>290</td>
<td>170</td>
<td>20</td>
</tr>
</tbody>
</table>

(*) TWh of the considered fleet

Source: 2005 and 2012 ANDRA reports; 2012 CEA-Andra study
New concept under study by Andra: higher footprints (from 30% up to 80% according to the package)
RECYCLING is clearly the best strategy for achieving a SUSTAINABLE nuclear energy (while avoiding spent fuel accumulation)

Reprocessing makes waste management easier and safer, while keeping high standards of safety and quality as well as having very low environmental impact: this provides a steady back-end solution for the long term future.

Strong collaborative R&D efforts on advanced fuel cycles are still in progress worldwide (and especially in Europe for hydro, and in USA-Korea for pyro).

Quite extensive industrial worldwide experience already exists on reprocessing and recycling: it is in particular an efficient and mature industry in France.
THE PROGRESSIVE INTRODUCTION OF FRS AND OF MATERIALS MULTI-RECYCLING ALLOW FOR:

- a reduction of the net production of Pu
- … until Pu inventory stabilization
- a global reduction of Pu inventory (vs open cycle or current cycle)
- a global reduction of natural U needs (down to 0) and of front-end operations
- a reduction of wastes (from the mine to the HLW)
- a reduction of HLW footprint
- could even more decrease thank’s to Am transmutation