Novel Processes for the Treatment of ILW
Topics for today

• The challenge
• Current technology
• Polymeric encapsulation
• Hot Isostatic pressing
• Thermal treatment
• Conclusions
The ILW challenge at Sellafield

<table>
<thead>
<tr>
<th>Description</th>
<th>Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIXEP Magnox Sludge</td>
<td>Magnesium salts</td>
</tr>
<tr>
<td>SIXEP Sand/Clino</td>
<td>Clinoptilolote and sand</td>
</tr>
<tr>
<td>Magnox Pond Sludge</td>
<td>Magnesium salts</td>
</tr>
<tr>
<td>Plutonium Contaminated Materials</td>
<td>General process waste from alpha plants</td>
</tr>
<tr>
<td>Pile Fuel Cladding Silo</td>
<td>Al, Magnesium, Graphite, Uranium &amp; other</td>
</tr>
<tr>
<td>Future decommissioning wastes</td>
<td>Concrete, brickwork, plant equipment</td>
</tr>
<tr>
<td>Contaminated soils</td>
<td>Soils</td>
</tr>
<tr>
<td>Pond solids</td>
<td>Spent fuel, skips, isotope cartridges &amp; zeolite</td>
</tr>
<tr>
<td>Miscellaneous orphans</td>
<td>Various</td>
</tr>
<tr>
<td>Pile Fuel storage pond waste</td>
<td>Spent fuel pond sludge</td>
</tr>
<tr>
<td>Magnox Swarf Storage Silo</td>
<td>Various ILW forms from sludges to solids</td>
</tr>
</tbody>
</table>
Challenges

Silo wastes from historic reprocessing activities

Plutonium contaminated wastes from current operations
Challenges

Sludges from legacy storage facilities
Current Waste Treatment Processes

Encapsulation in grout is used on 4 plants at Sellafield for a variety of wastes from flocs to compacted plutonium contaminated waste.
Polymer Encapsulation
Polymeric Encapsulation – Currently Used and In development Resins

- Trawsfynydd IX resin encapsulation in VERI (Vinyl Ester Styrene) – left
- Pile Fuel encapsulation trials in Epoxy - below
Polymer Encapsulation – Other Options

- Thermoplastic encapsulant – top right.
- Water absorbing surfactants in polymer – below right.
- Silicone Rubber encapsulant in progress – below left.
Alternative Encapsulants

- Magnesium Phosphate
  - Possible alternative to OPC for the encapsulation of mild steel, aluminium and metallic uranium.
  - Showing promise but an appreciable amount of work still to be done

- Alumino silicate Geopolymers
Geopolymers

“crystalline aluminosilicates partially dissolved in a concentrated alkaline medium to produce an amorphous geopolymeric gel interspersed with undissolved crystalline particles”

- Many variants of geopolymer available and can be tailored to suit the waste.

- Under investigation for use in the UK

- SIAL* licensed in Czech and Slovak Republic

- Industrial application:
  - Sludge from NPP A-1 – in inorganic and organic coolant
  - Sludge from NPP V-2
  - Sludge and spent resins from NPP Temelin
  - Oil and sludge from NPP Mochovce

- *SIAL registered trademark of AMEC Nuclear Slovakia s.r.o.
SIAL matrix

- Typical characteristics (20% waste loading) –
  - Compressive strength – 10 MPa (24 hours)
    15-30 MPa (28 days)
  - Leach resistance - Li index (ANSI16.1 1986)
    - $9 \times 10^{-10}$ $^{137}\text{Cs}$
    - $12 \times 10^{-14}$ $^{90}\text{Sr}$
    - $14 \times 10^{-18}$ $^{241}\text{Am}, ^{239}\text{Pu}$
  - Radiation stability to 10 MGy
  - Microbial stability and resistance
  - Minimum expansion of product
  - No free liquids
  - Long-term self-recovery of cracks
  - No heat evolution on maturing
Consolidation using Hot Isostatic Pressing
Ceramics for Pu Residues – Process steps

- Size Reduction
- Calcination
- Blending
- Granulation
- HIP
Performance - Pilot stage

Innovation through collaboration – NNL, Sheffield University and ANSTO
Ceramics for Pu Residues – Product Characteristics

Product
• Flexible wasteform, either full ceramic or a glass-ceramic
  – Zirconolite (CaZrTi$_2$O$_7$) as Pu host phase,
  – alumino-borosilicate glass as a flexible matrix.

