IFNEC-RNFSWG Workshop on Approaches to Financing a Multinational Repository – Challenges and Alternate Approaches

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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  - details are often unpublished and/or difficult to access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

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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'

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National GDF costs estimates depend on major non-technical policy decisions

- number of GDFs planned/permitted (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)

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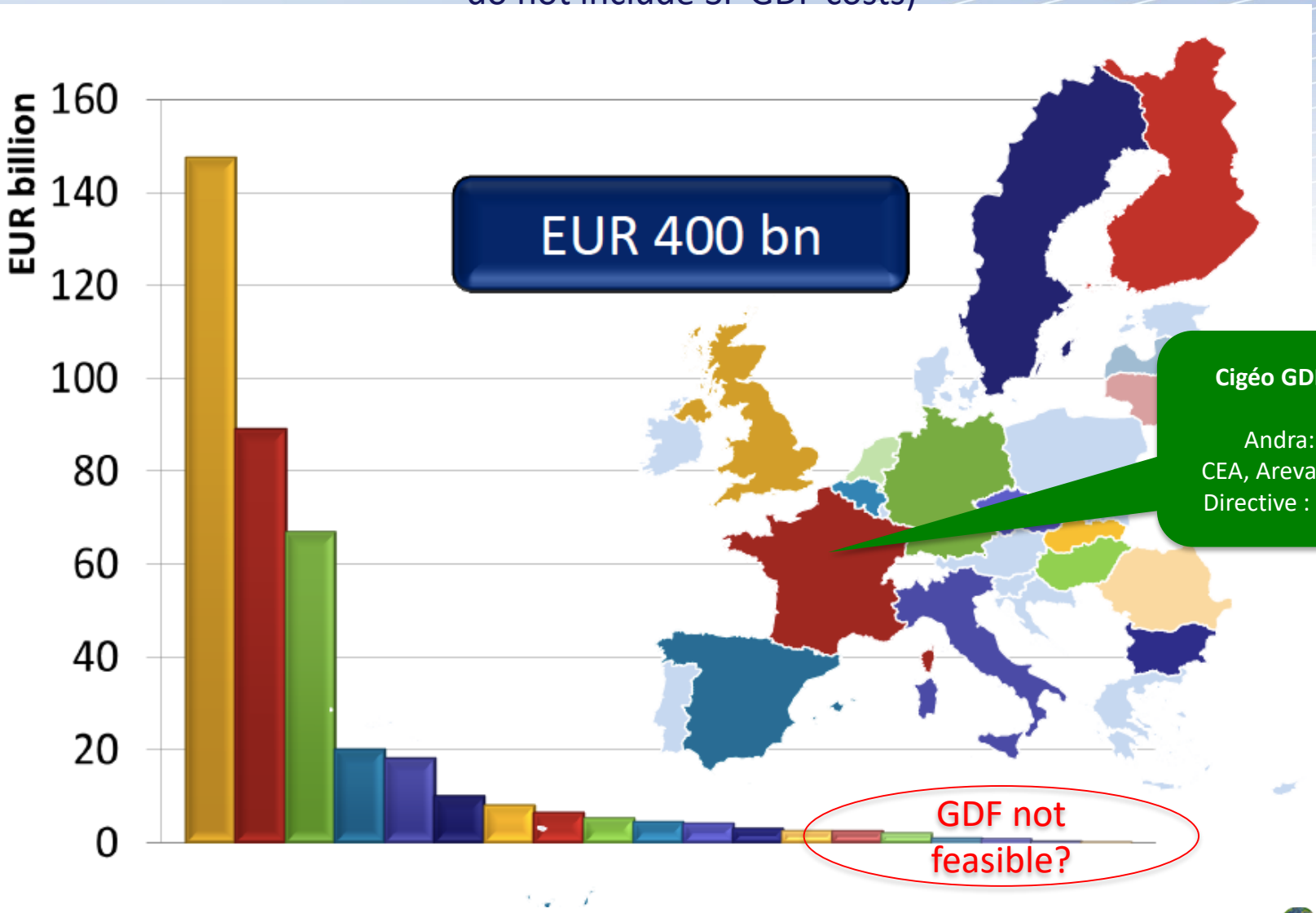
GDF costs within total RWM costs

