Implications of canister design & materials on closure welding for deep geological disposal canisters for high level nuclear waste & spent fuel

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TWI – An Extension of your Resources

- Research & Technology Organisation
  - Established in 1946
- Industrial Membership based
  - Effectively owned by Members and run by representatives from Member Companies
- Non-profit distributing
- Five UK locations and 13 international offices
- 900 staff
Scope

- Global drivers
- Spent fuel and high level waste
- Geological disposal
- Materials selection
- Long term integrity
- Closure welding
- Summary
- Proliferation of nuclear power – low C energy
- Nuclear Power Generation wastes
- (31 countries) expanding volumes
- Research reactors
- Medical isotopes
- Military waste
- Spent nuclear fuel (SNF)
- Vitrified (high level) waste - reprocessing (HLW)

“Each country is ethically and legally responsible for its own wastes”
1000MW (1GW) nuclear reactor - 27 tonnes of spent fuel/yr
Reprocessed – 3m³ vitrified waste
1000MW coal fired– 400,000 tonnes/yr of ash
- Avoid
- Re-use
- Re-process
- Disposal
  - Deep sea
  - Off planet
  - Transmutation

Waste solutions

International Consensus

Long Term Deep Geological disposal
The last 100k years

- 100,000BC: Modern Homo sapiens in Omo, Ethiopia
- 30,000BC: Oldest known art
- 10,000BC: End of the last ice age
- 3,100BC: Stonehenge complete
- 28,000BC: Neanderthals Extinct
- 2,500BC: Giza
Geological disposal Strategy - Multiple barriers

- Fuel pellet of uranium dioxide
- Copper canister with cast-iron insert
- Spent nuclear fuel
- Cladding tube
- Bedrock
- Bentonite clay
- Final repository for spent nuclear fuel

Courtesy SKB
POSIVA/SKB - copper and cast iron Engineered barrier system

Courtesy SKB/Posiva
## National Projects

<table>
<thead>
<tr>
<th>Nation</th>
<th>Favoured materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>Copper/cast iron</td>
</tr>
<tr>
<td>Finland</td>
<td>Copper/Cast iron</td>
</tr>
<tr>
<td>France</td>
<td>Steel/ Alumina</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Steel / copper</td>
</tr>
<tr>
<td>Japan</td>
<td>Steel</td>
</tr>
<tr>
<td>USA</td>
<td>Nickel Alloy/steel - dry storage</td>
</tr>
<tr>
<td>Canada</td>
<td>Copper/steel</td>
</tr>
<tr>
<td>S.Korea</td>
<td>Copper/cast iron</td>
</tr>
<tr>
<td>Belgium</td>
<td>Steel</td>
</tr>
<tr>
<td>UK</td>
<td>Copper/cast iron</td>
</tr>
<tr>
<td>Spain</td>
<td>Steel</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Copper/cast iron</td>
</tr>
</tbody>
</table>

Others: -
Germany
Czech republic
Geology of Repository site
Canister Performance

- Containment and immobilisation
- Lithostatic pressure - rock overburden
- Hydrostatic - Ground water pressure
- Bentonite Swelling pressure
- Ice Load – next ice age
- Local corrosion
- Long term corrosion
- Handling and emplacement
- Retrieval for re-use
- Legacy
- Identification
Canister Materials

- Ceramics
- Metals
- Composite – coated metals
- Copper – OFHC
- Cast Iron
- Steel - plain carbon steel
- Stainless steel
- Titanium alloy
- Nickel alloy
- ODS alloys
Copper Corrosion Barrier
Manufacture of Iron Insert
Closure processes

- Bolting – Gaskets
- Adhesives – Durability
- Brazing – Galvanic corrosion
- Thermal spray – possibilities
- Welding
  - Fusion
    - Arc processes
    - Power beams
  - Solid state
    - Friction
    - Forge processes
Closure weld process requirements

