Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal

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Partners of RED-IMPACT

23 partners + 2 subcontractors

Nuclear Industry & Utilities 32%
Waste Agencies 18%
Research 50%

KTH-Sweden: Coordinator
FZJ-Germany: Co-Coordinator

Belgium: BN; SCK-CEN
Czech Republic: NRI; RAWRA
EC: ITU-Karlsruhe
France: Areva ANP, CEA; COGEMA
Germany: FANP; GRS; IER; KKP
Netherlands: NRG
Romania: CITON
Slovakia: DECOM, VUJE
Spain: CIEMAT; EA; ENRESA
UK: NexiaSolutions; NIREX; UC

EC CONTRACT NO. FI6W-CT-2004-002408
Duration: March 2004 – September 2007
Working procedure

1. Definition of fuel cycle
2. Heavy Metal mass flow
3. Neutronic calculations
4. Mass flow in reprocessing units
   - Actinide losses: 0.1% in HLW, 0.02% in ILW
   - Volatile Activation + Fission Products
     - I: 1% in HLW, 1% in ILW
     - $^{14}$C: 10% in HLW
     - Cl: 1% in HLW, 0.2% in ILW
5. Waste inventories
6. Waste disposal analyses
7. Estimation of environmental, economic and social indicators
Investigated Fuel Cycles

• **Industrial scenarios**
  – **Scenario A1**: (reference) : once through open cycle with Gen-II / III reactors
  – **Scenario A2**: mono-recycling of plutonium in Gen-III reactors
    (+ variants e.g. Th-MOX, IMF, PWR vs. BWR etc.)
  – **Scenario A3**: Multirecycling of Pu (only) in Sodium Fast Reactors (EFR)

• **Innovative scenarios**
  – **Scenario B1**: Multi-recycling of Pu & MA in Sodium Fast Reactors (EFR) plus advanced PUREX
  – **Scenario B2**: multi-recycling of plutonium in Gen-III reactors and burning of Minor Actinides in ADS plus advanced PUREX & PYRO
  – **Scenario B3**: mono-recycling of plutonium in Gen-III reactors + burning of plutonium in Gen-IV fast reactors + burning of Minor Actinides in ADS including advanced PUREX and PYRO (*reduced efforts*)
Cradle-to-Grave

A1: 5.354 spent fuel assemblies / TWh_{el}  B1: 1.644 canisters / TWh_{el} (HLW_{vitr.})
Performance indicators

The indicators have been divided into two major groups:

• “Technical” indicators related to waste management issues:
  – composition of the waste; number of SF-assemblies, number of canisters,
  – size of the repository; gallery length \textit{(influenced by heat load)}
  – long-term performance of the repository system:
    • individual annual dose;
    • radiotoxicity flux released into the biosphere;
    • integrated radiotoxicity flux released into the biosphere.
  – Inclusion of ILW

• Economic, Environmental and Societal sustainability (EES) indicators
  – Production cost & external cost
  – Fuel import dependencies, resource consumptions
  – Proliferation and terrorist attack resistance
  – Health impacts on workers & public in normal operation & accidents
  – etc.
Priorities

Plutonium Management has strongest Impact!
Focus on most important MA!!!
## Thermal output and length of disposal galleries (Clay)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Clay: allowable thermal output at disposal time (W/m)</th>
<th>Total needed gallery length (m/TWhe)</th>
<th>Relative needed gallery length (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>354</td>
<td>5.922</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>332 / 376</td>
<td>5.743</td>
<td>0.970</td>
</tr>
<tr>
<td>A3</td>
<td>365</td>
<td>3.479</td>
<td>0.587</td>
</tr>
<tr>
<td>B2</td>
<td>379</td>
<td>2.895</td>
<td>0.489</td>
</tr>
<tr>
<td>B1</td>
<td>379</td>
<td>1.882</td>
<td>0.318</td>
</tr>
<tr>
<td>B1-separation of Sr</td>
<td>1.273</td>
<td></td>
<td>0.215</td>
</tr>
<tr>
<td>B1- separation of Cs and Sr (Cs-waste disposed after 100 a)</td>
<td>0.439</td>
<td></td>
<td>0.0741</td>
</tr>
</tbody>
</table>

**Reduction by a Factor of 3 (A1 vs. B1)**

Removal of Cs & Sr would allow further reduction
Repository in granite

Concept: Enresa, Spain

• Bentonite saturated after 20 a, corrosion starts
• Sequential failure of canisters from 1300 to 10000 a
• Average time for H$_2$O to reach biosphere 8400 a
• **Diffusion and sorbtion retards the transport of many nuclides**
• Release to river ($10^6$ m$^3$/a), exposed group use river water
Long-Lived Fission Products dominate Doses (A1 granite)
Granite: calculated doses
(all scenarios, Enresa)

Differences mainly due to Iodine removal during reprocessing !!!
Calculated doses in Clay
(all scenarios, SCK•CEN)

A1: LWR-direct
A2: LWR-Mono
A3: LWR-Multi
B1: SFR-Multi
B2: SFR+ADS
Variant scenarios of B1
(calculated e.g. for Granite)

Impact of waste matrix lifetime
Thorium: Reduction of MA

Secondary Fuels

Actinides: Long-term Radiotoxicity !!!