• Pu fully immobilised (chemically bound) in ceramic phase, impurities partition to glass phase

Proliferation Resistance
• Normalised Pu leach rates 10^{-5} to 10^{-4} g m^{-2} d^{-1}
• 2 to 3 orders of magnitude better than HLW glass
Ceramics

• Durable -Replicates a natural rock formation still containing natural U after ~3 billion years

• Wide processing window to handle variety of chemical feed stocks

• Highly uniform product with homogenous distribution of plutonium

• Multi stage process required
Thermal Treatment
High temperature waste immobilisation technologies

Diagram showing the process:
- Feed system
- Off-gas cleaning
- Secondary waste return
- Copper cold crucible
- Discharge
- Cathode
- Coupling zone
- Reaction chamber
- Anode

Equations:
- $\text{Ar, } \text{N}_2, \text{O}_2, \text{H}_2\text{O}$

Image of a waste immobilisation facility.

Sellafield Ltd
<table>
<thead>
<tr>
<th>Technology</th>
<th>Technology Suppliers</th>
<th>Nuclear Track record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma</td>
<td>Rtech “PACT”</td>
<td>Zwilag &amp; Tsuruga</td>
</tr>
<tr>
<td>Joule Heating</td>
<td>IS Inc “Geomelt”</td>
<td>Hanford, Maralinga etc</td>
</tr>
<tr>
<td>Joule Heating Melter</td>
<td>Energy Solutions</td>
<td>Hanford, Sav’ River, West Valley</td>
</tr>
<tr>
<td>Plasma</td>
<td>Phoenix Solutions</td>
<td>JAERI, Japan</td>
</tr>
<tr>
<td>Steam Reformation</td>
<td>“Thor” Studsvik</td>
<td>Erwin, TN, &amp; Idaho USA</td>
</tr>
<tr>
<td>Calcine - HIP</td>
<td>ANSTO “Synroc”</td>
<td>Sellafield, Idaho, Australia</td>
</tr>
<tr>
<td>Calcination</td>
<td>Areva</td>
<td>Cap la Hague</td>
</tr>
<tr>
<td>Plasma</td>
<td>Tetronics</td>
<td>PCM &amp; SIXEP Research</td>
</tr>
<tr>
<td>Plasma</td>
<td>PAM 200 - KAERI</td>
<td>Inactive LLW/PCM/ILW</td>
</tr>
<tr>
<td>Induction Heating CC</td>
<td>CEA/Areva/KHNP</td>
<td>LILW - Ulchin Power Plant</td>
</tr>
<tr>
<td>Plasma</td>
<td>EER Ltd/Radon</td>
<td>LILW in Russia</td>
</tr>
<tr>
<td>Plasma</td>
<td>MSE TA Inc</td>
<td>Hazardous Chemical</td>
</tr>
<tr>
<td>Induction Melter</td>
<td>Kurion</td>
<td>Trials for DOE (Hanford)</td>
</tr>
</tbody>
</table>
Products - Glass, Ceramics or Mixtures

Ceramic from Magnox Sludge Surrogate - magnesium silicates and titanates

Borosilicate glass incorporating Surrogates of Magnox Sludge and Plutonium Contaminated Waste
## Summary of thermal treatment

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Minimal pre treatment requirements</td>
<td>• Capital cost</td>
</tr>
<tr>
<td>• Large feed envelope</td>
<td>• Nuclearisation</td>
</tr>
<tr>
<td>• Destruction of reactive material</td>
<td>• Off gas system required to minimise gaseous discharges</td>
</tr>
<tr>
<td>• The final waste form is robust, free of organic material.</td>
<td>• Process controls need to be carefully designed to compensate for the feed variables</td>
</tr>
<tr>
<td>• Product is suitable for long term storage and disposal.</td>
<td>• Waste characterisation</td>
</tr>
<tr>
<td>• Volume reduction from 3 to 100 fold</td>
<td></td>
</tr>
<tr>
<td>• Minimal secondary wastes</td>
<td></td>
</tr>
<tr>
<td>• Lifetime costs can be less than encapsulation technologies</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• Sellafield currently uses encapsulation and vitrification processes for a number of ILW and HLW materials

• Alternative options being evaluated for difficult waste forms and with the possibility of improving the process and waste form

• Alternative encapsulants such as polymers offer benefits especially for metallic wastes forms and resins

• HIPping has been demonstrated to convert plutonium wastes into durable ceramics

• Thermal processes have benefits of volume reduction and durability but nuclear maturity for ILW is limited