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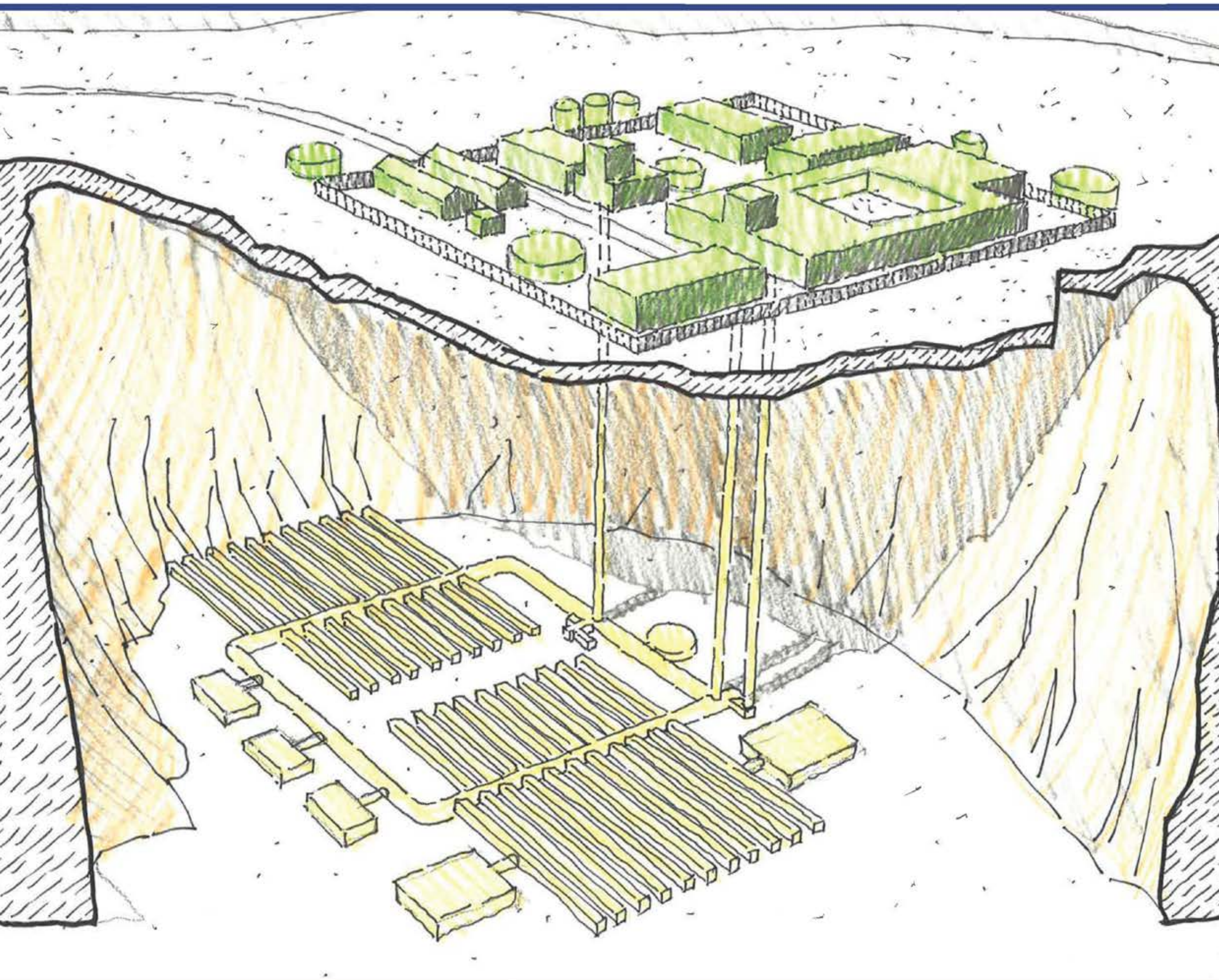

RADIOACTIVE WASTE STORAGE AND DISPOSAL FACILITIES IN SOUTH AUSTRALIA

Quantitative Cost Analysis and Business Case

9 February 2016

CLIENT: NUCLEAR FUEL CYCLE ROYAL COMMISSION

Radioactive Waste Storage and Disposal Facilities in South Australia – Quantitative Cost Analysis and Business Case

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Authors:	Darron Cook, Charles McCombie, Neil Chapman, Nigel Sullivan, Rohan Zauner, Tim Johnson
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Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
Floor 11, 452 Flinders Street
Melbourne VIC 3000
PO Box 312, Flinders Lane
Melbourne VIC 8009 Australia
T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com

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Executive Summary

Key findings / conclusions

- There is substantial and ongoing unmet international demand for services to manage and permanently dispose of radioactive waste, and spent nuclear reactor fuel in particular.
- The physical and demographic characteristics for above-ground temporary storage and deep geological disposal of radioactive waste are present across large areas of South Australia.
- Significant revenues from transfer of international spent fuel and other forms of waste could conceivably commence 10 years from the decision to launch detailed investigations, coinciding with moderate capital costs from delivery of above ground temporary storage facilities and low level waste disposal capability, with more costly deep underground facilities following some years later.
- The anticipated revenues from the project are dominated by income from the management and disposal of spent fuel from nuclear power stations, with intermediate level waste (ILW) making a smaller contribution. No project revenue is presumed to be derived from the management of low level waste (LLW), which is essentially a by-product of storing and disposing of the other two forms of waste.
- A financial model has been developed to consider cashflows. It assumes that revenue is received at the time of import of wastes to South Australia. The model assumes a reserve account to pay for costs that are incurred after waste stops being imported and a State Wealth fund that receives 15% of the revenues – comparable to a mining royalty.
- Total project revenues of AUD257 billion are modelled from management of 138,000 tonnes of spent nuclear fuel and 390,000 m^3 of intermediate level waste under baseline pricing and market share assumptions. The present value of these revenues earned over more than 50 years is AUD19.2 billion at 10% real discount rate and 73.4 billion at 4% real.
- These revenues are compared against project cash costs of AUD145.3 billion (operating and capital costs) and royalty payments to the State of AUD38.6 billion, for total project costs of AUD183.9 billion. The present value of these costs, which are primarily incurred after year 21, is AUD7.6 billion at 10% real and AUD31.9 billion at 4%.
- For baseline revenue and cost scenarios, the project generates a net present value (NPV) of AUD11.5 billion over its 120 year operating life, including net operating reserve account transfers, at 10% pre-tax real discount rate. At a social discount rate of 4% the project NPV becomes AUD40.3 billion.
- The NPV of royalty payments that are assumed to be paid to the State (at 15% of gross revenue) provide an additional AUD2.9 billion and AUD11.0 billion at 10% and 4% discount rates, respectively. Presuming this project is operated as a state venture, the project results and royalty payments sum to an overall benefit to the State of AUD14.4 billion and AUD51.4 billion respectively.
- The project will support some 600 full time high value operational jobs across all facilities, including a corporate headquarters in Adelaide, plus additional contract hires (security, catering, grounds maintenance)
- In addition, the construction project is estimated to generate between 1,500 jobs through the establishment phase, to a peak of 4-5000 full time positions through the initial establishment of the underground facilities in years 2021 through 2025.
- Four generalised types of waste storage and disposal facility are considered in the study:
  - Interim storage facility (ISF) for high and intermediate level wastes – surface facility
  - Geological disposal facility (GDF) for high level waste (HLW) that is mostly spent fuel (SF) – deep underground
  - Intermediate depth underground repository (IDR) for long-lived intermediate level wastes (ILW)
  - Low level waste repository (LLWR) – near surface, for low level wastes (LLW)

- Each was considered under a variety of scenarios, with the preferred combination being: an independent low level waste facility, an independent interim storage facility and a combined geological disposal facility and intermediate depth underground repository on a single site.
- The table below presents the undiscounted whole of life capital cost for the baseline development and the typical annual operating cost for the preferred combination, at its mature state.

Facility / scenario	Purpose	Baseline capital cost AUD2015 million	Annual operating cost AUD2015 million
Low level waste repository (LLWR)	Disposal of LLW arising from operations at other waste management facilities	820	13.1
Interim storage facility (ISF) (average opex across life)	Interim storage prior to final disposal in combined GDF and IDR	2,200	98.0
Geological disposal facility (GDF) co-located with intermediate depth repository (IDR)	Disposal of HLW / SF and ILW in a shared underground repository	38,000	641.1

- The baseline capital costs are for 50% of accessible waste inventories available up to 2090 and cover the physical size of the respective facilities and associated infrastructure, the need for mid-life facility renewals and decommissioning and closure costs. Figures are real, undiscounted and include a risk factor in line with Class 5 (conceptual) cost estimates.
- Operating costs are shown at mature state. In addition to these named facilities (left hand column) additional overhead costs, such as corporate office operations, port operations, and material handling and transportation fees have been included in whole of life modelling. Figures are real, undiscounted and include a risk factor in line with Class 5 (conceptual) cost estimates.
- The overall operating cost is calculated to be in the range AUD877 to 908 million per annum for the first 40 years of operation (under the baseline or 50% market share scenario) and AUD765 to 795 million after year 40, owing to the decrease in annual packaging costs at the interim store as packs start to be reused rather than purchased.

Objective / purpose

- This business case considers the management of international radioactive waste which does not have a local solution, as well as potential Australian wastes from a nuclear power programme. The analysis draws on numerous international precedents to build a concept of foreseeable costs and revenues from various development scenarios for this sector, as well as applicable timelines and risk factors.
- The overall outcomes are presented in terms of net present value over various timescales, internal rate of return for funds invested and the tangible economic benefit to the State of South Australia under various market demand and whole of life costing assumptions.

Method

- High level capital costs for based on inspection of overseas design concepts for each facility type, and development of analogous costs to deliver them in South Australia using typical cost benchmarks. Specialised capital equipment costs were derived from international commercial rates, converted to 2015 Australian dollars.
- The costs of enabling infrastructure such as a sea port, land transport and utility connections were estimated based on benchmark rates for non-metropolitan South Australia, and nominal assumptions about quantity/distance required.

- Capital and operating costs for underground disposal were derived from detailed overseas cost estimates, appropriately scaled to the foreseeable scenarios in place in South Australia.
- Operating costs including dedicated and contract labour, facility maintenance, utilities, equipment and accommodation leases were also prepared based on existing design concepts and analogous Australian examples from the resource sector and elsewhere.

Inputs / assumptions – spent nuclear fuel (high level waste)

- There is a well-documented, growing international stockpile of high level waste (largely spent nuclear fuel arising from nuclear power stations) which currently lacks a long term management / disposal solution.
- Many of the countries which currently lack a local solution for their waste also have firm plans for future nuclear power generation, which will give rise to further waste from existing and new reactors. Furthermore there are other countries with advanced plans to introduce nuclear power which are also considered likely to seek an external solution for their waste.
- According to international bodies such as the IAEA, the total global amount of spent fuel currently in temporary storage awaiting permanent disposal or reprocessing, is some 390,000 tonnes as presented in Figure 1. This is expected to grow to 1,060,000 tonnes by 2090. This total is a rounded value that excludes high level waste from Australia since there are no advanced plans for nuclear power at this time. Of this 2090 total, it is estimated that some 276,000 tonnes or 26% will be held by countries with current or historic nuclear power programmes which don't have a recognised local solution for their high level radioactive waste or have declared their intention to find an offshore solution for it[1]. This 26% is regarded as the 'total accessible market' for South Australia. Countries with major nuclear power programmes and legacy waste stockpiles which are intentionally excluded from our estimates include China, Russia, USA, France and UK. The total inventory of this accessible market and the foreseeable market share is limited to historic and current nuclear power programmes and those in development anticipated to be in service by 2030, presuming a 60 year operating life. Further 'upside' from later programmes which commence beyond 2030 has been excluded from our analysis.
- The baseline scenario in the business case is that 138,000 tonnes or 50% of this fraction of the global 2090 stockpile is managed and disposed of in South Australia as per Figure 2, below.

Figure 1 – potential spent fuel inventory available to South Australia (total to 2090). ('Accessible market for spent nuclear fuel'); tonnes of uranium equivalent

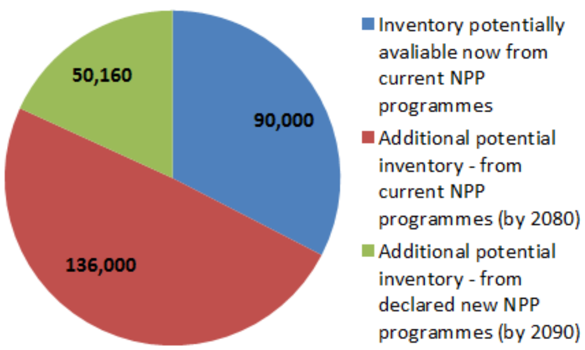
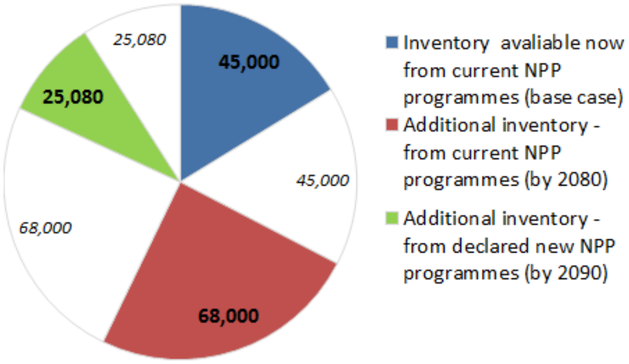


Figure 2 – baseline assumption – market share of accessible spent nuclear fuel for management and disposal to 2090; tonnes of uranium equivalent ***Total 138,000 or 50% of Figure 1 total.***



- Countries' willingness to pay for waste storage and disposal services, which provides a guide to the potential revenues from providing this service, is derived from reported lifetime costs of electricity generation for nuclear reactors and other sources.
- The price to charge (PTC) for management and disposal in South Australia is determined after deducting an average of USD0.15 million per tonne in preparatory costs incurred by customers for initial (on-site) management and storage of spent fuel and its packaging and transportation to South Australia.

[1] Based on a rate of 19 tonnes of uranium or equivalent heavy metal per gigawatt hour of installed capacity per annum.

- The direct costs reported in international publications for spent fuel management associated with nuclear power programmes among countries with access to a local solution is around USD1.0 million per tonne. International experience suggests that willingness to pay is be far higher than this baseline direct cost, and will be influenced by the extent to which a timely and reliable waste management solution improves access to finance, regulatory approvals and political acceptability for the continuation, expansion of nuclear power programmes.
- On this basis, the lower bound South Australian PTC would be between USD 0.850 million per tonne of spent fuel (or USD 1.0 million per tonne, *less* initial storage and delivery costs of USD 0.15 million) and USD1.35 million (USD1.5 million less the preparation charge), however it may conceivably be far higher.
- To achieve a balance between a highly conservative low price estimate and the potential significant price upside which exists among candidate countries, we have determined a baseline PTC of USD1.35M for the accessible market, based on an average price of USD 1.5 million *less* initial storage and transfer costs. This USD price converts to a PTC of AUD1.75 million per metric tonne of spent fuel based on a long term exchange rate of 0.77 US cents per AUD.
- Alternative scenarios modelled include capture of smaller and larger proportions of the available market (25% and 75%) and a variety of revenue rates per tonne of spent fuel.

Inputs / assumptions – intermediate level waste

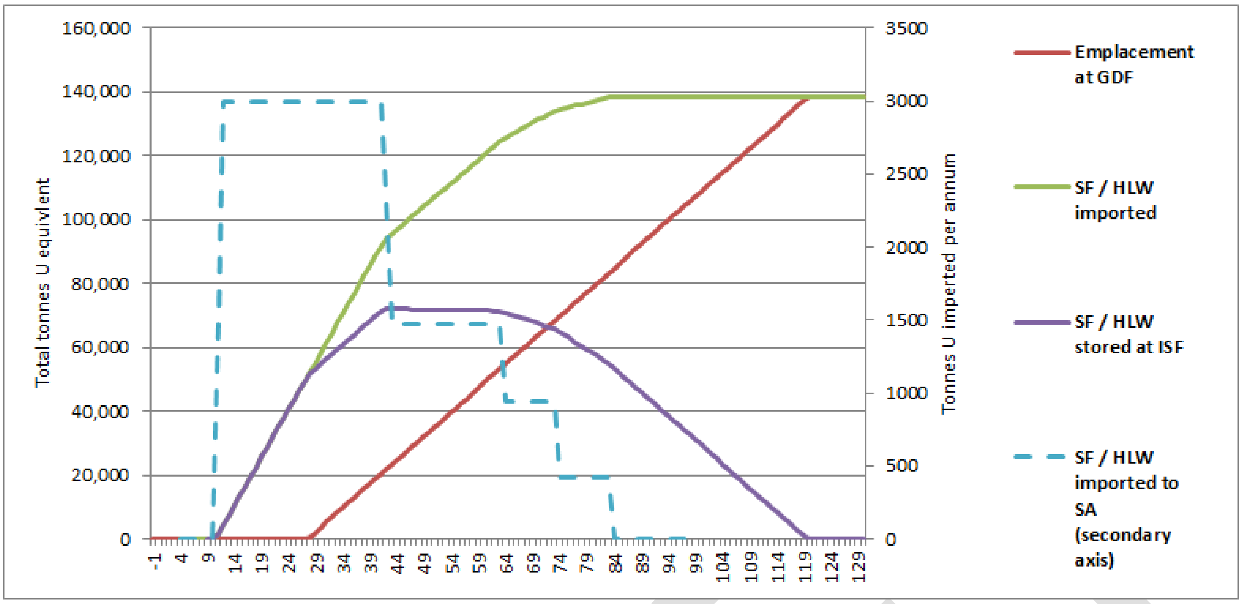
- In addition to HLW / spent fuel from reactor programmes, intermediate level waste from nuclear power generation is also stockpiled around the world and continues to be produced in association with nuclear power generation.[2] The current accessible stockpile of ILW in need of an offshore solution is some 270,000 m^3 (limited to the same candidate countries as spent nuclear fuel), growing to some 782,000 m^3 by 2090 from current and declared new power programmes. This is just over 3% of the anticipated global stockpile that is heavily influenced by activities other than power generation. It is also assumed under the baseline that a market share of 50% of this stockpile, or 390,000m^3 (rounded value) will be serviced by the South Australian facilities. This excludes ILW currently held by the Commonwealth of Australia or the States.
- The commercial model applies revenues of AUD40,000 per m^3 of ILW under the baseline scenario, based on global experience.
- The total inventory of high level and intermediate level waste which is considered potentially accessible to Australia both now and in the future (to 2090 for new programmes) is summarised in the table below.

Waste form / availability	Total available now from current programmes	Total available by 2080 from current programmes	Total available by 2090 from assumed new programmes	Total available by 2090 (pre rounding)
Spent nuclear fuel (SF) in tonnes heavy metal (tHM)	**89,979**	**226,360**	**50,160**	**276,520**
Intermediate level waste (ILW) in cubic metres (m^3)	***269,471***	***624,030***	***158,400***	***782,430***

- The timing of costs and revenues is based on the anticipated timeframe for planning and development of the different facilities, including site selection and analysis, safety case development and regulatory approvals, and the rate of delivery of materials to South Australia.
- The overall project timeline is summarised in Figure 3, which shows the movement of material to South Australia, at a rate of 3,000 tonnes per annum (dashed blue line, RHS axis) over a period starting in year 11 and ending in year 83 (this allows for 10 years' storage of spent fuel at client countries prior to import). Over this time a total of 138,000 tonnes of spent fuel is imported and disposed of, initially at the interim store (purple line) and then eventually at the GDF (LHS axis).

[2] The rate of future ILW production is based on an assumption of 60m^3 per annum per gigawatt installed capacity.

Figure 3 Timeline of spent fuel transfers between interim storage and disposal throughout the operating period



- Figure 3 also shows how with an end-of-importation in year 83 the interim store would continue to operate for a further 25 years, to ensure that all of the spent fuel was sufficiently cooled to be ready for underground disposal. Spent fuel will be transported to the GDF at a rate of 1,500 tonnes per annum and the GDF will operate until the last spent fuel was received and then be decommissioned and closed prior to an indefinite monitoring period of many hundred years.
- Operational costs were prepared on a per annum basis to enable various market share scenarios to be analysed (with smaller or larger market share scenarios operating for shorter or longer periods, respectively according to fixed rates of throughput). Total operating costs across the portfolio at the mature state are estimated to be some AUD750 million per annum (excluding facility renewals and sustaining capital expenditure).

Scenarios modelled

- The following configurations of facilities were modelled:

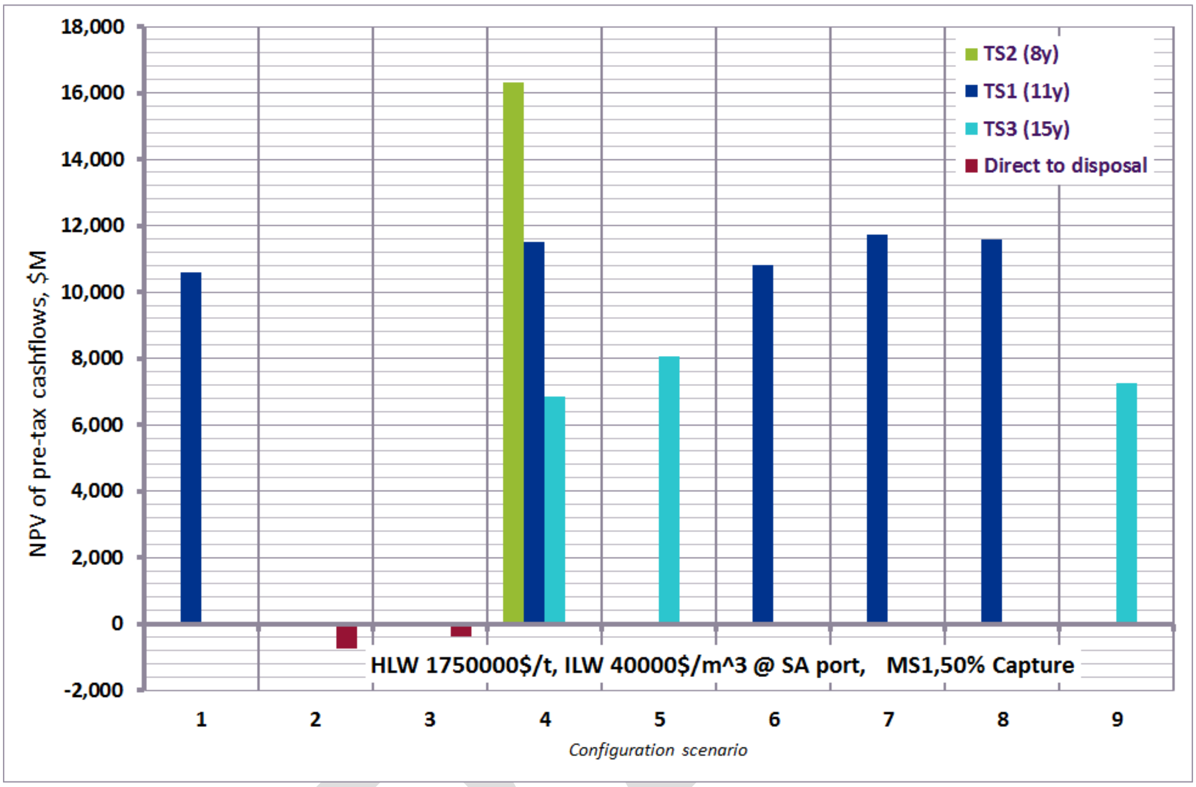
Configuration Scenarios (CS)	Costal location	Inland location	Inland location	Inland location
CS 1: standalone facilities	ISF	LLWR	IDR	GDF
CS 2: no ISF		LLWR	IDR	GDF
CS 3: no ISF, co-locate GDF & IDR		LLWR	GDF & IDR	
CS 4: co-locate GDF & IDR, 'baseline' case	ISF	LLWR	GDF & IDR	
CS 5: all facilities at coastal site	All four facilities			
CS 6: co-locate 000 and LLWR	ISF	LLWR & IDR		GDF
CS 7: ISF & LLWR co-located, GDF & UDR co-located, 'optimised' case	ISF & LLWR		GDF & IDR	
CS 8: LLWR co-located with GDF & IDR	ISF		GDF, IDR & LLWR	
CS 9: all facilities at inland site			All four facilities	

ISF - interim storage facility; LLWR – low level waste repository; IDR – intermediate depth repository; GDF – geological disposal facility

- In addition the sensitivity to capture of the baseline inventory was evaluated as was the minimum capture required to give a positive NPV under conservative, adverse conditions. Capital and operating cost over-runs were also evaluated.

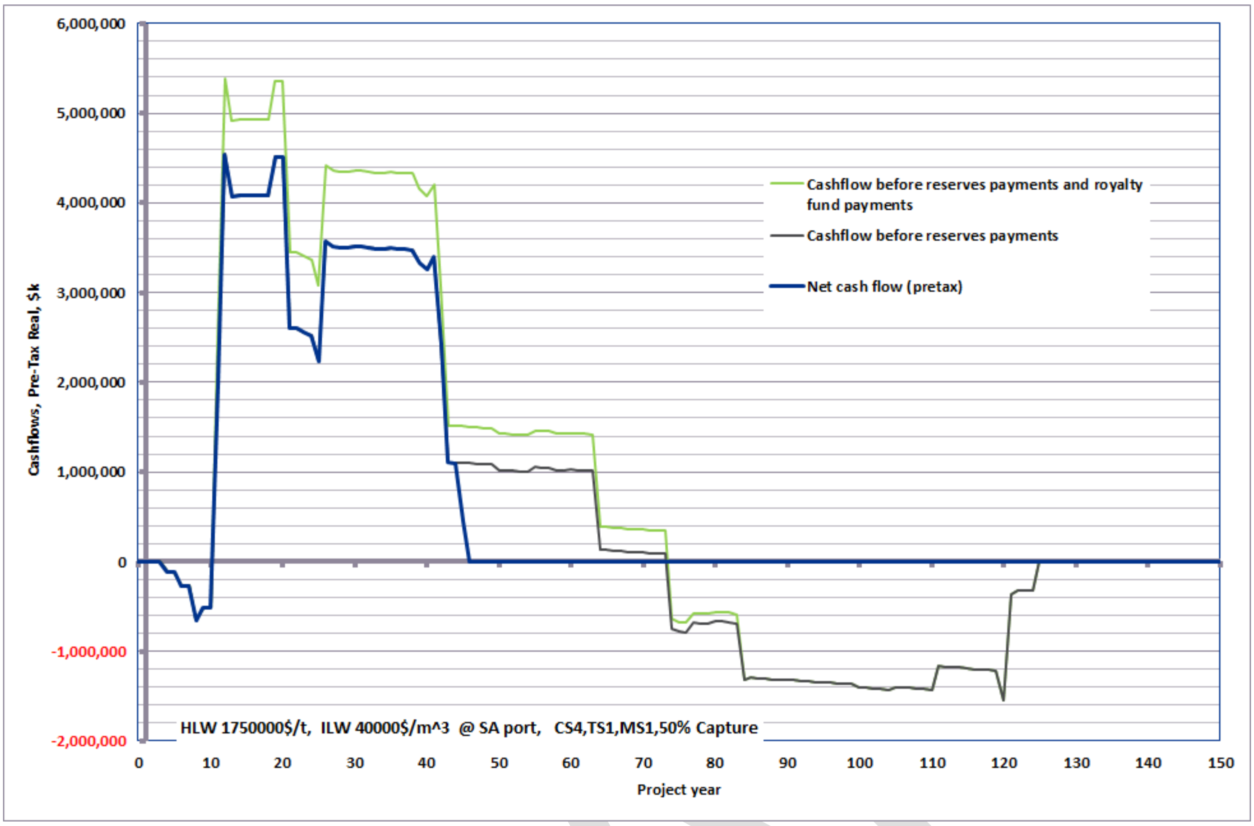
- The different configurations of the facilities generally show a similar NPV. The exceptions are the two scenarios (2 & 3) which do not include the interim store where the delayed revenue makes the NPV negative and the two scenarios (5 & 9) which necessarily have delayed timing. Earlier timing of implementation, as shown for scenario 4 has a large beneficial effect.

Figure 4 : Net present value comparison in Australian dollars for the configuration scenarios (CS)



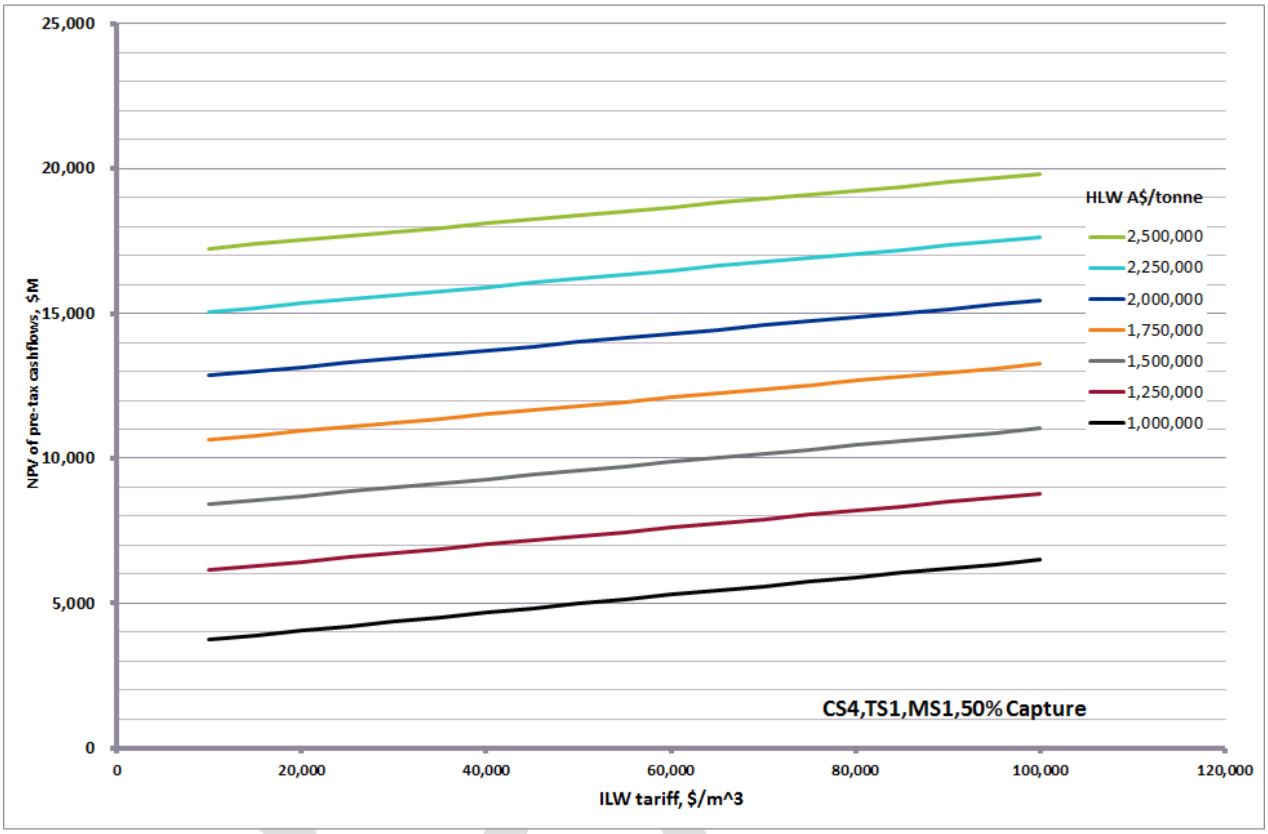
- Total international revenue generated under the base-case model would be around AUD257 billion (2015AUD real undiscounted) over the 120 year life of the project, with total expenditures of about AUD145 billion (including construction, operating, decommissioning and closure costs, but excluding royalties) over the same period.
- The project cashflow profile under the baseline scenario is presented in Figure 5, below, which demonstrates the significant net revenues to the project during the receipt phase (to year 75) and then ongoing operational costs thereafter, funded by a reserve account set aside for this purpose.

Figure 5 : Project cashflow (in AUD) for baseline assumptions (configuration scenario 4)



- Figure 6, below, shows a large NPV for the range of likely PTC revenues in the baseline market scenario, ranging from AUD1 million to AUD2.5 million per tHM, and AUD20,000 to AUD100,000 per cubic metre of intermediate level waste: in no cases modelled does the NPV approach zero. At 25% market capture, baseline project NPV decreases from AUD11.5 billion to AUD 6.8 billion (at 10% real discount rate).

Figure 6: Impact on NPV (in AUD) of PTC for HLW and ILW for base case scenario



Source: Jacobs modelling

- At the baseline PTC of AUD1.75 million per tonne some 15% of the available stockpile of spent fuel at the time of Final Investment Decision is required for commercial feasibility. This amounts to 15,500 metric tonnes of spent fuel
- Cost over-runs of 50% for both the capital and operating costs was found to reduce the NPV of the baseline scenario of AUD 11.5 billion to AUD 8.78 billion (at 10% discount rate).

Benefits to South Australia

- The benefit to the state from this project may be characterised in a number of ways, and will be influenced by its operating and ownership structure (ie whether public or private, Australian or overseas owned, etc).
- The impact will include direct and indirect employment, the development and sustainment of supporting industries (not measured in this analysis) as well as significant royalty receipts and net revenues (which may also accrue to the state, depending on ownership model chosen) which combine to deliver a profound economic impact for the state.
- The overall *cash* benefit to the State is the sum of the project NPV plus the royalty payment made to the State Wealth fund. For the baseline scenario the project NPV grows to AUD11.5 billion by year 50 after which it is essentially flat as there are no further income payments, based on median cost and revenue assumptions and 10% pre-tax real discount rate. At a social discount rate of 4% this project NPV becomes AUD40.35 billion.
- The NPV of royalty payments that are assumed to be paid to the State at 15% of revenue are an additional AUD2.8 billion and AUD11.0 billion at the two respective discount rates or AUD38.6 billion in undiscounted, real terms. The project and royalty payments sum to an overall present value cash benefit to the State of AUD14.4 billion and AUD51.36 billion for the two discount rates, respectively. As spent fuel is stored at the ISF for several decades and could be recovered from the GDF after encapsulation but before final sealing into the disposal galleries there is also potential for re-sale should spent fuel attract a value for re-use in new generations of nuclear reactor. This could both provide a further income stream and avoid some significant costs, particularly if the transfer was from the ISF not the GDF. This potential upside has not been modelled.
- The business case analysis concludes that there is a robust commercial basis for proceeding with further detailed technical, market and regulatory investigations of the potential for this project to be established over the coming decades in South Australia.

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Introduction

This report describes the commercial outcomes from a range of theoretical operating scenarios for a radioactive waste management sector based in South Australia.

The analysis draws upon international experience in the planning, development and operation of various forms of radioactive waste management and disposal facility to develop a picture of the timelines, revenues and costs which may apply if development of this sector were pursued in South Australia. The report is divided into five papers, as follows:

Paper 1 draws on overseas examples to describe the siting prerequisites, design principles and benchmark costs for the four key types of radioactive waste facility - to suit high level waste / spent (nuclear reactor) fuel; intermediate level waste and low level waste in either temporary above-ground storage and below ground disposal. The paper finds that there appears to be an abundance of locations with suitable physical and demographic features across South Australia to host the various types of facilities, including a sea port to receive the material from overseas. This paper also highlights the extent of research and development which has taken place in radioactive waste management throughout the world which a South Australian industrial complex would draw from.

Paper 2 explains the size and nature of the international market for radioactive waste management and disposal services. It also describes the available inventory of high level- and intermediate level waste which could conceivably be managed by South Australia. They key market of interest is for management of spent (nuclear) fuel from commercial nuclear reactors, for which willingness to pay is far higher than for other forms of waste. This paper describes the size and projected future growth of the total global stockpile of high level waste / spent fuel, the market share which may be taken by South Australia, and the commercial terms which could apply, based on published evidence. Despite the large and ongoing growth in spent fuel over the next 100 years, the market modelling presumes that waste imports (and direct revenues) would cease after 85 years, with further maintenance and management to continue for another ~50 years before closure and monitoring in perpetuity thereafter.

Paper 3 describes the development of concept level capital costs for the planning, design and development of the facilities to manage and store the waste and then close / decommission the facilities. As the facilities each have a long operating life, a distinction is made between 'initial capital' which is spent in order to achieve initial operating capability and commissioning, and 'sustaining capital' which is spent to extend the technical capacity and remaining life of the facilities beyond. The paper lists the various sources which were used to develop the cost estimates and the assumptions made.

Paper 4 describes the transport, logistics and onsite operating models for the different forms of waste management and storage facility, and their foreseeable annual operating costs at all stages of their life.

Paper 5 presents the cost, revenue, schedule and other assumptions which were applied in the development of a commercial cash flow model for a radioactive waste management project in South Australia. The model outputs demonstrate that the net revenues which would accrue to South Australia from providing radioactive waste management services to selected countries are likely to be significant, and be sufficient to establish both a sizeable State Wealth Fund for the benefit of South Australians and a separate reserve allocation to address later life, decommissioning and closure costs plus a perpetual site monitoring and safety assurance beyond its operational life.

While the robustness of the business case findings is derived from an inherent conservatism regarding both costs and revenues, the report notes several areas for continuing research and investigation which would be appropriate at the pre-feasibility and later development stages for this project.