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



…typically at the 10 to 50% levels

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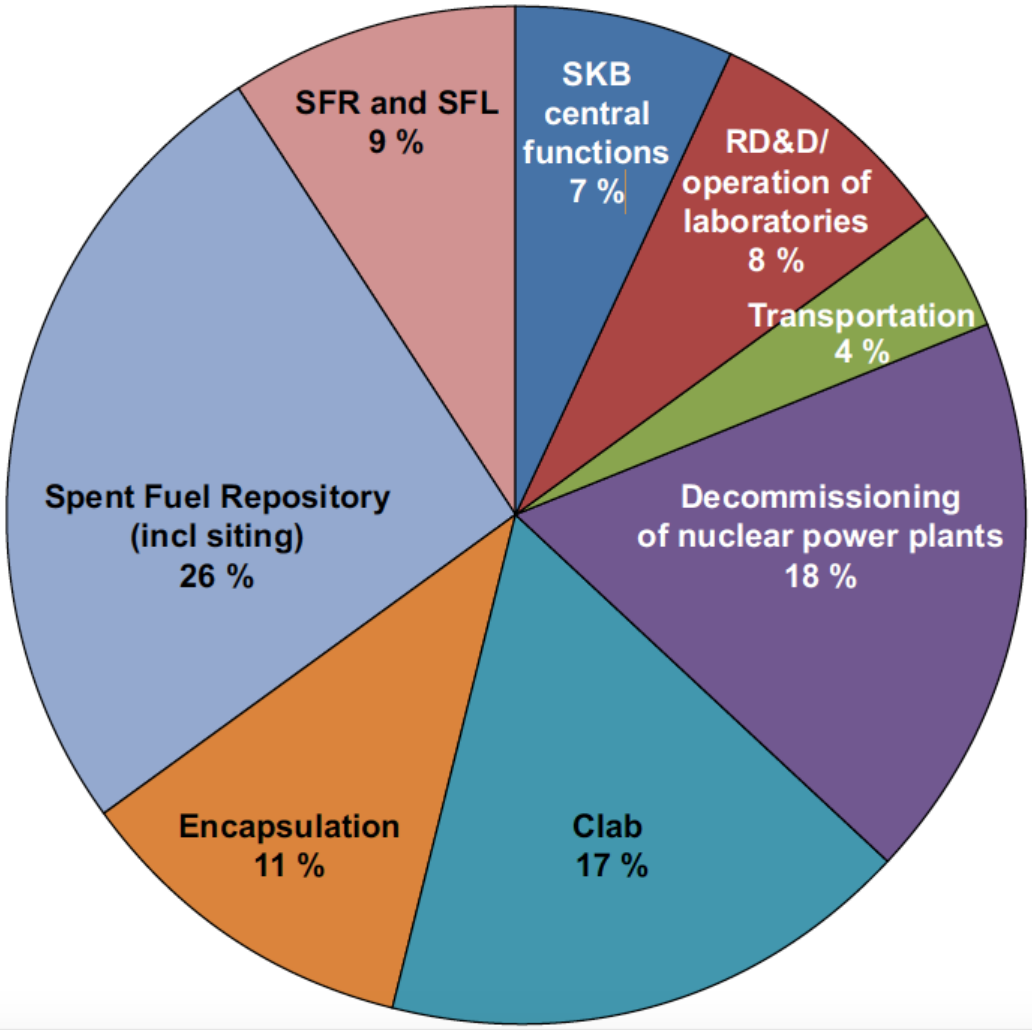
Example GDF costs within overall RWM Programme Costs for NPPs: Sweden (Plan 2016)



