The Costs of Geological Disposal

Neil Chapman

ERDO-WG and Arius Association
Some Background

• Cost estimates of geological disposal have been made by most national programmes
  – they vary in the way that they are calculated and can thus be difficult to compare
• National cost estimates made regularly and published in some countries (e.g. Sweden, Slovenia): outputs needed to underpin legal requirements for setting fees for national waste management funds
• Other programmes have made few or irregular estimates (e.g. F, FIN, CH, UK, NL, USA)
  – details are often unpublished and/or difficult to access
  – only the high level numbers are in the public domain
• UK government also used a cost estimate for disposal of SF to establish a final price and cap that it would use to charge operators of new NPPs to dispose of their wastes in a national GDF:
  – incorporates ‘optimism bias’ (on cost estimates) and ‘risk fee’ into the prices
  – assigns some fixed costs of building national GDF for legacy wastes to future users
Approaches to costing

• Use analogue national programmes
  – useful in the early, generic stages of a national or multinational programme
  – many distinct differences between programmes: inventories, legislation, schedule, labour costs...

• Work Breakdown Structure
  – bottom-up engineering approach: constrained by availability of data
  – applicable as programmes become more evolved

• Parametric models
  – statistical historical variance across a project (or similar projects): durations might not be long enough
Existing guidance

• NEA, 2010: *Cost Estimation for Decommissioning: an international overview of cost elements, estimation practices and reporting requirements*

• EDRAM published a short note on how to cost GDFs in 2012

• IAEA is currently developing a TECDOC on “Costing methods and funding schemes for radioactive waste disposal programmes”

• Some nations have formal guidance on costing major national infrastructure projects extending over long periods, e.g.:
  – US Government Accountability Office
  – UK Treasury ‘Green Book’
National GDF costs estimates depend on major non-technical policy decisions

- number of GDFs planned/permited (e.g. several countries plan/have separate geological facilities for SF/HLW, ILW, LILW)
  - e.g.: whether they will be co-located and use shared access
- timing of commencement of disposal with respect to (e.g.) NPP decommissioning
- total expected waste inventory
  - only ‘legacy’ or up to close-down of existing NPPs
  - ‘legacy’ + new build – future arisings
- whether and how long the GDF must remain open before closure (e.g.: to facilitate waste retrieval)
GDF costs within total RWM costs

EU Waste Directive Responses: Nov 2017. Total national RWM Programme Costs (although many do not include SF GDF costs)

Cigéo GDF (BEUR)
Andra: 34.4
CEA, Areva, EDF: 20
Directive: ‘now 25’

...typically at the 10 to 50% levels
Example GDF costs within overall RWM Programme Costs for NPPs: Sweden (Plan 2016)

- Programme costs: c. 9.5 BEUR
- spent fuel GDF: 26%
- + encapsulation: 37%
- + RD&D: 45%
- + WMO: 52%

For a relatively small NP programme, GDF costs are a significant fraction of overall RWM programme costs
GDF Fixed and Variable Cost Examples

• Fixed
  – site selection and permitting
  – surface handling facilities
  – transport infrastructure
  – access shafts/tunnels
  – access closure and sealing
  – environmental monitoring

• Variable
  – emplacement tunnels, vaults, boreholes
  – disposal operations
  – (encapsulation of SF/HLW)
### Example GD fixed to variable ratios (2008 SAPIERR-2 study)

<table>
<thead>
<tr>
<th>SKB data</th>
<th>Posiva data</th>
<th>Nagra data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Item</td>
<td>F/R ratio</td>
<td>Cost Item</td>
</tr>
<tr>
<td>Siting</td>
<td>100:0</td>
<td>Above ground* facilities</td>
</tr>
<tr>
<td>Construction</td>
<td>30:70</td>
<td>Above ground* operations</td>
</tr>
<tr>
<td>Operation</td>
<td>20:80</td>
<td>Above ground* decommissioning</td>
</tr>
<tr>
<td>Closure</td>
<td>0:100</td>
<td>Repository facilities</td>
</tr>
<tr>
<td>R&amp;D and Admin</td>
<td>100:0</td>
<td>Repository operations</td>
</tr>
<tr>
<td>Encapsulation</td>
<td>10:90</td>
<td>Repository closure</td>
</tr>
</tbody>
</table>

* items mainly concern SF encapsulation activities
USA Base Case SF Repository Cost Breakdown (MUSD\textsubscript{2012})