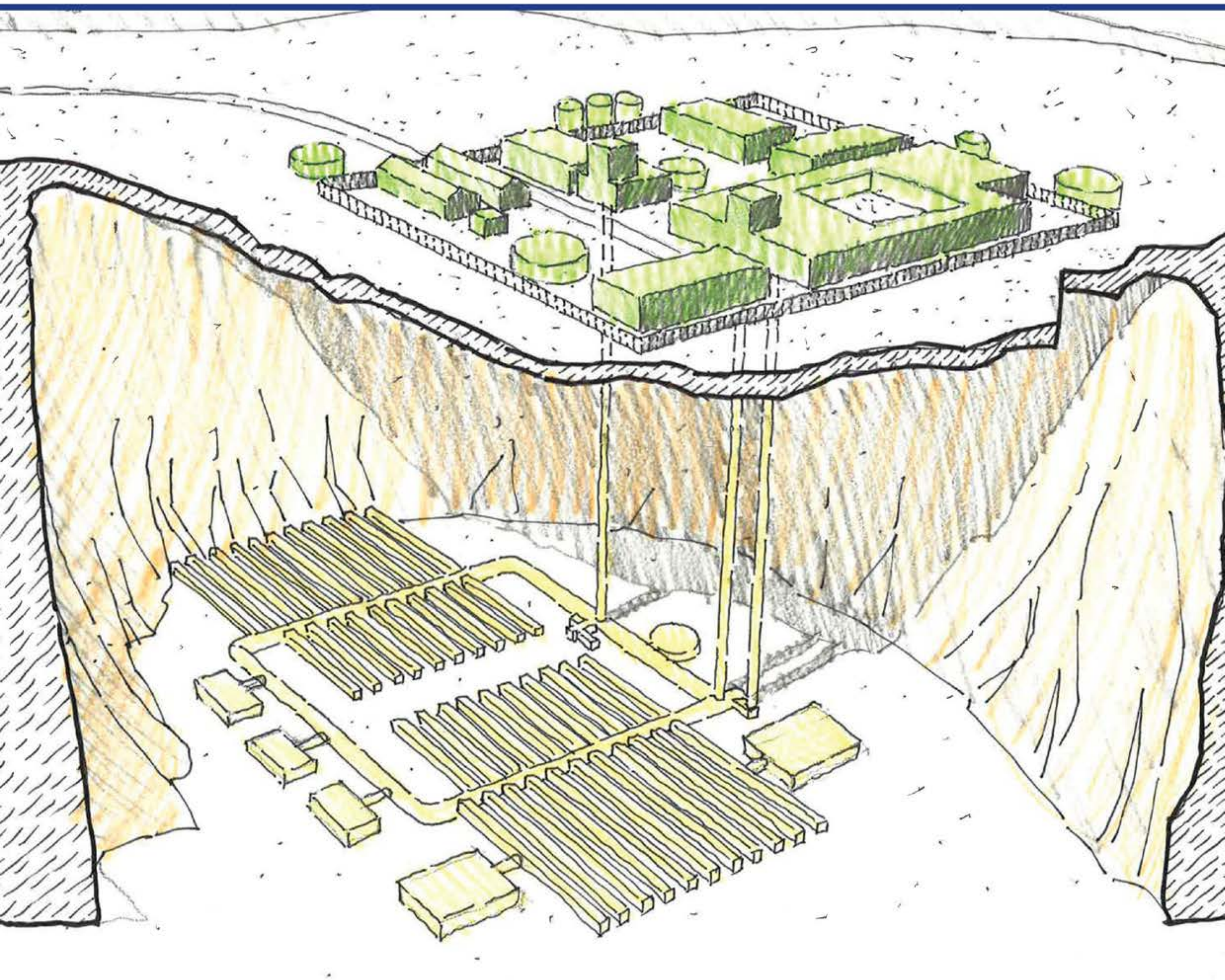
Jacobs was the lead consultant and project manager for this report, prepared for the South Australian Royal Commission into the Nuclear Fuel Cycle. Specialist input and peer review was provided by sub-consultants MCM International (Radioactive Waste Management) and APK (Cost Estimation).

Glossary

Abbreviation	Meaning
AUD2015	Real Australian dollars in year 2015
AACE	Association for the Advancement of Cost Engineering
AUD	Australian dollars
AusIMM	The Australasian Institute of Mining and Metallurgy
BRC	Basement rock concept
BWR	Boiling water reactor
CAPEX	Capital cost estimate
CHF	Swiss Francs
DECC	Department of Energy and Climate Change (UK)
DOE	Department of Energy (US)
DPC	Dual-purpose canisters
DSC	Dry shielded canister
DSS	Disposal system specification
DWT	Dead weight tonnes
E	Euro
E&I	Electrical & instrumentation
EBS	Engineered barrier system
EIA	Environmental impact assessment
EncP	Encapsulation plant
EPBC	Environmental Protection and Biodiversity Conservation (Act)
EPCM	Engineering, procurement and construction management
EPRI	Electric Power Research Institute (USA)
FA	Fuel assembly
GA	General arrangement
GDF	Geological disposal facility
GST	Goods and services tax
GWd / t	Gigawatt days per tonne
HIC	High isolation concept
HLW	High level waste
HSM	Horizontal storage module
IAEA	International Atomic Energy Agency
IDR	Intermediate depth repository (for LILW / ILW)
ILW	Intermediate level waste (also known as long lived intermediate waste, LILW)
IMO	International Maritime Organisation
INS	International Nuclear Services Limited

Abbreviation	Meaning
ISF	Interim storage facility
ISFS	Interim spent fuel store alternatively described as ISF
Jacobs	Jacobs Group (Australia), the consultant
LILW	Long lived intermediate level waste (ILW)
LLW	Low level waste
LLWR	Low level waste repository
LOA	Length overall
M	Millions
m^3	Cubic metres
MAA	Multi attribute analysis
MOX	Mixed oxide (fuel)
MPC	Multi-purpose canister
MTO	Material take off
MTPA	Million tonnes per annum
MtU / MtHM	Metric tonnes uranium / metric tonnes heavy metal
NDA	Nuclear Decommissioning Authority (UK)
NDF	Nuclear disposal facility
NEA	Nuclear Energy Agency (OECD)
NEA-OECD	Nuclear Energy Agency – Organisation of Economic Cooperation and Development
NPP	Nuclear power plant
ntk	Net-tonne-kilometres
OSOM	Over size over mass
PFS	Prefeasibility study or private fuel storage
PWR	Pressurised water reactor
PTC	Price to charge for disposal of spent fuel
R&D	Research and development
RMS	Requirements managements system
SA	South Australia; South Australian
SARC	South Australian Royal Commission into the Nuclear Fuel Cycle (the Client)
SEA	Strategic environmental assessment
SEK	Swedish Kroner
SF	Spent fuel (also described as used fuel (UF)
SFL	Long-lived low and intermediate level waste (Swedish abbreviation)
SI	Siting investigation(s)
SKB	Svensk Karnbranslehantering AB (Swedish Nuclear Fuel and Waste Management Company)
SSG	Specific safety guidance
TC	Transfer cask

Abbreviation	Meaning
TDS	Total dissolved solids
TeU	Tonnes of uranium equivalent
tHM	Tonnes heavy metal
THMC	Thermal, hydrological, mechanical and chemical
TOLC	Transfer of liability cost
tU	Tonnes uranium (metric)
UF	Used fuel also known as spent fuel (SF)
UOX	Uranium oxide
URCF	Underground rock characterisation facility
USD	US dollars
VLLW	Very low level waste
WAC	Waste acceptance criteria



PAPER 1

SITING, DEVELOPMENT AND OPERATIONAL CONCEPTS AND COSTS FOR DISPOSAL AND INTERIM STORAGE OF RADIOACTIVE WASTES

Paper 1 – Siting, development and operational concepts and costs for disposal and interim storage of radioactive wastes

1. Introduction

This paper draws on overseas examples to describe the siting prerequisites, design principles and benchmark costs for the four key types of radioactive waste facility - to suit high level waste / spent (nuclear reactor) fuel; intermediate level waste and low level waste in either temporary above-ground storage and below ground disposal.

The paper finds that there appears to be an abundance of locations with suitable physical and demographic features across South Australia to host the various types of facilities, including a sea port to receive the material from overseas.

Numerous benchmark costs and design principles from overseas facilities, to suit different physical environments are discussed, with direct relevance to this quantitative cost analysis of a potential radioactive waste management industry in South Australia.

This paper also highlights the extent of research and development which has taken place in radioactive waste management throughout the world which a South Australian industrial complex would draw from.

2. Geological disposal facilities: matching design to geological environment

2.1 Introduction

The overall aim of a geological disposal facility (GDF), which is regarded as a permanent solution to management of the wastes, is to remove a hazardous material from the dynamic, natural surface environment to a stable location, where it will remain, protected from disturbance by disruptive natural or human processes.

A fundamental factor is the types of geological environment that could be available to host a GDF, as the host rock and geological environment define the most appropriate engineering concepts to choose for this study. It is outside the scope of this project to evaluate siting possibilities in South Australia in any detail, but some confidence is required that suitable host rocks in appropriate environments do exist, and some indication of potential host rock types is essential.

2.2 Conceptual basis of geological disposal

Materials that are placed underground will slowly degrade and even the most stable deep geological environments will eventually change with the passage of geological time, but the hazard potential of the wastes also decreases by natural radioactive decay. Safety assessment work looks at the balance of these processes in order to gauge health and environmental impacts of a disposal facility, far into the future.

The conceptual basis of geological disposal has been firmly established internationally for the last 35 years as being based upon the **'multi-barrier system'**, whereby a series of engineered and natural barriers act in concert to isolate the wastes and contain the radionuclides associated with the wastes. The relative strengths of the various barriers at different times after closure of a disposal facility and the way that they interact with each other depend upon the design of the disposal system, which itself is heavily dependent on the geological environment in which the facility is to be constructed. Consequently, the multi-barrier system can work in different ways at different times in different disposal concepts.

As noted above, the multi-barrier concept of disposal addresses two principle goals with respect to providing safety - the *isolation* of the wastes and the *containment* of the radionuclides associated with the wastes:

- **Isolation**: safely removes the wastes from direct interaction with people and the environment – to achieve this means finding locations and geological environments for a disposal facility that are deep, inaccessible and stable over long periods (for example, where rapid uplift, erosion and exposure of the waste will not occur) and which are unlikely to be drilled into or deeply excavated in a search for natural resources in the future.
- **Containment**: means retaining the radionuclides within various parts of the multi-barrier system until natural processes of radioactive decay have reduced the hazard potential considerably – for many radionuclides, disposal concepts can provide total containment within the immediate environs of the waste package until they decay to insignificant levels of radioactivity. Nevertheless, the engineered barriers in a disposal facility will degrade progressively over hundreds and thousands of years and lose their ability to provide complete containment. Because some radionuclides decay extremely slowly and / or are mobile in deep groundwaters, their complete containment is not possible. Much of safety case assessment work involves evaluating the fate and impact of these extremely low concentrations of radioactivity that might eventually reach people and the surface environment, even though this may not happen until many thousands of years into the future.

Both of these key functions are especially important in the early years after closure of the disposal facility when the hazard potential of the wastes is highest. The radioactivity and radiotoxicity of SF declines by a factor of many thousands over a period of some hundreds to a few thousand years after disposal. Consequently, providing isolation and containment over this 'early' period of extremely high hazard potential is paramount and is one of the key objectives when siting and designing a GDF. The radioactivity of SF eventually declines to levels similar to natural uranium ore formations over a period of around a hundred thousand years or so. By this time, the enormous reduction in hazard potential that has occurred means that the primary isolation and containment functions of geological disposal have largely been achieved, but the possible impacts of the residual radionuclides on people and the environment still need to be considered, out to around a million years. Safety assessment thus continues to calculate risks to people for a long period after isolation and containment have done their main work and have immobilized the vast bulk of the radionuclides deep within the rock until they have decayed away.

The various components of the multi-barrier system contribute to fulfilling the high-level safety objectives of isolation and containment in different ways and over different timescales. It is common to define **safety functions** for each component, which set out what that specific barrier component contributes towards post-closure safety. For any given barrier, these functions vary from GDF concept to GDF concept, from time to time and between geological environments. In keeping with the concept of the multi-barrier system, the overall safety of a disposal system does not depend upon any one of these functions alone, but upon how the functions interact with each other as a function of time as the closed disposal facility slowly evolves. Table 2.1 provides a comprehensive list of safety functions that is generic with respect to these variables – a simple examination of the table shows that not all the safety functions can be achieved at any one time or for every disposal concept.

Table 2.1 : Post-closure safety functions of the principal barriers in the multi-barrier system

Barrier component	Safety function
Wasteform	• the wasteform (for both HLW / SF and ILW) should provide a stable, low-solubility matrix that limits the rate of release of the majority of radionuclides by dissolving slowly in groundwaters that come into contact with it
Waste container	• protect the wasteform from physical disruption (e.g. by movement in the bedrock) • prevent groundwaters from reaching the wasteform for a period of time • after corrosion has breached the container, to act as a partial barrier limiting the movement of water in and around the wasteform • control the redox conditions in the vicinity of the wasteform by corrosion reactions, thus controlling the solubility of some radionuclides • allow the passage of gas from the wasteform out into the surrounding engineered barrier system
Buffer or backfill around the waste container	• protect the waste container from physical disruption (e.g. by movement in the bedrock) • control the rate at which groundwaters can move to and around the waste container (e.g. by preventing flow) • control the rate at which chemical corrodants in groundwaters can move to the waste container • condition the chemical characteristics of groundwater and pore water in contact with the container and the wasteform so as to reduce corrosion rate and / or solubility of radionuclides • control the rate at which dissolved radionuclides can move from the wasteform out, into the surrounding rock • control or prevent the movement of radionuclide-containing colloids from the wasteform into the rock • suppress microbial activity in the vicinity of the waste • permit the passage of gas from the waste and the corroding container out into the rock

Barrier component	Safety function
Mass backfill	• restore mechanical continuity and stability to the rock and engineered barrier region of the facility so that the other engineered barriers are not physically disrupted (e.g. as a clay buffer takes up water and expands) • close voids that could otherwise act as groundwater flow pathways within the facility • prevent easy access of people to the waste packages
Sealing systems	• cut off potential fast groundwater flow pathways within the backfilled facility (e.g. at the interface between mass backfill and rock) • prevent access of people into the backfilled facility
Natural geological barrier	• isolate the waste from people and the natural surface environment by providing a massive radiation shield • protect and buffer the engineered barrier system from dynamic human and natural processes and events occurring at the surface and in the upper region of the cover rocks (e.g. major changes in climate, such as glaciation) • protect the engineered barrier system by providing a stable mechanical and chemical environment at depth that does not change quickly with the passage of time and can thus be forecast with confidence • provide rock properties and a weakly dynamic hydrogeological environment that controls the rate at which deep groundwaters can move to, through and from the backfilled and sealed facility, or completely prevent flow • ensure that chemical, mechanical and hydrogeological evolution of the deep system is slow and can be forecast with confidence • provide properties that retard the movement of any radionuclides in groundwater – these include sorption onto mineral surfaces and properties that promote hydraulic dispersion and dilution of radionuclide concentrations • allow the conduction of heat generated by the waste away from the engineered barrier system so as to prevent unacceptable temperature rises • disperse gases produced in the facility so as to prevent mechanical disruption of the engineered barrier system

One of the main tasks of the GDF programme will be to consider how an appropriate GDF **concept** (multi-barrier system and safety concept, based upon a set of safety functions) can be matched closely to the potential geological environment(s) in which the GDF could be constructed – the main constraint on choice of concept being the host rock and surrounding rock formation properties. Solutions can be found that meet regulatory requirements in different ways for different environments, as there are various ways to build an integrated multi-barrier system using different combinations of the various strengths of barrier functions.

Some national programmes have focused on only one geological environment, mainly because their national geological conditions restricted the choices available (e.g. Sweden and Finland are largely restricted to ancient basement rocks). This, in turn, has led to a focus on just one or a few GDF concepts. Others have chosen to focus the majority of effort on a particular geological environment, even though they have had a range available (e.g. Germany, on salt). Where countries possess a wide range of possible geological environments and adopt a voluntarism approach to siting (e.g. UK and Japan), then the matrix of possibilities is wider and these countries may have to retain a range of GDF options ‘active’ throughout the development stage, until a final site is identified.

Thus, identifying the approach to concept selection is intimately linked with the approach adopted to GDF siting and needs to be considered at the outset of the programme.

The UK GDF programme uses generic concepts as the basis for **illustrations** that are applicable for hard rocks, weaker sedimentary formations such as clays, and for evaporites such as salt domes. A small number of 'reference concepts' is also used for general purposes, such as developing cost models and exploring waste disposability criteria. Deciding on how many concepts to propagate through the GDF programme and how to use them (and, importantly, how to constrain what they are used for) will be an important topic. In addition, defining the point at which 'concepts' give way to 'design' must also be considered.

A general point here is that it is important for the GDF programme to maintain a flexible approach to design before a site or geological environment is identified.

2.3 Siting a GDF

As the geological disposal facility (GDF) siting is the most time consuming and uncertain, and its eventual location affects choices for the location of the other facilities, it is dealt with first, followed by siting the interim storage facility (ISF or ISFS) and the low level waste repository (LLWR). The aim is to provide information on what drives the selection of sites and on the technical approaches and consequent cost elements of siting.

Based on the presumed siting potential for a GDF in South Australia, two suggested geological environments are used to introduce possible design concepts for a GDF for HLW / SF and for an intermediate depth repository (IDR) for longer-lived, more active LILW that will require geological disposal (this is also a form of GDF). These design concepts are based on international analogues and cost data from these national projects are used to provide cost estimates for the GDF for the current project, based on the reference inventories derived elsewhere in this study.

It is often said that finding a suitable and acceptable site for a GDF is the most difficult aspect of a whole waste management programme. This has certainly proved to be the case in many countries and the long experience of siting difficulties worldwide is well recognized. In this Section, we look at the various aspects of siting that project would need to address, looking first at technical and then at societal matters.

2.3.1 General aspects of approaches to siting

A most important strategic decision will be the approach that is to be taken to finding a GDF site. It is generally agreed that there are three main types of approach that might be adopted:

- technically led: based on identifying preferred geological environments and geographical conditions;
- volunteer community led: adapting GDF concept to site conditions at volunteer sites that have not been eliminated after applying exclusion guidelines;
- mixed: finding volunteer communities within preferred areas that are first identified by using technical guidelines.

Historically, the first approach, whilst attractive to the scientific and technical community because it involves narrowing down, using broad technical principles, to an available site that fits the principles best, is the one that has always had problems. This is because it amounts to 'nomination' and the public may see it as driven entirely by some higher authority that has poor contact or no contact with their own interests. Consequently, focus has turned to the other two approaches.

The essence of any successful siting programme is that it is consensual and inclusive from the outset and all aspects of the repository project are transparent. The process must allow for active inclusion of the local communities at all stages.

The overall goals of the GDF siting programme should be to enable the implementing body to:

- deliver, within a reasonable time window and with an economically justifiable approach, a site or sites that are technically, politically and societally acceptable for a GDF (possibly also site / sites for long-term interim storage facilities), for all relevant long-lived radioactive wastes;
- show that the selected site(s) meet nationally and internationally accepted standards with respect to operational and long-term safety and environmental impact;

- pursue a staged and progressive approach to identifying host communities (sites) at an appropriate time in the project schedule, while avoiding premature, external pressures to identify hosts at the outset;
- maintain flexibility and responsiveness in its operations, while presenting its work in a clear, transparent and auditable fashion.

The following guiding principles are suggested here. The siting approach should:

- Be based upon a transparent selection process associated with agreed and well-defined siting factors including social factors, that identify clearly unsuitable areas (using Exclusion Factors), required (necessary) characteristics and preferred (favourable) properties of suitable sites;
- Seek volunteer host communities from within the wide regions that are not excluded a priori and evaluate them on their merits;
- Be published in advance of any work starting and allow a period for consultation with key national stakeholders during a period when the overall legitimacy of the siting programme is being established.
- Be structured in clear steps with clear decision points and well-defined responsibilities for all stakeholders involved at these points;
- Be flexible enough to adapt to changing requirements over the course of the project and the findings of each stage – it should be amenable to adjustment to accommodate stakeholder requirements at key stages;
- Provide up-to-date information to the publics and stakeholders at each stage, with defined mechanisms and decision points for public feedback throughout the programme; Not aim at finding the 'safest site' (as this can never be demonstrated) but at finding safe sites that are the most suitable, taking all siting factors into account;
- Where there is more than one potential site, be able to compare these transparently using the siting factors and the selection process referred to above;
- Involve the regulatory agencies from the outset, to facilitate their work and make the licensing steps more transparent and efficient;
- Achieve a solution on the required timescales at reasonable cost and with reasonable use of resources.

Deciding whether these suggestions are culturally, societally and politically appropriate for the South Australia project will be a major initiating step in the programme.

2.3.2 IAEA standards and guidance on GDF siting

It would be expected that the search for a suitable site would follow recognised IAEA standards and guidance. The most recent guidance of the IAEA on siting and site characterisation for a GDF is contained in Specific Safety Guide SSG-14 (IAEA, 2011a). This notes that:

Location of a geological disposal facility at an appropriate depth in a stable geological formation provides protection of the facility from the disruptive effects of geomorphological processes such as erosion and glaciation. Location away from known areas of underground mineral resources and other valuable resources will reduce the likelihood of inadvertent disturbance of the geological disposal facility.

An appropriate depth for the geological disposal facility should be determined, with account taken of the nature and the hazard of the waste, local geological and hydrogeological conditions, including the hydraulic head gradients, and geochemical and geomechanical characteristics.

With respect to site characterisation, SSG-14 notes the IAEA Specific Safety Requirement (No.15 in SSR-5, IAEA, 2011b) that:

> *Site characterization for a disposal facility*
>
> *The site for a disposal facility shall be characterized at a level of detail sufficient to support a general understanding of both the characteristics of the site and how the site will evolve over time. This shall include its present condition, its probable natural evolution and possible natural*

events, and also human plans and actions in the vicinity that may affect the safety of the facility over the period of interest. It shall also include a specific understanding of the impact on safety of features, events and processes associated with the site and the facility.

The guidance document says:

In the siting process for a radioactive waste disposal facility, four stages may be recognized:

i. the conceptual and planning stage,

ii. the area survey stage,

iii. the site investigation stage

iv. the stage of detailed site characterization leading to site confirmation for construction of the disposal facility.

Site investigations progress from generalized studies at the early area survey stage to a programme of progressively more detailed characterization as specific objectives are addressed and uncertain features are targeted. Detailed site characterization is required for site confirmation for construction of the disposal facility and may continue through the phases of construction and operation.

Site characterization is an activity undertaken in order to understand the natural features, events and processes at a site (at the present time, in the past and potentially in the future) and to describe adequately their spatial and temporal extent and variability. Site characterization contributes to a comprehensive description of the site, which may include information concerning anthropogenic characteristics (e.g. land use and transport infrastructure for environmental studies). There should be a clear understanding of the context and of the objectives for any site characterization in order to define properly the degree and focus of the site characterization activities that will be necessary. Site characterization will comprise data acquisition (i.e. mensuration, sampling and monitoring) and the interpretation of that data to generate information and knowledge. Site characterization will essentially begin at the earliest stage of the investigation of a site and is expected to become more intensive as the facility development programme progresses through to confirmation of the site and commencement of construction.

Detailed investigations leading up to and including the site confirmation stage should be undertaken at the preferred site (or sites) to characterize the geological and hydrogeological system in sufficient detail to: (a) Support or confirm the selection of a preferred site (or sites); (b) Provide additional site specific information required for detailed design, safety assessment, environmental impact assessment and for licensing of the disposal facility.

Site characterization should comprise both surface based investigations and underground investigations. The latter may be undertaken as a precursor to commencing construction of the disposal facility, whereby characterization and in situ experiments could be carried out in an underground laboratory or rock characterization facility at the potential disposal site. Alternatively, underground investigations might be carried out as an integral and early part of disposal construction, in which case authorization for construction (but not operation) is based only on results from surface based investigations. Surface based investigations should include, but not be limited to, remote sensing (e.g. satellite monitoring, aerial photography, seismic surveillance) and airborne surveys, geological and geochemical mapping and sampling of outcropping strata, surface based and borehole geophysical investigations, borehole sampling, logging and hydrogeological testing.

2.3.3 Technical aspects of finding potentially suitable sites

An element of the approach suggested in Section 2.1 is to use **exclusion criteria** to initiate the siting programme. This has been used recently in both Japan and the UK. The concept is straightforward, but a crucial aspect is that it is linked to a subsequent volunteer process. Exclusion criteria are designed to remove clearly technically unsuitable regions from consideration at the outset. They are generally based upon considerations of tectonic and geological stability or resource potential and identify areas that are highly likely to be perturbed in the next thousands of years by major natural events or human activity. Proximity to recent volcanic activity, active faults and regions of high uplift and subsidence, together with the presence of significant natural resource potential or the presence of major bodies of exploited groundwater often feature in these preliminary exclusion criteria. The intention is to link these to a volunteer programme that will consider any location that comes forward, on its merits, provided that it is not excluded a priori by these measures.

A key consideration in establishing exclusion criteria is to have an understanding of the period over which effective **stability** is sought. Typical timeframes for consideration are 10,000 or 100,000 years and their choice is related to the **hazard potential** of the wastes. However, the approach to assessing stability and the link to the exclusion criteria is a subtle issue that will require careful discussion with earth scientists, safety assessment experts and regulatory experts[3]. This is, for example, a central matter in the development of the Japanese geological disposal programme. In the most recent UK siting programme (currently being updated), the British Geological Survey has been responsible for testing whether any volunteer sites passes the exclusion guidelines.

2.3.3.1 Comparing potential sites / areas

If more than one potential site emerges from whatever site identification programme is adopted, then they will need to be compared at some stage. A decision on <u>when</u> to do this is an important part of siting strategy. Strategically, there are various ways of approaching this issue – for example, it might be decided that:

- there should be concurrent programmes at multiple sites to make the process valid;
- or, that work can begin when the first (possibly only) site emerges;
- all candidate sites need to be compared based on a roughly equivalent level of information at each;
- that all sites have to have at least a minimum level of site characterisation work before any can be rejected or relegated;
- that sites can be ranked using only the currently available information on a desk study basis;
- social consensus measures taken; and so on.

Clearly, there are several strategies that are possible and need to be considered. The decisions that are made here need to be transparent and the approach needs to be published in advance.

There are various techniques available for comparing siting options, two of which are mentioned here. The first method addresses the issue of confidence in long-term geological stability of a site. Even if a site passes the exclusion screening test, it may still be susceptible to tectonic impacts, for example. Different sites will have different levels of susceptibility and it might be decided that this needs to be factored into any comparison exercise – possibly before any field investigations are launched. This kind of work helps to **prioritize** work on sites and to decide how resources are divided between 'competing' sites.

At some stage, sites may need to be compared on the basis of a wide range of factors (environmental impacts, safety, cost, engineering feasibility, local issues and other non-technical factors, etc). Here, the use of **multi-attribute analysis** (MAA) is a possible and well-tested method to compare a set of contending sites. The technique provides quantitative support to inform decision-makers and can help to justify their choices and make them more transparent. Other stakeholders can be involved in the MAA process so that their views and preferences can be clearly expressed and accounted for.

A warning when establishing the site selection methodology is that, while it may be useful to define preferred thermal, hydrological, mechanical and chemical (THMC) properties for host rock and surrounding formations, it is unhelpful to set up rigid, quantitative bounds for these properties in terms of what would be acceptable / unacceptable. The rationale here is that it is the **integrated behaviour** of the total system that is important, not one property in isolation – acceptable performance can be achieved by various combinations of property values for the specification or performance of the different system components. Nevertheless, some programmes have found it useful to define a limited number of technical 'stop' criteria from these THMC properties for use during site investigations – the discovery of a particular property would make a site difficult to develop (e.g. hard to

[3] Marginal areas may be unduly excluded from consideration if the exclusion criteria haven't been matched to absolute no-go zones. The criteria can be very sensitive if matched to *undesirable* factors instead.

make a safety case). An example is the discovery of oxygenated waters at depth in a saturated crystalline rock environment (Sweden).

2.3.4 Site investigations

This section does not attempt to cover the considerably detailed aspects of planning and executing site investigations (SI), but identifies the topics that will need to be considered.

2.3.4.1 Stages in site investigations

All SI programmes tend to be designed in stages that are closely linked to the site selection programme. The stages lead to narrowing down from a group of sites to one or two sites for detailed characterization and then to the final choice of a preferred site. Even with only a single site in the programme, SI will still be carried out in stages. Defining the SI staging plan needs to be done early in the site selection programme development phase. A typical set of stages for a multi-site programme could be as follows:

- preliminary exploratory SI to clarify basic geological environment and structure at all sites (e.g. typical early programmes of mapping and limited deep drilling combined with geophysics);
- comparison of sites to identify a smaller, preferred group, *possibly* leading to more detailed work at these sites aimed at clarifying major uncertainties;
- selection of, say, two or three sites;
- initial detailed investigations involving deep and shallow drilling, sampling, surface and groundwater studies, in situ stress measurements at depth, ecosystem studies etc
- possible decision to focus on a single site;
- finalize the detailed surface investigations, including specific characterization of major features controlling site behaviour and of shaft and access rock volumes;
- selection of final site and licensing for GDF construction;
- underground investigation phase during construction, extending the database into the target rock volume in much more detail, with continued observation and monitoring.

The last of these stages is seen as increasingly important to a GDF programme, as it confirms and refines assumptions and models that will apply to the operational period of a GDF using the continued observations made as construction proceeds.

It may be decided to link this last stage to a distinct stage in which specific underground facilities are developed for testing or for demonstration of technologies. For example, a part of the GDF construction works may be developed specially for engineering and methodology demonstration (e.g. for support and stabilisation system and, eventually, for EBS emplacement). This is often called an underground rock characterization facility (URCF), as in the Finnish GDF currently under development at Olkiluoto, or a “demonstration facility”.

2.3.4.2 Importance of integration

Each of these stages needs to be closely linked to equivalent stages in parallel GDF concept option and design selection, continued updates to the safety case and environmental impact assessment, cost estimation and strategic programme development. The reason is that information must flow both from the SI into these projects and, vice versa, back into the planning of the SI work. The other areas of work must be regarded as ‘end users’ of SI information, often with specific demands for specific information, but the decisions being reached in these other areas will also affect what needs to be investigated, when and in what level of detail.

Establishing this level of integration and planning the flow and interchange of information is a critical aspect of establishing a GDF programme. It has been found useful to document ‘site understanding’ at key points in the SI programme, with the commonly accepted terminology of ‘**site descriptive models**’ now being much used. SDMs provide an integrated picture of what is known about all relevant aspects of a site and are a snapshot in time. The SDMs are used as the basis for similar milestone documentation produced by other end users – for example, iterative safety case development.

2.3.4.3 Availability of site investigation techniques

In general terms, adequate tools and techniques are available for carrying out site investigation (SI) work from the surface in all accessible environments. Techniques and tools used in different environments have developed to varying levels of maturity, both in measurement capability and in modelling and interpretation capabilities. Clearly, capabilities continue to improve in almost every area of site characterization and can be expected to continue to do so in the future, so that a site investigation in twenty years' time might be using more advanced data-gathering or interpretation methods in almost any field of geosciences. Nevertheless, there are recognized areas where difficulties in measurement or interpretation could still be encountered today.

2.3.4.4 Keeping local communities informed and involved

Some programmes have identified an early and important role for some form of **site liaison committee**, which meets regularly to keep communities informed and to discuss issues that arise. In particular such committees can play an important role in decision-making. The scope of liaison should be about the whole geological disposal programme itself, not just about the SI work. There will be a clear interest in the community in receiving information on the likely local impacts of a GDF and any associated facilities (interim stores, encapsulation plant) on matters such as environmental impacts (noise, traffic, dust, water quality), employment (a potentially positive impact) and the effects on local services and industries (where the timescales of facility operation will obviously be of great interest – is it a 20 year project followed by abandonment of the community, or has the project got considerable and valuable longevity for the community).

Obtaining community buy-in to planning decisions will be critical to good working relationships over the long operational lifetime of the GDF. Areas where the community representatives may feel that they have a particular interest include:

- the location of specific facilities;
- the general design and appearance of surface facilities;
- GDF operational schedules and methodology;
- local transport of materials and personnel;
- inspectability, retrievability and GDF 'open period'.

In many of these areas, the GD implementer may not have strong or decisive views themselves and may be willing to be guided by local opinion. Others impinge on safety and operational aspects and the implementer may only be able to take advice up to a certain level – and the regulatory body will always, of course, have a final word on some aspects. Nevertheless, community involvement will provide great benefits to all sides of the project.

The issue of retrievability, inspectability and closure policy will be of considerable interest and it might be expected that the views of both the communities and the implementer will evolve through the many decades of the GDF programme. It could take many years, even generations, before a final approach or decision (e.g. to close and seal a GDF) can be agreed. A gently progressive, phased approach needs to be considered, which does not foreclose on any possibilities until all parties feel comfortable to take a committing decision on these questions.

2.3.5 Elements of the initial stages of a GDF programme

This Section identifies the various component elements of the first stages of a GDF programme, which the implementer will need to plan and set in place. The integration of these programme elements is of critical importance, as each requires information from the others and they all develop in parallel. The section only considers the GDF programme elements up to the point of final site selection and licensing for construction.

It should be expected that the GDF programme will be planned in **stages**, closely linked to critical milestones such as launching a siting programme, narrowing down to sites for detailed investigation, final site selection, licensing, GDF construction etc. Deciding the precise nature of these stages is an important initiating step in the GDF programme and needs to be done in collaboration with key stakeholders such as the government and the regulatory agencies.

2.3.5.1 Disposal system specification

An entry point to defining the programme as a whole is to establish a specification for the disposal system (the disposal system specification: DSS), which will evolve and become more detailed and prescriptive as the programme matures.

The aim of a specification is to set out the **requirements** on the whole system and the consequent requirements on all the components of the system. The specification describes the functions of each system component and has a technical description of how these functions are provided. In some countries, a clear starting point for this is given by requirements laid down by the regulators (which can be very specific), but it is also possible to begin by looking at IAEA baseline documents. At the highest level, DSS requirements can be expressed in terms of safety, environmental impact and costs. Clearly, each of these can be broken down into more detailed requirements and into requirements on the system components. The component elements of the disposal system requiring specification are:

- waste storage system;
- waste packaging and encapsulation system;
- waste transport system;
- GDF design and operational systems.

Several programmes now utilize a formal **requirements managements system** (RMS) to handle the DSS. The benefits of doing this are the formality that is introduced into recording the technical justifications of why a system is designed as it is. Because requirements and justifications are expected to evolve with time, the RMS is also used to make a formal record of why and how changes are made to system specifications. Over a multi-decade programme, this type of information is otherwise easily lost.

It is to be expected that the requirements of different components of the disposal system will occasionally conflict, which will mean that modifications will need to be accommodated – in design or in operating procedures, for example.

2.3.6 GDF design

GDF design begins at a conceptual level and evolves into site-specific designs and, eventually into a pre-operational design. It is not possible to settle on a specific GDF concept until the host rock is known and the range of potential sites is identified – for example, hard rock sites will require different GDF concepts to sites with weaker sedimentary rocks. For co-disposal of HLW / SF and ILW, it will be necessary to carry forward a range of concept options for both parts of the GDF.

It is advisable to maintain flexibility in terms of concept options, at least over the first years of the programme. For any given host rock there are already different concept options that could be utilized and it would be sensible to allow the GDF programme to explore these options and their implications. This flexible approach is counter-posed to an approach that would, for example, 'import' a GDF design option directly from another programme at the beginning of the programme. This latter approach might not be the most efficient or economic way forward.

Narrowing down to a preferred concept and then to a specific design needs to keep pace with the growing certainties that arise from the siting programme and, of course, each step must match the evolving DSS requirements. This process is sometimes termed 'optioneering' and, in its latter stages, is clearly a form of engineering optimization. Linking the design development to every other aspect of the programme so as to have an integrated approach will be a key planning matter for the implementer.

2.3.7 System safety assessment

The first version of the DSS will establish a basic safety requirement that will be related, for example, to standard IAEA fundamentals of geological disposal. The next step will be to establish a **safety concept** that is linked to a specific concept option (or set of concept options) and which explains how the concept and its execution can meet the basic goals of short and long-term safety. Once a safety concept is established, it is possible to explore the performance of the GDF system in more detail and produce a first **safety case**. A safety case will be based upon safety assessments that will need to consider each element of the system and will develop progressively, from generic through to increasingly specific as the siting programme proceeds.

It is normal practice to have a staged development of the safety case and the underlying safety assessment that keeps pace with the development of the programme. As with the design work outlined in the previous section, this would move from generic through to site specific and eventually to a safety case that will support license application for construction and / or operation of the GDF. For the GDF, integration of safety assessments with the developing design and site characterization work will be critical and a key aspect of programme planning. Integration of the various parts of the safety case bulleted above is also a critical activity, as there may be conflicting requirements arising from each separate component of the total safety case that will need to evaluated and accommodated by design or procedural modifications.

Based on the experience of advanced disposal programmes, it might be expected that three or more full system assessments would be produced from the start of the programme up to the point of license application.