- 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

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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)*

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Example GD fixed to variable ratios
(2008 SAPIERR-2 study)

SKB data		Posiva data		Nagra data	
Cost Item	**F/R ratio**	**Cost Item**	**F/R ratio**	**Cost Item**	**F/R ratio**
Siting	100:0	Above ground* facilities	100:0	Siting	100:0
Construction	30:70	Above ground* operations	20:80	Construction	50:50
Operation	20:80	Above ground* decommissioning	100:0	Operation	40:60
Closure	0:100	Repository facilities	30:70	Closure	0:100
R&D and Admin	100:0	Repository operations	20:80	R&D and Admin	100:0
Encapsulation	10:90	Repository closure	90:10	Encapsulation	30:70

* items mainly concern SF encapsulation activities

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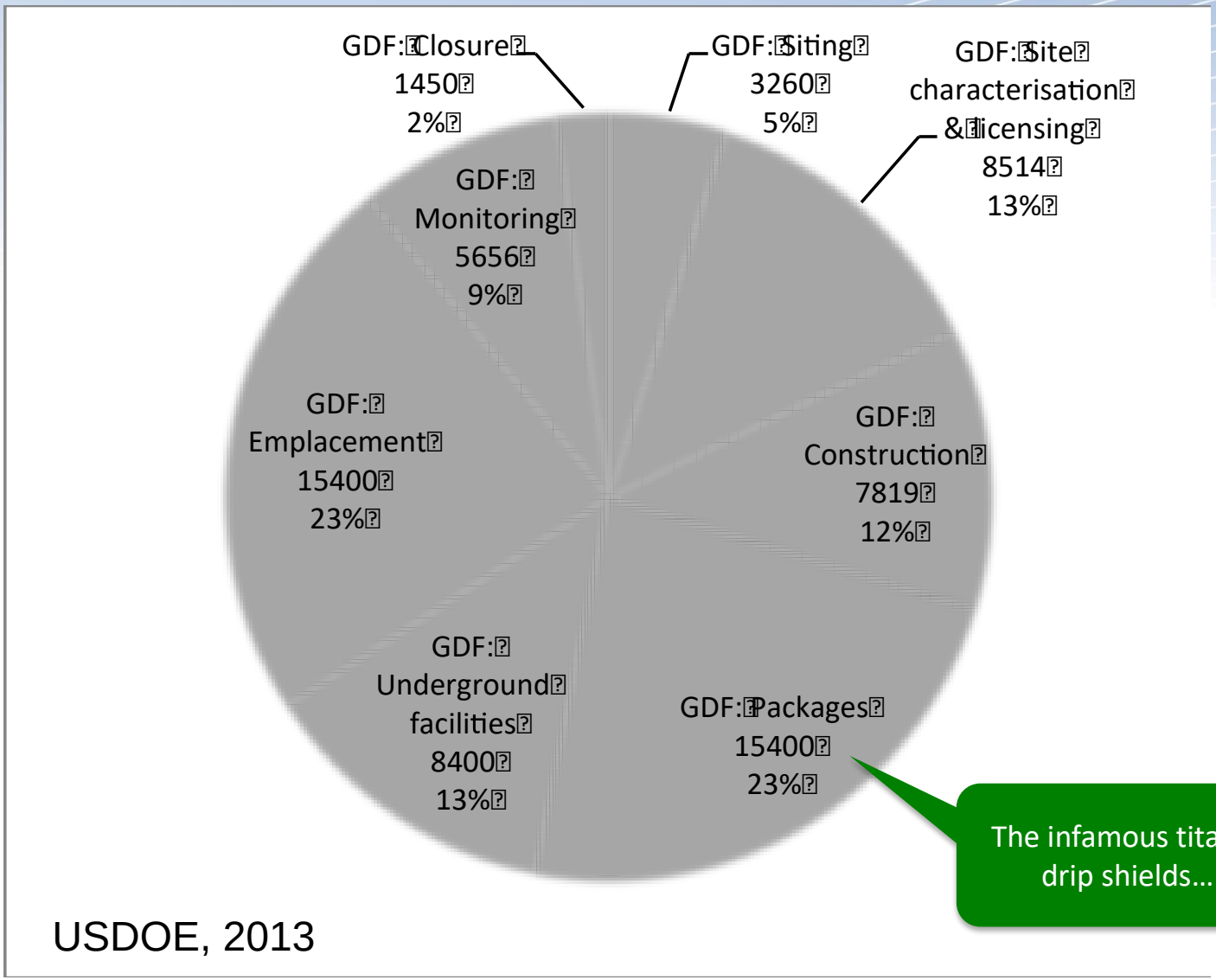
USA Base Case SF Repository Cost Breakdown ($MUSD_{2012}$)



