Fuel Cycle Perspective – Indian Context

C. P. Kaushik
Waste Management Division
Nuclear Recycle Group
BHABHA ATOMIC RESEARCH CENTRE
Trombay, India

GCNEP-IAEA Theme Meeting on ‘Strategies and Opportunities for the Management of Spent Fuel from Power Reactors in the Longer Timeframe’
GCNEP, Bahadurgarh, INDIA
(November 25-29, 2019)
• Three Stage Nuclear Power Programme
• Nuclear Fuel Cycle in India
• Glass – a suitable conditioning matrix for HLLW
• Management of HLW
• Evolution of partitioning techniques in India
• Recovery of valuable radionuclide – wealth from waste
• Futuristic Fuel Cycle
• Management of ILW, LLW and low level solid waste
• Summary
Three Stage Nuclear Power Program

**Stage 1:**
Power generation primarily by PHWR & Building fissile inventory for stage 2
Present Status: 22 Reactors operational – 6780 MWe Installed capacity
Future: 63,000 MWe additional capacity by 2050 @ 2000 MWe / year

**Stage 2:**
Expanding power programme Building U233 Inventory
Present Status: Research Reactor FBTR
Operational, 500 MWe commercial reactor under construction

**Stage 3:**
Thorium Utilisation for Sustainable power program
Present Status:
Research Reactor KAMINI Operational, 300 MWe commercial reactor under design
### Nuclear Power Plants in India

**Current Installed Capacity in India**: 6.78 GW*

**Additional Capacity by 2032 in India**: 15 GW**

* [https://wwwnpcilnicin](https://wwwnpcilnicin)  ** [https://wwwdaegovin](https://wwwdaegovin)

<table>
<thead>
<tr>
<th>Power Plants</th>
<th>Types</th>
<th>No.</th>
<th>Total capacity (MWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Under Operation</strong></td>
<td>18 PHWRs</td>
<td>22</td>
<td>6850</td>
</tr>
<tr>
<td></td>
<td>2 BWRs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 PWRs</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Under Construction/Commissioning</strong></td>
<td>6 PHWRs</td>
<td>9</td>
<td>6700</td>
</tr>
<tr>
<td></td>
<td>2 PWRs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 FR</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Under Planning</strong></td>
<td>10 PHWRs</td>
<td>12</td>
<td>9000</td>
</tr>
<tr>
<td></td>
<td>2 PWRs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Gorakhpur, Haryana

**Additional Information**

- [Gorakhpur, Haryana](https://wwwnpcilnicin)
- [https://wwwdaegovin](https://wwwdaegovin)
Fuel Cycle Options

Once Through Fuel Cycle

Fuel Manufacturing

Fissile partly spent
Fertile partly converted

Spent Fuel Repository

Huge energy potential!!

Reprocessing

Long lived waste Repository

Closed Fuel Cycle

Aim at improvisation for further volume reduction
Contains
✓ Fission Products (FPs)
✓ Actinides (Ac) and
✓ Bulk amount of unused Uranium.
Only < 1% fuel gets converted to Fission Products and Actinides.

High Level Radioactive Liquid waste (HLW)

HLW contains many valuable FPs which have direct societal application towards healthcare, agriculture and industry.

In Indian philosophy - “Spent Fuel is a resource”

Closed Fuel Cycle – for optimal utilization of resources

Recycle & Reuse

Electricity

Fresh fuel

Spent fuel

Reprocessing

U & Pu Oxides
“Radioactive material and sources of radiation should be handled in Atomic Energy Establishment, in a manner, which not only ensures that no harm can come to workers in the Establishment or any one else, but also in an exemplary manner so as to set a standard which other organizations in the country may be asked to emulate.”

- Dr. Homi J. Bhabha
Classification of Waste

1. Liquid waste is classified on the basis of concentration of radioactivity
   - Low Level Waste
   - Intermediate Level Waste
   - High Level Waste

2. Solid waste is categorized on the basis of half life of radionuclide and surface dose rate
   - Cat – I (Surface dose < 0.2 R/hr)
   - Cat – II (Surface dose > 0.2 to < 2 R/hr)
   - Cat – III (Surface dose > 2 R/hr)
   - Cat – IV (Alpha content > 4000 Bq/g)

3. Gaseous Waste
Components of HLW

HLW arises from the reprocessing of Spent Fuel from the following reactors:
- PHWR
- LWR
- FR
- Futuristic Reactors

HLW Composition depends on:
- Type of reactor
- Type of fuel
- Burnup
- Cooling period
Containment and isolation from human environment till decays to innocuous level is the genesis of management of HLW.

Glass: A suitable conditioning matrix for HLLW in view of long term durability.
Natural Analogue
- a testimony of long term durability of glass

Natural Glasses (Basaltic & Obsidian) is a testimony of the long term durability of the glasses for ascertaining containment of radioactivity for external period of time.