2.3.8 Environmental impact assessment

Environmental impact assessments (EIAs) are likely to be carried out for various activities in the overall disposal programme, as they may be required by regulators and will also be needed for internal planning purposes and for presenting the GDF programme to stakeholders. Generally, an EIA would address the non-nuclear environmental impact assessments, although some countries wrap the radiological impacts into the overall EIA process. Some countries also require a strategic environmental assessment (SEA), which looks at the broader impacts of disposal and at alternatives to disposal (e.g. long term storage, retain status quo etc) and is intended to justify the whole disposal programme in a wider national or international context.

Activities for which an EIA might be needed include:

- field investigations (drilling, setting geophysical lines, setting up stream and river monitoring systems);
- construction and operation of an URCF;
- GDF construction;
- GDF operation;
- GDF closure.

The scope of any of these EIAs is likely to include assessments of the impacts of:

- ground engineering;
- waste and water discharges;
- spoil storage and management;
- surface and groundwater supply impacts;
- visual and noise impacts;
- ecological impacts.

Well before the main stages of GDF activity that begin with the first underground construction work (e.g. for a URCF), it is advisable to have begun a comprehensive programme of baseline environmental monitoring. The aim is to have a thorough characterization of undisturbed natural conditions at the site prior to the start of major site work, which could perturb these conditions. This acts as a valuable reference point for all subsequent monitoring of environmental parameters and can also avoid problems by establishing exactly which perturbations are then caused by the GDF work and which might be purely natural anomalies. It is normal practice to begin to establish this baseline database in the initial stages of the site investigations. It should cover all major characteristics of both the surface and the deep environment.

Before GDF closure, the implementer will be expected to make or accept proposals for long-term land use and availability for future development. It is likely that an EIA will be required to support this planning and the availability of a baseline will also be valuable at this time in the far future.

Example: Australian high-isolation concept

The high-isolation concept (HIC) developed for Australian conditions under the Pangea proposal aimed to provide a natural barrier system that could, by itself, provide substantially complete containment for the time period of interest in evaluating safety (Black and Chapman, 2001). The HIC design concept is described later in this report. Although such a repository would also contain a robust engineered barrier system (EBS), the performance of the repository would not be expected to depend on this once the repository has been sealed. In particular, the environments evaluated were selected so that there is essentially no flow of groundwater through the GDF. Consequently, the mobile radionuclides can only move by the much slower process of diffusion, in static groundwaters. This means that even the most mobile radionuclides would decay before they were able to reach the biosphere. Only the longest-lived mobile radionuclides would be released, in concentrations that are of no radiological concern, in tens of thousands or hundreds of thousands of years' time.

The HIC concept achieved this by choosing sites that have groundwater systems with low energy, because there are minimal hydraulic gradients combined with minimal recharge of groundwater by rainfall. These can be found in flat, arid areas. Low rainfall and the deposition of salt blown far inland from the sea, coupled with mineral dissolution and high evaporation near the surface, effectively increases the salinity of the recharge water, which sinks, undergoes slow reaction with the rock, and forms a naturally layered groundwater body, in which densities increase with depth. This configuration is naturally stable and requires more energy to disrupt the groundwater system than in the case of a freshwater system.

Ideally, there would be no groundwater flow at repository depths in such systems, and there would be evidence that this situation had been stable for hundreds of thousands of years or more. Transport of mobile radionuclides from the repository in groundwater could only take place by diffusion and the bulk of the rock above the repository would act as a diffusive barrier to movement. Only if a radionuclide were able to diffuse through this barrier, perhaps several hundreds of metres thick, without decaying, would it be able to move in slowly flowing groundwaters at shallower depths.

The HIC also involved choosing sites with simple, stable geology whose future behaviour can be demonstrated by extrapolation of natural processes that have already occurred at the site in question, progressively, over hundreds of thousands, or millions of years. This involves choosing sites that have extensive, relatively simple geological structure and which are reasonably predictable spatially (e.g. a large region underlain by an unfolded, unfaulted, monotonously uniform sedimentary sequence).

It must also be possible to show that the climate of the region has been changing with some uniformity and large scale (not detailed) predictability on timescales of about a hundred thousand years and has not been subject to marked or rapid changes that could significantly affect the deep groundwater system (e.g. ice cover during glaciations). The concept also involves avoiding areas containing what could today, or in the foreseeable future, be considered seriously as potentially significant mineral and energy resources.

The high-isolation concept was described by a set of *signature characteristics*, which concern safety, demonstrability, and economic feasibility of the project. These characteristics were selected to correlate strongly with the 1994 IAEA guidelines for deep geological repositories. They are summarised in Table 2.2.

Table 2.2 : Signature characteristics for high-isolation sites (Black and Chapman, 2001)

a) Characteristics contributing to long-term safety

Characteristic	Purpose
1. Stable geology in a tectonically inactive area: no relevant impacts from recent or likely future tectonic or neotectonic activity over the next 1Ma: a generally low tectonic stress regime is advantageous	Minimal risk of disruption of the repository by either slow tectonic processes or tectonically driven events. Consequently, a number of scenarios (that may need to be considered in depth in some national programmes) can be dismissed as of little or no relevance: • volcanicity • uplift or subsidence • major fault movements
2. Extensive flat topography over a wide region around the site	Minimises: • potential energy driving flow in the groundwater system • likelihood of erosion
3. Arid climate that has been stable with respect to major perturbations for hundreds of thousands of years, with a good record from climate indicators	Minimises: • energy in the groundwater system (recharge of deep waters) • likelihood of erosion • human activity in the biosphere Enhances reliability of predictions of future biosphere No possibility of ice cover in a future glaciation
4. Geological structure with no high conductivity pathways to the surface: most readily provided by extensive near-horizontal layered sediments	Ensures no direct connection for any driving force to move groundwater and radionuclides directly to the biosphere. Clay-rich sediments can have strong anisotropic permeability, with dominantly horizontal water movement, as well as high retardation capacity for radionuclides
5. Lack of currently recognised significant mineral or energy resources	Minimises likelihood of future human intrusion through drilling or excavation
6. Absence of extensive aquifers and major karstic limestone and dolomite formations in the region	Minimises likelihood of contamination of potable groundwater and ensures no direct hydraulic connection to high energy groundwater systems some distance from the immediate repository region
7. **7.** Presence of an adequate thickness (~100m) of low permeability rock with good construction properties, at several hundred metres depth below the surface	Minimises groundwater movement through the repository, possibly also ensuring that there is no flow in the repository zone (only exceptionally slow diffusion) Allows construction of disposal tunnels and vaults and ease of operation over an extended period
8. Presence of stratified saline groundwater (from around 5 g / l TDS to > 35 g / l: true brines)	Minimises likelihood of utilisation of deep groundwater (e.g. for development of agriculture) Inhibits upward movement of radionuclides from repository located within denser groundwater horizons at depth
9. Presence of a stable, reducing geochemical environment	Minimises the solubility of many radionuclides

b) Characteristics that help to demonstrate long-term performance

Characteristic	Purpose
10. Simple geological structure	Simple geology is more spatially predictable and easier to characterise and describe. It is easier to have confidence that the features controlling long-term stability are well understood
11. Presence of dense, non-potable, saline groundwater	Provides readily understood idea of long-term safe isolation
12. Very old groundwater in the host formation	Proves that the repository zone has been isolated from the surface for long periods, demonstrating that current groundwater flow is negligible
13. Presence of stable, ancient (e.g. > 1 Ma) geomorphology, landscape and soil profiles	Demonstrates that the site has not been subject to significant erosion or dynamic surface processes for considerable periods of time

c) Characteristics that enhance the economic feasibility of the repository

Characteristic	Purpose
14. Relative ease of site characterisation	Simple geology is easier to characterise, thus reducing the cost of site investigations and associated work needed for design and safety studies
15. Lack of susceptibility to climate change impacts	Repository does not have to be constructed at a great depth to avoid, for example, rock affected by glaciations in the last million years and the potential impacts of future glaciations. This reduces the rock engineering costs of construction
16. Remoteness and physical isolation of an arid site with no significant prospects of other large-scale developments in the near future	Allows flexibility of layout of surface facilities, reduces problems with legal planning issues and societal impacts, allows ready access for surface survey work and minimises public exposure to waste transportation Results in greater impacts of the proportion of national financial benefits allocated locally, owing to smaller size of local communities and regional development programmes
17. High natural isolation provided by the geological and hydrogeological environment	Reduced requirement for expensive engineered barriers (buffers and overpacks) within the repository has a significant impact on overall costs of disposal

2.3.9 Steps in HIC siting

The HIC search procedure was envisaged as a six-stage process originally intended to start at a global level in stage 1.

- **Stage 1** is a high-level desk study that results in the identification of regions that are arid or semi-arid and are geologically stable over the time period of concern for waste containment. The procedure results only in the identification of large regions and is likely to overlook potentially suitable smaller regions.
- **Stage 2** involves more detailed, individual desk study assessment of selected broad regions, introducing a first evaluation of topography, geological environment, and mineral and energy resources. It also involves

a more detailed consideration of climate. It produces a group of geological provinces (identifiable geological entities, such as major sedimentary basins) that match the principal high-isolation characteristics.

- **Stage 3** involves initial access to the regions of interest and the application of much more detailed local knowledge derived from discussions with national organisations such as environmental agencies and geological surveys. It produces a list of **survey areas**, the size of which is defined by what can effectively be evaluated by a single survey using airborne geophysics during stage 4.
- **Stage 4** may be required, depending on the extent of information available within national databases, and would involve airborne geophysical studies of Survey Areas to obtain improved information on large scale, deep rock structures. It results in the definition of **candidate siting areas**, whose size is a function of how far results from a single borehole (drilled in stage 5), when combined with well-designed geophysical techniques, can be utilised to define geological structure and rock properties.
- **Stage 5** involves the drilling of a single deep borehole (typically of the order of 1000 – 2000 m in depth) within each candidate siting area, linked to more extensive ground geophysical surveys: in particular, seismic surveys similar to those used in oil and gas exploration. It may be appropriate to move directly from stage 3 to stage 5, depending on the extent of detailed local information. The results from stage 5 should allow the nomination of a group of preferred sites for more detailed study.
- **Stage 6** involves detailed drilling and testing to obtain a comprehensive understanding of site properties that would be sufficient to make a decision on whether to proceed to underground excavation. The decision on whether to carry out stage 6 investigations in parallel at more than one preferred site within a country would need to be taken at the end of stage 5, on the basis of many factors, including non-technical matters. For example, it may be decided that the short-list of sites from stage 5 all display sufficiently similar technical properties that the risk of finding adverse geological features is small enough to warrant focussing on one site. That site might be identified on the basis of social factors, for example by a volunteer community approach.

Following stage 6, site investigations would move underground, with any further characterisation of the site taking place from shafts and drifts (in a underground rock characterisation facility). As discussed earlier, regional, area- and site-specific performance and safety assessments would be required to assist with comparisons and with related design studies, at intervals throughout the stages.

2.3.10 GDF siting and site work (to the point of operation) timeline

Integrating the site identification, approval and SI work into the main programme can dominate scheduling. There are frequently unplanned-for delays in obtaining permissions at every step of the siting work and these are often completely out of the implementer's control, as they involve political and legal decisions. It can thus be difficult to make a robust time plan for the other elements of the programme that may be waiting for information from the siting programme (e.g. design, safety assessment).

If a programme runs without unreasonable delays, then typical durations that might be expected for the main stages can be:

- initial site identification: 2 to 5 years
- permissions for surface-based, intrusive site investigations: 1 to 2 years
- site investigations (with associated safety assessment, GDF design and economic work to enable site selection): 5 to 8 years
- comparison of sites leading to final selection of preferred site: 2 to 3 years
- underground construction and investigation as part of a URCF phase leading up to the point of initial GDF operation: 5 to 7 years.

This gives a total duration for a 'smooth' project based upon voluntarism and with no licensing problems of between about 15 and 25 years. As noted above, several activities run in parallel to the siting work and interchange information with it.

This schedule is expected to commence after the legal and regulatory framework is established. Hence the overall times are anticipated to be five years longer. For modelling purposes we have assumed 23 years before ILW starts to be emplaced (five years for establishing the framework plus eighteen years for project execution) and 27 years for HLW / SF – which includes two years of testing after physical completion of the facility.

2.3.11 Cost analogues for facility siting

A range of studies from some of the more advanced national programmes provides a good indication of the costs of siting work for the waste management facilities. A number of the studies are firmly based on actual experience, with sites having been selected and in the licensing stage. Nevertheless, actual costs should be expected to vary from these analogues as a result of many factors, including delays in the overall programme, any requirements to look at multiple locations in parallel, skilled resource limitations, unforeseen complexity or problems encountered in site investigations (including the need to abandon a site and move to an alternative location) or safety case development, licensing delays, permission and stakeholder engagement delays etc. For this reason, it is advisable to include a margin for uncertainty when estimating costs.

2.3.12 GDF siting costs

Three examples are cited here: the Swedish SF GDF programme (SKB, 2014), the planned UK GDF programme for HLW / SF and ILW (NDA-RWM, pers. comm. to C. Eldred) and the Swiss programme for HLW / SF disposal (SwissNuclear, 2011). Sweden has selected its GDF site and effectively completed its site investigations, and is in the construction licensing stage. The Swiss programme is part way through site selection and has only a small way into site characterisation, whereas the UK programme is conceptual, but is based on past experience with site investigation for a GDF at the Sellafield site.

Table 2.3 below abstracts siting costs from the published information on waste management programme costs. It should be noted that the original studies use different assumptions and include different activities, so the numbers cannot be compared absolutely, but are strongly indicative. In fact, they are relatively similar, with a median cost converted to AUD2015 of 614 million.

Table 2.3 : Summary of European and UK siting costs for GDF facilities

National GDF programme	Geological environment	Siting costs inflated to present day (millions)		Comments
		Local currency	AUD	
Sweden (SF)	Precambrian basement granites-granodiorites	4325 SEK	721	Does not include R&D costs associated with siting
Switzerland (SF and HLW)	Partially indurated sedimentary rocks (marly clays)	432 CHF	630	Does not include URCF, estimated at a further 1318 million AUD
Switzerland (LILW)		330 CHF	482	Assumes separate location from HLW / SF, but the two GDFs may be co-located. Does not include URCF, estimated at a further 862 million AUD
UK (HLW / SF and ILW co-disposal)	Open. Estimates based on previous work at Sellafield in Palaeozoic basement volcanics under Mesozoic sedimentary cover.	274 GBP	598	Estimated cost per site. Several sites might be investigated.
Median Cost			**614**	

As noted for the UK estimates, this figure would need to be increased if more than one site were studied in detail. However, it should also be noted that if site selection was predicated on simpler and more uniform geological environments, site investigation costs would be reduced. Also, the figures in this Table vary in the amount of past work that was required in the national programme on multiple sites, or on failed siting studies. For example, the UK spent about the same amount as indicated here in its failed investigations at the Sellafield site (estimated cost of £250M).

For these reasons, we propose a conservative figure of **750 million AUD** as an appropriate value to use in the commercial model. We note that this figure is intentionally conservative, however it is appropriate given the uncertainty associated with process applied for site selection.

2.4 Design features of the GDF for HLW / SF

Based on the assessment of potential siting environments in South Australia presented in Section 2.3.10 and analogous environments in GDF projects in other countries, we have identified components of the most developed and relevant GDF concepts to use as the basis for this costing study. These have been taken from the advanced GDF programmes in Switzerland (Nagra), Sweden (SKB), Finland (Posiva) and the UK (NDA-RWM):

High isolation concept for sedimentary rocks ('HIC model')

- GDF for HLW and SF: Nagra in-tunnel disposal concept for the Opalinus clay, with an adapted engineered barrier system (EBS) appropriate to the HIC environment
- GDF for LILW: Nagra vault disposal concept for the Opalinus clay.

Strong, basement rocks concept ('basement rock model')

- GDF for HLW and SF: KBS-3H in-tunnel disposal concept being evaluated in Sweden and Finland, with an adapted engineered barrier system (EBS) appropriate to the arid environment[4]
- GDF for LILW: NDA-RWM 'Nirex Reference' vault disposal concept for basement rocks, which was designed to accommodate a wide range of LILW from a complex nuclear power programme.

2.4.1 High isolation concept (HIC) model

There are several alternative detailed designs which may be considered for the high isolation concept. An engineered barrier system (EBS) for disposal in a high-isolation environment may be achieved via a simple mild-steel waste packages (for SF, perhaps with a cast iron insert to accept the fuel assemblies) emplaced in steel tubes, located in boreholes in the rock, or along tunnel floors (Apted et al, 2001). Here we assume the latter model, with the space around the emplacement tube backfilled with crushed rock and bentonite clay (which is available in large quantities from a commercial quarry near Mildura, Victoria)[5]. Backfilling would take place as each tunnel section is completed. This is shown schematically in Figure 2.1, with Figure 2.2 showing the close similarity with the Nagra (Switzerland) concept for sedimentary host rock, but which does not use an emplacement tube. Figure 2.2 also shows the concept for backfilling around the packages (or emplacement pipe, in the model proposed in this study).

In this concept, waste packages (either SF or HLW) would be spaced out by approximately 3 m, at about 8 m centre-to-centre distances for SF, depending on package size (there could be a range of package lengths to accommodate different types of fuel assembly (FA), but we assume here a uniform overpacked disposal container length of 5 m). For the shorter HLW canisters (2 m long), the centre-to-centre distance would be about 5 m. Depending on the site properties, individual disposal tunnels (c. 2.5 m diameter) could be several hundred metres long. A spacing of 40 m between disposal tunnels is assumed. Figure 2.3 shows a typical layout

[4] The selection at this stage of conceptual costing development for the 3H (horizontal emplacement) rather than the 3V (vertical) is based on the smaller excavation volumes required for the 3H design, based on analysis of options for the Olkiluoto site (SKB 2008). The final selection of emplacement method at the Olkiluoto site in Finland is yet to be made and is in influenced by the local geology, including local geological fracture zones.

[5] Depending on the geological conditions and site, it may be possible to use other locally derived materials rather than the high-specification bentonite used in other concepts.

envisaged by Nagra, with long emplacement tunnels reflecting the uniform lithology envisaged. Here, we conservatively assume that emplacement tunnels have a maximum length of 300 m (holding about 30 SF containers).

Figure 2.1 : Pipe-in-tunnel EBS system for the HIC, (Apted, et al., 2001).

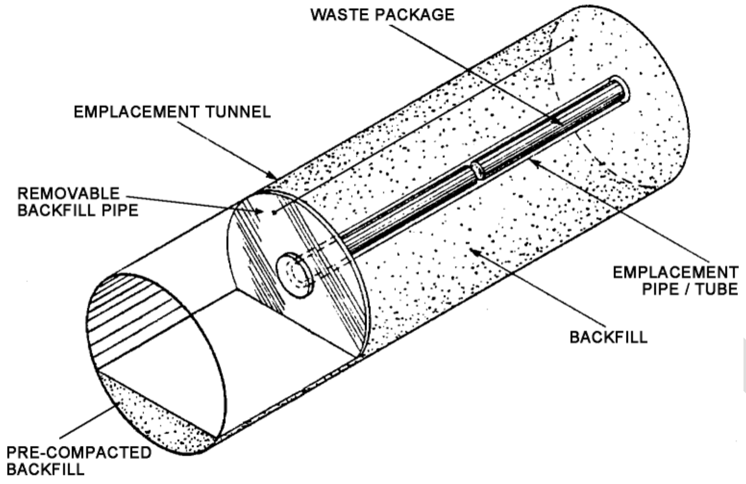


Figure 2.2 : Analogous Swiss model for SF disposal in sedimentary rocks: Nagra website (see text for discussion).

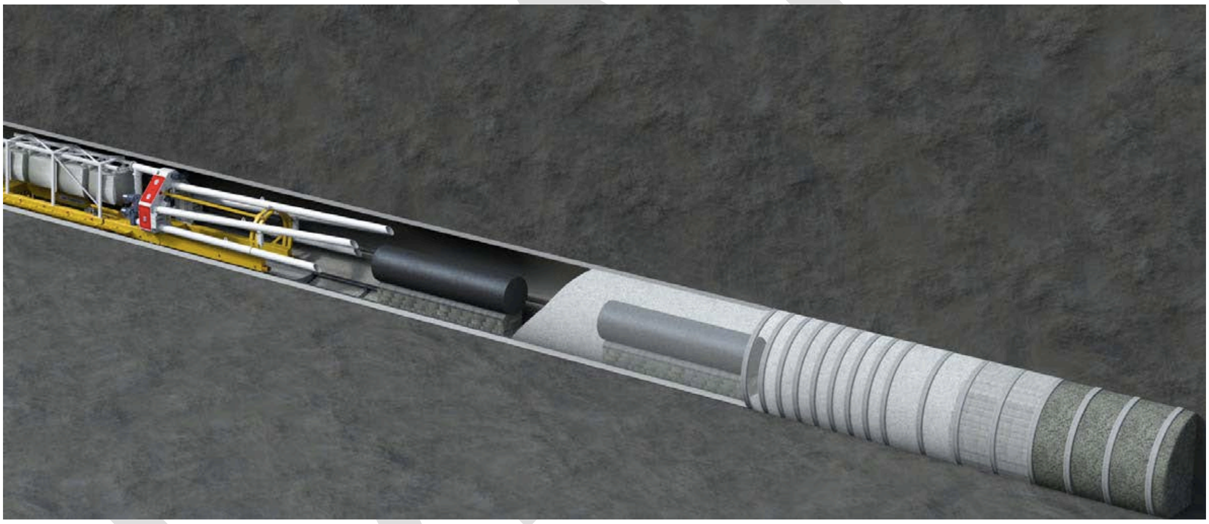
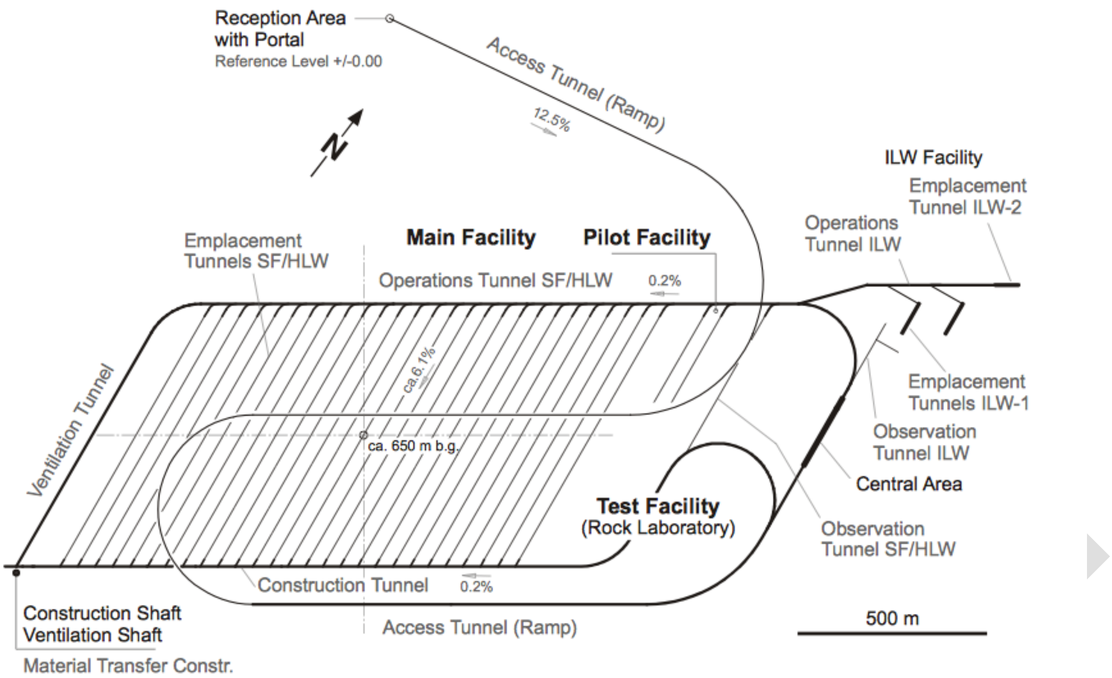


Figure 2.3 : A possible layout for disposal tunnels for SF and HLW in sedimentary rock, envisaged by Nagra (Nagra, 2001b). A small LILW co-disposal vault facility is shown on the right-hand side

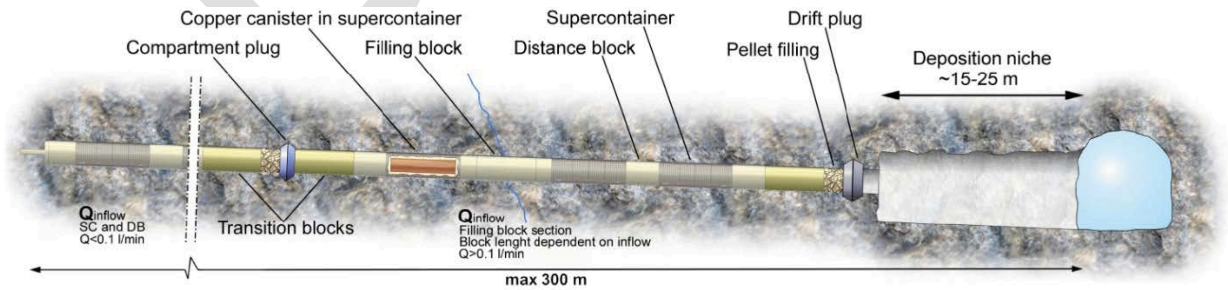


2.4.2 Basement rock model

Although all of the development work for spent fuel disposal in Sweden and Finland that is currently going through the licensing process is based on the so-called KBS-3V (vertical placement) concept, there is considerable interest in SKB (Sweden) and Posiva (Finland) in the evolved KBS-3H (horizontal placement) concept, because it offers considerable economies of space and excavated rock volume. The engineered barrier system (EBS) concept and the safety case for both systems are similar, and the main difference between them is that 3V uses vertical emplacement of SF packages in boreholes drilled from the disposal tunnel floors (single package in each hole), whereas 3H uses long horizontal boreholes with no effective annulus around the waste packages, which are emplaced in 'supercontainers' that integrate other elements of the EBS.

Here, we assume a similar emplacement model to 3H (shown in Figure 2.4), but with the same mild steel container for SF (and HLW) discussed for the HIC Model, instead of copper, which is one of the main components of the KBS-3 EBS. The option for a supercontainer is left open here, and such decisions would depend on site characteristics.

Figure 2.4 : The KBS-3H disposal concept for SF (from Posiva, 2013).



It can be seen from Figure 2.4 that disposal holes are 100 to 300 m long, with supercontainers separated by about 3 – 5 m with bentonite distance blocks. Longer holes can have plugs at intervals and an end plug isolates each disposal hole from the access tunnel from which it is constructed and operated. Emplacement boreholes are 1.85 m in diameter and 100 - 300 m long, drilled sub-horizontally from a niche in the side of a c.6-7 m section deposition tunnel. Each borehole is designed to take 20 - 30 supercontainers, spaced at between about 7 to 10 m, depending on SF dimensions and thermal characteristics.

Various spacings are possible between the emplacement tunnels. Posiva (Finland) has evaluated spacings of 30 and 40 m. Here we conservatively assume the larger figure, to allow for disposal of higher thermal load (higher burn-up) fuel.

The cost of the copper and mild steel canisters which house the SF at their final position under the HIC and BRC concepts, respectively, vary by a large margin. Each canister holds 2 tU of spent fuel, and is proposed to be fabricated off site and delivered to the location of the GDF in South Australia, most likely at the same time as the SF travels from the ISFS under the complete solution scenario. The estimated costs of the canisters, derived from overseas cost estimates, is as below in Table 2.4.

Table 2.4 : Estimated disposal canister costs per unit (AUD2015)

Canister type (2 tU capacity)	Estimated cost / unit (delivered) AUD2015
Copper	320,000
Steel	50,000

In order to remain appropriately conservative in the face of uncertain siting characteristics, the cost modelling undertaken for the encapsulation and GDF emplacement has presumed the use of copper canisters, noting that this may potentially overstate the recurrent (materials) cost by a large margin, depending on the final rock formations and isolation concept which is selected in practice.

The overall appearance of a basement rock GDF, with associated underground rock characterisation facility (URCF) can be seen in Figure 2.5 (below), which shows the Finnish Olkilouto disposal complex and the associated ONKALO facility that was recently licensed for further extension into the national SF repository. The system of shafts and incline to access and ventilate the GDF are shown, along with the central work area and the ‘panels’ of tunnels for disposal of the SF containers. The ONKALO URCF that has been used to gain in-situ geological information and allow tests and experiments all the way down to disposal depths (to support design and safety case development for licensing purposes) comprises the access ramp, some of the shafts and part of the central tunnel area at the base of the access region. Note that this illustration is for the KBS-3V emplacement concept. Figure 2.5 shows the layout for the KBS-3H concept. The access ramps, first shafts and much of the central work area have already been constructed as part of the initial URCF stage.

Figure 2.5 : Illustration of the planned SF repository at a depth of 400-450 m at Olkiluoto in Finland. (Source: Posiva website, Finland and Posiva 2011).

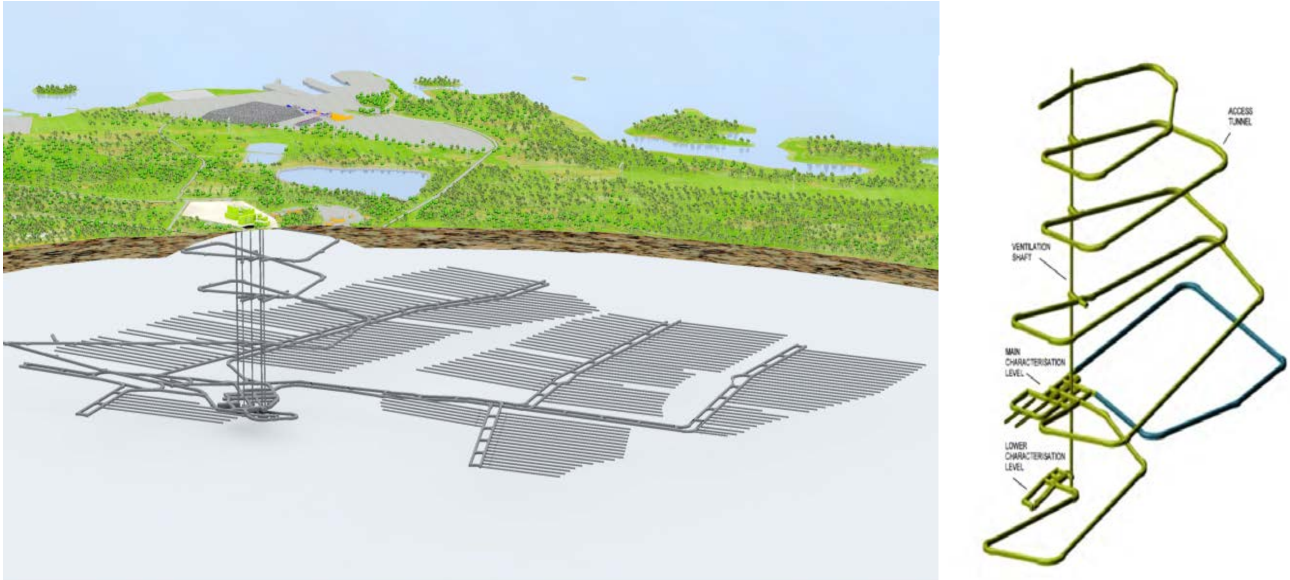
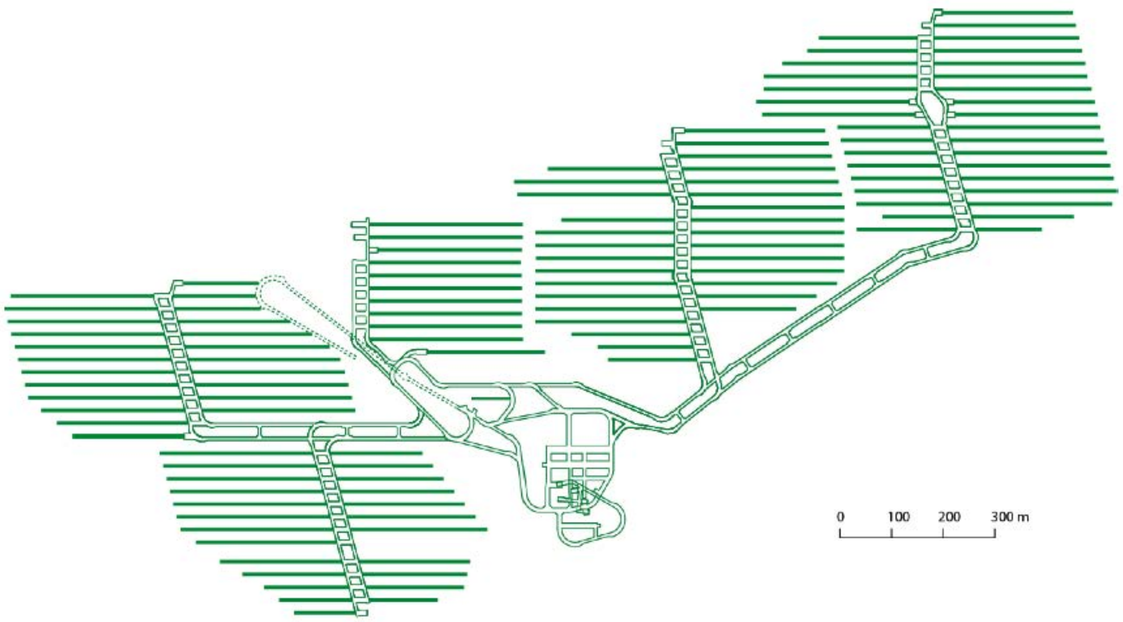


Figure 2.6 (below) shows one possible layout that would accommodate the KBS-3H concept at the site, illustrating how geological features such as major fracture zones control the geometry of the panels of disposal tunnels and access routes. Note that the layout is strongly influenced by the presence, location and dimensions of major fracture zones in the rock. In less complex geological environments (e.g. in some sedimentary formations), a simple layout would be feasible. Emplacement boreholes (drifts) are 25 m apart with a maximum length of 300 m and are accessed from parallel 'central tunnels' (20 m apart) which permit working on both sides at once. Common deposition niches (see Figure 5) are formed by the short connecting tunnels between the central tunnels. In this model, with space for 3102 waste containers, there are 122 emplacement drifts with a total length of 31.5 km, utilising a total length of 9.2 km of central tunnels. The excavated volume of the emplacement drifts is 84,800 m^3 and of the central tunnels 441,000 m^3 (Posiva, 2013).

Figure 2.6 : Plan view of a KBS-3H layout at disposal depth for the Olkiluoto site (Posiva 2013).



2.5 Design features of the GDF for intermediate level waste (ILW)

Intermediate level waste (ILW), sometimes referred to as long lived intermediate level waste (LILW), is generated in various sectors of the nuclear fuel cycle. For countries with no other fuel cycle facilities, the main sources of arisings are nuclear power plant (NPP) operations and decommissioning. Some countries separate these wastes into shorter-lived LLW and longer-lived or more active ILW and route them for near-surface and geological disposal respectively. Others, such as Sweden and Finland, route all operational wastes and much eventual decommissioning waste for underground disposal in various facilities (both operating and planned) at depths of between 50 and 250 m. Here, we assume that a co-disposal facility could be flexible in terms of capacity to take the majority of the ILW if required and emplace them in medium-depth vaults (e.g., at around 200 m depth). Some user countries might have surface disposal facilities that would take the lower activity and shorter lived components of their operational and decommissioning wastes and might only want to send the components that are best handled by geological disposal to an international facility.

2.5.1 ILW high isolation concept (HIC)

The conceptual model used here is based on that developed by Nagra (Swiss) for use in the relatively strong Opalinus clay formation. It comprises concrete lined caverns with internal concrete structures to hold LILW packages as shown in Figure 2.7. Larger caverns might be practicable, depending on the host rock properties and depth and we assume here that c.9 m wide x c.11 m high internal dimensions, with a 30 cm liner, could be feasible (a model being evaluated in the current UK programme). This concept is shown Figure 2.8 and the dimensions are those that are used in the scaling approximations of Section 2.6.

Figure 2.7 : The Nagra concept for LILW vaults in the Opalinus clay, showing disposition of different package dimensions (Source: Nagra, 2001b).