USDOE, 2013

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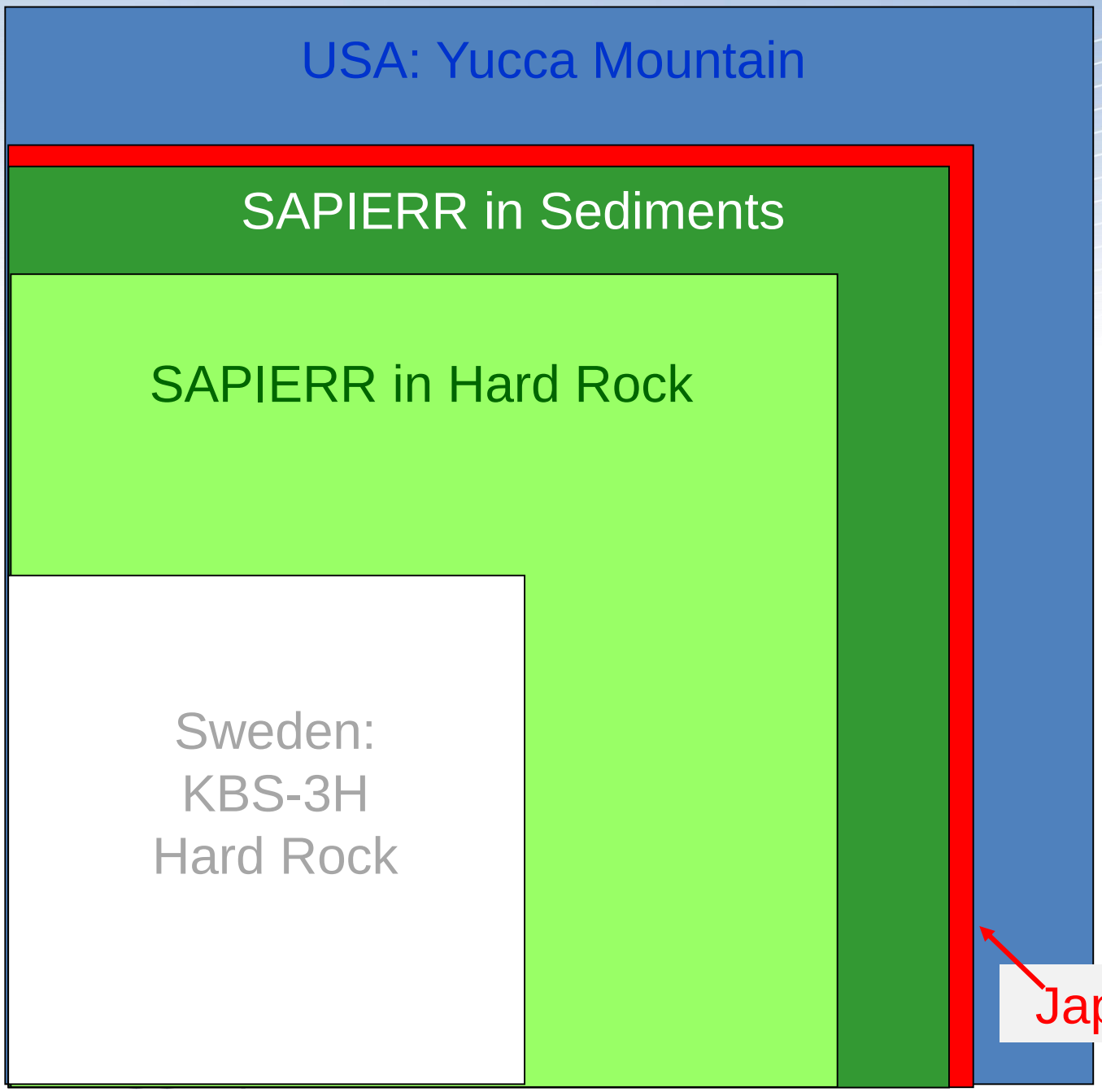