USDOE, 2013

- GDF: Closure 1450 (2%)
- GDF: Siting 3260 (5%)
- GDF: Site characterisation & licensing 8514 (13%)
- GDF: Monitoring 5656 (9%)
- GDF: Construction 7819 (12%)
- GDF: Emplacement 15400 (23%)
- GDF: Packages 15400 (23%)
- GDF: Underground facilities 8400 (13%)

The infamous titanium drip shields....?
USA: Yucca Mountain

SAPIERR in Sediments

SAPIERR in Hard Rock

Sweden: KBS-3H
Hard Rock

Japan

SAPIERR-2

14 countries

A European Regional Repository could be large on a global scale

it would use the best technologies available internationally

it would build on sharing 30 years of European R&D
SAPIERR-2: disposal costs: overall conclusions (2006 data)

• Total disposal costs for ‘large’ inventory (c.26,000 tHM SF; 360 m³ HLW; 31,000 m³ ILW): ~ 10 BEUR

• Additional savings can be made by having one rather than two repositories

• Little overall cost advantage in having a single encapsulation plant

• Overall impact of a shared rather than numerous solo solutions ~ 15 - 25 BEUR saving to Europe
## Economies of Scale

**SAPIERR 2: separate repositories (hard rock): MEUR**

*(based on the 14 SAPIERR-1 participating countries)*

<table>
<thead>
<tr>
<th>Country</th>
<th>Shared R&amp;D</th>
<th>Apart R&amp;D</th>
<th>Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>1330</td>
<td>1330</td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>3470</td>
<td>3070</td>
<td>&gt;25 BEUR</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>3020</td>
<td>2700</td>
<td></td>
</tr>
<tr>
<td>Croatia</td>
<td>1330</td>
<td>3650</td>
<td></td>
</tr>
<tr>
<td>Czech Rep</td>
<td>3300</td>
<td>3060</td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>2840</td>
<td>2690</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>2700</td>
<td>3200</td>
<td></td>
</tr>
</tbody>
</table>

*Shared: 10 BEUR  
Apart: 37.7 BEUR  
Saving >25 BEUR  
About half is on shared R&D  
Even if no further R&D were needed, saving is still c. 15 BEUR*
Effects of changed assumptions and boundary conditions

Sweden: spend profiles and amounts from SKB’s Plan 2013 and Plan 2016
ERDO-WG: Work-in-Progress Example
what might it cost to dispose of national wastes in a co-disposal repository?

<table>
<thead>
<tr>
<th>National Programme 'Type'</th>
<th>SF tonnes</th>
<th>HLW m³</th>
<th>ILW m³</th>
<th>No. of 'units'</th>
<th>% working capital</th>
<th>Share of 15 years working capital (MEUR)</th>
<th>2006 disposal cost, based on 'units' (MEUR)</th>
<th>Total, including share capital (MEUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only ILW</td>
<td>0</td>
<td>0</td>
<td>300</td>
<td>24</td>
<td>0.7</td>
<td>3.6</td>
<td>11.6</td>
<td>15</td>
</tr>
<tr>
<td>Research/medical</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>0.1</td>
<td>0.5</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>Complex historic</td>
<td>299</td>
<td>10</td>
<td>4000</td>
<td>536</td>
<td>16.5</td>
<td>80.0</td>
<td>260.1</td>
<td>340</td>
</tr>
<tr>
<td>Large SF amount</td>
<td>2504</td>
<td>0</td>
<td>1500</td>
<td>1372</td>
<td>42.3</td>
<td>204.6</td>
<td>665.6</td>
<td>870</td>
</tr>
<tr>
<td>HLW; no SF</td>
<td>0</td>
<td>110</td>
<td>3000</td>
<td>973</td>
<td>30.0</td>
<td>145.2</td>
<td>472.2</td>
<td>618</td>
</tr>
<tr>
<td>Small SF amount</td>
<td>620</td>
<td>0</td>
<td>300</td>
<td>334</td>
<td>10.3</td>
<td>49.8</td>
<td>162.0</td>
<td>212</td>
</tr>
</tbody>
</table>

Based on:

'Unitised Equivalent Costs' for waste disposal: 2 tonnes SF = 0.15 m³ HLW = 12.5 m³ ILW
SAPIERR 2 disposal cost calculations (2006 figures), with siting and R&D costs paid by 15 years input to ERDO working capital
### Actual ‘Small Programme’ national GDF costs in Europe
(without encapsulation costs)

