IMPACT OF PARTITIONING ON HIGH LEVEL WASTE MANAGEMENT
IN INDIAN SCENARIO

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Advance Fuel Cycle for Waste Burden Minimization
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Indian Nuclear Fuel Cycle: Today

U (natural) → UOX fuel → PHWR

- Volume Reduction
- Near Surface Disposal

PUREX → Heavy metal α Bearing HLW

- Vitrification
- Interim Storage

Repository

Reprocessing of carbide fuel

- Mixed Carbide fuel For Fast breeder test reactor
- Mixed Oxide fuel for Prototype Fast Breeder Reactor

PHWR

Vitrification Facility, Trombay

Reprocessing Facility, Tarapur

Vitrified Waste Storage Facility, Tarapur
Present Management of High Level Waste: 3-Stage Programme

- Glass Pouring
- Shielded Transportation
- Cask Assembly
- Air-cooled Storage
- HLW Canister Welding
- Deep Geological Repository
- HLW from Reprocessing
Partitioning of minor actinides & FPs from HLLW

- Partitioning (& transmutation) of minor actinides from HLLW leads to **reduction of radio toxicity** of the waste addressing:
  - Long term concerns for repositories,
  - simplified repository design
  - increase in public acceptance

- Such a strategy also favours **recovery of useful fission products**

- Minor actinides so separated can be **transmuted** in accelerator driven sub critical systems (ADSS) or fast breeder reactors (FBRs)

- Special **tailor made matrices** for separated radionuclide – Alternate development

*Demonstration of partitioning process: consequence of industrial scale availability of novel solvents*
Operational Engineering Scale Partitioning Facilities in India

• **Actinide Separation Demonstration Facility : Tarapur**
  – Operational since Nov. 2013 & being operated on demonstration basis
  – All the cycles operated simultaneously at Processing rate ~ 30L/hr
  – Demonstrated actinide partitioning from HLW along with An/Ln separation
  – All secondary waste streams suitably addressed

• **Solvent Extraction Facility, Trombay**
  – Operational since January 2015 & is under continuous operation
  – Continuously pre-treats high salt loaded legacy waste at Trombay leading to separation of active constituents from bulk of the inactive constituents
  – Recovery of Cs-137 and its conversion to caesium pencil – Spin Off
  – Strontium-90 recovery for societal benefits – (Under Implementation)
## Solvent Systems Deployed

### ASDF Tarapur

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Separation Type</th>
<th>Solvent Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle 1</td>
<td>U Separation</td>
<td>30 % TBP in n-dodecane</td>
</tr>
<tr>
<td>Cycle 2</td>
<td>An + RE separation</td>
<td>0.2 M TEHDGA in 30% IDA in dodecane</td>
</tr>
<tr>
<td>Cycle 3</td>
<td>An/Ln Separation</td>
<td>0.2 M D2EHPA in n-dodecane (TALSPEAK)</td>
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### Solvent Extraction Facility, Trombay

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<td>30 % TBP in n-dodecane</td>
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<td>Cycle 2</td>
<td>Cs Separation</td>
<td>0.03 M Calix Crown (CC6) in 50% IDA in dodecane</td>
</tr>
<tr>
<td>Cycle 3</td>
<td>Sr, Ln and An Separation</td>
<td>0.4 M TEHDGA in 10% IDA in dodecane</td>
</tr>
</tbody>
</table>
The Actinide Separation Demonstration Facility, Tarapur & Solvent Extraction Facility, Trombay

- Throughput to match vitrification process
- Multi step process based on solvent extraction
- Facilities has been designed as per the conventional basis of design of radiochemical plant

Overall Layout of the integrated Facility
Overall Block Diagram for ASDF/SSMF, SSSF, Tarapur

- **U Removal Cycle**
  - TBP
  - HLW
  - U Product to ROP
  - Spent Solvent from PREFRE

- **MA Separation Cycle**
  - TEHDGA
  - U Lean HLW

- **Ac/Ln Group Separation Cycle**
  - D2EHPA
  - Ac/Ln Product

- **Spent Solvent Management Facility**
  - Recovered dodecane casking
  - Aq. After Alkaline Hydrolysis & Carbonate solution for immobilization
  - Novel solvent casking

- **Ac. Product Storage**
  - Rare earth solution for vitrification/cementation
  - for Vitrification