SAPIERR-2

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

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SAPIERR-2: disposal costs: overall conclusions (2006 data)

- Total disposal costs for 'large' inventory (c.26,000 tHM SF; 360 m3 HLW; 31,000 m^3 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

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Economies of Scale

SAPIERR 2: separate repositories (hard rock): MEUR

(based on the 14 SAPIERR-1 participating countries)

Austria	1330	Latvia	1330
Belgium	3470	Lithuania	3070
Bulgaria	3020	Netherlands	2700
Croatia	1330	Romania	3650
Czech Rep	3300	Slovakia	3060
Hungary	2840	Slovenia	2690
Italy	2700	Switzerland	3200

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

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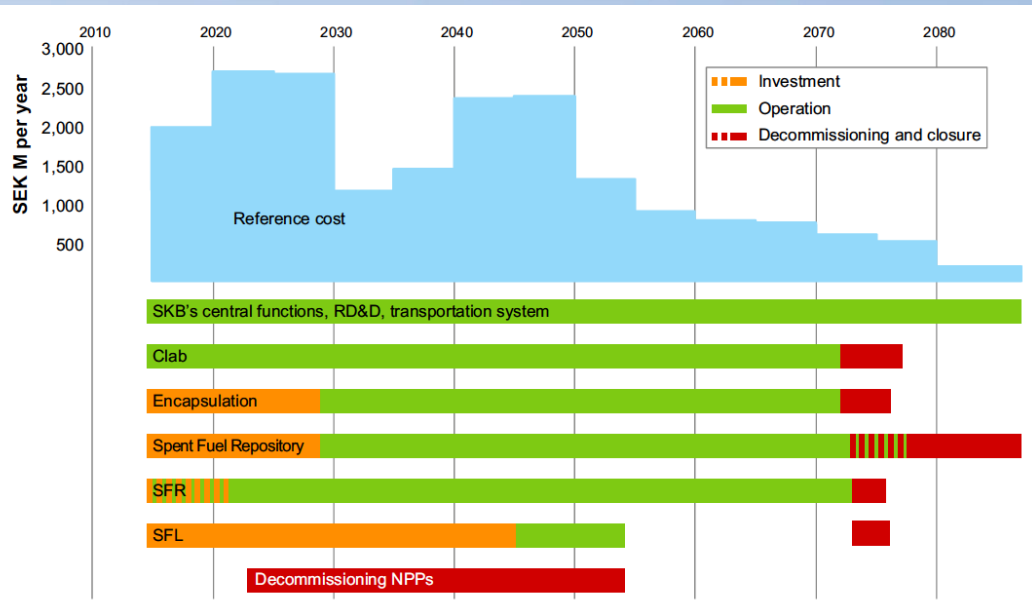
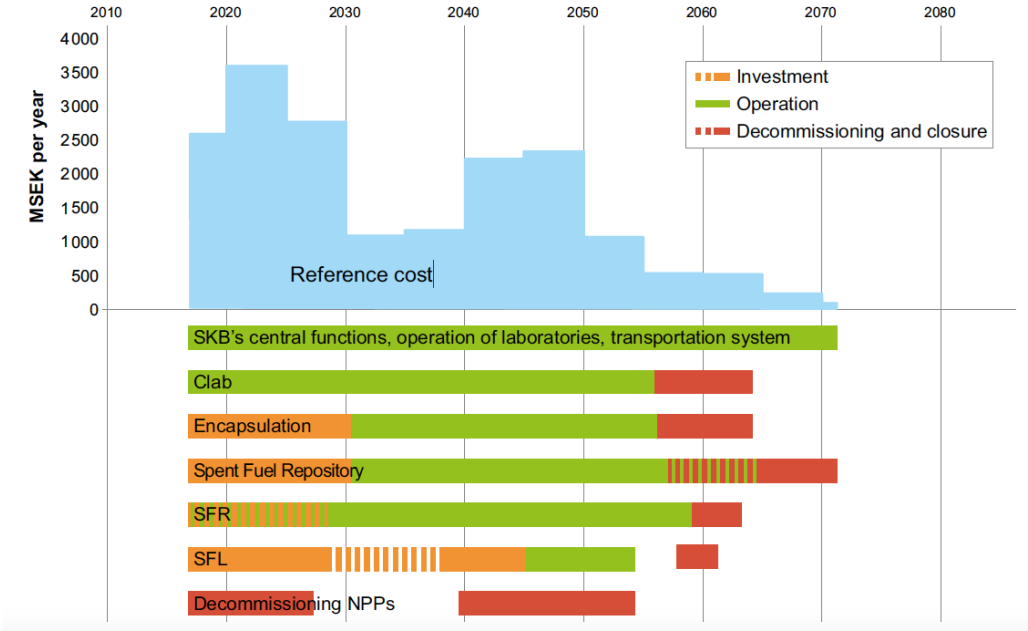
Effects of changed assumptions and boundary conditions