- Robust - simple
- Remote and automatic
- Radiation hard
- Proven
- Inspectable
- Repairable
- Low defect rate
- Sufficiently rapid
- Mechanical properties
- Corrosion performance
- Defect tolerant
Closure Weld characteristics

- Practical, implementable, inspectable
- Long term reliability
- Resistant to all potential failure mechanisms
- Mechanical properties – avoid breaching
  - Applied stresses
- Corrosion mechanisms
  - Material
  - **Welding induced residual stress**
  - Existing flaws
  - Environment
  - Hydrogen/radiation embrittlement
 EB weld in steel – hoop direction as-welded and after PWHT

Figure Error! No text of specified style in document. -1 Predicted residual stresses midway along the 2 halves of the flat plate model in the a) as-welded condition and b) in the PWHT condition.
Electron Beam closure welding

Canister
remote
lid placing
mechanism

Gun
column

Canister
Canister lid
EB welding of copper
Friction Stir Welding
Friction Stir Welding (FSW) of 50mm Thick Copper
Canister closure welding - process selection

Electron Beam Welding

Friction Stir Welding
Mock-up welding demonstrations
C-Mn steel

190mm thick EB closure weld
RWMC C-Mn steel weld 190mm wall thickness
EB welding cell
SKB Canister Laboratory
- UNS N060220

- Nickel 56%, Chromium 22%, Molybdenum 13%, Iron 3%, Cobalt 2.5%, Tungsten 2.5-3.5%, Vanadium 0.35%

- Cost ~$62k/tonne (1 can requires up to 10t)
Solution anneal 1150 deg C + quench
Canister fabrication & Closure welding
Full Diameter – short length closure trials
### Comparison of Estimated Welding Times for GTAW and RPEB Welding for Alloy 22

<table>
<thead>
<tr>
<th>Description</th>
<th>Multi-Pass GTAW Weld</th>
<th>Single-Pass RPEB Weld</th>
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</thead>
<tbody>
<tr>
<td>Travel Speed (mm/minute)</td>
<td>200</td>
<td>750</td>
</tr>
<tr>
<td>No. of Passes</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Lid Weld Time (in minutes)</td>
<td>251.3</td>
<td>8.4</td>
</tr>
</tbody>
</table>

**Comparison of Estimated Welding Times for GTAW and RPEB Welding for Alloy 22**
Extended Lid
Outer Lid Alloy 22
Middle Lid Alloy 22
Stainless Steel Lid
Stainless Steel Spread Ring
Stainless Steel Inner Vessel
Alloy 22 Outer Barrier

Simpler closure weld

Site recommendation design
Current design
Potential RPEB designs
Comparative corrosion rates for GTAW, RPEB weld, and base metal specimens in SCW, 1M HCl, and NaCl solutions.
As-welded residual stress

Longitudinal (weld direction) residual stress contour plots in the as-welded condition for the GTAW and RPEB weld samples

RPEB welding peak tensile residual surface stress ~75% less than GTAW
Local heating for residual stress control

As-welded

After local heating
- Equal or better materials performance in terms of corrosion, metallurgical stability, and as-welded residual stress
- Welding repeatability and reliability
- Cost savings
- Hot cell operation
Cost savings Influenced by Welding process selection

- Reduced distortion - minimum overstock
- Faster welding times (X30)
- Elimination of weld filler metal
- Reduced machining times
- More favorable distribution of residual stresses
- Surface inspection critical
- Initiation of environmentally assisted cracking
- Volumetric inspection – high static load
- Accidental damage
- Remote/automatic
- Radiation hard
- Phased Array UT
- Eddy current
- Radiography - Linac
Automated UT inspection
• Deep geological disposal of SF and HLW – recognised most favourable option

• Material selection influence –
  □ geological conditions
  □ activity of waste
  □ lifetime requirements

• Canister Design & material - profound influence on closure welding process selection & inspection methods

• Safe and reliable closure method essential for continuation of nuclear energy generation
Thank you

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