Additional Notes:
- HLW
- U Lean HLW
- MA Lean HLW
- Spent Solvent from Prefre
- U Product to ROP
Basic process: Decontamination of HLW by Solvent Extraction

- **HLW**
  - Gross $\alpha$: 6 mCi/L
  - Gross $\beta$: 8.77 Ci/L

- **Solvent Extraction**
  - 1st Cycle: U
  - 2nd Cycle: Cs
  - 3rd Cycle: Sr, Ln, An

- **Raffinate (ILW, Short Lived)**
  - To Tk4 after neutralization
  - Gross $\alpha$: $1-5 \times 10^{-4}$ mCi/L
  - Gross $\beta$: 2-3 mCi/L

- **Spent Solvents**
  - Washed Solvents
  - Cementation
  - CWP (L&IL)

- **Evaporation & Vitrification**
  - U Solution Recycle
  - VWP (HL)

- **Conversion to Cs Pencil**

- **Recycle/Treatment**
Process Performance
• ASDF which is based on indigenous efforts, inaugurated by Hon. President of India on November 15, 2013.
• Has processed 13 m³ of High Level Liquid Waste (HLLW) till date

**Performance**

Cycle 1 - 99.65% removal of residual U& Pu
Cycle 2 - 99.95% removal of alpha activity
Cycle 3 - 97.8 % An/Ln separation

With the successful commissioning of this facility, India has taken a step forward towards reducing the long term concerns of HLLW, an endeavor pursued globally.
Performance of Solvent Extraction Facility, Trombay

Salient Feature of Operation:

HLW Treated: 34,000 lit in 1 year

• 85000 Ci of Cs-137 recovered, concentrated and vitrified to produce Cs glass.
• Sr, Ln and An separated, concentrated and vitrified
• Six nos of VWP canisters produced resulting in loading of 5500 lit of HLW per canister.
• Raffinate activity ($\beta$-$\gamma$) ~ 2 mCi/lit and ($\alpha$) ~ $1 \times 10^{-4}$ mCi/lit.

DF ($\beta$-$\gamma$) : 3500
DF ($\alpha$) : > 30000

In cell view of solvent extraction system

50 nos of Cs pencil produced and deployed for Blood irradiation
Steps for production of Cs-137 Glass pencil

1. Separation of Cs from HLW
2. Vitrification of Cs solution
3. Deepening of Cs glass pencil
4. Shielded cask for transportation of Cs pencil
5. Production of Cs glass pencil
6. Welding of lid on Cs glass pencil

Blood Irradiator

Shielded cask for transportation of Cs pencil
### Brief comparison of management techniques (Trombay legacy HLW)

<table>
<thead>
<tr>
<th></th>
<th>Direct Vitrification</th>
<th>Solvent extraction based Pre-treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HLW Loading</strong></td>
<td>250 Lit/canister</td>
<td>5500 Lit/canister</td>
</tr>
<tr>
<td>(due to sulfate &amp; presence of inactive salts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expected No of canisters for present inventory</strong></td>
<td>1000</td>
<td>45</td>
</tr>
<tr>
<td><strong>Processing rate</strong></td>
<td>10-15 m³ per year</td>
<td>40-60 m³ per year</td>
</tr>
<tr>
<td><strong>Fission product partitioning</strong></td>
<td>Not feasible</td>
<td>Separation of Cs &amp; Sr feasible, usable for societal applications</td>
</tr>
</tbody>
</table>

*This pre-treatment step which partitions the waste thereby separating active components from bulk inactive salts is unique in nature being the first kind in World.*
Partitioning of HLW : A Changing Scenario
Partitioning of HLW: A changing Scenario

- Process flow sheets have been demonstrated for separation of the following
  - Minor Actinides
  - Fission products (Cs & Sr)

- Partitioning primarily aimed at:
  - Transmutation of Minor actinides and some of the long live FPs
  - Resource utilisation of FP’s like Cs & Sr

- As a transition step can we incur benefits in the short time frame by vitrification of separated radionuclides (A preliminary feasibility study carried out)
Partitioning of HLW: A changing Scenario

- A feasibility study carried out to analyse impact of partitioning on waste volume/heat load for vitrification of separated radionuclide's for HLW from PHWR & PFBR