Sweden: spend profiles and amounts from SKB's Plan 2013 and Plan 2016

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ERDO-WG: Work-in-Progress Example

what might it cost to dispose of national wastes in a co-disposal repository?

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

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

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Actual 'Small Programme' national GDF costs in Europe

(without encapsulation costs)

Approximate costs: MEUR	Sweden: GDF for c. 12500 tonnes of SF	Finland: GDF for c. 9000 tonnes SF	Switzerland: GDF for c. 3850 tonnes SF and HLW (includes an RCF)	Sweden: GDF for c. 16000 m3 LILW (assumed co-located with SF GDF)	Switzerland: GDF for c. 92000 m3 LILW (includes an RCF)
Siting & permitting	480		420		320
Construction	1900	820	1900	100	1120
Operation	660	740	840	30	460
Closure	630	220	220	40	140
Total	**3670**	**1780**	**3380**	**170**	**2040**

Construction costs dominate

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Estimated ‘Large Programme’ GDF Costs

	Approximate cost BEUR	
Canada	13	spent fuel
UK	16	all legacy wastes: no ‘new build’
Japan	22	mainly HLW
France	20 - 35	all current NP waste
USA	48	YMP: GDF construct, operate, close
USA	96	YMP: total lifetime cost
South Australia	97	MNR: 138k tHM, 390k m^3 ILW

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Some comparative disposal costs per tHM & m^3

(note: data of various ages)

Spent Fuel

Country	Cost per tU MUSD 2015
Switzerland	1.74
Sweden	0.89
Finland	0.69
UK (DECC)	0.57
UK Jackson low*	0.82
UK Jackson high*	1.09
Korea**	0.32
USA (YMP) 2008	0.88
Average	**0.88**

ILW

Country	Cost per m^3 kUSD 2015
Switzerland	31.42
Sweden	11.31
UK (DECC)	26.39
Average	**23.04**

Some figures now rather old

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.

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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

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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
https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/

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