Plutonium Management in Small Nuclear Country

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Introduction

Small nuclear country

- evolution of existing nuclear technology rather than strong participation on revolution solution development
- future introduction of FR should not be endangered
# Plutonium surplus (1/3)

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of uranium</td>
<td>5.90547E+05</td>
</tr>
<tr>
<td>Sum of neptunium</td>
<td>3.33015E+02</td>
</tr>
<tr>
<td>Sum of plutonium</td>
<td>5.62261E+03</td>
</tr>
<tr>
<td>Sum of americium</td>
<td>8.51769E+02</td>
</tr>
<tr>
<td>Sum of curium</td>
<td>2.78415E+00</td>
</tr>
<tr>
<td>Sum of californium</td>
<td>1.02119E-13</td>
</tr>
<tr>
<td>Sum of actinides</td>
<td>5.97357E+05</td>
</tr>
<tr>
<td>Sum of fission products</td>
<td>1.54463E+03</td>
</tr>
<tr>
<td>Total</td>
<td>5.98902E+05</td>
</tr>
</tbody>
</table>

Element masses in the spent fuel of NPP V1 Bohunice
Plutonium surplus (2/3)

Plutonium balance

- NPP V1 Bohunice – 55 reactor-years > 5.6 t of Pu
- NPP V2 Bohunice and NPP Mochovce (2 units) – 65 reactor-years > min. 6 t of Pu
- min. 11 t of Pu is available
- SUPER PHENIX needs for the start-up less than 9 t of Pu

Mass of abundant Pu

- is min. 2 t even if FR reactor is started in Slovakia
- is growing instantly – 4 units in operation, 2 more from 2013, 1 or 2 more later on
Plutonium surplus (3/3)

<table>
<thead>
<tr>
<th>Locality</th>
<th>No</th>
<th>Type</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bohunice</td>
<td>2</td>
<td>VVER-440 - 213</td>
<td>-</td>
</tr>
<tr>
<td>Mochovce</td>
<td>2</td>
<td>VVER-440 - 213</td>
<td>-</td>
</tr>
<tr>
<td>Mochovce</td>
<td>2</td>
<td>VVER-440 - 213+</td>
<td>Under construction</td>
</tr>
<tr>
<td>Bohunice</td>
<td>?</td>
<td>?</td>
<td>Under preparation</td>
</tr>
</tbody>
</table>

Nuclear units in Slovakia
Reducing cycles (1/7)

Alternative partially closed fuel cycles:
- with inert matrix fuel – IMF
- with Th and Pu without spent Th fuel reprocessing - PuThOX
- with Th and Pu and with spent Th fuel reprocessing - UPuThOX

Reference fuel cycles:
- classical open fuel cycle – UOX
- classical MOX
Reducing cycles (1/7)

<table>
<thead>
<tr>
<th>reactivity coefficients</th>
<th>fuel type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UOX</td>
</tr>
<tr>
<td>dro/dcb (%/g/kgH₂O)</td>
<td>-6.5295</td>
</tr>
<tr>
<td>dro/dTm (%/deg)</td>
<td>-2.9950E-04</td>
</tr>
<tr>
<td>dro/d(Tm+den) (%/deg)</td>
<td>-1.6594E-02</td>
</tr>
<tr>
<td>dro/dTf (%/deg)</td>
<td>-1.8748E-03</td>
</tr>
</tbody>
</table>

Comparison of reactivity coefficients
Reducing cycles (2/7)

Delayed neutron fraction comparison
Reducing cycles (3/7)

PuThOX fuel cycle (7.9 of UOX cores needed)

PuThOX Fabrication → VVER-440 (PuThOX core) → Storage → Reprocessing

UOX Fabrication → VVER-440 (UOX core) → Storage → UOX

ThOX → Pu - all isotopes

9.74% Pu (5.40% Pu-239)

1.24% Pu

4.2% U-235

enriched U

PuThOX

Wastes

URT

FP MA
0.1% Pu
0.1% U

U
Reducing cycles (4/7)

UPuThOX fuel cycle (3.4 of UOX cores needed)
Reducing cycles (5/7)

Pu - all isotopes + MA

6.94 vol.%

1.40 wt% Pu+MA in UOX

IMF fuel cycle (self-cleaning)

IMF Fabrication

VVER-440 (IMF/UOX core)

Storage

VVER-440 (UOX core)

Reprocessing

UOX

Waste

URT

FP 0.1% MA
0.1% Pu
0.1% U

IMF

U

4.2 wt% U-235

enriched U

6.94 vol.%

1.40 wt% Pu+MA in UOX

FP 0.1% MA
0.1% Pu
0.1% U

IMF

U
Reducing cycles (6/7)

Model of combined VVER-440 assembly
Reducing cycles (7/7)

<table>
<thead>
<tr>
<th></th>
<th>UOX</th>
<th>PuThOX</th>
<th>UPuThOX</th>
<th>IMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu initial</td>
<td>0</td>
<td>97.38</td>
<td>41.42</td>
<td>14.05</td>
</tr>
<tr>
<td>Pu in spent fuel after 5y cooling</td>
<td>12.37</td>
<td>51.39</td>
<td>15.25</td>
<td>3.21</td>
</tr>
<tr>
<td>MA in spent fuel after 5y cooling</td>
<td>1.48</td>
<td>6.15</td>
<td>3.39</td>
<td>1.22</td>
</tr>
<tr>
<td>Pu transmutation rate (%)</td>
<td>0</td>
<td>47.22</td>
<td>63.18</td>
<td>77.08</td>
</tr>
<tr>
<td>Pu transmutation rate (kg/TWhe)</td>
<td>0</td>
<td>13.22</td>
<td>17.64</td>
<td>7.32</td>
</tr>
<tr>
<td>Pu generation rate (kg/TWhe)</td>
<td>32.2</td>
<td>15.5</td>
<td>10.5</td>
<td>6.2</td>
</tr>
<tr>
<td>MA generation rate (kg/TWhe)</td>
<td>3.8</td>
<td>3.3</td>
<td>2.9</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Potential of Pu transmutation
Reducing cycles (7/7)

Key effects demonstrated:

- important exploitation parameters are not distorted at IMF cycle

- electricity production in LWRs with alternative cycles is connected with smaller generation of Pu and MA

- the best in this way is cycle with IMF
Conclusion (1/2)

Pu management

- Pu mass in SNF is sufficient for FR start-up in Slovakia
- Pu smaller production can be reached by partially closed fuel cycle with IMF or Th
- remaining Pu and MA can be transmuted later in FRs or MSRs
Conclusion (2/2)

Positive effects of IMF and Th application

- no expensive and time-consuming unit reconstruction
- simplified construction of deep repository
- reduction of nonproliferation problems
- partial replacement of natural uranium by reprocessed plutonium