<table>
<thead>
<tr>
<th>Major oxides</th>
<th>Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>71.18</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.36</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>9.71</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.26</td>
</tr>
<tr>
<td>Na₂O</td>
<td>5.51</td>
</tr>
</tbody>
</table>

Obsidian Glass

<table>
<thead>
<tr>
<th>Major oxides</th>
<th>Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>49.11</td>
</tr>
<tr>
<td>TiO₂</td>
<td>2.41</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.81</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>15.99</td>
</tr>
<tr>
<td>CaO</td>
<td>9.44</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.20</td>
</tr>
</tbody>
</table>

Basaltic Glass
3 Stage Programme for Management of HLLW

1. HLW From Reprocessing
2. Glass Pouring
3. Canister Welding
4. Immobilisation
5. Interim Storage
6. Deep Disposal
7. Shielded Transport Cask
8. Air Cooled Storage
9. Geological Disposal Facility
Vitrification Plants in India

WIP, Trombay

AVS, Tarapur

WIP, Kalpakkam
Melters for Vitrification
- three generations of melters

**Induction Heated Metallic Melter**
- Capable of handling variation in waste characteristics
- Ease of operation and handling
- Easy decommissioning

**Joule Heated Ceramic Melter**
- Higher temperature
- Higher throughput
- Continuous operation

**Cold Crucible Induction Melter**
- Higher temperatures
- Feasibility for future matrices
- Expected long melter life
Inside view of SSSF, Tarapur

- Natural convection air cooling vault
- Heat removal capacity ~ 3 MW
- 1790 nos. of locations
- One overpack per location
SELECTION OF GEOLOGICAL MEDIA

Granitic formation lying in tectonically stable zones.

Massive uniform and large extent in three dimensions.

Minimum fracture zones, joints and intrusions.

Without ground water and away from major surface water bodies.

Away from the known mineral deposits.

Away from dense population areas, the tourist spots and ecologically important places.

MULTI-BARRIER CONCEPT
Reduction of Radiotoxicity

Waste after reprocessing with actinide partitioning

Waste after reprocessing without partitioning

Radiotoxicity of Uranium Ore

Time (Years)

Relative Radiotoxicity
Impact of Partitioning on Waste Volume

Vitrified Waste for Disposal

Nearly obviates the requirement of geological disposal facility

Without Partitioning
With Partitioning
With Partitioning & Transmutation

Waste Volume
Partitioning: an innovative technique

Separation of minor actinides by solvent extraction, ASDF, Tarapur
- Reduction in long term radio-toxicity
- Amenable for transmutation
- By and large qualitative removal

Waste volume minimization and opportunity for recovery of radionuclides for societal benefits

Recovery of Fission Products by solvent extraction, WIP, Trombay
- Separation of Cs-137 from U lean HLW using Calyx Crown-6 for production of Cs pencil
- Separation of Sr-Ac from U and Cs lean HLW using TEHDGA for production of Y-90 for therapeutic application
Development and Deployment of Novel Solvents
-a key for partitioning

- Calix Crown-6
- TEHDGA
- DADA
- Tetrapodal Amide

- In house Development
- Commercial Production
- Plant Scale Deployment
- Ligand Modelling

FABRICATION OF NOVEL SOLVENTS IN LARGER AMOUNT ENABLED THE PARTITIONING OF WASTE
Wealth from Nuclear Waste

Waste is no more a “waste”, rather it’s a “resource”.

Rich source of Cs-137, Sr-90, Ru-106 and other radionuclides having societal applications

Cesium-137
- Blood Irradiation
- Food Irradiator
- Sewage Hygenisation

Strontium-90
- Radio – pharmaceutical

High Level Radioactive Liquid waste (HLLW)

Ruthenium-106
- Irradiation source
- Cancer treatment
Cs-137 Glass Pencil Making from HLW at WIP

- Separation of Cs from HLW
- Re-melting of Cs glass in SS pencil
- Shielded cask for transportation of Cs pencil
- Welding of lid on Cs glass pencil
- Blood Irradiator
- Vinification of Cs solution
- Vitrification of Cs Solution
- Testing & Transportation
- Welding & Decontamination

Cs-glass in SS pencil

Diameter = 23 mm
Length = 204 mm
Volume = 70 cc (Wt. = 170 gms)
Activity = 250 Ci
Shipment of Cs glass pencil

for their use as source in blood irradiator to prevent
Transfusion Associated Graft Vs Host Disease (TA-GVHD)

Handing over of 1st cask of Cs glass pencils for blood irradiator

Handing over of 10th cask of Cs glass pencils for blood irradiator

- 200 numbers of Cs glass pencils produced so far
- Specific activity of Cs glass pencils increased to 4.5 Ci/gm from 2 Ci/gm to make suitable for other irradiator applications