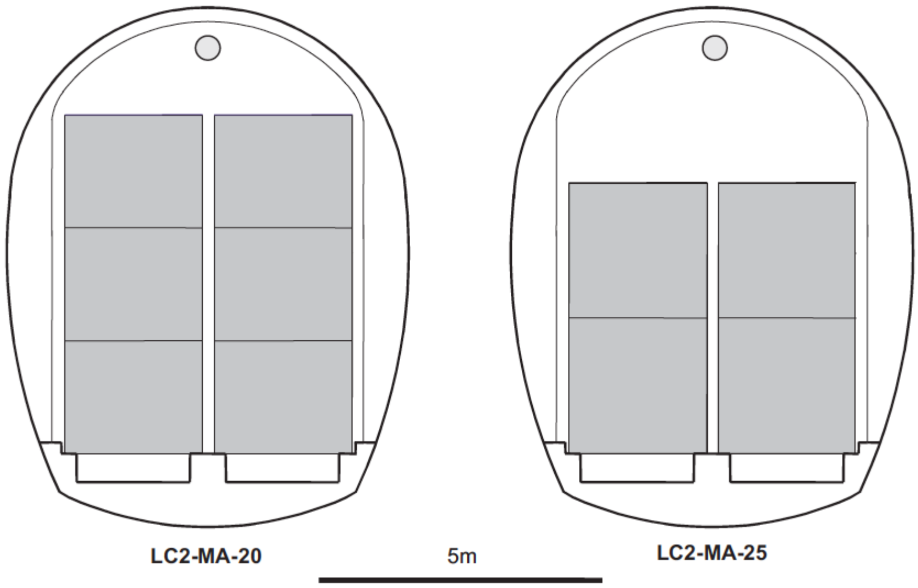
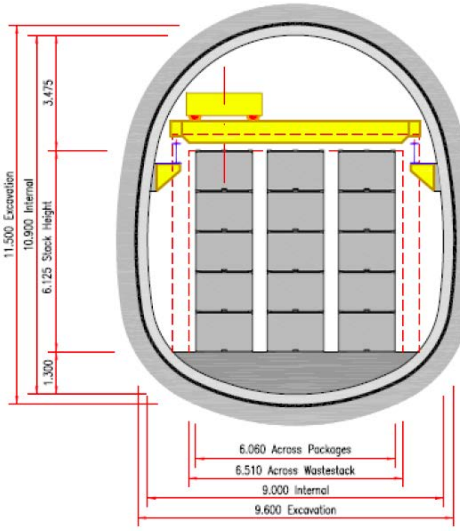


Figure 2.8 : Cross-section of the UK concept for a vault in lower strength sedimentary rocks to contain unshielded ILW packages. The waste packages would be emplaced by overhead crane. (Source: NDA, 2010).



Larger caverns provide flexibility to handle a range of package dimensions. We assume that the operators would define a standard set of package sizes that could be suitable for all potential users.

2.5.2 ILW basement rock concept

Figure 2.9 and Figure 2.10 shows a cross-section of the concept developed over many years in the UK for vault disposal of ILW in hard basement rocks. The waste packages would be emplaced by fork-lift vehicle. (Source: NDA, 2010). The UK has a large inventory of ILW requiring geological disposal, much of it generated by the reprocessing of nuclear fuel.

Figure 2.9 : Cross-section of the UK concept for a vault in basement rocks to contain shielded ILW packages, emplaced in 4m boxes.

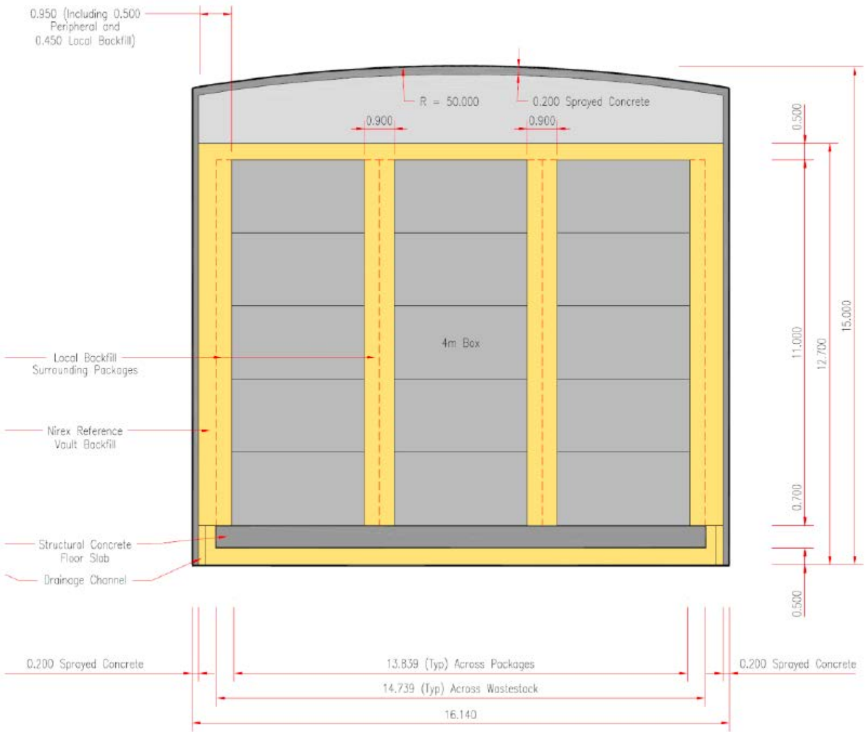


Figure 2.10 : Artist's concept for a vault for unshielded ILW packages, emplaced by overhead crane. The dimensions of the cavern are the same as those for shielded ILW shown in Figure 9 (Source: NDA, 2010).

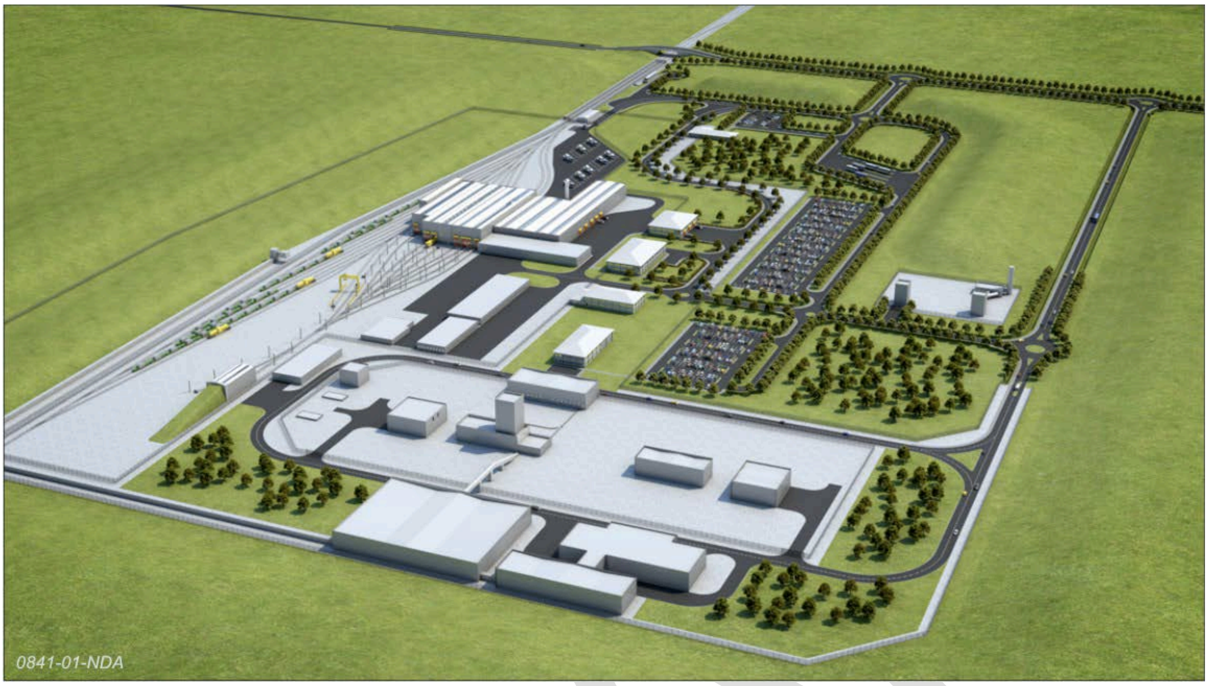
In the UK concept, the caverns are stabilised with standard rock support systems for hard rock excavations (e.g. bolts, mesh, shotcrete) with additional concrete structures to allow movement of packages and vehicles. The voidage between package stacks is filled with a cementitious backfill. The excavated dimension is approvimately16 m x 16 m and individual caverns could be some hundreds of metres in length, depending on geological conditions.

An alternative to caverns for some categories of higher activity ILW is to use concrete-lined vaults in cylindrical silos.

2.5.3 GDF surface facilities

Figure 2.11 (below) gives an indication of the scale of surface facilities that would be required at a GDF site. It shows both road and rail access to the facility, shaft headers, waste reception and other infrastructure.

Figure 2.11 : Artist's rendering of the surface facilities for a co-disposal (HLW and ILW) GDF (Source: NDA, 2010).



2.6 Cost benchmarking for GDF

2.6.1 Scaling approximations

Using the conceptual designs outlined above, scaling approximations can be made that relate the variables related to disposal volume to m^3 of ILW and tonnes uranium (tU) of SF that might be emplaced in a co-disposal (HLW and ILW) GDF. This allows the variable costs for inventory scenarios of different sizes to be calculated. Compared to SF volumes, HLW amounts are relatively small and would be a small increment on the space requirements for SF. They are not included in the approximations given below.

For SF, the approximations assume that all fuel assemblies (FAs) are contained in 5 m long overpacks with outside diameter (OD) of 1.05 m that are spaced at an average centre-to-centre distance of 9 m. These values are conservative in that smaller packages will be feasible for some FAs (some slightly longer containers may also be needed) and closer spacings may be possible, depending on thermal characteristics of the fuel and the host rock. For the purposes of these approximations, each SF container holds 2 tU.

For ILW, a range of standardised package sizes could be used. The approximations assume that the space utilisation rate (i.e. ratio of packaged waste volume to backfill, liners, concrete structures and other vault furniture) is about 0.35 for the HIC concept and 0.5 for basement rock concept, although unshielded ILW packages handled remotely by overhead crane in the basement rock concept could have a lower utilisation ratio of around 0.4.

Table 2.5 below shows the approximate scaling factors that can be applied based on these assumptions for the two geological environment cases of the HIC and the basement rock concept (BRC). 'Central tunnel' refers to the tunnels that connect the emplacement tunnels or vaults and not the main access to the GDF and its central facilities. These are assumed to be an average of 7 x 7 m in size for both host rock concepts.

Table 2.5 : Scaling volume approximations per tU Sf and 100m3 of LILW

	HIC		BRC	
	HLW / SF	ILW	HLW / SF	ILW
Emplacement tunnel / vault length (m)	4.5	3.1	4.5	0.8
Emplacement tunnel / vault volume (m^3)	22.1	308.2	5.1	196.4
Central (spine) tunnel length (m)	5.3	0.5	0.8	0.1
Central (spine) tunnel volume (m^3)	261.3	25.4	40.8	6.2
Total excavated length (m)	9.8	3.6	5.3	0.9
Total excavated volume (m^3)	283.4	333.6	45.9	202.6

It should be noted that these approximations do not consider additional shaft or ancillary works that may be needed if the GDF reaches a certain size.

2.6.2 GDF costs from analogous international programmes

Cost estimates of geological disposal have been made by most national programmes. These vary in many ways and can be difficult to compare but, together, provide the most direct means of estimating costs for the SA project under consideration. National cost estimates are made regularly and published in some countries (e.g. Sweden) because the outputs are needed to underpin legal requirements for setting fees for the national waste management funds. Other programmes have made few or irregular estimates (e.g. UK, CH, F) and the detail of many of these are unpublished and difficult to access – only the high level numbers are in the public domain. In the UK, the government has not only made a cost estimate for the disposal of SF, but has used this to establish a final price and cap that it would use to charge the operators of new NPPs to dispose of their wastes in a national GDF. The approach (DECC, 2010) incorporates both an ‘optimism bias’ (on the cost estimates) and a ‘risk fee’ into the prices and assigns some of the fixed costs of building the national GDF for legacy wastes to the future users at new NPPs.

Because the details of the estimates are not always available, it is not possible to compare costs precisely and attention should thus be focussed on the main components. Even here, the cost headers used by each national programme include different items, calculated in different ways. For example, as many programmes have been trying to develop GDFs for decades, past R&D, management and siting costs are included in different ways in headline cost items. EDRAM, the association of national waste management agencies, have tried to establish a common system for cost comparison (EDRAM, 2012), but there is no evidence that it is yet in widespread use.

This Section brings together the most recent and relevant GDF cost estimates to illustrate the potential costs that the SA project would have to manage. These data are then extrapolated to give a range and median values of cost per tU for disposal of SF and per m^3 for disposal of ILW in the GDF. These figures can then be used in scaling cost estimates for GDFs for different sizes of SF and ILW inventory.

2.6.3 Spent fuel and HLW disposal costs

The data sources used for evaluating HLW / SF disposal costs are:

- Sweden: Plan 2013: relevant for the basement rock concept model (SKB, 2014).
- Finland: 2005 Cost estimate for the SF repository at Olkiluoto: relevant for the BRC model (Posiva, 2005).
- Switzerland: 2011 cost estimate for HLW / SF disposal: relevant to the HIC model (SwissNuclear, 2011).
- UK: Government pricing model for new build SF disposal (DECC, 2010).

The Swedish data (past and future costs) for the spent fuel repository to be constructed at Forsmark, on the Baltic Sea coast are shown in the Table below, converted to 2015 values and then to AUD. The Forsmark GDF will contain about 12,000 tU of SF.

Table 2.6 : Swedish SF benchmark cost data (Forsmark) per tU

Item	Cost (MSEK)	MSEK 2015	AUD 2015 million
GDF for c.12,500 tU spent fuel			
Siting & permitting	4,338	4,204	723
Construction	17,130	16,599	2,855
Operation	5,930	5.746	988
Closure	5,690	5.514	948
Total	**33,088**	**32,062**	**5,515**
Encapsulation plant for SF (EncP)			
Construction	4,838	4,688	806
Operation	11,070	10,727	1,845
Decommissioning	240	233	40
Total	**16,148**	**15,647**	**2,691**
Total cost: GDF and EncP	**49,236**	**47,710**	**8,206**

SKB reports a significant past and future expenditure on the national radioactive waste management programme overall management costs and RD&D, a large part of which can be assigned to the spent fuel disposal project. The total of these costs at 2015 values would be equivalent to AUD3505 million.

Posiva (2005) provides cost estimates for the SF GDF being constructed at the Olkiluoto site in Finland, which would hold about 9000 tU of SF. These figure were updated to December 2009 values for the top-level cost elements in a 2013 publication (Aikas, 2013), as shown in the Table below.

Table 2.7 : Finnish benchmarked costs of SF disposal (totals)

Item	Cost (MEUR)	MEUR 2015	AUD 2015 million
Above ground construction	150	165	264
GDF & ONKALO (URCF) construction	550	604	967
Operate encapsulation plant	1.200	1.318	2.109
Operate repository	630	692	1107
Disposal canisters	580	637	1.020
Transport	20	22	35
Dismantle and manage wastes	10	11	18
GDF closure	190	209	334
Total	**3.330**	**3.656**	**5.854**

The data from Switzerland cover both SF disposal and vitrified HLW from that portion of SF that has been reprocessed and which will be disposed of in similar containers along with the SF.

The amount of SF involved is the equivalent of about 3850 tU, which includes the 771 tU that have been sent for reprocessing and returned as HLW (with a consequent reduction in the total packaged volume of HLW / SF for disposal, which is currently estimated to be about 7300 m^3). It can be seen that the Swiss cost estimates include other items to those from Sweden and Finland, such as transport container management.

The anticipated operational period of waste emplacement for the HLW / SF GDF (and the ILW GDF: see next Section) is 15 years, followed by a period of 50 years of monitoring, after which the repository is finally closed.

Table 2.8 : Swiss benchmark costs for SF disposal

Item	Cost (MCHF)	MCHF 2015	AUD 2015 million
HLW / SF (HAA / LMA) GDF			
Siting & permitting	439	432	626
(Underground) rock lab: construct & operate	918	903	1,309
Repository construction	1,077	1,059	1,535
Operation	884	869	1,261
Monitoring	998	982	1,423
Closure	229	225	326
Total	**4,546**	**4,470**	**6,481**
HLW / SF encapsulation plant			
Siting & permitting	9	9	13
Rock lab: construct & operate	36	36	52
Construction	715	703	1,020
Operation	634	624	904
Monitoring	22	21	31
Total	**1,416**	**1,393**	**2,019**
Cleaning HLW / SF storage / transport containers			
Construction	120	118	171
Operation	107	105	153
Monitoring	3	3	5
Total	**231**	**227**	**329**
Grand total	**6,192**	**6,089**	**8,829**

In summary, the three models selected above indicate total GDF costs for disposing of the national SF inventories of between about AUD 6 and 9 billion. To these figures must be added both capital and operating transport costs and project management cost, plus any necessary R&D costs, although it is considered that advantage can be taken of the considerable amount of international R&D that has been completed over the last 40 years and is now deployed in project implementation.

The above data have focussed on GDF costs. The UK government is unique in having looked at pricing of SF disposal. In the UK, a national GDF is to be constructed for the >60 years of 'legacy wastes' that have accumulated from the development of nuclear power. This will be state-owned and operated. The government will then sell a disposal service to the operators of new NPPs that are to be built in the future. DECC took national costs estimates and developed a pricing model that is based on best estimate disposal costs produced by the Nuclear Decommissioning Authority. DECC (2010) reports illustrative worked examples for SF disposal costs, consequent price to users and the price cap, as shown in the Table below, which also shows the values inflated to 2015 levels and converted to AUD.

Table 2.9 : UK modelled pricing for disposal of SF, per tU (£2010 converted to AUD2015)

Item	Total cost	Expected price	Cap
Million GBP per tU	0.312	0.600	0.978
Inflated to 2015 (14.5%)	0.365	0.701	1.143
AUD 2015 million (at 2.18 / GBP)	0.795	1.528	2.491

The above data, plus less formal cost estimates, can be evaluated and interpreted to arrive at a range of costs for disposal of SF on a per tonne basis. Table 2.10 below shows the range of values derived from this analysis, along with an average value.

Table 2.10 : Average SF costs per tonne (whole of life)

Country	Cost per tU AUD 2015 million
Switzerland	2.434
Sweden	1.128
Finland	0.650
UK (DECC)	0.795
UK Jackson low*	1.149
UK Jackson high*	1.525
Korea**	0.452
Average	**1.162**

*The figures for 'UK Jackson' are from a study carried out after the DECC consultation, on behalf of Greenpeace, which disagreed with the DECC study basis (see: *'Estimating the disposal costs of spent fuel' Nuclear Engineering International, October 2011, 45-46*).
**See Kim and Choi, 2006. This study was based on the Finnish costing approach and carried out in collaboration with Posiva.

The average GDF disposal cost of about AUD1.2 million per tU (including capital and operational costs, closure and rehabilitation or decommissioning costs) provides an illustrative benchmark figure for this project.

This figure can be cross-checked against a recent comparative study carried out by the OECD Nuclear Energy Agency (NEA, 2013), which cites the spent fuel disposal costs estimated in a range of studies aimed at looking at the costs of different fuel cycle options. The studies included estimates for geological disposal of spent fuel and were carried out between 1994 and 2011. The nominal costs are shown in the table below (uncorrected for time of estimation but converted to AUD at a rate of 1.4).

Table 2.11 : Averaged cost of SF disposal (per tU), NEA 2013

Study cited*	Cost per tU AUD million
AFCI (2009)	1.431
MIT (2011)	0.687
NEA (1994)	1.187

Study cited*	Cost per tU AUD million
NEA (2006)	0.918
Rothwell (2011)	0.308
Harvard (2003)	0.661
BCG (2006)	1.054
Oxford (2011) Low	0.554
Oxford (2011) High	2.775
Average	**1.064**

*see NEA, 2013 for source references

Although the average value does not take account of the uncorrected nature of the figures, it is close to the values derived from the analysis carried out in this report and gives support to the bench-mark figure suggested above.

The figures also show a somewhat wider range than derived here. The 2013 NEA study made its own estimates for encapsulation and disposal costs. The 'reference' and 'high' NEA data are interpolated and extrapolated to the 'low' inventory of 65,000 tU used in this study in the Table below. The 'low' inventory is used here as it lies mid-range in the NEA study and also relates most closely to the normalised 60 year GDF operational period assumed by NEA.

Table 2.12 : Reference costs for SF encapsulation and GDF disposal (NEA, 2013)

	Reference cost / tU AUD2015 million	'High' cost / tU AUD 2015 million
Encapsulation	0.183	0.213
GDF disposal	0.386	0.861
Total	**0.569**	**1.074**

The reference cost is considerably lower than the bench-mark value identified in the current study, which is closer to the 'high' value estimated by the NEA, and is also at the lower end of the values that NEA has cited from other studies (whereas its 'high' value is close to the 'average' of these studies, shown above). The reasons for this are not clear, but could relate to whether siting, R&D and other costs have been included. NEA also points out the large uncertainties in this type of comparison, noting that *"A synopsis of all the differences between the studies and models is very difficult, especially considering the differences in scenario definitions and various underlying assumptions"*.

2.6.4 ILW disposal costs

The Swedish data are only those for the future costs of the SFL repository for ILW (mainly reactor core and other decommissioning components) that will be located at a depth of about 200 m at an, as yet, undecided location. The cost values are for disposal of about 16,000 m^3 of wastes and are presented as for the Swedish SF data in the table below.

Table 2.13 : Benchmark Swedish cost data (ILW)

Item	Cost (MSEK)	MSEK 2015	AUD 2015 million
Construction	860	833	143
Operation & maintenance	280	271	47
Closure	380	368	63
Total	**1520**	**1473**	**253**

The Swiss data are for a separate GDF for ILW, with the same operating and pre-closure monitoring periods as for the Swiss HLW / SF GDF described above (15 and 50 years). Although both repositories might be co-located, the cost study has assumed that they might have to be independent of each other and thus contains both siting and its own URCF costs.

The volume of packaged waste involved is 59,000 m^3 arising from the NPPs and 33,000 m^3 from medical, industrial and research activities, many of these being outside the nuclear power sector.

The cost figures shown in Table 2.14 below are strikingly different from those of the Swedish programme. This is likely to be because the Swedish estimates contain no element for siting the facility and no URCF.

Table 2.14 : Benchmark Swiss (NAGRA) cost data for ILW and GDF construction

Item	Cost (MCHF)	MCHF 2015	AUD 2015 million
ILW (SMA) GDF			
Siting & permitting	336	330	479
Rock lab: construct & operate	600	590	856
Repository construction	577	567	822
Operation	480	472	685
Monitoring	701	690	1000
Closure	144	142	205
Grand Total	**2839**	**2791**	**4047**

The UK pricing data from the DECC study discussed above are based on the same assumptions as for SF disposal: that a national GDF for legacy wastes would offer a disposal service to new-build NPP operators for disposal of their operational (and eventual decommissioning) LILW. Table 2.15, below, shows the estimated costs of disposal of such wastes and a worked example of the consequent price and cap that might be applied.

Table 2.15 : UK benchmarked costs for ILW disposal, per m3

	Total cost	Expected price	Cap
kGBP per m^3	14.50	25.90	48.40
Inflated to 2015 (16.85%)	16.94	30.26	56.56
AUD 2015 thousand (2.18 / GBP)	36.94	65.98	123.29

As for SF and HLW, the above estimates can be combined to give an overview of the GDF costs per m3 for disposal of LILW, which are shown in the Table below.

Table 2.16 : Average European and UK benchmark costs for the management of ILW

Country	Cost per m^3 AUD 2015 thousand
Switzerland	43.99
Sweden	15.83
UK (DECC)	36.94
Average	**32.25**

The considerable skew in the costs between the Swedish, compared to the UK and Swiss estimates, is evident. As discussed above, this is likely to be because the UK and Swiss estimates include the siting and URCF activities. The average value shown above of about AUD32.3 thousand per m^3 is thus likely to be a conservative benchmark figure for this project.

2.6.5 European shared repository cost data

In 2008, the SAPIERR project carried out for the European Commission completed a study on the feasibility and implications of several European countries sharing a multinational GDF for HLW / SF and ILW. Part of this study was an economic analysis that used previous versions of the national data sources discussed above and developed scenarios for a co-disposal GDF in different host rocks, with costs scaled according to different total inventory assumptions (Chapman et al., 2008). Scaling was carried out by making assumptions as to the split of fixed and variable GDF costs within the source data. The scaling assumptions are shown in the Table below:

Table 2.17 : European data and fixed / variable cost factors[6]

Swedish data		Finnish data		Swiss data	
Cost item	F / V ratio	Cost item	F / V ratio	Cost item	F / V 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

*the above ground facilities and operations are dominated by encapsulation

The table below abstracts the SAPIERR scenarios that are relevant to the current project and shows the estimated costs for a co-disposal GDF to hold the above inventory, and the associated encapsulation plant, showing the differences resulting from host rock and data source. The 2006 data have been inflated and expressed as AUD2015 in the right-hand column using a notional (i.e. not country specific) EUR inflation rate of 12.5%.

[6] The reference SAPIERR inventory (waste production to 2040) was 25,637 t spent fuel (SF), 355 m^3 vitrified high level wastes (HLW) and 31,000 m^3 long-lived intermediate level wastes (ILW). This is considerably larger than the Finnish, Swedish and Swiss inventories of SF.

Table 2.18 : SAPIERR scenario outcomes adapted to the Australian context

Scenario	Total cost MEUR 2006 values	Total cost AUD 2015 million
Hard rock repository, using Swedish and Finnish data	8170 (S) 9690 (F)	14,715 17,542
Sedimentary rock repository, using Swiss data	8330	15,003

These costs, are 2 or 3 times greater than the current cost figures for national SF GDFs. This reflects the larger SAPIERR inventory and the inclusion of an IDR for the ILW to form a co-disposal facility. They are also based on national estimates that are now more than 10 years old.

2.6.6 Commentary on GDF costs

The cost values presented in Section 2.6 are useful indicators of the scale of costs for constructing, operating and closing a GDF. They can also be used to make a first order estimate of costs for different sized inventories, which can be compared to more detailed analyses that look at specific cost components in an Australian context.

Bearing in mind that the inventories vary, the range of costs for a GDF for HLW / SF is from about 6 to 9 billion AUD and the cost of a separate GDF for LILW is in the range 0.25 to 4 billion AUD, but the two national values have markedly different inventories (a factor of about 6). Siting and permitting costs (which are currently included in some of the national estimates here and are accounted for separately in this project) amount to less than 10% of the costs. The higher SAPIERR co-disposal GDF costs, which range from 14 to 17 billion AUD, reflect the larger inventory of HLW / SF.

The average unit costs of disposal can be used to make a first estimate of the GDF costs for the reference inventories developed for the current project. These are shown in the Table below.

Table 2.19 : Averaged unit costs for disposal, applied as a top-down estimate for the Australian SF, ILW context

	SF (tU)	Avgas cost / tU AUD 2015 million	Cost AUD 2015 million	ILW (m^3)	Avg cost / m^3 AUD 2015 million	Cost AUD 2015 million	Total AUD 2015 million	SF / ILW cost ratio
Baseline	138,000	1.162	160,356	390,000	0.03225	12,578	172,934	93%
Upper case	207,000	1.162	240,534	590,000	0.03225	19,028	259,562	93%
Lower case	69,000	1.162	80,178	195,000	0.03225	6,289	86,467	93%

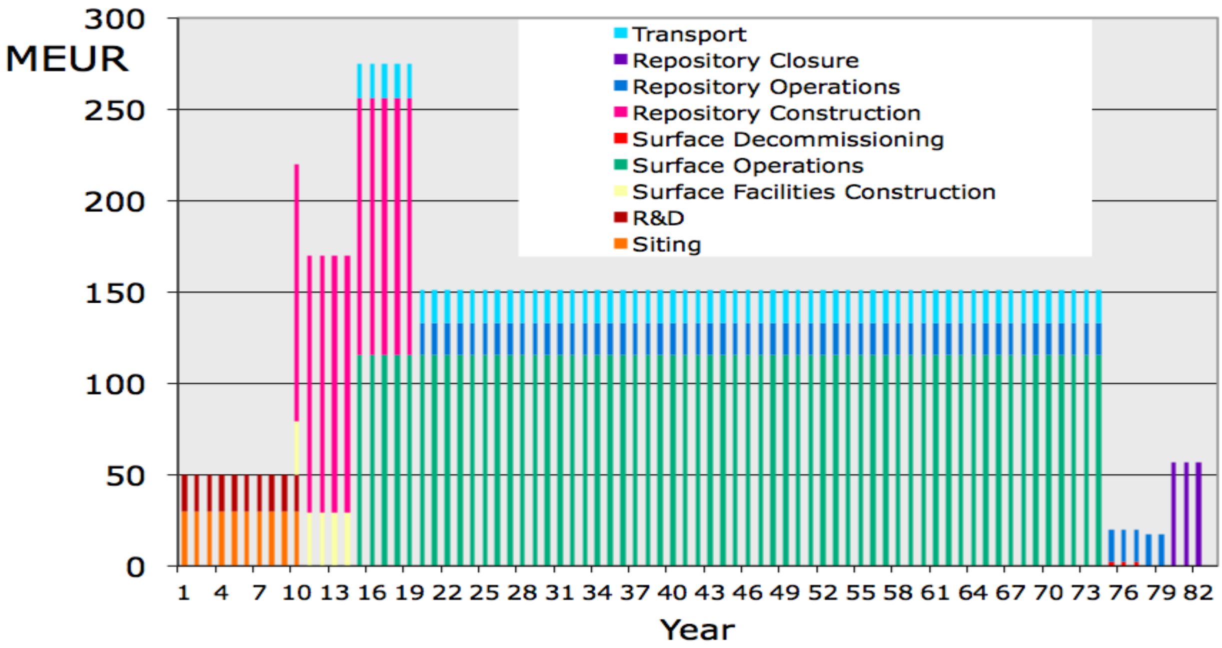
A number of points can be made about these figures:

- SF disposal costs dominate the total at about 93%, regardless of case;
- the figures are considered conservatively high, as there are likely to be economies of scale that have not been taken fully into account: the average unit costs include a relatively high percentage of fixed costs from the national examples used, owing to their relatively small SF inventories;
- the average SF costs incorporate a range from AUD0.65 to 2.43 million per tU: owing to the dominance of SF costs, even small changes to the cost per tU has a considerable effect on the GDF total (e.g. the lower value, from Finland, reduces the total baseline cost from AUD163 billion to 96 billion.

2.6.7 Spend profiles

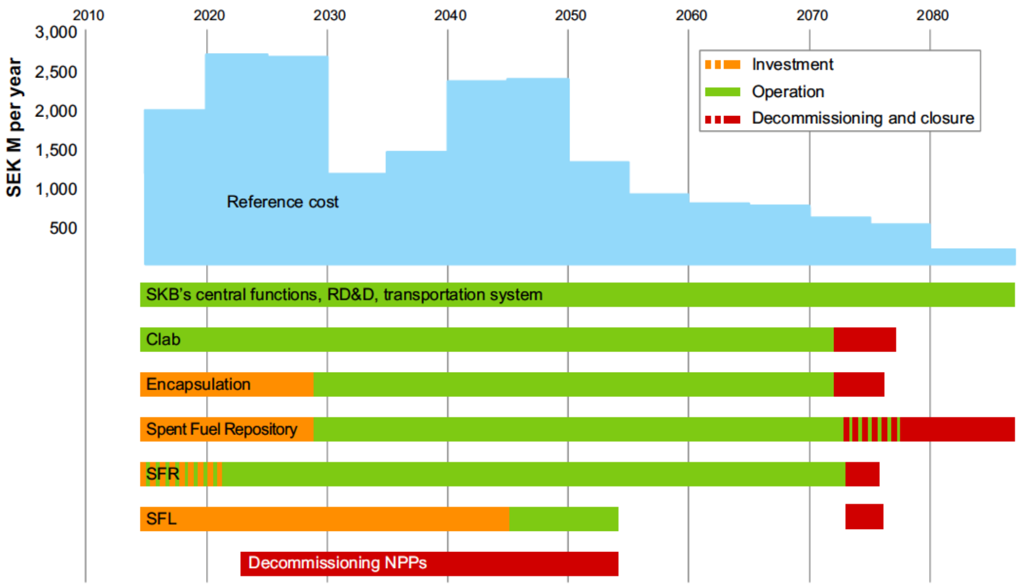
The spend profile on a GDF is uneven over the development, operation and closure period. The SAPPIERR project produced a clear example of how there is an early peak in costs as the initial capital investments are made after a construction license is approved, followed by a long period of relatively high operational costs and a small peak at the time of closure. This is illustrated in Figure 2.12, for the SAPIERR 'large inventory' case.

Figure 2.12 : Modelled Spend profile for the shared European GDF modelled in the SAPIERR project (Chapman et al., 2008)



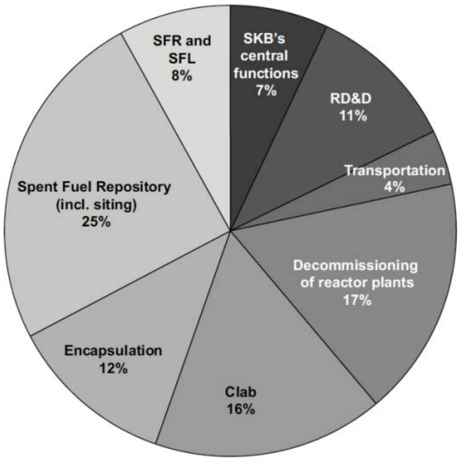
A comprehensive spend profile was developed for the future costs of the Swedish programme, which puts GDF costs in the context of other waste management costs such as transport, storage and NPP decommissioning. Note: Clab is an interim (wet) storage facility for all spent nuclear fuel from Swedish nuclear power reactors, located at Oskarshamn. Figure 2.13 shows a projected future spend profile to about 2090. The high, early investment costs of the GDFs for SF and ILW (SFL), as well as the SF encapsulation plant, are evident.

Figure 2.13 : Projected future spend profile for the Swedish radioactive waste management programme (SKB, 2014).



The division of costs across the whole programme (including headquarters as “SKB’s central functions”, and wet storage prior to disposal, listed as “Clab”) is shown in Figure 2.14, where it can be seen that the SF encapsulation and GDF costs comprise about 37% of the programme costs. The costs for the GDF for ILW (SFL) are combined with those for the existing LILW shallow rock cavern repository (SFR), but still amount to only 8% of the total. It is notable that programme management and RD&D costs together amount to 18% of programme costs.

Figure 2.14 : Division of total costs for the Swedish radioactive waste management programme (SKB, 2014)



2.7 Applicability of benchmark GDF development costs to South Australia

The cost benchmarks above provide useful reference points for the development of a conceptual cost for a GDF (whether HLW, ILW or co-located) by demonstrating the relative costs of different project elements, and how consistent some costs are with respect to scale of waste stored or the scale of operations (units managed per unit of time). As noted above, the annual operating scale and eventual maximal waste stored under the South Australian baseline scenario GDF is far larger than any facility currently in existence, and hence parametric estimation of costs for South Australia requires detailed and clear primary cost data, as well as a reliable means for applying the parametric conversion.

Unfortunately most of the cost benchmarks are silent on either their maximum rate of waste management (which would enable their operational costs to be scaled up or down to suit the South Australian model) or on their length of operations in years (which would also provide insight into annual operating costs), or on their approach to facility renewals (midlife capital injections, etc) nor do most cases provide a clear distinction between costs to develop initial operational capacity and the costs of later expansion(s).

The Finnish (Posiva) case study is the most complete and detailed of the available case studies for GDF development (both capital and operating costs), and together with design insights for ILW management gained from Nagra and other sources, provides the basis for the derived concept costs for underground and aboveground facilities for the South Australian GDF concepts (HLW / SF and ILW).

The development of the GDF costings from the available information is described (in Section 5.11 on page 140).

3. Interim (dry cask) storage facility

There have been proposals in the past for international SF storage for a limited period of time (perhaps decades) with the fuel eventually being returned to the original owners. It is conceivable that some countries (e.g. Taiwan, South Korea, or Italy) that are having current problems establishing national storage facilities could become customers of such a store. Much more plausible, however, is that an international interim storage facility (ISF) would be part of a wider suite of services including perhaps reprocessing and certainly final disposal. In principle, a centralised storage facility could be situated independently of other facilities, with one obviously attractive option being at a port where foreign SF could be received. Another option is at the site of a related spent fuel management facility – e.g. a reprocessing plant, an encapsulation plant of a geological repository. In this report we consider the options – at the receiving port and at a chosen repository site.

It should be noted at the outset that the specifications in the statement of requirement already lead to a narrowing of the range of potential storage concepts. Wet storage in pools (as e.g. at CLAB in Sweden) and dry storage in vaults (as e.g. at HABOG in the Netherlands) are ruled out. The dry cask storage technology proposed is currently becoming the most common method for storing SF; one reason is that this are considered to be safer and easier to secure than are the fuel storage ponds in use at most nuclear power plants. Furthermore, the expensive casks can purchased as and when needed so that large initial capital expenditures needed to implement a large vault or pool storage facility that can accommodate the full inventory that will be stored are not necessary.

Designs for dry storage systems are developing rapidly and a potential Australian facility would be implemented only years into the future. Accordingly, there is little point is aiming today at a detailed cost comparison between commercially available systems. Instead, a brief review is presented of differing concepts and then one of the most advanced and versatile systems is chosen as a reference case. This is the system offered by Holtec. It is also the system selected for the pad-based spent fuel storage facility that was proposed by the company Private Fuel Storage (PFS) for construction in Utah in the USA. A comprehensive EIS was prepared for this facility and two independent cost studies were based on its engineering design.

3.1 Dry cask storage systems

Dry cask storage options may be categorised by the form of waste that they are intended to house (whether SF or HLW), their operational purpose (whether transport, dual use transport and storage or storage only), their method of construction (massive forged metal, concrete, concrete over metal, etc) or their intended orientation (horizontal or vertical).