<table>
<thead>
<tr>
<th>Approximate costs: MEUR</th>
<th>Sweden: GDF for c. 12500 tonnes of SF</th>
<th>Finland: GDF for c. 9000 tonnes SF</th>
<th>Switzerland: GDF for c. 3850 tonnes SF and HLW (includes an RCF)</th>
<th>Sweden: GDF for c. 16000 m3 LILW (assumed co-located with SF GDF)</th>
<th>Switzerland: GDF for c. 92000 m3 LILW (includes an RCF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siting &amp; permitting</td>
<td>480</td>
<td>420</td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>1900</td>
<td>820</td>
<td>1120</td>
<td>100</td>
<td>1120</td>
</tr>
<tr>
<td>Operation</td>
<td>660</td>
<td>740</td>
<td>460</td>
<td>30</td>
<td>460</td>
</tr>
<tr>
<td>Closure</td>
<td>630</td>
<td>220</td>
<td>140</td>
<td>40</td>
<td>140</td>
</tr>
<tr>
<td>Total</td>
<td>3670</td>
<td>1780</td>
<td>2040</td>
<td>170</td>
<td>170</td>
</tr>
</tbody>
</table>

Construction costs dominate
## Estimated ‘Large Programme’ GDF Costs

<table>
<thead>
<tr>
<th>Country</th>
<th>Approximate cost BEUR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>13</td>
<td>spent fuel</td>
</tr>
<tr>
<td>UK</td>
<td>16</td>
<td>all legacy wastes: no ‘new build’</td>
</tr>
<tr>
<td>Japan</td>
<td>22</td>
<td>mainly HLW</td>
</tr>
<tr>
<td>France</td>
<td>20 - 35</td>
<td>all current NP waste</td>
</tr>
<tr>
<td>USA</td>
<td>48</td>
<td>YMP: GDF construct, operate, close</td>
</tr>
<tr>
<td>USA</td>
<td>96</td>
<td>YMP: total lifetime cost</td>
</tr>
<tr>
<td>South Australia</td>
<td>97</td>
<td>MNR: 138k tHM, 390k m³ ILW</td>
</tr>
</tbody>
</table>
Some comparative disposal costs per tHM & m³
(note: data of various ages)

<table>
<thead>
<tr>
<th>Spent Fuel</th>
<th>ILW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td><strong>Cost per tU MUSD 2015</strong></td>
</tr>
<tr>
<td>Switzerland</td>
<td>1.74</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.89</td>
</tr>
<tr>
<td>Finland</td>
<td>0.69</td>
</tr>
<tr>
<td>UK (DECC)</td>
<td>0.57</td>
</tr>
<tr>
<td>UK Jackson low*</td>
<td>0.82</td>
</tr>
<tr>
<td>UK Jackson high*</td>
<td>1.09</td>
</tr>
<tr>
<td>Korea**</td>
<td>0.32</td>
</tr>
<tr>
<td>USA (YMP) 2008</td>
<td>0.88</td>
</tr>
</tbody>
</table>

*S*Study carried out after DECC consultation, on behalf of Greenpeace; disagreed with DECC study basis (*‘Estimating the disposal costs of spent fuel’ Nuclear Engineering International, October 2011, 45-46).*

**Kim and Choi, 2006. Study based on Finnish costing approach; carried out in collaboration with Posiva.**

Some figures now rather old
So, what *does* geological disposal cost?  
...some conservative, round figures

- **Spent fuel**: around 1 million USD/tonne  
  - larger programme <1 MUSD; small programme >1 MUSD
- **long-lived ILW**: around 20,000 USD/m$^3$
- **A small national GDF programme**: around 2 - 5 billion USD
- **A large national GDF programme**: around 15 – >50 BUSD
- **GDF as proportion of small national RWM programme**: c.25 to 50%
- **GDF as proportion of large national RWM programme**: c.10 to 30%
- **Cost saving for a small national programme from sharing in a MNR**: at least 30 – 50% of ‘stand alone’ cost *(SAPIERR 2 project, 2008)*
- **A specific example of saving from possible sharing**:  
  - Slovenia-Croatia: shared or separate near-surface repositories (LILW)?  
  - sharing increases investment costs by only 13% compared with 100% for separate facilities
1 MUSD/tonne is an affordable SF disposal cost

• 1 tHM @ produces around 440 M kWh of electricity
  – (55000 MWd/t thermal at 33% efficiency)

• Selling price in France (0.2 USD/kWh) gives a revenue from 1tHM of about 88 MUSD
  – Production costs (about 0.025 USD/kWh) = 11 MUSD
  – Disposal cost = 1 MUSD

• Disposal PRICE for a commercial multinational facility?
  – say, 1.5 MUSD and upwards?

• Both cost and possible prices are affordable
  – especially in a shared facility, with costs reduced below 1 MUSD/t

https://www.eia.gov/electricity/annual/html/epa_08_04.html