India happens to be the first country in the world to recover Cs-137 in such a large quantity from waste and deploy it in non dispersible form for various societal applications
Recovery of Sr-90 from Waste

90Strontium is used for milking of 90Y for radiopharmaceutical applications

Extractant DCH18C6 is synthesized in house at BARC

Extractant: 0.1 M DCH18C6 in 50% octanol : 50% xylene

✓ Batch Size: 2.5 L
✓ Nature of Feed: 2 M Acidic
✓ Sr-90 in Feed: 4 mCi/lit
✓ % Extraction of Sr-90: 99.6%

Removal of Sr from High Level Liquid Waste based on multi step process deploying novel solvents on supported liquid membrane

Sr-90 recovery from HLLW is used for milking of Y-90 and supplied to hospitals for radio-pharmaceutical applications
Ru-106: Eye Cancer Treatment

Separation of $^{106}\text{Ru}$ from waste

Electro-deposition on silver

$^{106}\text{Ru}$ deposited silver disc

Preparation of plaque

Dressing and QA testing

Plaque developed at BARC
Ideal Fuel Cycle (Back End)

- Spent Fuel → PUREX
  - Recovery of Residual Pu & U
    - Np, Tc → Transmutation
    - U, Pu → Recycle
  - High Level Waste → Recovery of Cs & Sr
    - Cs, Sr → Heat Source
  - Ln & An Bulk Separation
    - Ln → Recovery of PGMs
      - Ln, FP → PGM
      - FP → Value Recovery
  - Selective separation of An from Ln
    - Cm, Am → ADS
      - Fast Breeder
    - Ln → Recovery of PGMs
      - Ln, FP → PGM
      - FP → Value Recovery
  - Separation of Am from Cm
    - Cm, Am → Fast Breeder
      - ADS
Management of ILW

1985

- Bituminization
- Cementation

High waste volume for disposal

Present Treatment Practice

Pre-treatment using IX  Concentration  Conditioning

Waste volume for disposal is reduced

160 m$^3$ Cementized product per 100 m$^3$ waste

15 l Glass product + 3 m$^3$ Cementized product per 100 m$^3$ waste
Management of Low Level Waste

Existing process

Treatment: Chemical Co-precipitation based process
Conditioning: Cement Matrix

Challenges

- Separation of Ru and Tc from LLW.
- Alternate to cement matrix
- LLW from decommissioning → Complexant, Corrosive acidic solution bearing
- Detergent wastes → Complexant bearing

Innovations

- Selective sorbents for removal of Cs & Sr
- Membranes as pre-treatment measure

Near zero discharge of radioactivity to environment
Low Level Solid Waste Treatment Methods

(for wastes with surface dose < 0.2 mGy/h)

**COMPACTION**
(plastic & rubber)

**COMBUSTION**
(cellulosic)

**MELT DENSIFICATION**
(Polythene)

The non-treatable wastes are directly disposed

VRF : 3 - 5

VRF : 30 - 50

VRF : 5 - 30
New technology for solid waste management

Plasma assisted incinerator / pyrolyzer for Cat – I solid waste

Co-ordinating agency : L&PTD- BARC , IPR- Ahmedabad

- Conventional incinerator only caters to cellulosic wastes (VRF= 30-50)
- Plasma based system will cater to all Rubber/Plastic/ Cellulosic waste ( VRF – 30)
- 500 kg of inactive mixed waste processed successfully
- 500 kg of actual radioactive cellulosic waste processed successfully (upto 5 mR/hr)
Near Surface Disposal for Radioactive Solid Wastes

**Reinforced Concrete Trenches (RCT)**

**Stoned lined Trenches (SLTs)**

**Multitier RCC Disposal Modules (MRDM)**
2/3 below ground
1/3 above ground

- Better Land Utilization
- Structural Improvement

NSDFs are co-located on reactor site in INDIA
Summary

• Waste management is a evolving process and we have made a sea change in management of waste having emphasis on waste volume minimisation, recovery of radionuclides and their deployment for societal benefits using indigenously developed processes and methodologies.

• India is on the driver seat for recovery of huge amount of Cs-137, conversion into non-dispersible form and its deployment as a blood irradiator to prevent Transfusion Associated Graft Vs Host Disease (TA-GVHD).

• Demonstration of recovery of Sr-90 (for milking of Y-90 for radio-pharmaceutical application) and Ru-106 (for fabrication of Ru plagues for eye cancer treatment) from the waste has proved “Waste is no more a waste, rather it’s a resource”.

• Partitioning of HLLW is a step towards Ideal Fuel Cycle, thereby reducing volume of waste for eventual emplacement in Geological Disposal Facility.
Volume of High Level Vitrified waste generated for power consumption of an average family for entire life.

Thank You

For your kind attention...