A summary of the most common permutations of dry cask system is presented in in Appendix A.2, with a number of illustrative examples of the most commonly used systems presented below.

3.2 Illustrative examples of dry storage systems

For each of the technologies, a short description and a pictorial example are provided below in combination with one of the infrastructures.

3.2.1 Dual purpose transport / storage casks

Dual purpose transport / storage casks fall into the general categories, cast metal, massive forged, composite forged and concrete.

Cast metal casks

The only manufacturer of cast metal casks is GNS of Germany whose Castor casks have a body composed of one single casting of ductile cast iron. In order to improve the neutron moderation, axial boreholes are drilled into the cask wall and moderator rods made of polyethylene are inserted. The majority of Castor casks are used in Germany for the storage of SF and HLW glass from reprocessing. The Castor cask is significantly cheaper than massive forged casks.

Massive forged metal casks

In its transport configuration, the forged metal cask TN24 G consists of the following components: a basket assembly which locates and supports the fuel assemblies and provides sufficient neutron absorption to satisfy nuclear criticality requirements, a containment vessel including a closure lid and metallic seals which provides radioactive materials' containment and maintains an inert gas atmosphere, a thick-walled, forged steel gamma shield shell, bottom shield and lid shield plate which provide shielding around the containment vessel, and a radial neutron shield surrounding the gamma shield shell. Figure 3.1 (below) shows a pictorial representation of a TN 24 G Cask and a picture of the external pad storage at Prairie Island in the USA.

The TN casks are, due to their large forgings, very expensive in comparison to other dry storage systems, especially concrete. However, licensing risk is very low and the time required is predictable. Further the capacities of these casks are high, although no higher than those now obtainable in the newest concrete dry storage systems.

Figure 3.1 : TN24G Cask and TN 40 casks on storage pads at Prairie Island (Source: Roland, Samson 2001)

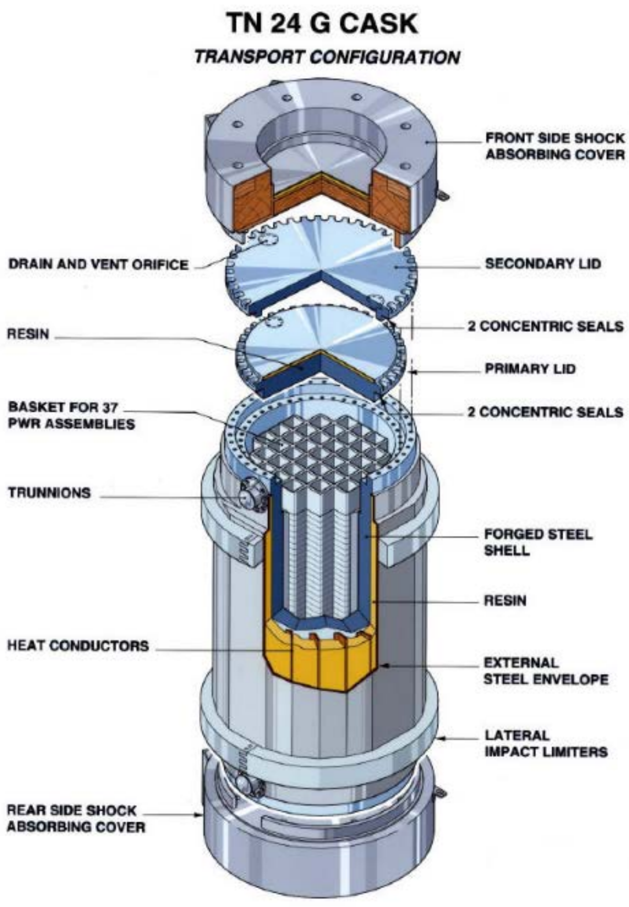


Figure 3.2 (below) shows TN 24 and TN97L casks in robust storage buildings at Doel in Belgium and ZWILAG in Switzerland respectively (Approachv, et al. 1999).

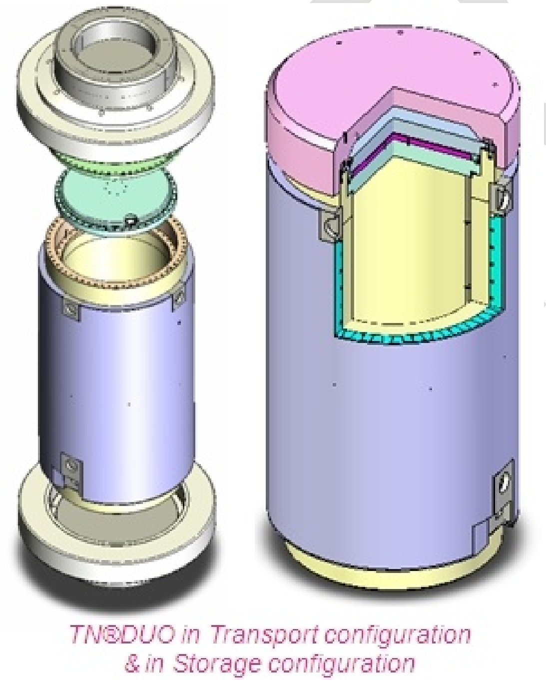
Figure 3.2 : TN 24 and TN97L casks in robust storage buildings at Doel in Belgium and ZWILAG in Switzerland respectively

Composite forged metal casks

This type of cask has only recently entered the market in response to the spiraling costs of the massive forged metal casks. The HISTAR 180 cask has an outer diameter of approximately 2700 mm without impact limiters and approximately 3250 mm with impact limiters. The maximum gross weight of the loaded HI-STAR 180 package is 140 Metric Tons. The HI-STAR 180 cask is due to its composite forgings significantly cheaper than the casks composed of massive forgings. This cask type has high capacity but its thermal limits are lower than those currently being obtained by other casks.

As competition to the HISTAR, TNI has designed a new cask designated the TN DUO (24 to 37 SF assemblies, 65 GWd / t) which is expected to be available from 2015 onwards. The TN DUO concept is for a massive shell composed of several forged pieces. Figure 3.3 shows a pictorial representation of the TN DUO concept [Garcia 2010].

Figure 3.3 : Pictorial representation of the TN DUO concept (Source: TN International)



This type of cask design can be expected to have a similar cost to the HI STAR 180 cask and will cost significantly less than massive forged metal casks although more than concrete storage systems.

Concrete transport / storage casks

The only commercially available dual purpose transport / storage cask that is fabricated out of reinforced concrete is the GNS CONSTOR cask. The CONSTOR concept consists of a sandwich design with an outer and inner shell made of steel. The design does not rely on the concrete for structural integrity. Inside the concrete, steel reinforcement is arranged to improve strength and heat removal properties. Figure 3.4 (below) shows CONSTOR Cask being stored outside at the Ignalina NPP in Lithuania.

The CONSTOR cask, while transportable, has low heat capacity and is very heavy. Much higher capacity concrete storage systems exist where a metal transport cask is used to transport an MPC. Importantly, the transport of this cask type after very long storage periods may not be possible due to the gradual degradation of the reinforced concrete.

Figure 3.4 : Design characteristics of the CONSTOR casks and storage at Ignalina (Image Source: GNS)

3.2.2 Multi-purpose canister (MPC) storage systems: storage separate from transport

In the United States, MPC storage systems are widely used; in these a transferable canister is used to contain the spent fuel and this is then stored either in concrete casks or in above or below ground concrete storage modules. In addition to this TNI have recently introduced an MPC system (TN NOVA – purchased by the Swiss utility KKL for SF storage in ZWILAG) where the storage cask is a simple steel overpack.

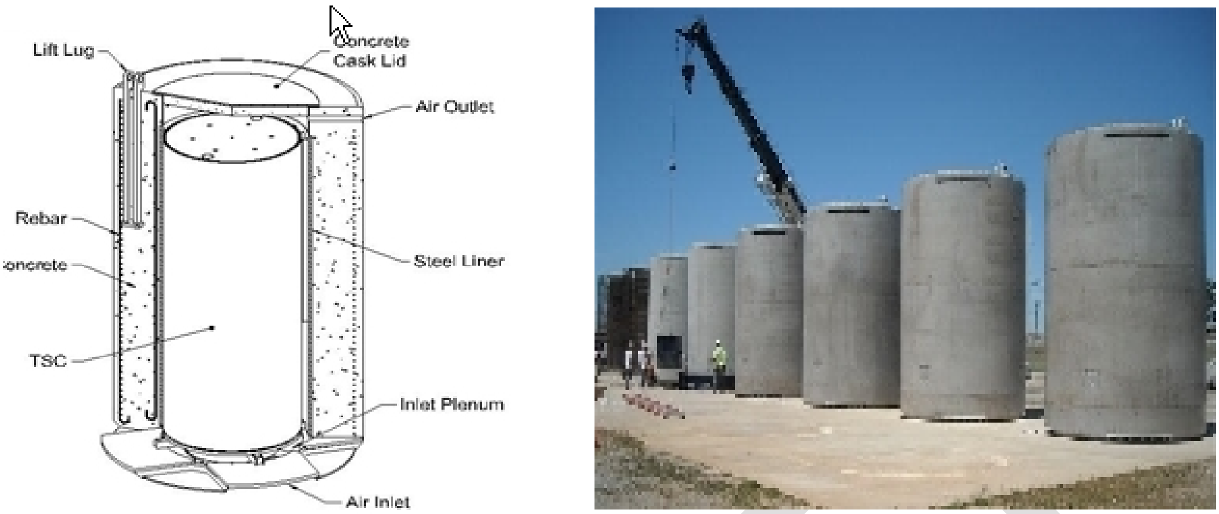
MPC in concrete casks

An example of an MPC in a concrete cask is the NAC MAGNASTOR system. The following details are taken from the NRC Certificate of Compliance. The MAGNASTOR system (the cask) consists of the following components: (1) transportable storage canister (TSC), which contains the spent fuel; (2) concrete cask, which contains the TSC during storage; and (3) a transfer cask, which contains the TSC during loading, transfer and unloading operations. The cask may store up to 37 pressurized water reactor (PWR) fuel assemblies or 87 boiling water reactor (BWR) fuel assemblies.

Figure 3.5 shows a cut away diagram of the Magnastor system as well as a photograph of these casks on a storage pad.

The costs of concrete MPC storage systems are comparatively low and as the transport system is separate from storage this can either be replaced periodically or if storage operations cease for a prolonged period of time then a new transport cask can be purchased and licensed when transport operations restart. This system has high capacity and can accept high heat loads (~ 35.5 kW).

Figure 3.5 : Pictorial representation of the Magnastor storage system and storage on a pad



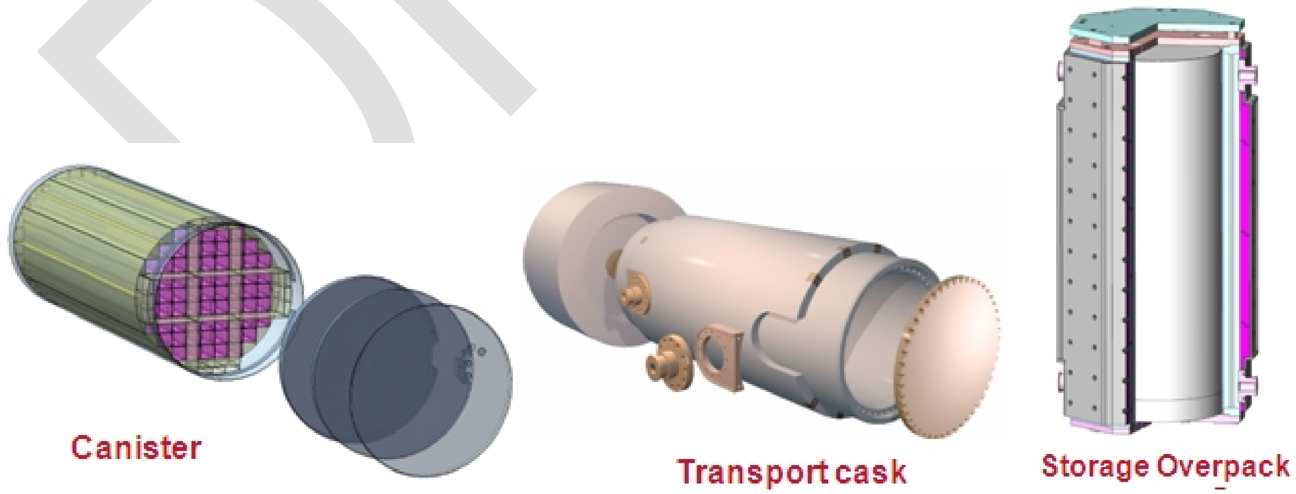
NAC web site: [http: / / www.nacintl.com /](http://www.nacintl.com/)

MPC in simple steel storage over pack

In the TN NOVA concept, the spent fuel is stored inside a welded MPC which is placed in a metallic storage overpack and stored in the vertical position. The MPC is transferred horizontally into the storage over pack and up-righted into a vertical position for storage. No critical lifts are needed outdoors. Operations with the TN®NOVA over pack are equivalent in terms of function and operational sequence to those of the NUHOMS storage module. The PWR version can contain up to 37 SF assemblies with a maximum burn-up of 65 GWd / t and maximum initial enrichment of 5 % U235 by weight.

The TN NOVA cask is a very new and innovative alternative to the massive forged metal casks, with the added benefit that the transport and storage systems are separated by using an MPC but in this case a simple metal over pack is used for storage. This permits storage in robust storage halls where space is limited (concrete casks have in comparison with metal casks a significantly larger diameter to provide the same degree of shielding). Figure 3.6 shows a pictorial representation of the TN NOVA concept [Garcia 2010].

Figure 3.6 : Pictorial representation of the TN NOVA concept (Source TN International)

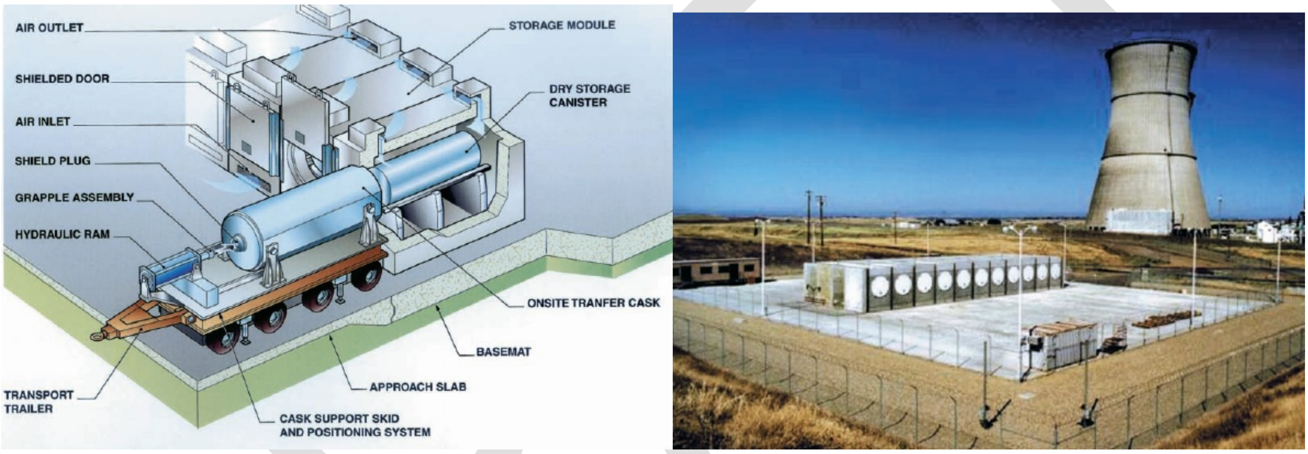


MPC in above ground concrete modules

An example of an MPC in a concrete module is the TNI NUHOMS system. The following details are taken from the NRC Certificate of Compliance for the HD system. The NUHOMS HD System is a horizontal canister system composed of a steel Dry Shielded Canister (DSC), a reinforced concrete Horizontal Storage Module (HSM-H), and a Transfer Cask (TC). The welded DSC provides confinement and criticality control for the storage and transfer of irradiated fuel. The concrete module provides radiation shielding while allowing cooling of the DSC and fuel by natural convection during storage. The TC is used for transferring the DSC from / to the spent fuel pool building to / from the HSM-H. It is designed to hold 32 PWR fuel assemblies.

The costs of concrete MPC storage systems are comparatively low and as the transport system is separate from storage this can either be replaced periodically or if storage operations cease for a prolonged period of time then a new transport cask can be purchased and licensed when transport operations restart. Further, as this system is widely used in the USA, these costs, especially licensing, can most probably be shared over the number of users of the transport cask. This system has high capacity and can accept high heat loads (~ 40 kW). Figure 3.7 shows a pictorial representation of the NUHOMS system as well as a photograph of the system installed at Susquehanna NPP in the USA.

Figure 3.7 : Pictorial representation of the NUHOMS storage system and storage at Susqhehanna NPP



Source: TN Inc web site

MPC in below ground concrete modules

One example of below ground concrete modules is the Holtec HI-STORM 100U underground storage system which is described more fully in the following section. If an underground system is required, the HI STORM 100U certainly has potential. However, in comparison with other aboveground concrete MPC systems the cost is likely to be significantly higher.

3.3 Selection of a dry cask system

3.3.1 General considerations for assessing storage systems

The fundamental safety requirements on a spent fuel storage system are that:

- the radioactive materials are fully contained within the system,
- the decay heat can be safely transferred out of the system at all times,
- there is no possibility of criticality during storage or during any of the handling processes, and
- radiation exposures to workers and the public are minimised, both under normal operating conditions and in case of accidents or malevolent acts.

From these, one can derive specific safety relevant criteria that can be used in the selection of a preferred storage system.

In addition, the selection will be influenced by practical aspects related to

- the variety of potential wastes being received
- the handling operations to be carried on the spent fuel itself and on the any containers needed for transport or storage of the fuel, and
- siting issues including space requirements, geotechnical or environmental restrictions and public acceptability.

Finally, economic considerations will play an important role. To be considered are the following aspects:

- capital costs;
- maintenance costs;
- decommissioning costs; and
- financing requirements and their timing.

An important point when considering storage systems that may end up being operated for many decades is that potential future developments must be taken into consideration. This issue is addressed in IAEA TECDOC 1532 which highlights the issues below.

- **trend to larger cask:** As designers try to load more fuel into a cask, there will be significant increases in their size and weight. This will limit the margins for lifting equipment and ground load. It will also require larger transfer and transport means.[7]
- **trend to high burn-up and mixed oxide (MOX) fuel use:** The current methods employed to handle these fuel types are either to keep them for a longer period to decay in the cooling pool, load them together with lower burn-up or longer cooled spent fuel, or to filling only part of the available spaces at the cost of underrating the cask usage.
- **burn-up credit:** Enhancements in burn-up credit applications are making progress in some countries so that more used fuel may be brought into close proximity.
- **multi-purpose system and standardisations:** The increasing use of casks for dual-purposes and the complications introduced by having a diversity of storage casks (e.g. maintenance of licenses over long time periods) may lead to efforts to produce a uniform container design compatible with diverse package designs.
- **safety and security of spent fuel:** Nuclear safety and security have become a topic of acute debate on nuclear facilities, including spent fuel storage. For this reason, underground options (such as the Holtec Hi-Storm 100U are attracting some interest.
- **retrievability of spent fuel:** Unless multipurpose casks that can also be used for disposal are utilised, consideration needs to be given to fuel retrieval if fuel is to be sent for repackaging at a repository or for reprocessing.
- **licensing issues:** It is conceivable that operators of new facilities may request initial operating licenses for periods beyond the 20 years traditionally approved by regulatory authorities.
- **public acceptance:** Interest in transportation and storage of spent fuel is no longer restricted to the technical experts. Increasingly further stakeholders including the public and policymakers at all levels expect to be consulted.

[7] This also reduces the likelihood that the canister can be emplaced in the SA geology, necessitating repackaging at the encapsulation plant, as assumed in our conceptual operating model

3.3.2 Holtec reference storage system

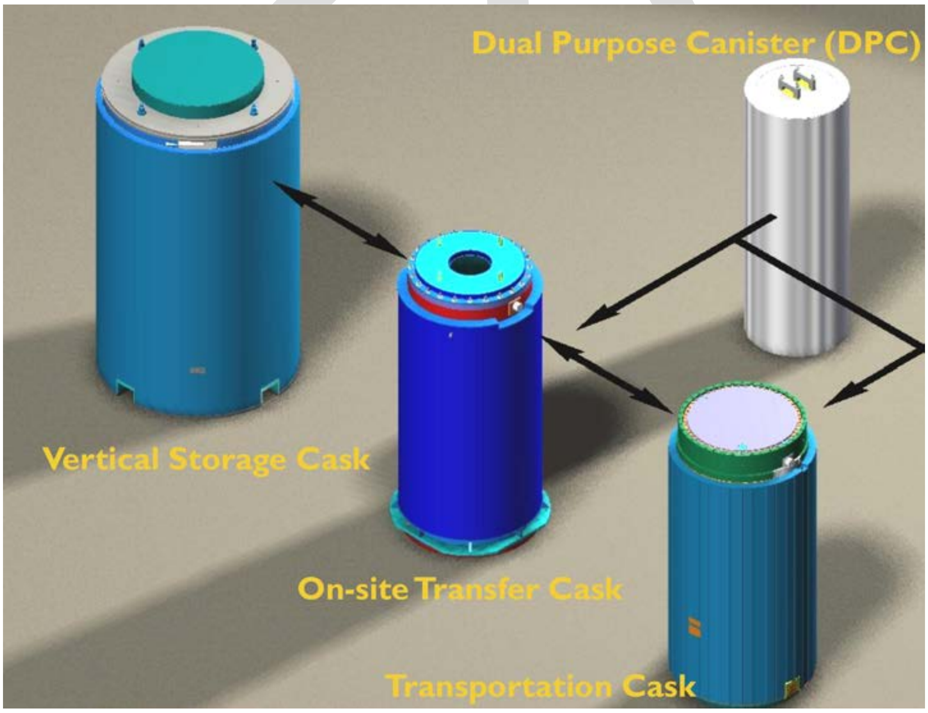
The selection of the most suitable casks for any dry storage facility is best approached via a multi-attribute analysis since this enables a transparent weighting of the key criteria. Typically these criteria can be grouped under major headings, e.g.

- security and safeguards
- engineering simplicity, flexibility and availability
- wastes and decommissioning
- regulation
- societal
- environmental
- economic

For the current concept phase of this study, it is premature to address the problem at this detailed level, however. Furthermore, for an international facility that would receive spent fuel from many clients, a versatile system is of the utmost importance. Accordingly, for this concept study we have selected the Holtec storage systems as an illustrative example.[8] This form of cask is widely used or planned to be implemented in various countries and . The range of Holtec casks is summarised below.

This system is simplified in that the spent fuel is sealed in multipurpose canisters at the power plant. Consequently, during subsequent transfer of these canisters to transport casks and later to storage modules there should be no contamination issues. The MPCs must be shielded during transport and storage. The system envisioned is illustrated in Figure 3.8. It should be noted, however, that a multinational facility offering storage and disposal services to a range of clients would ultimately be compelled to have facilities which include the ability to handle bare spent fuel delivered in transport casks without being hermetically sealed within these casks.

Figure 3.8 : System of casks to be employed (DPC rehoused in several dry cask 'overpacks') Source: Holtec International



[8] Holtec International is among largest vendors of dry storage casks globally and serves over half of the nuclear units in the US (as of 2015). Other significant manufacturers include AREVA ("Transnuclear" in the US), BNG Fuel Solutions, NAC International and Westinghouse.

Holtec HI-STAR 100:

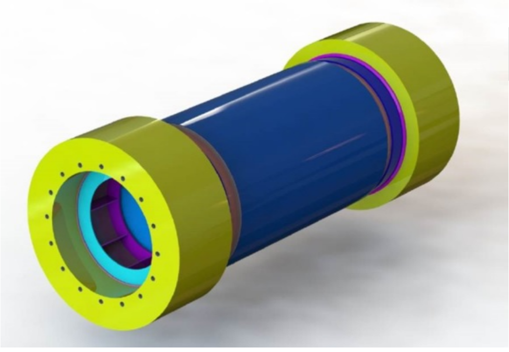
This is the nuclear industry's first high-capacity, multi-purpose canister (MPC) technology-based system which can store the spent nuclear fuel on an ISFS pad, and can also transport a highly radioactive payload over land or water. The HI-STAR 100 transport package is MPC-based and fully compatible with the MPCs licensed for the HI-STORM 100 and HI-STORM 100U systems which are purely for storage. The used fuel does not need to be re-packaged from the HI-STORM 100 overpack for placement in the HI-STAR 100 off-site transportation overpack; the used fuel remains fully sealed in the dual purpose MPC.HI-STAR 100 is engineered to accept one multi-purpose canister containing a 68-cell fuel basket for BWR fuel, a 24-cell flux-trap or a 32-cell non-flux trap fuel basket for PWR fuel. The HI-STAR cask has an outer diameter of approximately 2700 mm without impact limiters and approximately 3250 mm with impact limiters. The maximum gross weight of the loaded HI-STAR 180 package is 140 MT.

Figure 3.9 : HI-STAR cask for storage and transport (Source: Holtec International)

The HI-STAR casks must later be transported to an ISF, an encapsulation plant or a repository.

Figure 3.10 shows a transportation cask designed to transport all Holtec MPCs (multi-purpose canisters)

Figure 3.10 : HI-STAR transport container (Holtec International)



The HI-STAR casks are for transport or for storage. More robust purely storage systems are the HI-STORM systems that can be above or below ground. HI-STORM 100 is strictly a storage device, albeit a rugged and robust one and is a considerably less expensive storage option per unit than HI-STAR, even after allowing for the cost of repackaging. HI-STORM is a vertical ventilated system that promotes passive air cooling of the stored canister.

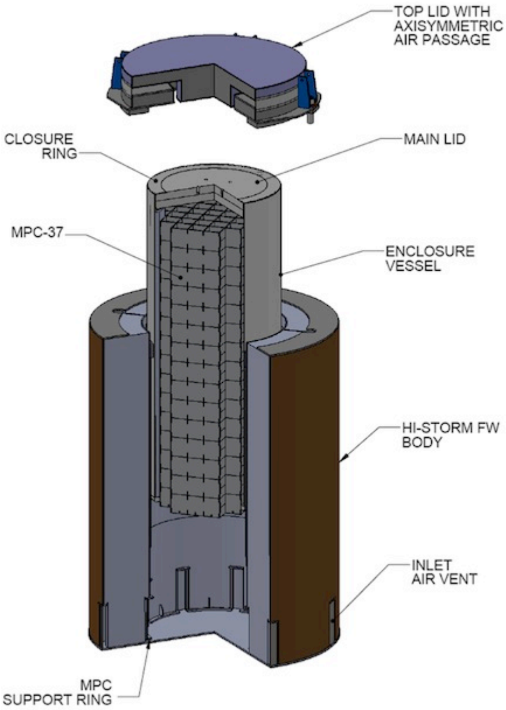
HI-STORM and HI-STAR are entirely modular storage devices; all HI-STAR 100 and HI-STORM 100 components are completely compatible. With an all-structural steel skeleton and twenty-six inches of concrete enclosed in the annular space between two concentric ductile metallic shells, HI-STORM 100 embodies the best attributes of metal and concrete. Unlike HI-STAR 100, however, HI-STORM 100 cannot be placed in the cask pit; loading of the fuel in the MPC must be carried out using another device named HI-TRAC (acronym for Holtec international transfer cask).

Above-ground HI-STORM module

In practically every region of the world, above-ground HI-STORM can be deployed in a free-standing configuration, although the design readily lends to anchoring it to an ISF pad if required. The anchored configuration has been licensed by the NRC under general certification.

The above-ground HI-STORM overpack is a METCON (metal / concrete), heavy-walled cylindrical vessel that consists of inner and outer cylindrical steel shells. These members enclose a thick concrete wall that is installed following assembly of these components. It has a heavy bolted concrete and steel lid.

Figure 3.11 : HI-STORM FW (Holtec International Storage Module Flood and Wind) Image Source: Holtec International



HI-STORM FW is Holtec's highest capacity multi-purpose canister (MPC) system for the dry storage of used nuclear fuel. HI-STORM FW is designed to provide physical protection of the used fuel, radiation shielding, and passive heat removal during interim storage. HI-STORM FW maintains the MPC in the vertical orientation in a concrete overpack; minimizing the size of the ISF and enabling efficient cooling through natural convection. The HI-STORM FW dry cask storage system consists of interchangeable sealed metallic MPCs which contain the fuel; a vertically ventilated storage overpack constructed from a combination of steel and concrete, which contains the MPC during interim storage; and a variable weight transfer cask (HI-TRAC VW) which contains the MPC during loading, unloading, and transfer operations.

Figure 3.12 : HI-STORM 100U (Holtec International Storage Module Underground)

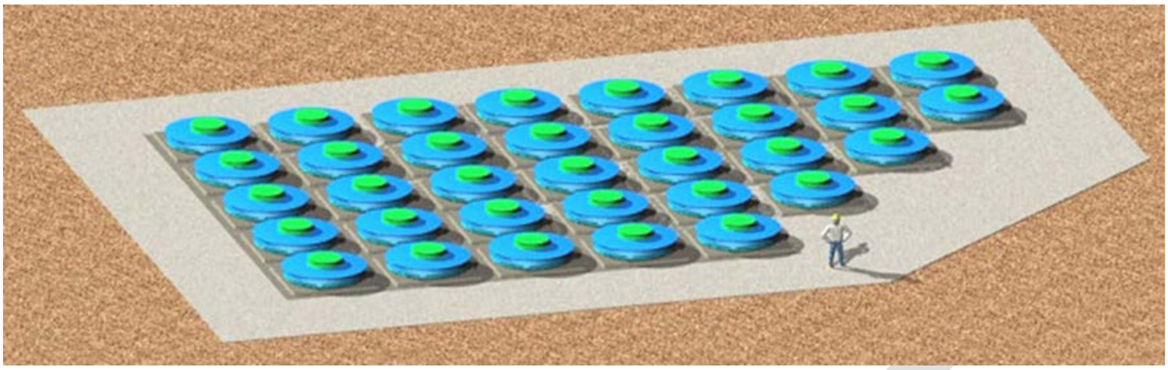


Image source: Holtec Asia

HI-STORM 100U is the underground counterpart of the presently licensed above-ground models – HI-STORM 100 and HI-STORM 100S. The common fuel confinement device used to store fuel and High Level Waste in all HI-STORM models is the Holtec multi-purpose canister (MPC), which is externally identical for storing PWR and BWR fuel, but differs in its internal anatomy depending on the type of fuel being stored. Its principal characteristics are:

- fuel is stored vertically in a strength-welded, all-stainless canister (MPC).
- compatible with all other Holtec dry storage components such that both underground and aboveground HI-STORMs can be deployed at the same ISFSI site using nearly identical loading equipment.
- MPC stored underground and thus made less accessible to threats and hazards of any kind.
- thermal performance is enhanced, not degraded by floodwater intrusion.
- engineered to prevent significant solids deposit in the storage capacity under windborne sand and debris.
- less surface area is required for storage as casks are spaced more closely together
- designed to allow vanishingly small site boundary dose.
- prospective for better social acceptance due to smaller footprint and less visually conspicuous (less than two feet above ground level).
- economical to decommission.

Essential data on HI-STORM 100U	
Maximum seismic levels for general certification	horizontal: 1.25g's; vertical: 0.8g's
Maximum height of the lid (above the crawler riding roadway)	60 cm
MPC types	MPC-68 (BWR), MPC-32 (PWR), MPC-24 (PWR)
Maximum burn-up	68.2 GWD / MTU (PWR) 65 GWD / MTU (BWR)
Minimum module center-to-center spacing	4 m

HI-TRAC is an essential adjunct to HI-STORM. HI-TRAC is designed to optimize shielding and ease decontamination during loading and unloading operations. The design bases of the HI-STORM 100 and HI-STAR 100 systems bound all spent nuclear fuel characteristics, site design conditions and interfaces that exist in the vast majority of power reactor sites in the U.S. and abroad.

Figure 3.13 : Loading a surface HI-STORM Cask

Image Source: Holtec International

3.3.2.1 Loading and unloading a HI-STORM 100U

Installing an MPC in a HI-STORM 100U module, or removing it for packaging in the HI-STAR dual-purpose overpack for off-site transport, is simple enough to be completed in half of a work shift. **Figure 3.14** and **Figure 3.15** show an MPC being removed from a HI-STORM 100U module and packaged in the HI-STAR overpack ready to ship by rail.

Figure 3.14 : HI-TRAC bearing the MPC is staged over the HI-STAR overpack in the MPC transfer cavity

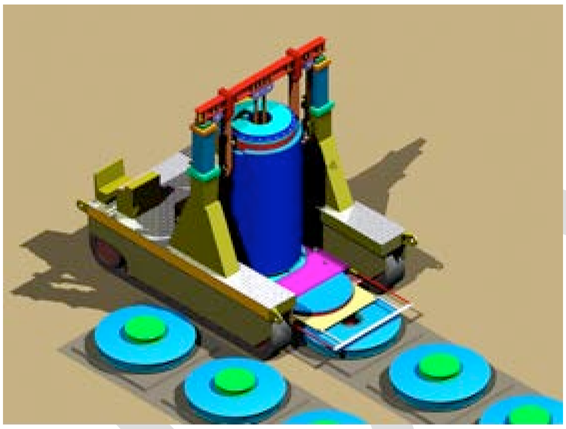


Image source: Holtec International

Figure 3.15 : MPC bearing HI-STAR with impact limiter installed on the rail car for off-site transport

Image source: Holtec International

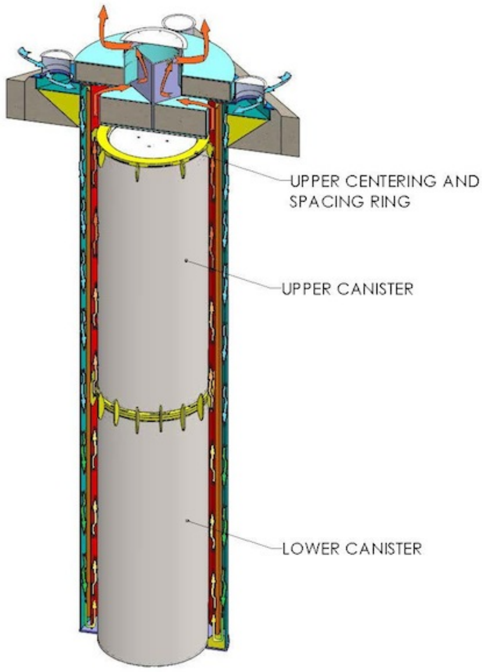
For the present study, the simplified assumption is made that all SF will be delivered in Holtec HI-STAR casks that can be stored on a concrete pad at the ISF or in other multi-purpose canisters that can be loaded into a HI-STORM cask above or below ground. The HI-STORM concrete storage casks can be made on site as required. It is also assumed that all cask costs will be borne by the client country since these would arise whether storage were to take place in the client country or in Australia.

The HI-STAR / HI-STORM system is the same as that which was proposed for the Private Fuel Storage facility for which a detailed EIS was prepared in the USA. It is efficient if all the SF can be delivered in sealed canisters prepared at the nuclear power plants, as is the aim in the USA. The cost estimates reviewed below are based on this system.

A more refined analysis of the possibilities could lead to a system which would be more beneficial to the operator of the ISF and possibly to the clients. The ISF host country could manufacture or purchase re-usable transport containers which would be sent to the client countries to fetch the SF. This could benefit clients who have not yet moved their SF to dry casks.

Moreover, new cask designs are still being developed and the configuration will certainly change over the lifetime of an Australian ISF. For example, HI-STORM CIS is a next generation underground storage design that will house used fuel packaged in any canister supplied by any cask vendor. In an international facility, the ability to accept fuel from a wide variety of clients is clearly important. The HI-STORM CIS vertical ventilated module (VVM) stores two multi-purpose canisters (MPCs) in a vertically stacked configuration in each cavity. Stacking two canisters ultimately halves the required storage area.

A 14 acre HI-STORM CIS ISFSI can store 4,000 canisters containing more than 50,000 tons of uranium. Image Source: Woodward (2015)



3.4 Interim storage facility siting costs

EPRI carried out a generic study of the costs of developing a national interim spent fuel storage facility (EPRI, 2009), from which the siting cost have been abstracted and presented in Table 3.1 below. The 2009 costs have been inflated by 9.6% and converted to millions of AUD2015 in the right-hand column.

Table 3.1 : Benchmark costs for siting for an interim storage facility in the US

GISF^ pre-license submittal phase: estimated costs for siting, design and engineering services		
	USD 2009 millions	AUD 2015 millions
Project management	3.0	4.6
Public information and stakeholder involvement	1.5	2.3
Geotechnical investigations and environment report development	2.0	3.1
Preliminary design, safety analysis, and preparation of license application	7.4	11.4

GISF^ pre-license submittal phase: estimated costs for siting, design and engineering services		
	USD 2009 millions	AUD 2015 millions
Subtotal pre-license submittal phase	**13.9**	**21.5**
Contingency: 30%	**4.2**	**6.5**
Total pre-license submittal phase	**18.1**	**28.0**

^Generic Interim Storage Facility (GISF) is the term used by the Electric Power Research Institute (EPRI) for ISF.