Thorium (3 x more)

Th/Pu MOX:
2x better Pu/MA consumption !!!
Human intrusion doses
(all scenarios, Nirex)
ILW-Packages

Source:
- Structural Parts of Fuel Assemblies
  - End-fittings, chopped claddings, grids etc.
  - Core & Blanket
- Reprocessing of ADS-Fuel (Zr-Nitride)
  - C-14, Cl-36, Nb-94 contents
  - Noble metals from Pyro-processing
- ADS core components
  - Pb-Bi, core support, window, accelerator tube

For granite repository:
- Waste matrix less retention
  - A1 0 m³/TWₚₑh
- Direct access of ground water
  - A2 2,5 m³/TWₚₑh
  - A3 5,3 m³/TWₚₑh
- doses start earlier
  - B1 5,3 m³/TWₚₑh
  - B2 3,3 m³/TWₚₑh
- ILW dominates till 20.000 y
Calculated doses for ILW in Granite (scenario A2, Enresa)
Doses for HLW + ILW in Granite

Scenarios A3 & B1

Scenario A2

Scenario A1

Scenario B2

Enresa calculation
Conclusions (1)

• **P&T Impact on repository dimensions** (heat load)
  – reduction of gallery length with a factor 3
  – a factor 5 in case of Sr separation
  – a factor 10 (or more) in case of *Cs and Sr separation*

• **P&T Impact on dose**: HLW disposal
  – limited: due to mobile fission and activation products
    \((^{14}\text{C}, ^{36}\text{Cl}, ^{79}\text{Se}, ^{99}\text{Tc}, ^{129}\text{I}, ^{135}\text{Cs}, ^{126}\text{Sn})\)
  – depends on amount of disposed \(^{129}\text{I}, ^{14}\text{C}, ^{36}\text{Cl}\) vs.
    discharged volatile isotopes during reprocessing
  – ADS-specific waste to be considered in more detail

• **P&T Impact on Human Intrusion dose**: significant

• **Impact of more stable matrix on dose**: significant
Conclusions (2)

• **ILW Impact on dose:**
  - Granite: ILW doses > HLW doses
    - consider use of low activation materials, add barriers (C-14)
  - Clay: ILW doses < HLW doses

• **Reduced generation of MA:** Th-MOX, IMF vs. Pu-MOX

• **Hetereogeneous recycling & other reactors** (BWR, HWR, HTR etc.)

• **Improved Partitioning / Reprocessing:** LLFP, volatile FP

• **Partitioning & Conditioning (P&C):** viable option

• **Cost / Benefit Evaluations:** science / industry dialog

• **Repository/waste package adaptation to P&T waste**

**Transition** to advanced reprocessing/conditioning: ASAP
Thanks for your attention
Assumptions

• A1: reference scenario: open cycle
  • Burn-up 50 GWd/tHM, UOX : $^{235}$U enrichment 4.2%
    – HLW: **5.354 spent fuel assemblies / TWh$_{el}$**
• B1: Fast neutron Gen IV & advanced PUREX
  • Burn-up: core 136 GWd/tHM (axial 15, radial 24)
    • MOX: 23.2% Pu + 2.7% MA
    – Vitrified HLW: **1.644 canisters / TWh$_{el}$**
• HLW disposal in 3 host formations
  – **Granite:** ENRESA (Spain), NRI (Czech Republic)
  – **Clay:** SCK•CEN (Belgium)
  – **Salt:** GRS (Germany)
Evolution of temperature

- Interface A1
- Interface A2 HLW
- Interface A2 MOX
- Interface A3
- Interface B1
- Interface B2 UOX
- Interface B2 MOX
- Interface B2 ADS

Legend:
- A1: LWR-open
- A2: LWR-Mono
- A3: LWR-Multi
- B1: SFR-Multi
- B2: SFR+ADS
Radiological impact

- Safety functions of repository system
  - Engineered containment
    - Container lifetime (2000 a)
  - Slow release of RNs
    - Waste matrix degradation (100,000 a)
    - Solubility limitation (reducing conditions)
  - Very slow transport
    - Diffusive transport through buffer (and clay formation)
    - Sorption on (clay) minerals
- Small releases of radionuclides into biosphere
Radiotoxicity Fluxes for Clay

A1

Significant impact of long-lived fission products!
Minor Actinides strongly immobilised!
Strong dependence on solubility limits!

B1
Human intrusion doses
(scenario A1, Nirex)

MA dominate Human Intrusion Scenarios
Human intrusion: required isolation times

<table>
<thead>
<tr>
<th>Comparator</th>
<th>Cigar Lake natural analogue</th>
<th>ICRP 10 mSv intervention level</th>
<th>ICRP 100 mSv intervention level</th>
<th>Radiotoxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLW/SF Types</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario B1: HLW</td>
<td>~200,000 a</td>
<td>~40,000 a</td>
<td>~1000 a</td>
<td>~300 a</td>
</tr>
<tr>
<td>Scenario B2: HLW from ADS fuel</td>
<td>&gt; 1 Ma</td>
<td>~70,000 a</td>
<td>~13,000 a</td>
<td>~300 a</td>
</tr>
<tr>
<td>Scenario A3: HLW</td>
<td>&gt; 1 Ma</td>
<td>&gt; 1 Ma</td>
<td>~70,000 a</td>
<td>~24,000 a</td>
</tr>
<tr>
<td>Scenario A1: spent UOX fuel</td>
<td>&gt; 1 Ma</td>
<td>&gt; 1 Ma</td>
<td>~100,000 a</td>
<td>~200,000 a</td>
</tr>
<tr>
<td>Scenario A2: spent MOX fuel</td>
<td>&gt; 1 Ma</td>
<td>&gt; 1 Ma</td>
<td>~200,000 a</td>
<td>~90,000 a</td>
</tr>
</tbody>
</table>
ILW: calculated doses in Clay (scenario A3, SCK•CEN)
Doses for HLW + ILW in Clay
(all scenarios, SCK•CEN)