- Partitioning Scenario 1 - Separation of Cs-Sr and Minor An/Ln (Without An-Ln Separation) followed by
  - Vitrification of heat generating Cs & Sr stream
  - Vitrification of Lean FP stream
  - Vitrification of MA along with RE(Ln) stream
  (Based on the successful results of the ASDF, Tarapur and WIP, Trombay for bulk Ac-Ln separation and Cs-Sr separation)

- Partitioning Scenario 2 - Separation of Cs-Sr and Minor An/Ln Followed by An-Ln Separation and
  - Vitrification of heat generating Cs & Sr stream
  - Vitrification of Lean FP & RE(Ln) stream
  - Vitrification of separated MA stream
  (Assuming Ac-Ln group separation is feasible with higher separation efficiencies resulting in alpha lean RE(Ln) stream)
## HLW Composition & Heat Load

<table>
<thead>
<tr>
<th></th>
<th>PHWR - 500 L/T</th>
<th>PFBR – 9750 L/T (Average of core &amp; blanket SA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gm/L (Oxide)</td>
<td>W/L</td>
</tr>
<tr>
<td>Cs-Sr</td>
<td>1.65</td>
<td>0.4116</td>
</tr>
<tr>
<td>Lanthanide/Rare earth</td>
<td>5</td>
<td>0.1054</td>
</tr>
<tr>
<td>Other FP</td>
<td>7.25</td>
<td>0.1086</td>
</tr>
<tr>
<td>Minor Aactinide</td>
<td>0.153</td>
<td>0.0096</td>
</tr>
<tr>
<td>CP&amp;Added Chem.</td>
<td>8.94</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>0.635</td>
</tr>
</tbody>
</table>

PFBR - average HLW concentration resulting from reprocessing of core SA (100 GWD/T peak burn up) with axial blanket & radial blanket SA (~5 GWD/T).
Basis of vitrified waste volume estimation for different partitioning scenario

HLW presently vitrified directly using borosilicate glass matrix by either induction or joule melter. Both these technologies imposes a limit on the glass pouring temperature of ~950°C. Waste oxide loading in glass is on account of this limitation.

- For direct vitrification of PHWR waste – waste oxide loading of 21.8% due to limit imposed by heat/Mo.
- For direct vitrification of PFBR waste - waste oxide loading of 16.8% due to limitation of total lanthanides including inactive Gd.
- Cs-Sr loading in glass is based on the 2700 W/Canisor (450 Kg) to limit the centreline temperature.
- For vitrification of Ac-Ln stream waste oxide limitation is based on 8% Ln limit.
- For vitrification of Actinide stream, Alpha loading limit is estimated based on $10^{19} \alpha/g$ disintegration limit.
- Lean FP/Ln glass loading is considered 30% to minimize vitrified waste volume due to relatively short life associated with the waste.
### Impact of Partitioning on High Level Waste Management

**Comparison of vitrified waste volume & heat load for different partitioning scenario**

**PHWR**

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<th>Partitioning Scenario 1</th>
<th>Partitioning Scenario 2</th>
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<tr>
<td></td>
<td>Kg/T</td>
<td>W/Kg</td>
<td>Kg/T</td>
</tr>
<tr>
<td>Actinide Waste</td>
<td>52.7</td>
<td>6.0</td>
<td>25</td>
</tr>
<tr>
<td>Cs-Sr Waste</td>
<td>34</td>
<td>6.0</td>
<td>34</td>
</tr>
<tr>
<td>Lean FP/Ln Waste</td>
<td>27</td>
<td>2.0</td>
<td>35</td>
</tr>
</tbody>
</table>

**PFBR**

<table>
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<tr>
<td></td>
<td>Kg/T</td>
<td>W/Kg</td>
<td>Kg/T</td>
</tr>
<tr>
<td>Actinide Waste</td>
<td>318</td>
<td>2.97</td>
<td>318</td>
</tr>
<tr>
<td>Cs-Sr Waste</td>
<td>101</td>
<td>6.0</td>
<td>101</td>
</tr>
<tr>
<td>Lean FP/Ln Waste</td>
<td>62</td>
<td>3.4</td>
<td>162</td>
</tr>
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</table>
Further R&D in this direction

- An-Ln Separation - improved separation efficiencies
- Recovery of Actinide for conversion to target preparation for transmutation studies
- Strontium Separation using Crown ether based solvent system to recover Sr separately
- Special matrices for separated radionuclide for waste volume reduction
Thank You For Your Kind Attention!

"Not all of us can do great things. But we can do small things with great love." ...Mother Teresa