EPRI (2009) also provides cost estimates for completing GISF siting by taking the project through the licensing stage, including all necessary legal and local liaisons, consultations, reviews and fees. This adds a further 40.3 million 2009 USD (AUD 2015 62.3 million) to the costs. As with the GDF, uncertainties need to be factored into these figures, even though they include a contingency sum of 30%.

Based on these figures, it is proposed to take a conservative cost estimate value for siting and licensing the ISFS of AUD100 millionM as an appropriate figure for the commercial model.

3.5 Siting the interim storage facility (IFS or ISFS)

The siting requirements and consequent site investigation programme for a storage facility for spent fuel and ILW are less onerous than those for the GDF as they largely concern the properties of the surface environment, and the same requirements would, in any case, apply also to the surface facilities of the GDF (e.g. waste receipt and handling facilities and the encapsulation plant). Consequently, the work required to characterise and qualify the ISFS site would be a sub-set of the type of site characterisation work needed for the GDF.

As with the GDF, there are IAEA Standards and guidance documents related to siting an ISFS. The safety requirements for siting nuclear installations (NS-R-3; IAEA, 2003) stipulate:

In the evaluation of the suitability of a site for a nuclear installation, the following aspects shall be considered:

a) The effects of external events occurring in the region of the particular site (these events could be of natural origin or human induced);

b) The characteristics of the site and its environment that could influence the transfer to persons and the environment of radioactive material that has been released;

c) The population density and population distribution and other characteristics of the external zone in so far as they may affect the possibility of implementing emergency measures and the need to evaluate the risks to individuals and the population.

Key aspects of siting are vulnerability to natural events and to foreseeable, significant changes in land use, such as the expansion of existing installations and human activities or the construction of high risk installations. The requirements say that pre-historical, historical and instrumentally recorded information and records, as applicable, of the occurrences and severity of important natural phenomena or human induced situations and activities shall be collected for the region and shall be carefully analysed for reliability, accuracy and completeness. Natural events to be considered include:

- earthquakes;
- potential for surface faulting (i.e. fault capability);
- extreme meteorological events (wind, precipitation, snow, temperature and storm surges);
- rare meteorological events (lightning, tornadoes, tropical cyclones);
- flooding (runoff resulting from precipitation or snow melt, high tide, storm surge, seiche and wind waves, high tide, wind effects on bodies of water and wave actions);
- water waves induced by earthquakes or other geological phenomena;

- floods and waves caused by failure of water control structures;
- slope instability;
- collapse, subsidence or uplift of the site surface;
- soil liquefaction;
- the behaviour of foundation materials (e.g. under static and seismic load and interacting with groundwaters).

Example: siting an ISFS in the USA

The 2012 study by ORNL carried out on behalf of the USDOE (ORNL, 2012) noted that there is well-defined regulatory guidance for siting an ISFS in the United States. Numerous potential site evaluation criteria (SEC) were identified in various sources related to health and safety, environment, socioeconomic, and engineering factors. The selected SEC were based on providing a high level of discrimination, using readily available data:

- land with a population density greater than 500 people per square mile (including a 20-mile buffer) is excluded.
- protected lands (e.g., national parks, historic areas, wildlife refuges) are excluded. However, Indian lands are specifically included based on recent volunteers to host an ISFSI.
- land with safe shutdown earthquake (SSE) peak ground acceleration (2% chance in a 50-year return period) greater than 0.2 g is excluded east of 104° W longitude (Rocky Mountain Front). Land with SSE peak ground acceleration greater than 0.4 g is excluded west of 104° W longitude.
- land too close to identified fault lines (length determines standoff distance) is excluded.
- land with moderate or high landslide hazard susceptibility as defined by the USGS is excluded.
- wetlands and open water are excluded.
- land that lies within a 100-year floodplain is excluded.
- land that lies within 50 miles of seawater or Great Lakes coast is avoided based on concerns regarding environmental corrosion, tsunamis, hurricanes, typhoons, seiches, and sea level changes.
- land that lies within 50 miles of the US border is avoided based on security concerns.
- land located in proximity to hazardous facilities is avoided.

3.6 Decommissioning of Interim storage

The paper by Howard et al.[9] is the most explicit on decommissioning the storage modules. It indicates that the concrete at the ISFS doesn't pose a decommissioning problem as it should be non-active. The more open question concerns the MPC metal canisters and their inner grids. It is hoped that direct disposal in the MPCs may become accepted in the future, but currently, the disposal concepts assume repacking (encapsulation of the spent fuel assemblies) at the GDF so that handling the steel waste resulting is an issue for the encapsulation plant. This is covered in the paper but the assumptions made (10m^3 LLW per cask are realistic).

According to HOLTEC 2012, the cask decommissioning waste is likely to be recyclable or non-active.

3.7 ISF siting and site work (to the point of operation) timeline

Integrating the site identification, approval and SI work into the main programme can dominate scheduling. There are frequently unplanned-for delays in obtaining permissions at every step of the siting work and these are often completely out of the implementer's control, as they involve political and legal decisions. It can thus be

[9] Howard, R., and van den Akker, B., Considerations for Disposition of Dry Cask Storage System Materials at End of Storage System Life, http: / / www.iaea.org / inis / collection / NCLCollectionStore / _Public / 46 / 062 / 46062901.pdf

difficult to make a robust time plan for the other elements of the programme that may be waiting for information from the siting programme (e.g. design, safety assessment).

If a programme runs without unreasonable delays, then typical durations that might be expected for the main stages can be:

- initial site identification and safety case to ARPANSA requirements : typically three years (years 1 to 3)
- siting work including surface-based, intrusive site investigations: 2 years (years 4 to 5)
- design development in parallel with site investigations: 2 years (years 4 to 5)
- environmental impact studies and licencing for construction: 3 years (years 6 to 8)
  - EPBC referral and license preparation
  - EPBC approval
  - safety case documentation (final) and peer review / ARPANSA approval
  - ARPANSA siting and construction licenses (based on design input)
- identification / permitting / adaptation / construction of harbour facilities: 3 years (years 6 to 8)
- construction and commissioning, licensing: 2 years (years 9 and 10)
  - ARPANSA operating license
- pilot testing (on and off site): 3 years (years 7 to 9)
- ready for first receipt of waste: year 11

This gives a total duration for a 'smooth' project based upon voluntarism and with no licensing problems of about 10 years. This assumes several activities run in parallel to the siting work and interchange information with it.

In order for shipments of waste to commence as soon as possible, this schedule is expected to commence in parallel with the development of the legal and regulatory framework – which is anticipated to be five years. If this development takes longer then the environmental impact and licencing studies etc will be delayed accordingly. For modelling purposes we have assumed that HLW / SF and ILW starts to be imported commencing in year 11.

3.8 Benchmark costing for interim storage

3.8.1 Costing data sources

The most recent guidance document is IAEA Nuclear Energy Series NF-T-3.5 - Costing of Spent Nuclear Fuel Storage. This lists the following cost categories and components:

Table 3.2 : Through life cost categories for radioactive waste storage

Category of costs	Project phase	Remarks
Capital	Project definitions	Alternatives are evaluated to select the best option. A plan for project implementation is established
	Design engineering	The facility is designed The investment plan is established
	Regulatory approval	Safety analysis documents are prepared Licences are issued by authority for the facility
	Construction	The facility is built

Category of costs	Project phase	Remarks
Operations	Spent fuel loading	Spent fuel is placed in storage in the facility Dry storage casks / modules are procured
	Storage Only	Monitoring is carried out and protection of the stored spent fuel is provided
	Unloading	Spent fuel is removed from storage Spent fuel is transferred to a transportation cask Spent fuel is shipped to an off-site destination
Closure and decommissioning	Decontamination and decommissioning	The fuel storage is decontaminated and dismantled Site is restored to its original condition.

The IAEA report NF-T-3.5 notes that the capital cost of a basic dry cask storage facility includes the pad and land on which the casks are to be stored, plus the security and monitoring equipment and facilities that are needed to protect the stored spent fuel. In some countries, a cask storage building may be required, significantly changing the capital cost and design cost for this option. The cost of the auxiliary equipment necessary to handle storage cask / modules, and canisters or baskets, place them into storage can be assumed to be a capital cost that is incurred upfront – prior to actual storage taking place. The cost of the actual casks / modules and associated canisters or baskets can be assumed to be incurred in year immediately preceding their actual use.[10]

Extensive information on a pad based ISFS is contained in the report, NUREG 1714, *Final Environmental Impact Statement for the Construction and Operation of an Independent Spent Fuel Storage Installation on the Reservation of the Skull Valley Band of Goshute Indians and the Related Transportation Facility in Tooele County, Utah*. This is the USNRC response to the major storage project submitted by the company Private Fuel Storage – and subsequently dropped due to sustained political opposition from the State of Utah.

The technical basis of this project was used to produce updated costs estimates in the report produced for EPRI by E. Supko, *"Cost Estimate for an Away-From-Reactor Generic Interim Storage Facility (GISF) for Spent Nuclear Fuel.* EPRI, Palo Alto, CA: 2009, 1018722". The figures quoted below are extracted from this 2009 report.

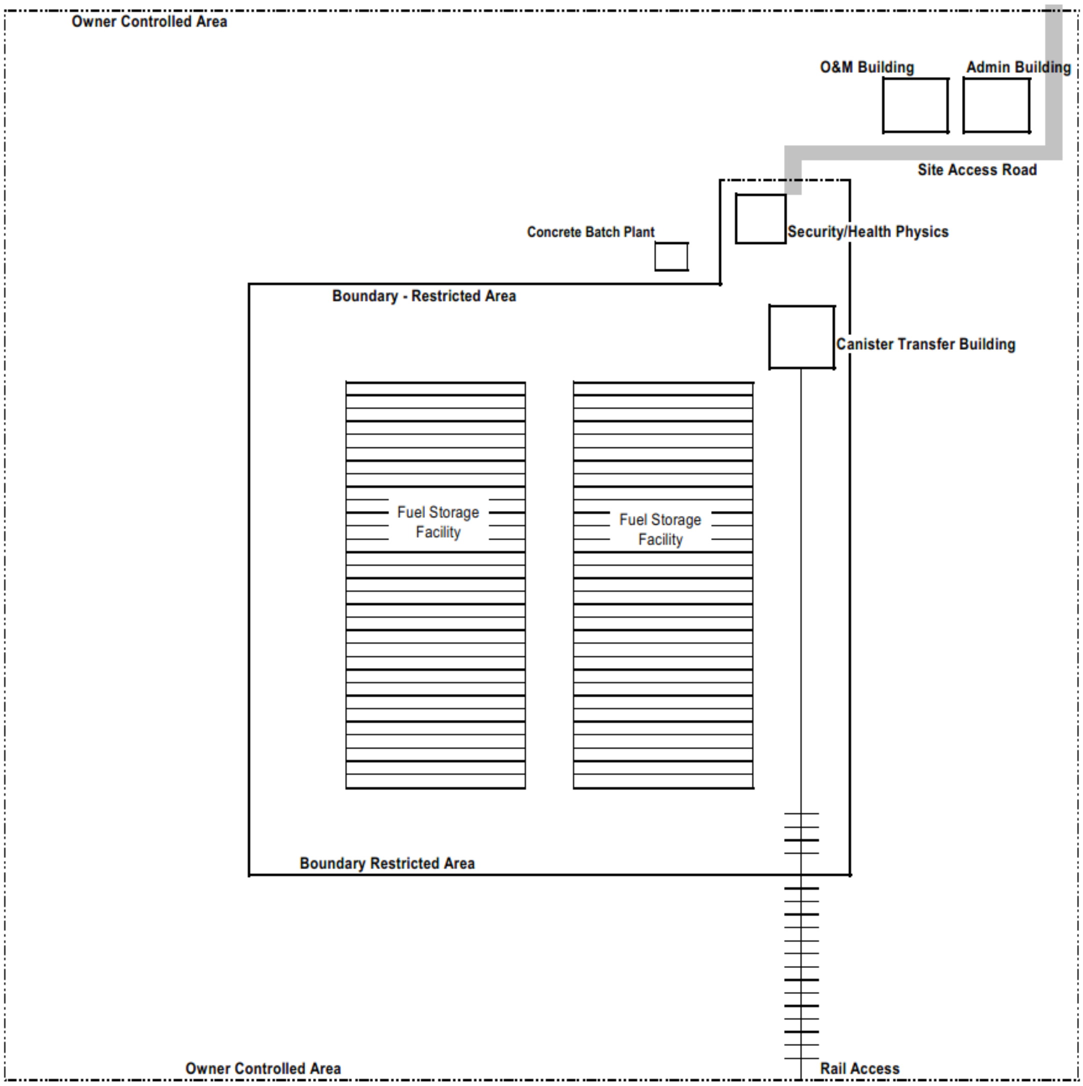
3.8.2 USA cost estimates from EPRI 2009 study

For the purposes of their analysis, EPRI relied upon the site plan, types of facilities, and facility sizes assumed in the Private Fuel Storage (PFS) Final Environmental Impact Statement, referred to above. The PFS proposal was for a dual-purpose canister-based system for storage and transportation of the SF, with all fuel assemblies having been sealed in metal canisters before loading into transport casks at the power plants. The number of loaded spent fuel canisters (each with 10 tonnes of SF) to be received at the proposed PFS was planned to be between 100 and 200 annually. At the site the sealed metal canisters containing SF would be loaded into steel / concrete storage casks that are then placed on concrete pads for storage. 4,000 storage casks would be needed to store a maximum of 40,000 tonnes of SF. The proposed operational time for the ISF was 40 years after which a US repository was assumed to be available. In this section, the focus is on the cost estimates derived later in 2009 for a facility based on the PFS design. Some more detailed technical descriptions of the proposed facilities are given in Appendix B in order to ease the estimation of costs for a potential future ISF in Australia.

[10] Some of the most detailed cost information related to dry cask storage on a concrete pad is contained in the 2013 report *"A Project Concept for Nuclear Fuels Storage and Transportation"* by Joe Carter, Scott Dam et.al.

The assumed configuration of the storage site is illustrated below.

Figure 3.16 : Layout of ISF in EPRI 2009 study based on the PFS project



The following information is given by EPRI. The site is bounded by a fence, within which there is a restricted area that would contain the ISF including the storage pads, the canister transfer facility, and a security / health physics building. fencing around the restricted area would consist of two 2.5m security fences. The inner fence would be separated from the outer nuisance fence by a 6m isolation area, as required by NRC regulations. Other buildings on the GISF site, such as an administration building, concrete batch plant, and operations and maintenance building would be located within the OCA, but outside of the restricted area security fences.

The costs estimates are made for dual purpose canisters and also for concrete storage overpacks. The cost items and as far as possible the components that contribute to these are summarised below. They are given in detail for an ISFS with a capacity of 40’000 THM, and comparisons are made with capacities of 20,000 tHM and 60,000 tHM. The capacity of the casks is assumed to be 10 tHM but variants are also examined.

The EPRI study breaks down costs into the following categories:

- ISF design, engineering, licensing and start-up professional services
  - pre-license application phase
  - license application review phase
  - Initial construction / pre-operations phase

- ISF capital costs
  - transportation infrastructure
  - ISF infrastructure
  - fuel storage facility
  - dual-purpose canister transfer and transportation equipment
- Annual operating costs
  - annual administrative costs
  - annual operating costs for canisters and concrete overpacks
  - other annual operating costs
- Annual labour costs
  - during loading or unloading periods
  - during caretaker periods
  - during loading and unloading periods
- Decommissioning costs
- Estimated workforce during construction and operation

The results are summarized below and the detailed component tables given by EPRI are reproduced in Appendix A.

The EPRI estimates assume that a 40,000 tonne capacity ISF would operate for a 40 year period. Alternative ISF capacities of 20,000 and 60,000 tonnes were also considered. During the first 20 years, the ISF would receive SF for storage at a rate of 2,000 tonnes per year, and during the second 20 years the ISF would ship SF offsite for subsequent waste management activities (permanent disposal, recycling, etc.). For a given facility capacity (e.g., 40,000 tonnes), the number of dual-purpose canisters (DPC) received for storage on an annual basis will depend upon the capacity of the DPCs. While EPRI refers to the ISF as accepting and storing DPCs, the ISF could also accept and store transport, aging and disposal (TAD) canisters that are currently under development by the DOE. A DPC (or TAD) package with a 10 tonne capacity would store approximately 21 PWR assemblies or 44 BWR assemblies. A higher-capacity DPC, such as those currently used for onsite storage at nuclear power plants, has a capacity of approximately 13 tonnes and would store approximately 32 PWR assemblies or 68 BWR assemblies.

In evaluating the costs for a 40,000 tonne ISF, EPRI assumed a capacity of 10 tonne per canister. EPRI also evaluated the impact of using canisters with a capacity of 13 tonne, which is more representative of the capacity of the dry storage canisters currently being used at the reactor sites. In evaluating the number of canisters received at an ISF with a capacity of 20,000 tonne or 60,000 tonne and the resulting costs, EPRI utilized an assumed 10 tonne DPC capacity to estimate ISF system costs.

Summary of Costs for a 40,000 MTU GISF

Cost Category	Cost Estimate (Millions 2009$)
Design, Engineering, Licensing and Startup Professional Services	**$ 67.4**
Capital Costs	
Transportation Infrastructure	**$176.5**
GISF Infrastructure	**$ 40.8**
Fuel Storage Facility (Note 1)	**$ 87.1**
Transportation Casks and Transport Equipment	**$189.3**
Subtotal Capital Costs	**$493.7**
Annual Operating Costs	
Administrative	**$ 3.2**
Concrete Overpacks	**$52.0**
Other: Transportation, License Fees	**$41.3**
Subtotal Annual Operating Costs	**$96.5**
Annual Operating Labor Costs	
During Loading or Unloading	**$8.0**
During Caretaker Period	**$3.7**
During Loading and Unloading	**$8.5**
Decommissioning	**$225.0**
Construction Staff (FTE)	
• **Pre-License Construction**	**130**
• **Modular construction during operations**	**20**
Operations Staff (FTE)	
• **During Loading or Unloading**	**85**
• **During Caretaker Period**	**40**
• **During Loading and Unloading**	**91**
Note 1: The Fuel Storage Facility would be built over the first 20 years of operation. The costs associated with initial construction of the Fuel Storage Facility are estimated to be $16.1 million (all excavation and grading, fencing and security system costs, plus sufficient storage pads to store the first 200 storage systems).	

Comparison of Cost and Staffing for a 20,000 MTU, 40,000 MTU and 60,000 MTU GISF Assuming 10 MTU Capacity Storage Systems

Cost Category	40,000 MTU GISF	20,000 MTU GISF	60,000 MTU GISF
Design, Engineering, Licensing and Startup Professional Services (Millions 2009$)	$67.4	$67.4	$67.4
Capital Costs (Transportation and GISF infrastructure, Fuel Storage Facility, and Transportation Cask Equipment) (Millions 2009$)	$493.7	$273.2	$690.3
Decommissioning (Millions 2009$)	$225.0	$112.8	$338.0
Annual Operating Costs (Millions 2009$)	$96.6	$50.3	$142.6
Annual Labor Costs (Millions 2009$)			
• During Periods of Loading or Unloading	$8.0	$5.3	$9.9
• During Caretaker Periods	$3.7	$3.7	$3.7
• During Periods of Loading and Unloading	$8.5	$5.7	$10.6
Construction Staff			
• Pre-License Construction	130	130	130
• Modular construction during operations	20	15	25
Operations Staff			
• During Loading or Unloading	85	58	106
• During Caretaker Period	40	40	40
• During Loading and Unloading	91	61	115

3.8.3 USA cost estimates from DOE 2013 2009 study

This detailed concept study analyses two storage options; one for a pilot facility that could store round 10,000 MT of SF and another for a full facility that would store 70,000 tonne and be expandable from there. In the present report, we will use only the data on the full scale facility. This is assumed to operate for 100 years and to accept spent fuel at a rate of 3000 tonne per year. If a conservative cask loading of 10 tonne is assumed this would require 7,000 casks; a trend to higher cask capacities is however present and this could reduce the cask number by around 25%. The DOE study considers all additional facilities that would be required at the ISF (e.g. laboratory, cask maintenance building) and also estimates transport requirements and costs.

The facilities at the site in the DOE study are comprehensive. They are expected to be able to accept dry casks of all types, to receive, handle, and store bare fuel packaged and shipped directly from storage pools, provide capability to conduct R&D, and to prepare SF for transport to the GDF (including packaging in final disposal canisters – which is in the present study assumed to take place at the GDF site). Unlike the EPRI study, the DOE report also covers the requirements for transportation to the ISF and then to the GDF. The facilities on site therefore include:

- laboratories
- fuel remediation
- bare fuel receipt
- canister repackaging
- storage pads
- security building
- rail yards
- office buildings and visitor center

The concrete pads would be able to hold horizontal storage systems with a rectangular footprint, or vertical storage systems using a concrete or steel cylinder-shaped over pack that stands on end. Only the latter is assumed in the present concept study for Australia.

The comprehensive report also addresses the issue of LLW produced at the ISF. An estimate for the lifetime production is 600-900 m^3. It also addresses the issue of decommissioning the ISF and includes cost for this in the cost estimates that are described below.

A schematic of the large ISF expandable to 70,000 tonne is illustrated below in Figure 3.17. The area required is 2.5 – 4 km^2. Also illustrated is the rail rolling stock that would be required. This is shown below in Figure 3.18.

Figure 3.17 : Conceptual arrangement of ISF site (DOE 2013)

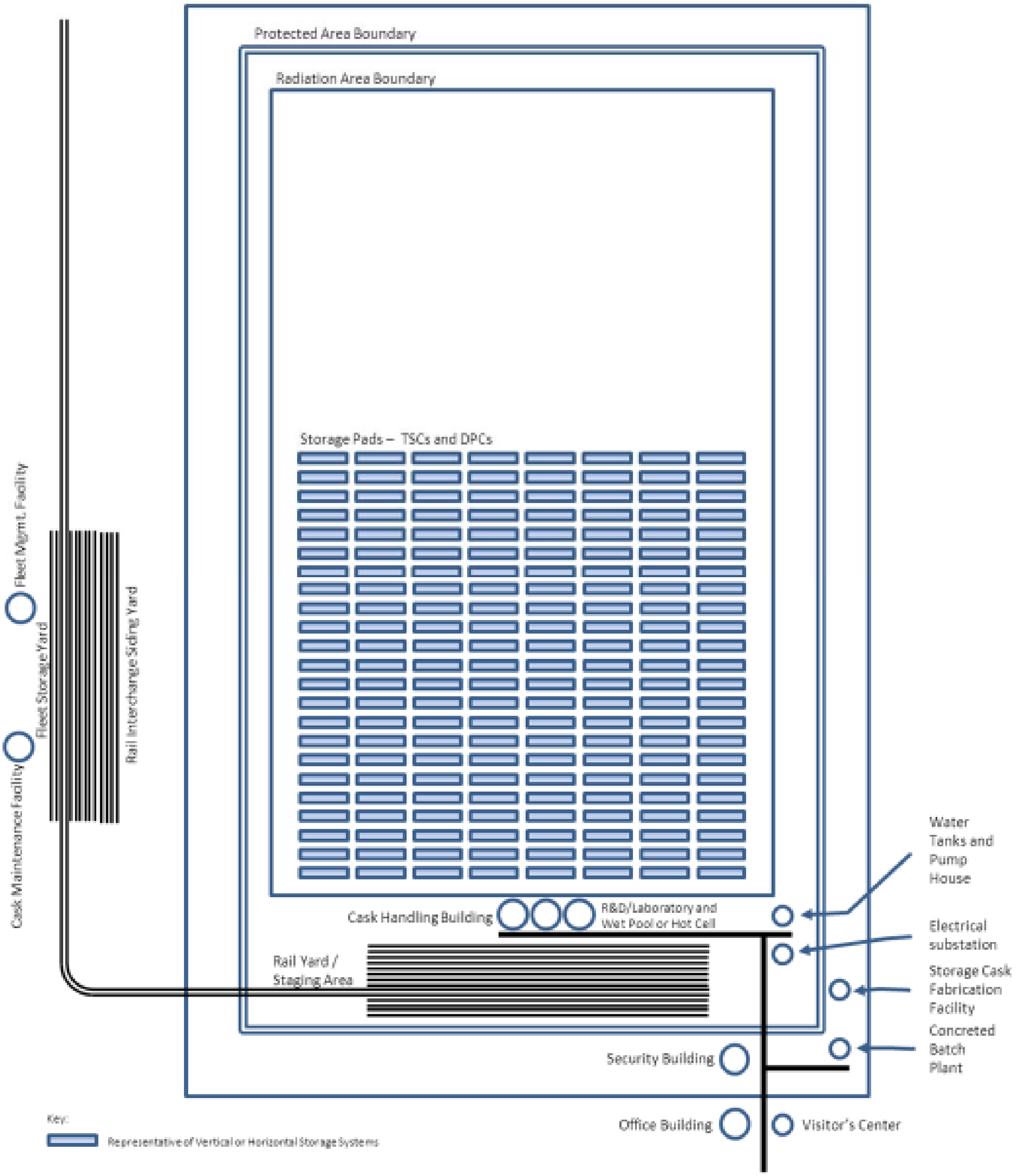
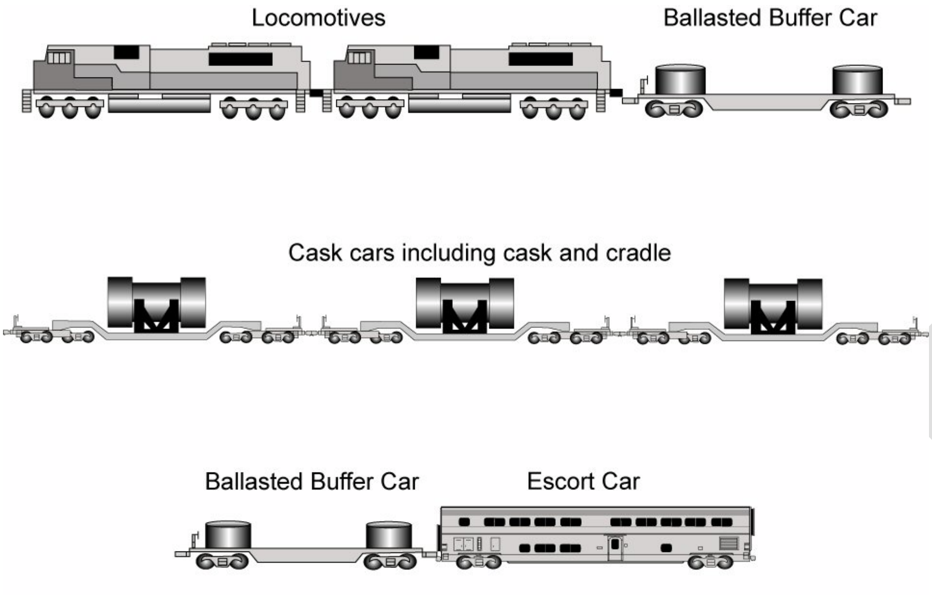


Figure 3.18 : Rolling stock



Cost estimates

The cost estimates cover all of the facilities mentioned and the costs for 2 years of storage casks.

Construction costs

The construction costs in MUSD (2012) are given below, with the 3 estimates labelled low, point estimate and high.

Figure 3.19 : Cost benchmarks for a 70,000 MtU ISF from DoE 2013 (USD2012 $M)

	Low	Point Estimate	High
Pilot with Transportation Equipment	705.2	1,007.5	1,511.2
ISF with Transportation Equipment	1,603.1	2,290.2	3,435.3
Laboratory Facility	748.7	1,069.6	1,604.4
Fuel Remediation Facility	453.4	647.8	971.6
Bare Fuel Receipt Facility	1,073.5	1,533.6	2,300.4

Operational costs per annum

These include: cask handling, storage system monitoring, R&D, maintenance, security and programme management. Staffing includes about 240 personnel for operations and 180 for transport; this includes a complement of 125 security personnel. In addition to labour, operational costs include materials, spare parts, utilities, supplies, taxes and insurance, and a 15% contingency on annual operating expenses.

At full scale operation, the estimated costs are

- operations and maintenance: 53 MUSD / y (no cask costs included)
- transportation: 40.1 MUSD / y

Decommissioning costs

The estimated decommissioning costs are USD 480 million (2012).

3.8.4 Other estimates

It is often problematic to interpret published cost figures for waste management or to compare estimates from different sources. Some causes of the difficulties are that:

- the studies include differing cost elements; for example, it is not always obvious whether costs for project management, R&D, regulatory interactions, public information, compensation of host communities etc. are included or not. Contingencies included in the estimates can also vary widely and can represent a large fraction (up to one third) of the costs.
- the times of the estimates vary and they should in principle be converted to a common reference date by allowing for price inflation.
- the type of cost estimate varies; sometimes undiscounted costs are given even for far future activities; sometimes there is a calculation to yield net present value of investments or life-cycle costs. If account is taken of discounting future costs, then a reference timetable for the waste management steps is needed.
- exchange rates vary significantly so that calculating back to a common currency can be misleading. Moreover, it can be argued that relative purchasing power rather than currency conversion rates gives a more useful comparison.
- there are inherent assumptions in the operating model which are not wholly applicable (such as the form or packaging that the waste will arrive in, the transformation / repackaging required for storage or transport and the duration of storage.

In this section, where possible cost estimates are quoted in the original currency, with the year of the estimate. The figures given must all be treated as guiding estimates, rather than precise predictions.

Figures given by Bunn et al 2001 are (60-80'000 USD / tHM), whereby this includes both purchasing and also loading costs (labour and equipment). Still higher cask costs are given by Alvarez et al 2003 (USD90-210 thousand per tHM), although the latter figure is for missile hardened casks. Another independent early estimate of cask costs alone was made by Hensing (1996). His quoted cask costs are DM2.5 million per Castor cask containing 10t of fuel; this high figure (equivalent to around USD 180 thousand per tonne) reflects the high costs of the Castor container.

The running costs for a dry store are quoted as USD2.6 million / y (Bowser et al 1994). Other running cost estimates from the USA are USD3-4 million / y (Bunn et al 2001). In the USA, the costs for implementing a new dry storage facility (without the casks) have been estimated at USD9-18 million by Alvarez et al 2003 or USD8-12 million in Bunn et al 2001 or USD12.4 million by Bowser et al (1994). Bunn et al (2002) quote an undiscounted cost for 40 years of cask storage of 1000t SF at a closed reactor site as USD250 million and point out that a 5% real discount rate would reduce the net present cost to USD160 million. In 2000, the Non-Proliferation Trust concept called for establishing a dry cask storage facility in the Russian Federation that would accept 10 000 tHM of spent fuel from other countries on a commercial basis, at a projected price of USD1.5 million per tHM. None of these concepts matured for a variety of economic, technical and political reasons.

In court cases where power utilities have sought damages against the US government for the costs of providing dry storage in the absence of a permanent repository, the costs quoted are USD1.04 million capital cost per cask plus USD0.24 million for the loading costs per cask.[11]

[11] https: / / ecf.cofc.uscourts.gov / cgi-bin / show_public_doc?2012cv0389-71-0). Other court cases gave similar cost claims.

3.9 Temporary storage of other wastes

The studies analysed above are purely for storage facilities for SF (or vitrified HLW). These are the waste streams that must be stored for decades on the surface to enable them to cool sufficiently and also the waste streams with the longest lasting radiotoxicity. The large volumes of ILW can in principle be disposed of independently and earlier than the SF since no cooling is required. In the present study, however, the lower cost option of co-disposal at the same site as the SF is the reference case.

Hence, space must be reserved at the ISF for all ILW that might be shipped before the GDF operates. The ILW, however, can be stored simply in weather resistant storage halls so that the associated costs are much lower. In this report we have assumed that the inventory of ILW already in storage in client countries or which will be produced over the next 20 years or will be in the form of 200l drums, concrete boxes or ISO containers.

3.10 Conclusions for dry storage (interim storage facility)

The design concepts illustrated and the descriptions of infrastructure and manpower requirements allow broad estimates to be made for similar facilities in Australia by adapting the specific costs estimated to the local Australian conditions. The scaling factors for the potential Australian repository are derivable by comparing the inventories foreseen. The original PFS project in the USA was for a storage facility that would keep 40,000 tonne of SF on 500 concrete pads for 40 years. The EPRI 2009 study used the same technical concept and examined inventories of 20,000, 40,000 and 60,000 tonne. The DOE 2013 study again used the PFS concept and assumed a final inventory of 70,000 tonne, following a smaller pilot phase.

The differences in inventory and concept in the present study for Australia are that a larger baseline SF inventory is postulated and ILW storage at the same site is also included. The total inventories for disposal are given below; the fraction of these that must be stored at the ISF site depends on the operational strategy chosen, ie the rate of material incoming to the ISF and the rate at which it leaves for final disposal, as well as the number of years that the ISF accumulates material prior to the disposal facility(ies) coming online. The operating model and inventory assumptions for the ISF are detailed in 3.6 on page 66) with the following results relevant for the ISF scale and scope.

Table 3 Baseline maximum inventories (rounded) – SF and ILW at an interim store

Scenario	SF inventory (by 2090) tHM	SF (max, year) , tHM	ILW inventory (by 2090)	ILW (max, year)
Upper case (75% of available)	207,000	127,000 tHM (82)	585,900 m^3	233,000 m^3
Baseline (50% of available)	**138,000**	**72,000 tHM (40)**	**390,000 m^3**	**173,000** m^3
Lower case (25% of available)	69,000	36,000 tHM (28)	195,000 m^3	112.000 m^3

The single cask system with only Holtec transport and storage casks would be more difficult to implement in a facility that must accept SF from a large number of countries and reactor types. A more detailed study on developing a versatile acceptance system covering SF from different reactors and also vitrified wastes would be valuable.

An important point concerns the capital costs of the storage casks themselves which represent a notable part of the overall costs. In a national waste management programme, unlike the transportation casks which will remain the property of the originating power plant (and will be returned to them once they are emptied at the ISF) storage casks will form part of the operating costs of the ISF. They will be directly borne by the ISF operator or will be passed on to the owners of the waste being stored.

The current estimated market cost of dual storage and transportation casks, such as a Holtec HI-Star is noted in EPRI (2009) as USD750,000 per cask and USD200,000 per (concrete) storage overpack (such as Holtec Hi-Storm, each with capacity of 10-13 tHM (24 PWR assemblies or 68 BWR assemblies[12]). For the purposes of the business case model, casks are regarded as operational costs (rather than capital) with the costs incurred one year prior to their use and are presumed to hold only 10 tonnes of SF per unit, an effective conservatism factor of 30%.

Another option is for the ISF operator to send his own casks to collect the SF at the client nuclear power plants. One advantage of would be that the ISFS representative can inspect the fuel before it is shipped. If the fuel already in casks, it is easier for the owner to ship, but the casks have to be opened at some point to repack for disposal and the ISF operator is then reliant on the quality assurance processes of the original utility. The optimum procedure depends on the range of the clients. If much of the inventory is composed of relatively small amounts of fuel from small or relatively small programmes then the shipping approach may be preferable. At the present stage of analyzing the international repository option, all of the assumptions related to cost and revenues are dominated by the rather subjective judgement of how much of the world's spent fuel would land in Australia.

[12] Pressurised water reactor (PWR) fuel assemblies weigh ~ 665kg and boiling water reactor (BWR) fuel assemblies weigh some 300kg each (

4. The low level waste repository (LLWR)

The typical approach to the permanent management of low level radioactive waste (LLW), and very low level radioactive waste (VLLW) is via “near surface disposal”. The IAEA defines this process as “the emplacement of solid or solidified radioactive waste containing predominantly short lived radionuclides in a disposal facility located at or near the land surface.”[1]

In practice, low level waste repositories (LLWR) for the disposal of low level radioactive waste may take many different forms, including trenches, above ground engineered structures, shallow excavated engineered structures or shallow silos or tunnels some tens of metres underground. All of these approaches may be applied to achieve the required level of containment and isolation of LLW from the biosphere and to provide a safe environment during the operational phase, which will typically extend for decades. For LLW, this is followed by a monitoring phase which typically lasts for 300 years. A few countries (e.g. Canada, Germany, Switzerland, Netherlands) have decided to put all radioactive wastes, including LLW into deeper underground repositories.

As noted in Paper 2 – Revenues and Willingness to Pay, the economics of low level waste management don’t support an international / regional solution. This is principally because the costs of local management are far lower than for an underground repository, the siting requirements are far less stringent (see next section) and the commercial, regulatory or technical pressures to manage it with any sense of urgency (such as for SF which accumulates beside NPPs) are generally absent.

The low level waste repository modelled here is intended to manage Australian-sourced low level waste streams which are derived from the operation (and eventual decommissioning) of the other facilities which store and dispose of higher order radioactive wastes. The quantity of low level waste managed is difficult to quantify, and hence a modular, expandable approach is taken, as described below.[13]

4.1 The LLWR design

As noted above, the essential design approach of the LLWR can take many forms, from a shallow trench where the natural environment provides the key containment and isolation of the waste, to an engineered, above ground structure, where a combination of engineered containment measures, including the facility itself, provide the necessary containment and isolation, until the radioactivity has decayed to insignificant levels.

The model prepared here follows the latter path, with the disposal of immobilised LLW materials within concrete containers which sit atop a concrete slab, initially during the operational phase under the cover of a light engineered structure and afterwards under long term covering comprising a series of synthetic and natural materials to provide a weatherproof and tamper resistant protective cover for a period of at least 300 years.

The LLW design as described is closely associated with the El Cabril low level waste management facility operated by ENRESA in southern Spain.[2] At this facility, LLW arrives at the facility in drums or other containers which are assessed for compliance with acceptance criteria and then placed inside reinforced concrete disposal cells of 2.25 m^3, with gravel placed between the waste containers.[3]

The immobilisation of the wastes within the concrete containers using gravel (or clays) increases the potential for retrieval at a later date, compared with the alternatives (either backfilling with mortar or direct emplacement of the drums / packages in a disposal cell). The containers are rated with a weight of some 5 tonnes, indicating a required craneage capacity of 10 tonnes (2 x n) to provide the necessary extent of redundancy.

[1] IAEA Safety Standards SSG-29, Near Surface Disposal Facilities for Radioactive Waste, 2014
[13] The accumulated low level waste which is held by the Commonwealth and future streams arising from ANSTO and other sources are independent of this analysis.
[2] For detailed description of the design principles of the ENRESA LLW and ILW facility in Spain, see http: / / www.radioactivewaste.gov.au / sites / prod.radioactivewaste.gov.au / files / files / / Enresa-report.pdf
[3] The containers themselves may be steel drums or another consistent form of packaging to facilitate verification of the integrity of the wasteform.

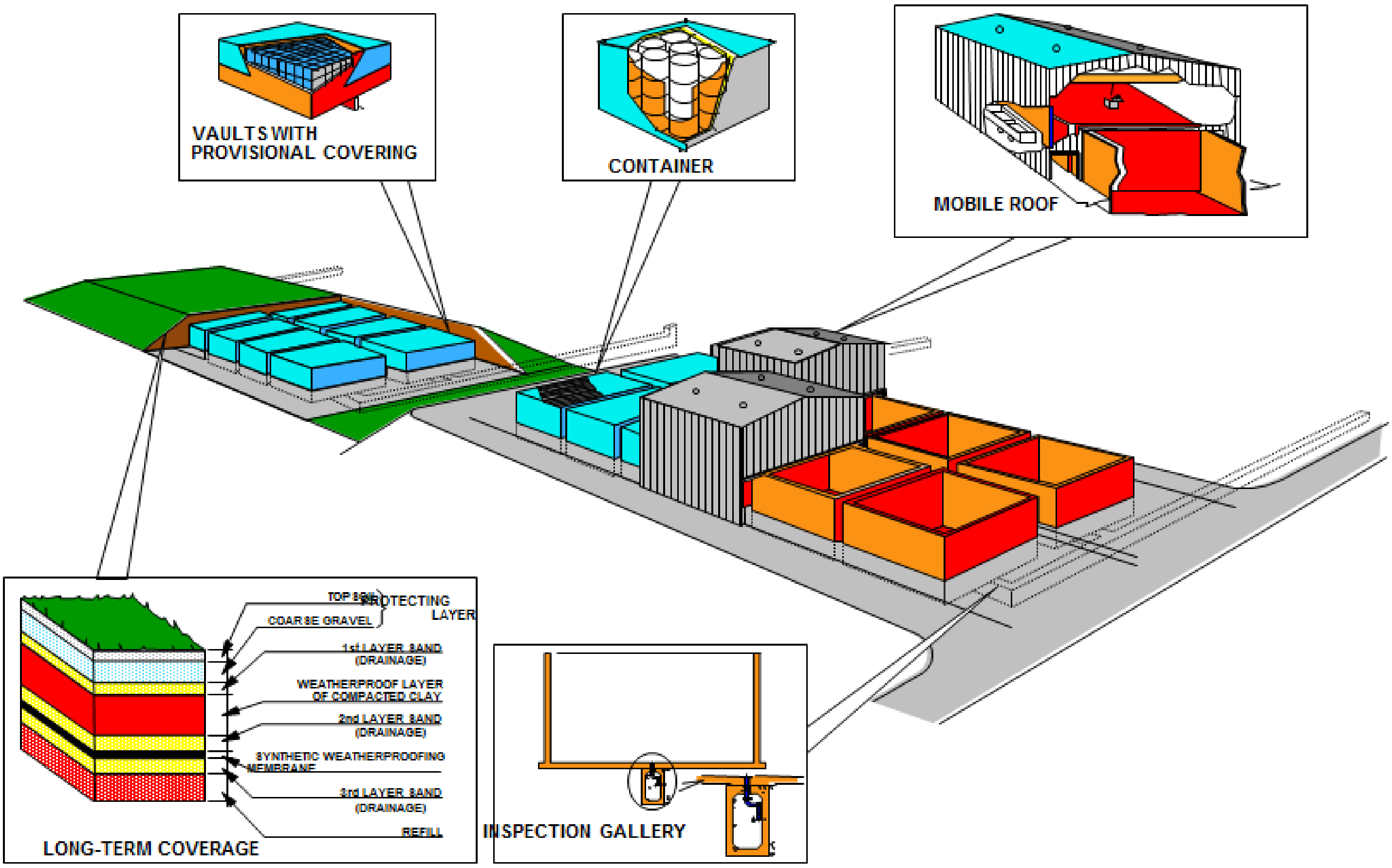


Figure 4.1 : El Cabril LLWR disposal facility, illustrative concept (source: ENRESA, 2015).

The second level of isolation / containment of radionuclides involves the emplacement of the concrete containers inside a concrete disposal cell (Figure 4.2) which itself is covered with a concrete lid once full with stacked containers and then buried beneath a multi layered weatherproof and tamper proof cover (Figure 4.3). The concrete form of the disposal cell itself is some 0.5 m thick.

Each concrete container of 2.25 x 2.25 x 2.20 metres hosts 18 x 220 litre steel drums of LLW, and each disposal cell with external dimensions of 24 x19 x10 metres has capacity for 320 containers or ~1,267 m^3 of disposed LLW material.

The ENRESA El Cabril concept involves the successive filling of a series of such disposal cells, covered during the operational phase either by a retractable / mobile roof model or via a series of fixed roof structures, with material emplaced by overhead gantry crane (as in Figure 4.2 and Figure 4.5).

The mobile roof design is the one used in practice in El Cabril, where a pair of moveable structures operates along a two parallel ‘lines’ of disposal cells as in Figure 4.4 (below).

Figure 4.2 : Aerial image of the El Cabril facility, southern Spain, showing mobile roof structure over LLW disposal cells (ANSTO, 2011)

Figure 4.3 : Concrete containers inside LLW disposal cell (under mobile roof) El Cabril, Spain (ANSTO, 2011)

The concepts for the South Australian LLW store and repository are similar to those in place at the El Cabril facility, which is selected due to its modular / expandable design, proven technology for safe operations and its relatively flexible siting requirements.

4.2 Siting the LLWR

The discussion in Section 3.5 on ISF siting covers, to a large extent, the requirements for and work required to site a LLWR. As discussed in the scenarios defined for the current project, it is assumed that a dedicated LLWR will be required for the wastes generated by the overall waste management project.

As discussed above in Section 2.5.3 the requirements for surface-based nuclear installations also cover the GDF surface facilities, so a suitable GDF site would necessarily be suitable for a surface LLWR in many respects – in particular those related to ground stability and vulnerability to external events. However, depending on the design of the LLWR, the geology of the disposal site should contribute to the isolation of waste and the limitation of release of radionuclides to the biosphere (requirements that are not necessary for the above-ground ISF). Thus, the hydrogeological and geochemical properties of the near-surface environment are key factors and need to be characterised. This is especially important for trenches and buried vault systems, but also for above-surface or partially excavated vaults that will eventually be mounded over. In all cases, the safety evaluation would need to account for possible releases to the shallow soils and groundwater environment after closure, even though the hazard potential of the wastes is substantially reduced after a few hundred years.

There is specific IAEA guidance related to surface LLWR siting and SSG-29 Appendix 1 (IAEA, 2014) covers the approach to siting and site characterisation. The guide notes, for example, that the hydrogeological characteristics of the host site should include low groundwater flow paths and long flow paths in order to restrict the migration of radionuclides. Expected changes in important hydrogeological conditions (e.g. gradient) due to natural events and the construction of the disposal facility should be evaluated. Preference should be given to sites with a simple geological setting that could make characterizing or modelling of the hydrogeological system easy and reliable.

The dispersion characteristics of the hydrogeological system may also be important and should be evaluated. SSG-29 notes that the site investigation work:

….will require site reconnaissance and investigations to obtain evidence on actual geological, hydrogeological and environmental conditions at the site. This would involve on-site surface and possibly subsurface (e.g. borehole) investigations supplemented by laboratory work. Other data relevant to a wider understanding of the site and a site description, such as transport access, demography and social considerations, should also be

gathered. Site investigation may progress in a number of stages that involve acquiring and interpreting consecutively more information, in order to select one or more preferred sites for detailed characterization.

A preliminary safety assessment should be carried out at a relatively early stage to indicate whether a site is potentially suitable for a disposal facility. The preliminary safety assessment should include the results of the preliminary site investigations and a description of the decision process used.

The iteration of investigations with safety assessments and the development of a safety case and an environmental impact assessment is similar in nature to and closely parallel with the work required to confirm a GDF site. Although the investigations, being mainly shallow, surface based and not involving URCF work, will be considerably less costly, the interpretation and analysis work leading to licensing would be of a similar scale, although also somewhat less costly.

4.3 LLWR siting and site work (to the point of operation) timeline

Integrating the site identification, approval and SI work into the main programme can dominate scheduling. There are frequently unplanned-for delays in obtaining permissions at every step of the siting work and these are often completely out of the implementer's control, as they involve political and legal decisions. It can thus be difficult to make a robust time plan for the other elements of the programme that may be waiting for information from the siting programme (e.g. design, safety assessment).

If a programme runs without unreasonable delays, then typical durations that might be expected for the main stages are considered to be similar to those for the ISF. Hence these can be:

- initial site identification and safety case to ARPANSA requirements : typically three years (years 1 to 3)
- siting work including surface-based, intrusive site investigations: 2 years (years 4 to 5)
- design development in parallel with site investigations: 2 years (years 4 to 5)
- environmental impact studies and licencing for construction: 3 years (years 6 to 8)
  - EPBC referral and license preparation
  - EPBC approval
  - safety case documentation (final) and peer review / ARPANSA approval
  - ARPANSA siting and construction licenses (based on design input)
- construction and commissioning, licensing: 2 years (years 9 and 10)
  - ARPANSA operating license
- pilot testing on site: 1 years (years 9)
- land transport and other infrastructure: 2 years (years 9 and 10)
- ready for first receipt of waste: year 11

This gives a total duration for a 'smooth' project based upon voluntarism and with no licensing problems of about 10 years. This assumes several activities run in parallel to the siting work and interchange information with it.

In order for shipments of waste to commence as soon as possible, this schedule is expected to commence in parallel with the development of the necessary legal and regulatory framework – which is anticipated to be five years. If this development takes longer then the environmental impact and licencing studies etc will be delayed accordingly. For modelling purposes we have assumed that LLW starts to be brought to site commencing in year 11.

4.3.1 LLWR siting costs

OECD (1999) includes benchmark costs for the planning and siting of the two main types of Low Level Waste Repository, near surface engineered facility and subsurface / cave facility types. The data are based on voluntary reports of OECD member countries' incurred costs, for both older, historic repositories as well as newer operating facilities. The results are summarised in (Figure 4.4 below)

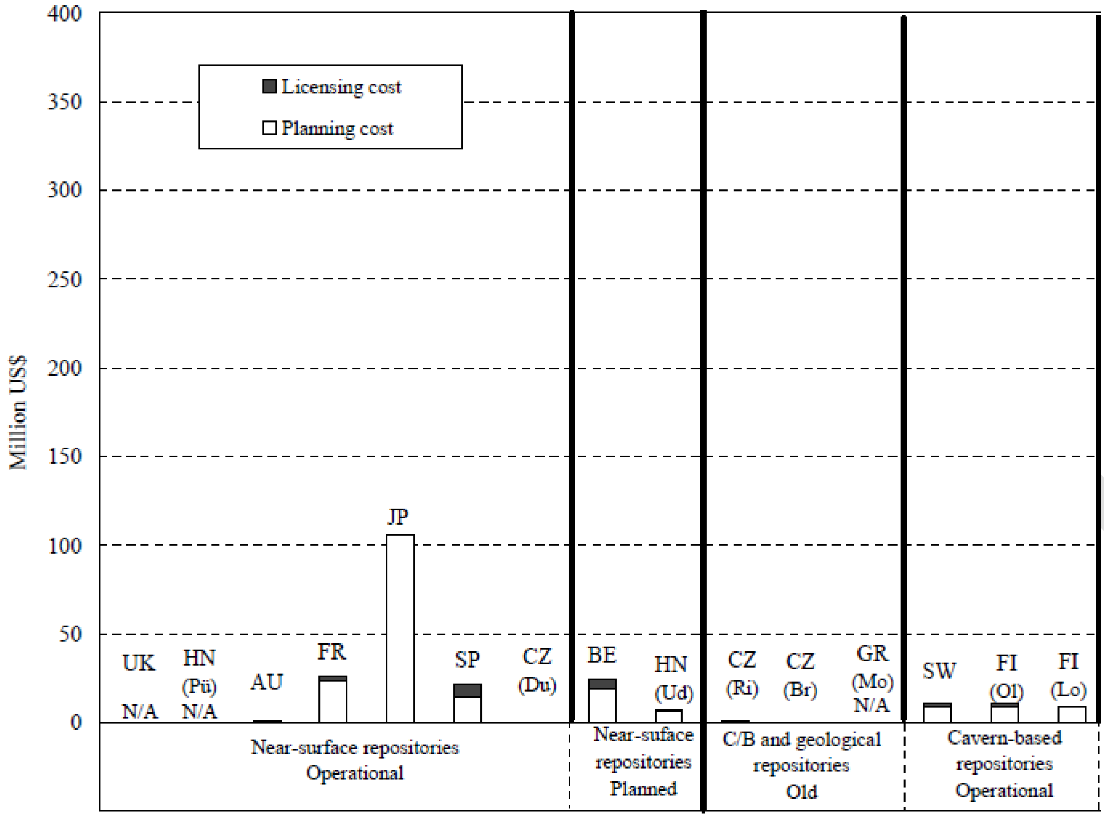


Figure 4.4 : Benchmark licencing and site selection costs, in USD Millions, (OECD 1999)

The results indicate a range from zero for older repositories (reflecting both a lack of accounting for costs as well as actual lack of material site study costs) to over AUD100 million for the Japanese near-surface LLWR at Rokkasho-mura. Together with these estimates, an allowance **of** AUD30 million has been applied for site investigations associated with the LLWR in our modelling.

4.4 Scale of LLW

The amount of LLW expected to arise from the management of other forms of waste is unable to be determined with accuracy at this stage, given changes in the technology of LLW waste minimisation[4] and the potential for decontamination and reuse of containers, trolleys and other equipment involved in HLW and ILW management.

In response to this uncertainty the essentially modular / scalable nature of the LLW design enables its ongoing expansion on as needs-basis. The initial build of the facility is for 16 disposal cells, to suit a volume of 20,275 m^3 of (compacted) LLW. This initial scale of facility is expected to provide sufficient capacity for at least two decades of operations. An allowance for a facility expansion programme of a further 16 disposal cells on a continuous 20 year development cycle has been incorporated into the capital cost analysis.

4.5 LLW cost benchmarks

Studies of historic construction costs for LLW repositories, whether near surface / engineered or subsurface / cavern facilities provide illustrative benchmarks for development of a similar facility in Australia.[14]

[4] For example the ANSTO-developed Synroc technology has the potential to dramatically reduce the amount of liquid low level radioactive waste accruing from radiopharmaceutical production. http: / / www.ansto.gov.au / AboutANSTO / MediaCentre / News / ACSTEST_040438

As with other forms of radioactive waste management facility, the costs may be divided into the following:

- licensing cost
- planning cost (including site selection / characterisation and safety case development)
- construction
- operation
- decommissioning
- post closure activities

Each of these costs are dependent on a range of factors, including the scale of operations (relative to the volume of waste received per annum and in total), the characteristics of the waste being received (whether conditioned for storage and disposal, packaged etc) the regulatory regime / requirements which are in place, various socio-political factors (such as incentive payments to host regions or communities), taxation and the cost of finance (OECD, 1999).

Operational costs are divided in to fixed and variable. The fixed costs include site environmental monitoring, security and protection and office / administration costs. Variable cost components vary with annual throughput of waste material, and include labour for transportation, conditioning, handling and disposal, inspection, radioactivity monitoring, maintenance and repairs as well as materials.

Meta-analysis by the OECD Nuclear Energy Agency (NEA) demonstrated economies of scale in construction of LLW repositories, however smaller economies of scale in the operations phase. A summary of actual and planned construction costs (Figure 4.5) and operating costs (Figure 4.6) determined by the OECD in 1999 are presented below.

Figure 4.5 : Benchmark construction costs for near surface LLW repositories (OECD, 1999) , by total volume

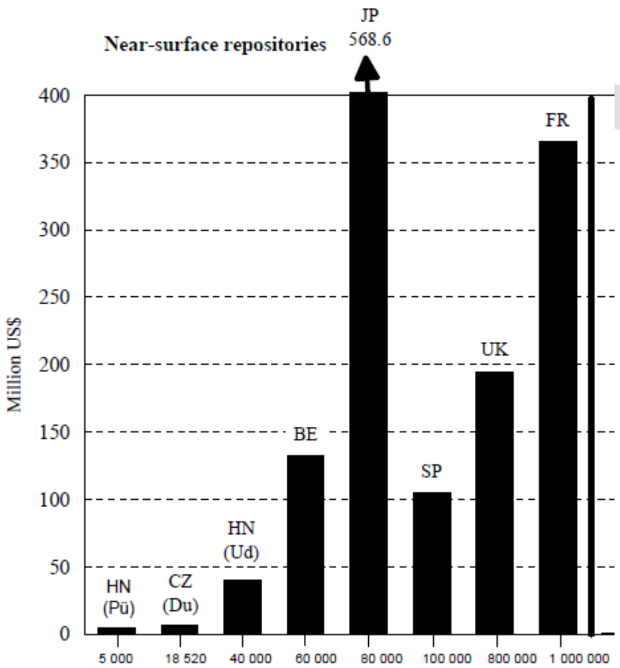


Figure 4.6 : Benchmark operating costs for operating and planned near surface LLW repositories ($USD per m3), OECD 1999

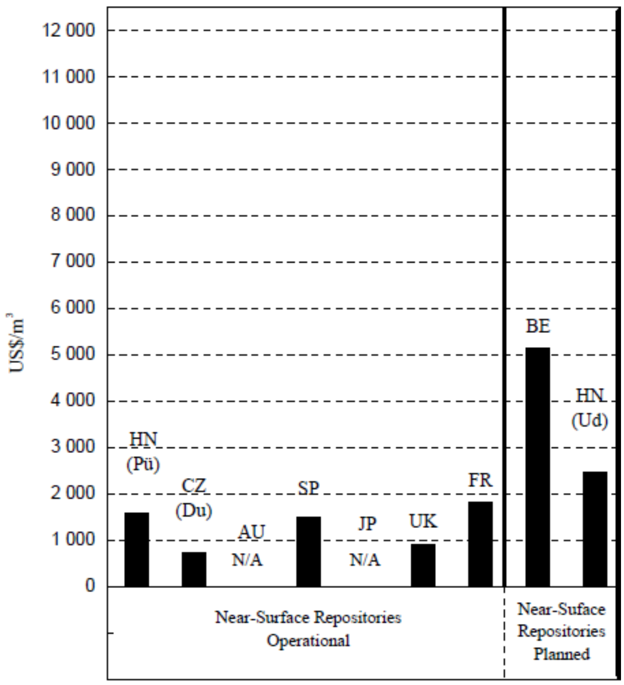


Figure 4.4 (above) present costs in 1999USD, converted from various home currencies and are a combination of actual costs incurred and anticipated costs, as well as facilities which manage only LLW and others which manage both LLW and very low level waste (VLLW) on the same site, with the latter requiring less shielding.

Figure 4.5 (operating cost benchmarks) shows a range of operating costs from USD 710/m3 in the Czech Republic to USD 5130 in a proposed LLW facility in Belgium. When converted to AUD[15] the range becomes AUD 1,789 to AUD12,927. The average of these two points is AUD 7,392.

A recent presentation regarding the El Cabril near surface engineered LLW disposal facility (ENRESA, 2015) provided a more comprehensive and up to date, verified capital cost for the development and eventual decommissioning of their facility than the original OECD estimate. Planning, construction and demolition/ of their facility, comprising 28 vaults for LLW (total waste volume of 35,476m^3) plus another 3 disposal cells for VLLW was 2014 € 230M, or an average of 2014 € 5,672 per m^3 of waste (assuming the three VLLW disposal cells also contained 1,267m^3 each). This cost equates to 2015AUD 8,863 per m^3.

Operating costs were also offered in the same summary analysis (ENRESA, 2015), at between €18-25 M (2014) per annum[16]. For an average waste management of 3,000m^3, this would equate to between €8,330 and €6,000 per m^3 or €7,500 and €5,400 in cash operating costs, excluding taxation.

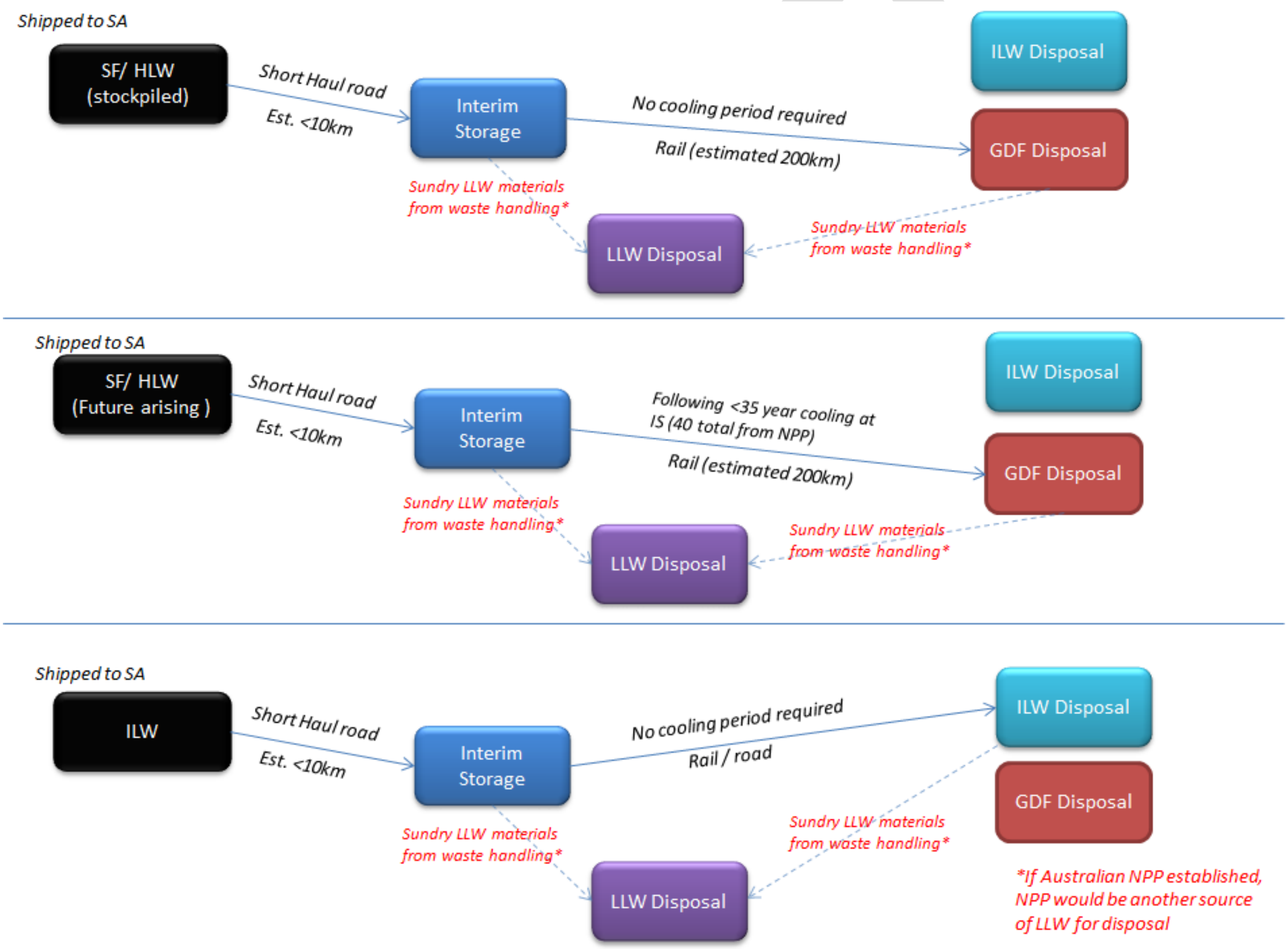
[15] Conversion factor of 2.52 into 2015 AUD (0.63 USD / AUD and escalation of 1.59 since 1999)
[16] The operating costs included 8% VAT and regional government taxes, presumed to total 10% overall.

5. Development of radioactive waste facilities

The preceding chapters present an overview of the range of technical and costing information in relation to radioactive waste management. While each facility type - low level waste disposal, interim storage, HLW / SF GDF and ILW GDF may be considered separately, in the context of a comprehensive service offering for radioactive waste management, they should be regarded as links in a single supply chain which is capable of meeting complex and significant international demand for waste management services.

There are essentially three pathways for the management incoming radioactive waste, depending on whether it is ILW or whether it is stockpiled or more recent HLW. The following diagram shows how the flow of these three categories is foreseen to be managed.

Figure 5.1 : Waste management pathways



Source: Jacobs

Figure 5.1 indicates how stockpiled HLW / SF, which does not require a cooling period, arrives by sea in a transportation cask, and is transferred to interim storage (likely close to the port) and then depending on logistics / backlog of material movements, sent to the GDF for disposal via rail. Sundry low level waste from the process goes to the low level waste facility (by road).

For HLW / SF which has not been stockpiled at the source location for an extended period (ie less than 40 years total) the material will arrive in a transport cask with as little as 5-7 years in wet-storage (10 years has been assumed for modelling purposes) and it will spend 33-35 years (30 years has been assumed for modelling purposes) in dry storage at the interim store before relocation to the GDF for disposal. As above, sundry LLW will be disposed of separately at an independent LLWR.

The third category of waste, ILW, will arrive in shipping containers (Section 2.5 of paper 4) and will be stockpiled at the interim store, at the same time as HLW / SF is stored, until it is logistically ideal to relocate it to a disposal facility (likely by rail). As with stockpiled HLW / SF, there is no further cooling period required for the underground disposal of the ILW (short lived ILW is expected to be disposed of within the source country). The ILW may or may not be co-located with the GDF, depending on siting and other characteristics, although as noted in Paper 3 (Capital Cost Estimation) and Paper 4 (Transport, Logistics and Operational Costs), there are significant cost savings from co-location of the two.

Provision of only part of the overall management chain, such as for ILW but not HLW / SF, or for only HLW / SF but not LLW is illogical, in the face of the integrated nature of the waste arising and customer's requirements.

The following section presents a description of the global inventory of existing and forthcoming radioactive waste which is estimated to be available to South Australia for long term management and disposal, and estimates of source countries' willingness to pay which may underpin a viable market to provide these services.

Appendix A. Dry storage

A.1 Dry storage guidance documents

Some countries have issued safety-related guidelines for the dry storage of spent fuel elements in pools or in storage casks Examples are:

- From the USA: CFR10 PART 72 - Licensing requirements for the independent storage of spent nuclear fuel, high-level radioactive waste, and reactor-related greater than class C waste
- From Switzerland: G05 / d - Transport- und Lagerbehälter für die Zwischenlagerung
- From Germany: RSK document - Sicherheitstechnische Leitlinien für die trockene Zwischenlagerung bestrahlter Brennelemente in Behältern

The IAEA has also issued numerous relevant documents over the past 20 years, including the following:

- IAEA Safety Series No. 116 (1994) - Design of Spent Fuel Storage Facilities.
- IAEA Safety Series No. 117 (1994) - Operation of Spent Fuel Storage Facilities.
- IAEA Safety Series No. 118 (1994) - Safety Assessment for Spent Fuel Storage Facilities.
- IAEA TECDOC-1100 (1999) - Survey of Wet and Dry Spent Fuel Storage.
- IAEA TECDOC-559 (1989) - Methods for expanding the capacity of spent fuel storage facilities.
- IAEA PS / SP-949 (1994) - Safety and engineering aspects of spent fuel storage.
- IAEA Technical Report Series No. 345 - Concepts for the conditioning of spent nuclear fuel for final waste disposal (1992).
- IAEA Technical Report Series No. 320 - Evaluation of Spent Fuel as a Final Waste Form (1991).

The recent rise in interest in dry storage has also led to the production of:

- IAEA TECDOC 1558 - Selection of Away-From-Reactor Facilities for Spent Fuel Storage, A Guidebook (2007).
- IAEA TECDOC 1532 Operation and Maintenance of Spent Fuel Storage and Transportation Casks / Containers (2007).
- IAEA Nuclear Energy Series NF-T-3.5 - Costing of Spent Nuclear Fuel Storage

A.2 Dry storage options summary

The full range of commercially available dry storage technologies for both SF and vitrified HLW is outlined in Table 5.1. This Table is based upon an IAEA TECDOC [IAEA 2007a], but has been updated and adapted for the current study.

Table 5.1 : Dry storage system options for SF and HLW – adapted and amended from IAEA TECDOC 1558.

ID No.	Design	Transport	Storage	Heat transfer	Containment	Shielding	Feature	Example
Spent fuel storage								
1a	Cast metal cask	Bolted secondary (transport) lid with elastomer seals and primary lid with metallic seals	Bolted secondary (storage) and primary lid with metallic seals	Conduction through basket and cask walls	Double bolted lids with metallic seals	Metallic wall	Dual purpose	GNS
1b	Massive or composite forged metal cask	Bolted secondary (transport) lid with elastomer seals and primary lid with metallic seals	Bolted secondary (storage) and primary lid with metallic seals	Conduction through basket and cask walls	Double bolted lids with metallic seals	Metallic wall	Dual purpose	ES, Holtec, MHI, NAC, TNI
1c	Concrete cask	Concrete cask with bolted lid(s) and elastomer seals	Concrete cask with bolted lid(s) and metallic seals	Conduction through basket and cask walls	Double bolted lids with metallic seals	Concrete wall	Dual purpose	GNS
2a	Forged metal transport cask & concrete over pack	Forged metal transport cask with bolted lid and elastomer seals	MPC in Concrete over pack	Air convection around canister	Double welded lids	Concrete wall	Vertical	ES, Holtec, NAC
2b	Forged metal transport cask & simple metal over pack	Forged metal transport cask with bolted lid and elastomer seals	MPC in simple metal overpack	Air convection around canister	Double welded lids	Metal wall plus additional neutron shielding	Vertical	TNI
2c	Forged metal transport cask & concrete module	Forged metal transport cask with bolted lid and elastomer seals	MPC in concrete module	Air convection around canister	Double welded lids	Concrete wall	Horizontal	TNI

ID No.	Design	Transport	Storage	Heat transfer	Containment	Shielding	Feature	Example
2d	Forged metal transport cask with underground concrete over pack	Forged metal transport cask with bolted lid and elastomer seals	MPC in concrete module	Air convection around canister	Double welded lids	Concrete wall	Vertical Under ground	ES, Holtec
3	Vault	Forged metal transport cask with bolted lid and elastomer seals	Steel lined tubes in massive concrete block	Air convection around tubes	Thimble tube	Concrete	1 FA per tube	Fort St Vrain, Paks
HLW glass storage								
1a	Cast metal cask	Bolted secondary (transport) lid with elastomer seals	Bolted secondary (storage) and primary lid with metallic seals	Conduction through basket and cask walls	Double bolted lids with metallic seals	Metallic wall	Dual purpose	GNS
1b	Forged metal cask	Bolted secondary (transport) lid with elastomer seals	Bolted secondary (storage) and primary lid with metallic seals	Conduction through basket and cask walls	Double bolted lids with metallic seals	Metallic wall	Dual purpose	TNI

A.3 Detailed dry storage cost estimates (EPRI 2009)

These estimates were developed by the US Electric Power Research Institute (EPRI) for a *Generic Interim Storage Facility* (GISF) for spent nuclear fuel. The

GISF Pre-License Submittal Phase: Estimated Costs for Siting, Design and Engineering Services

Description of Service	Cost Estimate (Millions 2009$)
Project Management	$3.0
Public Information and Stakeholder Involvement	$1.5
Geotechnical Investigations and Environment Report Development	$2.0
Preliminary Design, Safety Analysis, and Preparation of License Application	$7.4
Subtotal GISF Pre-License Submittal Phase	**$13.9**
Contingency: 30%	**$ 4.2**
Total GISF Pre-License Submittal Phase:	**$18.1**

GISF License Application Review Phase: Estimated Costs for Siting, Design and Engineering Services

Description of Service	Cost Estimate (Millions 2009$)
Project Management	$ 2.5
Public Information and Stakeholder Involvement	$ 1.5
NRC Fees for LA Review, EIS, and Hearing Process	$16.0
Technical and Legal Support During LA Review and Hearing Process	$ 6.0
Detailed design for GISF Facilities and Transportation Infrastructure	$ 4.5
State and Local Authority Review	$ 0.5
Subtotal: GISF License Application Review Phase	**$31.0**
Contingency: 30%	**$ 9.3**
Total GISF License Application Review Phase	**$40.3**

GISF Initial Construction/Pre-Operations Phase: Estimated Costs for Siting, Design and Engineering Services

Description of Service	Cost Estimate (Millions 2009$)
Project Management	$1.4
Public Information and Stakeholder Involvement	$1.5
Engineering and Legal Support During Construction	$2.3
System startup, dry-run testing	$1.7
Subtotal GISF Initial Construction/Pre-Operations Phase	**$6.9**
Contingency: 30%	**$2.1**
Total GISF Initial Construction/Pre-Operations Phase	**$9.0**

Transportation Cask Fleet Assumptions

GISF Capacity (MTU)	Cask Capacity (MTU)	DPC Receipt Rate (DPC/Year)	Transport Cask Turn-Around Time (Weeks)	MTU Shipped Per Year by Cask (MTU/year/Cask)	Cask Fleet Size (# Casks)
	(a)	(b)	(c)	(d) = [(a)*52 weeks]/(c)	[Annual MTU/(d)]
40,000	10	200	7	74	28
40,000	13	154	7	97	22
20,000	10	100	7	74	14
60,000	10	300	7	74	40

GISF Capital Costs: Transportation Infrastructure for a 40,000 MTU GISF

Description of Service	Cost Estimate (Millions 2009$)
Access road improvements	$ 3.0
Rail spur / rail siding construction	$ 6.0
Land improvements	$ 5.0
Rail locomotive: 14	$56.0
Rail escort cars: 14	$51.8
Rail buffer cars: 28	$14.0
Subtotal Transportation Infrastructure	**$135.8**
Contingency: 30%	**$ 40.7**
Total Transportation Infrastructure	**$176.5**

GISF Capital Costs: GISF Infrastructure for a 40,000 MTU GISF (Millions 2009$)

GISF Capital Cost Elements	Cost Estimate
Administration Building • Building construction • Furnishings, equipment, site improvements, utilities **Total**	$1.4 $2.3 **$3.7**
Security and Health Physics Building • Building construction • Furnishings, equipment, emergency diesel generator, vehicles **Total**	$1.0 $1.8 **$2.8**
Operations and Maintenance Building • Building construction • Furnishings, equipment, • Heavy lifting equipment **Total**	$1.7 $1.3 $3.0 **$6.0**
Canister Transfer Building • Building Construction • Canister transfer cells and equipment: 3 • Heavy lifting equipment and heavy haul equipment **Total**	$5.4 $7.5 $6.0 **$18.9**
Subtotal GISF Infrastructure	**$31.4**
Contingency: 30%	$ 9.4
Total GISF Infrastructure	**$40.8**

GISF Capital Costs: 40,000 MTU Capacity Fuel Storage Facility

GISF Fuel Storage Facility Costs	Cost Estimate (Millions 2009$)
Excavation and grading	**$3.0**
Concrete storage pads • 20 ft x 30 ft x 3 ft, per cask stored: 67 cubic yards/cask • 4000 DPCs stored • **reinforced concrete: $200/cubic foot**	**$53.6**
Security fence • 1500 ft x 1600 ft – 6,200 linear feet • Inner and outer security fences – 12,400 linear feet • fencing: $75/linear foot	**$0.9**
Security system • lighting, intrusion detection, CCTV, monitoring equipment	**$9.5**
Subtotal: Fuel Storage Facility	**$67.0**
Contingency: 30%	**$20.1**
Total Fuel Storage Facility	**$87.1**

GISF Annual Operating Costs: Administrative Costs, 40,000 MTU GISF

GISF Administrative Operating Costs	Cost Estimate (Millions 2009$)
Travel and Living Expenses • person crew • 100 rail shipments for 200 casks • $3,500 per rail shipment	$0.35
Annual office expenses: • Communications and reproduction, office supplies, office equipment and leases, office equipment maintenance and repair, postage, dues and subscriptions, insurance	$2.1
Subtotal: Annual Administrative Operating Costs	$2.5
Contingency: 30%	$0.7
Total Administrative Operating Costs	$3.2

GISF Annual Operating Costs: Dual Purpose Canisters and Overpacks, 40,000 MTU GISF

Dual Purpose Canister and Concrete Overpack Assumptions	Cost Estimate (Millions 2009$)
Dual Purpose Canister Costs • 21 PWR, $700,000 per canister: 116 PWR canisters/year • 44 BWR, $800,000 per canister: 84 BWR canisters/year	$148.4
Concrete Overpack Costs • $200,000 per overpack: 200 per year	$40.0
Contingency: • Dual Purpose Canisters • Concrete Overpacks	 $44.5 $12.0
Total costs: • Dual Purpose Canisters • Concrete Overpacks	 $192.9 $ 52.0

GISF Annual Labor Costs: Loading or Unloading, 40,000 MTU GISF

Labor Categories During Loading or Unloading	Estimated Annual FTE	Average Cost per FTE ($K)	Cost Estimate (Millions 2009$)
Administrative staff: • General manager, administrative assistants, public relations, financing and purchasing, accounting and payroll, governmental affairs	10	$82.5	$0.83
Security staff: assumes 4 staff per shift, 3 shifts	20	$55.0	$1.10
Engineering and technical staff • Nuclear and licensing engineers, health physics managers and technicians, quality assurance managers and technicians, transportation specialist, training	18	$80.0	$1.42
Maintenance and equipment operating staff: • Mechanical and electrical maintenance, crane and equipment operators, general plant workers, fire and EMT	19	$58.0	$1.10
At-reactor loading crews: • 2 per site, 9 sites per month	18	$70	$1.26
Subtotal: Labor during Loading or Unloading	85	$67.2	$5.7
Fringe benefits and contingency: 40%			$2.3
Total Labor Costs During Loading or Unloading			$8.0

GISF Annual Labor Costs: Caretaker Periods, 40,000 MTU GISF

Labor Categories During Caretaker Period	Estimated Annual FTE	Average Cost per FTE ($K)	Cost Estimate (Millions 2009$)
Administrative staff: • General manager, administrative assistants, public relations, financing and purchasing, accounting and payroll, governmental affairs	7	$89.3	$0.63
Security staff: assumes 4 staff per shift, 3 shifts	20	$55.0	$1.10
Engineering and technical staff • Nuclear and licensing engineers, health physics managers and technicians, quality assurance managers and technicians, transportation specialist, training	7	$80.0	$0.56
Maintenance and equipment operating staff: • Mechanical and electrical maintenance, crane and equipment operators, general plant workers, fire and EMT	6	$57.0	$0.35
Subtotal: Labor during Caretaker	40	$66.0	$2.6
Fringe benefits and contingency: 40%			$1.16
Total Labor Costs During Caretaker			$3.7

GISF Annual Labor Costs: Loading and Unloading, 40,000 MTU GISF

Labor Categories During Loading and Unloading	Estimated Annual FTE	Average Cost per FTE ($K)	Cost Estimate (Millions 2009$)
Administrative staff: • General manager, administrative assistants, public relations, financing and purchasing, accounting and payroll, governmental affairs	10	$82.5	$0.83
Security staff: assumes 4 staff per shift, 3 shifts	20	$55.0	$1.10
Engineering and technical staff • Nuclear and licensing engineers, health physics managers and technicians, quality assurance managers and technicians, transportation specialist, training	19	$79.0	$1.50
Maintenance and equipment operating staff: • Mechanical and electrical maintenance, crane and equipment operators, general plant workers, fire and EMT	24	$58.0	$1.37
At-reactor loading crews: • 2 per site, 9 sites per month	18	$70.0	$1.26
Subtotal: Labor during Loading and Unloading	91	$67.2	$6.1
Fringe benefits and contingency: 40%			$2.4
Total Labor Costs During Loading and Unloading			$8.5

In estimating the decommissioning costs for the GISF, EPRI assumed that decommissioning costs would be 20% of the GISF Fuel Storage Facility costs ($67 million, see Table 2-8) and 20% of the total costs of storage overpacks ($800 million assuming 200 overpacks/year for 20 years, see Table 2-10). Estimated decommissioning costs total $173.4 million (13.4 million plus $160 million) plus an assumed 30% contingency, for total decommissioning costs of $225 million.

Comparison of Capital Costs for a 40,000 MTU GISF Assuming 10 MTU and 13 MTU Capacity Storage Systems

Cost Category	40,000 MTU GISF (Millions 2009$)			
	10 MTU Capacity DPC		13 MTU Capacity DPC	
Transportation Infrastructure				
• Access roads/rail spur/land improvements		$14.0		$14.0
• Railcar locomotive	14 locomotives	$56.0	11 locomotives	$44.0
• Rail escort cars	14 escort cars	$51.8	11 escort cars	$40.7
• Rail buffer cars	28 buffer cars	$14.0	22 buffer cars	$11.0
Contingency		$40.7		$32.9
Subtotal Transportation Infrastructure		**$176.5**		**$142.6**
GISF Infrastructure				
• Administration building		$ 3.7		$ 3.7
• Security/health physics building		$ 2.8		$ 2.8
• Operations/maintenance building		$ 6.0		$ 6.0
• Canister transfer building		$18.9		$16.3
Contingency		$ 9.4		$ 8.6
Subtotal GISF Infrastructure		**$ 40.8**		**$ 37.4**
Fuel Storage Facility (Note 1)				
• Excavation and grading	4000 Overpacks	$ 3.0	3076 Overpacks	$ 3.0
• Concrete storage pads	12,400 lin. ft.	$53.6	11,080 lin. ft.	$41.6
• Security fence		$ 0.9		$ 0.8
• Security System		$ 9.5		$ 9.5
Contingency		$20.1		$16.5
Subtotal Fuel Storage Facility		**$87.1**		**$71.4**
Transportation Casks and Transport Equipment				
• **Transportation cask, impact limiter, railcar, cask skid**	28 casks	$145.6	22 casks	$114.4
• **Contingency**		$ 43.7		$ 34.3
Subtotal Transportation Casks and Equipment		**$189.3**		**$148.7**
Subtotal Capital Costs		**$493.7**		**$400.1**
Decommissioning		**$225.0**		**$174.0**

Note 1: The Fuel Storage Facility would be built over the first 20 years of operation. The costs associated with initial construction of the Fuel Storage Facility are estimated to be $20.0 to $20.9 million, for a 13-MTU or 10 MTU-capacity DPC, respectively (all excavation and grading, fencing and security system costs, plus sufficient storage pads to store the first 200 storage systems).

Comparison of Capital Costs for a 20,000, 40,000, and 60,000 MTU GISF Assuming 10 MTU Capacity Storage Systems

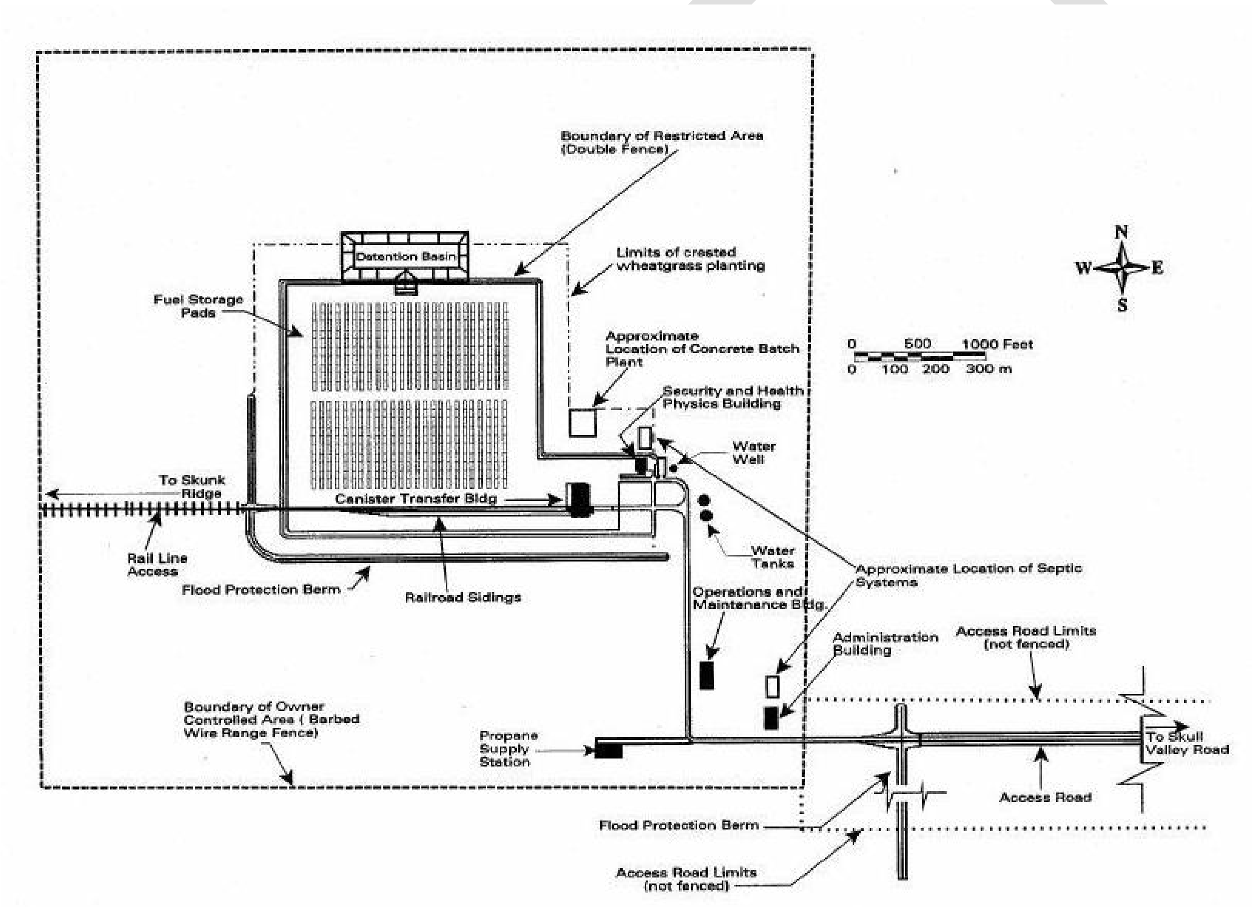
Cost Category	**Millions 2009$**					
	40,000 MTU GISF		**20,000 MTU GISF**		**60,000 MTU GISF**	
Transportation Infrastructure						
• Access roads/rail spur/land improvements		$14.0		$14.0		$14.0
• Railcar locomotive	14 locomotives	$56.0	7 locomotives	$28.0	20 locomotives	$80.0
• Rail escort cars	14 escort cars	$51.8	7 escort cars	$25.9	20 escort cars	$74.0
• Rail buffer cars	28 buffer cars	$14.0	14 buffer cars	$ 7.0	40 buffer cars	$20.0
Contingency		$40.7		$22.5		$56.4
Subtotal Transportation Infrastructure		**$176.5**		**$97.4**		**$244.4**
GISF Infrastructure						
• Administration building		$ 3.7		$ 3.7		$ 3.7
• Security/health physics building		$ 2.8		$ 2.8		$ 2.8
• Operations/maintenance building		$ 6.0		$ 6.0		$ 6.0
• Canister transfer building	3 transfer cells	$18.9	2 transfer cells	$16.3	4 transfer cells	$21.3
Contingency		$ 9.4		$ 8.6		$10.1
Subtotal GISF Infrastructure		**$40.8**		**$37.4**		**$43.9**
Fuel Storage Facility (Note 1)						
• Excavation and grading	Storage pads for	$ 3.0	Storage pads for	$ 1.5	Storage pas for	$ 4.5
• Concrete storage pads	4000 Overpacks	$53.6	2000 Overpacks	$26.8	6000 Overpacks	$80.4
• Security fence	12,400 lin. ft.	$ 0.9	9,200 lin. ft.	$ 0.7	15,600 lin. ft.	$ 1.2
• Security System		$ 9.5		$ 4.7		$15.1
Contingency		$20.1		$10.1		$30.4
Subtotal Fuel Storage Facility		**$87.1**		**$43.8**		**$131.6**
Transportation Casks and Transport Equipment						
• **Transportation cask equipment**	28 casks	$145.6	14 casks	$72.8	40 casks	$208.0
• **Contingency**		$ 43.7		$21.8		$ 62.4
Subtotal Transportation Casks and Equipment		**$189.3**		**$94.6**		**$270.4**
Subtotal Capital Costs	**$493.7**		**$273.2**		**$690.3**	
Decommissioning	**$225.0**		**$112.8**		**$338.0**	
Note 1: The Fuel Storage Facility would be built over the first 20 years of operation. The costs associated with initial construction of the Fuel Storage Facility are estimated to be $20.9 million (40,000 MTU); $10.7 million (20,000 MTU) and $32.3 million (60,000 MTU) . This includes costs for all excavation and grading, fencing and security system costs, plus sufficient storage pads for the first year of storage.						

Appendix B. Engineering details from PFS EIS

The EIS prepared by PFS for its license application contains extensive details on the siting, construction, operation and decommissioning of the storage facility on which the Australian project is modelled. In this Appendix, we extract key data which can be used for updated specific cost estimates prepared for an Australian context.

The basic site plan for the proposed ISFS proposed by PFS is shown in Figure B.1. A fence would mark the boundaries of the 330ha leased area - the owner controlled area (OCA) - and a 40 ha restricted-access area within the OCA would contain the storage pads and some of the support facilities. The restricted-access area would be located at the approximate centre of the OCA. Fencing around the restricted-access area would consist of two 2.4 m chain link security fences topped with barbed wire. The inner fence would be separated from the outer chain link nuisance fence by a 6 m (isolation area). Buildings and storage areas would primarily be located within the restricted-access area, with the exception of the administration building, concrete batch plant, and operations and maintenance building, which would be located on the site outside the security fences.

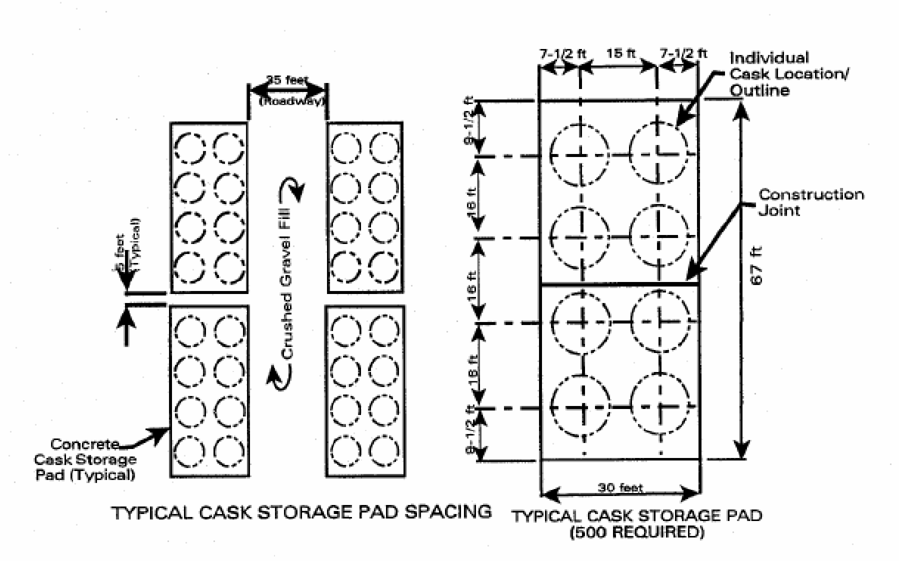
Figure B.1 : Proposed ISFS site plan



Source:

PFS proposed to construct the facility in three phases to enable early operation, with the first phase including all infrastructure and pad space for 1,000 of the total 4,000 casks foreseen. A work force of 130 persons was envisaged for this most intensive phase with only 43 staff being required during later phases. When fully completed, the proposed PFSF would contain modular concrete storage pads that would be 20×9×1 m and would hold up to eight storage casks in a 2 × 4 array. Five hundred such pads would be required for the 4,000 storage casks. Areas between the storage pads would be surfaced with a 20 cm thickness of compacted crushed rock and sloped toward the north to facilitate drainage. The PFA sketch is shown below.

Figure B.2 : PFA sketch



In the PFS design the casks would be concrete structures constructed on site. A concrete batch plant would provide concrete for construction of the facilities and the storage casks. The footprint of this batch plant would encompass approximately 0.8 ha and would be sized for a maximum capacity of 57 m^3 per hour. The total cement requirements for the infrastructure and the 500 pads would be 70,000 m^3 for the infrastructure and the 500 pads and 12,000m^3 for the concrete overpacks.

The storage casks would be cylindrically shaped concrete and steel structures, approximately 3.4m in diameter and 6.1m high. The steel liners of the casks would be manufactured off-site and transported to the proposed PFSF. The storage casks would be assembled on-site using concrete from the on-site batch plant and the steel liners supplied by the cask vendor. The casks would be assembled at the batch plant on an as-needed basis.

The canister transfer building would be a massive, reinforced-concrete, high-bay structure approximately 60m wide, 80 m long, and 27 m high. This building would facilitate the transfer of the SF canister from its shipping cask into the storage cask. To support the operations described in detail below, the canister transfer building would be equipped with a 180 tonne overhead bridge crane for moving the shipping casks, a 135 tonne semi-gantry crane for canister transfer operations, and three canister transfer cells to provide a radiation-shielded work space for transferring the SF canisters from the shipping casks to the storage casks. Shipping casks would be moved into the high bay portion of the building either on railcars or heavy / haul trailers, depending on which transportation option is chosen.

The security and health physics building would be located adjacent to the canister transfer building and would consist of a single-story, concrete masonry structure approximately 23 m wide, 37 m long, and 5.5 m high. This building would provide office and laboratory space for security and health physics staff and would house security, communication, and electrical equipment needed for these personnel.

An earthen diversion berm would be built (from materials removed from the storage pad area) around the uphill sides of the storage area to protect the site by diverting storm runoff away from the storage pads and into the natural drainage basin located to the north. On-site drainage at the storage pad area would be conveyed by a surface flow system to a 3 ha storm water collection and detention basin. The basin would be designed for a 100 year storm event.

A potable water supply system would be provided for the facility, taking water from either a groundwater well on the site or off-site sources. Because it is unlikely that a well drilled into the mid-valley aquifer would yield adequate quantities of water on demand, above-ground storage tanks would be erected for potable water, water for use in extinguishing fire, and water for the concrete batch plant. Water requirements would be similar to a light industrial facility having a 24 hour per day workforce, with the greatest water use being during construction for dust suppression and operation of the concrete batch plant. The peak daily water consumption from the on-site well during construction would be 38 m^3 / day.

Operation

A general discussion of SF transportation is provided below to give an overview of the complete operation. In addition to the operations described below for receiving SF at the proposed PFSF, once a permanent repository is available, operations would include transferring the stored SF canisters to shipping casks and transporting them to the GDF.

PFS proposed to use a dual-purpose canister system to transport the SF to the proposed PFSF. The steel canister that contains the SF is compatible with the HI-STORM 100 storage overpack (i.e. storage cask) to be used at PFS and the HI-STAR 100 transportation overpack (i.e. transportation cask) to be used for shipments between the originating power reactor generating company and PFSF. The sequence of operations is illustrated in Figure B.3 and discussed in the following paragraphs.

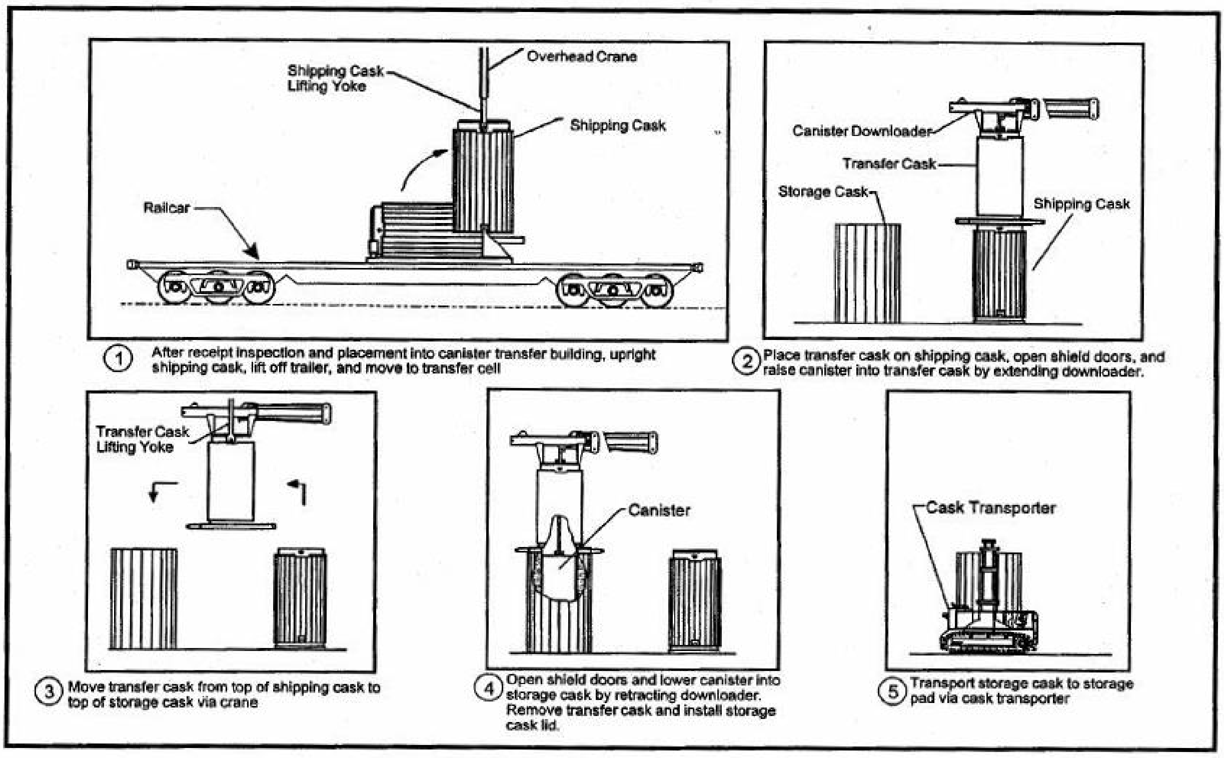
At the originating reactor site, multiple SF assemblies would be loaded into a metal canister, and the canister would be prepared for shipping, placed into the Holtec International HI-STAR 100 transportation overpack loaded onto a shipping cradle, and then attached horizontally to a railcar for shipment to the proposed PFSF in Skull Valley. The shipping casks are made of steel and weigh up to 130 metric tonne when loaded with the SF and the canister. If a reactor site cannot accommodate the shipping cask proposed by PFS, the reactor licensee would load SF (in the SF pool) into smaller “transfer” casks and then, using a dry transfer system, move the fuel from the smaller transfer casks into the larger shipping cask.

On average, approximately 150 (100 to 200) loaded shipping casks would be received at the proposed facility each year. For these shipments, PFS would use either of two, single-purpose, dedicated trains which would proceed from the originating reactor site directly the storage site. The PFSF would receive one (or up to two) trains each week carrying two to four loaded shipping casks per train; however, up to six loaded shipping casks per train could be accommodated by the proposed single-purpose trains.

At the PFSF, the railcars carrying the shipping casks would be pushed by locomotive into the canister transfer building, where the shipping casks would be removed from their railcars by crane (turned to a vertical position, and moved into a transfer cell. Inside the transfer cell, the shipping cask and the storage cask would sit side by side. The top of the shipping cask would be unbolted, removed, and set aside. Once the lid of the shipping cask is removed, the canister is surveyed for radiological contamination to assure it meets PFSF acceptance levels. In the unlikely event the canister is found to be contaminated above acceptable levels, PFS intends to close the lid of the HI-STAR 100 transportation overpack (i.e., shipping cask) and return it to the originating site.

If the canister meets acceptable contamination levels, the single failure-proof crane would then pick up an open-bottomed, shielded transfer cask and move it into position over the shipping cask. The sealed SF canister would be lifted out of its shipping cask into the transfer cask. The crane would be used to move the transfer cask (with the SF canister inside) from the top of the shipping cask to the top of the storage cask. Once the transfer cask is in position above the storage cask, the canister would then be lowered from the transfer cask into the storage cask. A lid would be placed and bolted on top of the storage cask prior to moving the cask onto a storage pad. A specially designed storage cask transporter, equipped with a 180 tonne hydraulic lifting beam and rolling tracks would be used to move each storage cask from the canister transfer building onto the storage pads. A schematic of the process is shown below.

Figure B.3 : Transfers of Spent Fuel at PFSF



Proposed storage cask system

The cask system being considered for use at the proposed PFSF is the Holtec International HI-STORM system. The cask supplier would be responsible for design and certification by NRC of the canisters, casks, and transfer equipment. The characteristics of the HI-STORM canister and storage cask are shown below.

Characteristics of the HI-STORM canister

Parameter	Value
Outside diameter	1.7 m (5.7 ft)
Maximum length	4.8 m (15.9 ft)
Capacity	24 PWR[a] assemblies ***or*** 68 BWR[b] assemblies
Maximum heat load	20.88 kW for PWR canister 21.52 kW for BWR canister
Material of construction	Stainless steel
Maximum weight (loaded with SNF)	PWR: 36.3 MT (40.0 tons) BWR: 39.6 MT (43.6 tons)
Internal atmosphere	Helium

[a]PWR = Pressurized water reactor
[b]BWR = Boiling water reactor

Characteristics of the HI-STORM storage cask system

Parameter	Value
Height	6.1 m (20.0 ft)
Outside diameter	3.4 m (11.0 ft)
Capacity	1 canister, loaded with approximately 10 MTU of SNF
Maximum radiation dose rate	
1 m (39 inches) from surface:	
Side	17 mrem/hr
Top	2 mrem/hr
On contact with surface:	
Side	35 mrem/hr
Top	5 mrem/hr
Top vents	9 mrem/hr
Bottom vents	15 mrem/hr
Material of construction	Concrete (core and lid) Steel (liner and shell)
Maximum weight (empty)	121.7 MT (134.2 tons)
Maximum weight (loaded with single SNF canister)	PWR[a]: 158.0 MT (174.2 tons) BWR[b]: 161.3 MT (177.8 tons)
Service life	More than 100 years

[a]PWR = Pressurized water reactor fuel assemblies inside canister.
[b]BWR = Boiling water reactor fuel assemblies inside canister.

Source: PFS/SAR 2001; Table 4.2-2.

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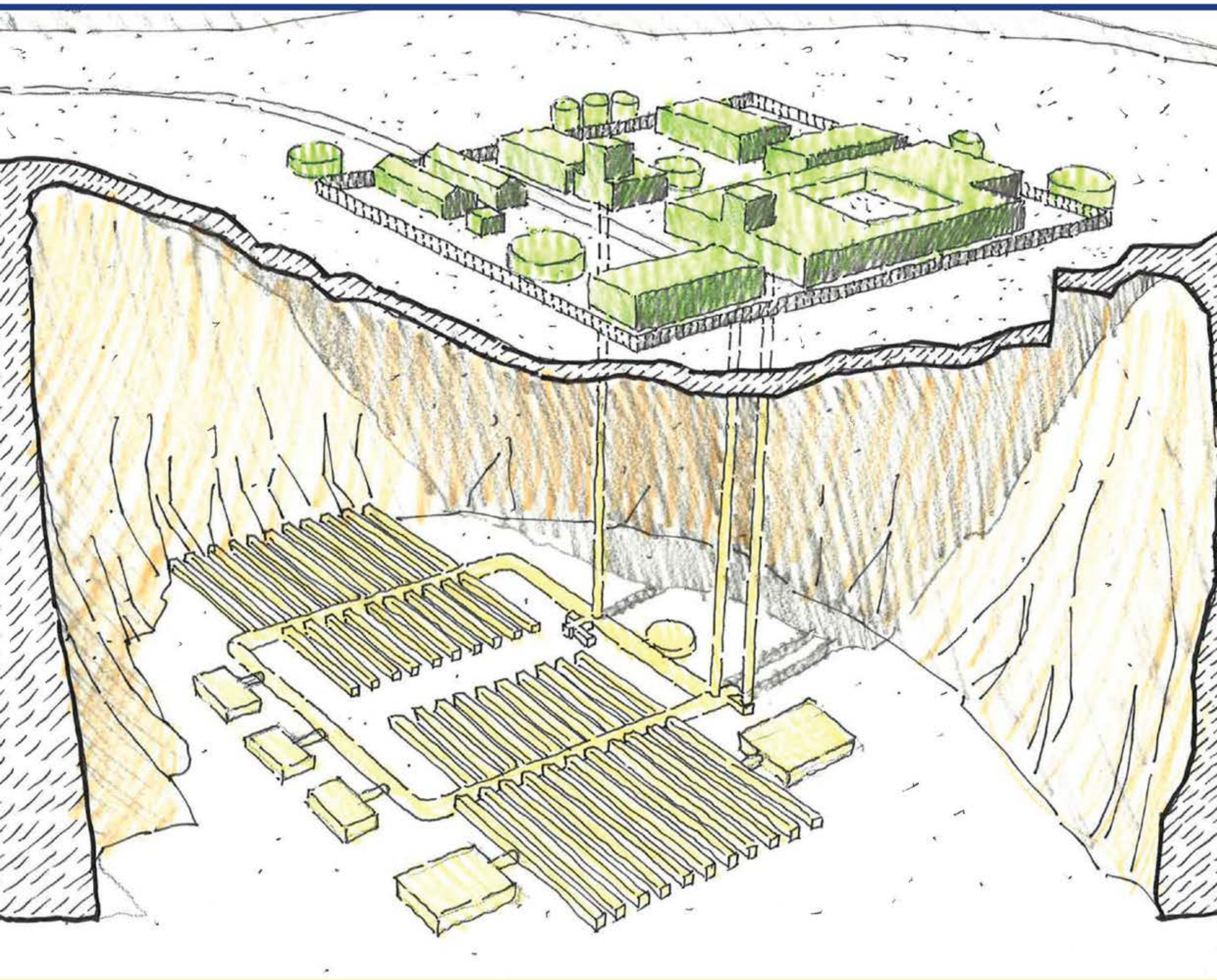

PAPER 2

POTENTIAL INTERNATIONAL INVENTORIES AND REVENUES

PAPER 2
POTENTIAL INTERNATIONAL INVENTORIES AND REVENUES
JACOBS mcm

Paper 2 - Potential international inventories and revenues

1. Introduction

This paper describes the potential international market for high level and intermediate radioactive waste management and storage services which is accessible to South Australia, and the market share thereof which may be captured.

The total market for these services is a function of both the total quantity of foreseeable waste arisings which will accrue around the world, and what is known about those countries' ability to manage, or declared plans to manage, their own waste stockpiles themselves or under a regional cooperative arrangement. The source material for the existing international inventory is largely drawn from publicly available reports, both multinational and for individual countries. Future waste streams are inferred from reported continuation of current and new nuclear power programmes and typical rates of waste created per unit of energy output.

The other element of the international market analysis is the basis for *willingness to pay* for these waste management services. The latter part of this paper then presents the available evidence of willingness to pay, as an input to the determination of overall revenues from management and disposal services.

PAPER 2
POTENTIAL INTERNATIONAL INVENTORIES AND REVENUES
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2. Approach to developing reference inventories

A list of countries that may be interested in using a foreign storage and disposal service rather than implementing national facilities was developed, as noted in Section 2.1, below. For these countries, the IAEA PRIS databased was used to examine the energy produced to date by all nuclear power plants (NPPs) that are shut down or in operation. This was used to back calculate the spent fuel that has been produced, using reasonable assumptions on the burn-up levels reached.

For reactors that are in operation or under construction, the future years of operation over an arbitrary 60 year lifetime were scaled by the expected annual spent fuel (SF) and intermediate level waste (ILW) arisings to arrive at reference figures based on experience.

In addition, a survey of the available literature was used to develop a list of planned reactors in programmes that are expanding or just beginning. For these the reference SF and ILW annual production figures were used, again assuming a 60 year reactor lifetime. Spent fuel from light water reactors (LWRs) and heavy water reactors (HWRs) are estimated separately since the SF annual production varies strongly between the two.

No account is taken of quantities of SF that have been or are foreseen for reprocessing since these will result in vitrified HLW which must be stored and disposed of in any event.

For ILW, the figures are variable and less predictable so that a standard quantity per GWe.y has been assumed for all reactor types.

The total inventories obtained were then scaled back, using professional judgment, to postulate which fraction of the total available inventories might be shipped to an Australian facility. Upper and lower estimates were also defined (see below in Section 2.3.5)

2.1 Selection of potential client countries

Within the global set of potential client countries with current, historic or planned nuclear power programmes, two specific groups were excluded from the countries considered as potential clients:

- Major nuclear power users which will be constrained to develop national solutions or already have structured programmes leading to a national disposal facility. Examples are the USA, France and the UK.
- Countries which have a declared policy or even a national law that prohibits exporting their radioactive wastes. Examples are Sweden and Finland.

China and India are also excluded because both countries have or will have large national nuclear programmes and are geared up to store and dispose of wastes themselves. China, with an active national repository programme (e.g. at Beishan in the Gobi desert), is considered more likely to become a competitor offering international disposal services than a client country for Australia.

Potential client countries with nuclear power programmes that are shut-down, operating or under construction are:

- Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria , Czech Republic, Germany, Hungary, Iran, Italy , Japan, Kazakhstan, Korea, Lithuania, Mexico, Netherlands , Pakistan , Romania , Slovakia, Slovenia , South Africa, Spain, Switzerland, Taiwan, Ukraine and UAE

Countries with credible plans for new reactors are:

- Turkey, Iran, UAE, Jordan, Egypt, Nigeria, Ghana, Bangladesh, Vietnam, Thailand, Malaysia, South Africa and Saudi Arabia

There is some uncertainty regarding wastes from Iran, Vietnam, Ukraine and Turkey which have contracts for nuclear fuel with Russia. In Russia import of waste is illegal while import of spent fuel (considered a resource) is acceptable, but as yet only for Russian supplied fuel. This leads to the following likely scenarios:

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- Iran – for the present programme of reactors it seems likely that Russia will supply some of the fuel and take back the spent fuel it originally supplied with no return of any associated wastes.
- Vietnam and Turkey – the position is less clear. The customers are understood to have the view that Russia will take away the fuel permanently, but Russia believes it will have an option to send back wastes.
- The Ukraine currently sources all of its nuclear fuel from Russia, but it will receive HLW back from any fuel reprocessed in Russia. In addition, it has recently commenced a process to diversify its fuel sources to include America and France. The Ukraine currently lacks sufficient storage options, with much of its fuel being stored (at a cost) in Russia or in interim (dry cask) storage. Given the tenuous nature of current arrangements with Russia, its growing reliance on nuclear energy and its lack of a developed disposal option, the Ukraine is considered a candidate country for an international solution.

We unaware of any indication that Russia would take away other ILW that also needs to go to a geological disposal facility.

As these three countries account for only a small fraction of the potential client countries wastes they have been included, noting that the fraction is less than the uncertainties assumed in the modelling scenarios.

Australia itself has not been assumed to be a future nuclear power user. If this did become the case, the impact of the resulting waste would have only a marginal impact on the potential amounts of waste that is being considered for disposal in Australia. Also, an international repository on the Australian economy would be affected less by the additional inventory than by the removal of the need for a purely Australian geological repository.

2.2 Assumptions in deriving country inventories

There are a variety of assumptions made in the determination of inventories of different forms of radioactive waste in existence, or which is foreseeable based on current declared plans, as follows:

2.2.1 Spent fuel (SF)

Present inventories of SF are derived from total electricity production data (sourced from the latest IAEA Power Reactor Information System (PRIS) database)[17], thermal efficiency of 1 / 3 and average burn-up of 40 GWd / t for light water reactors (PWR and BWR) and 8 GWd / t for heavy water reactors. LWR burn-ups were lower than this in early years, but increased in recent years.

Future inventories of SF are derived from the total expected years of future operation (assuming 60 year lifetime), 90% availability, 35% thermal efficiency and burn-up of 50 GWd / t[18] for light water reactors. This gives 19 t / year discharge of SF for a 1 GW power plant. For heavy water reactors a burn-up rate of 8 GWd / t was used, with 90% availability and thermal efficiency of 31%, giving an SF discharge of 132 tHM / year / GW. This was used for operational nuclear power plants and ones that are under construction and planned.

For a few reactors, there are no data on the electricity production in the PRIS database. Hence, present inventories of SF for these NPP are derived from years' of operation.

2.2.2 High level waste (HLW)

For the present calculations we neglect the fact that some SF that has gone to reprocessing or might in the future be reprocessed. This gives conservative upper limits for the SF inventory (0.161 m^3 of HLW is generated per tonne of heavy metal (tHM) SF[19]. In practice, for the selected countries, only a small fraction of SF has gone to reprocessing. More detailed assessment would be effected mostly by Japan which has an official policy of complete reprocessing.

[17] Downloaded Nov 2nd 2015 at https: / / www.iaea.org / PRIS / CountryStatistics / ReactorDetails.aspx?current=567)
[18] The issue of burn-up levels requires more detailed study since they have changed markedly over the years and are still increasing. Furthermore the burn-up reached determines the heat output of the SF and this has important impacts on storage times and storage technologies.
[19] Source: Schneider, M and Marignac, Y, 2008

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2.2.3 Intermediate level waste (ILW)

Present and future inventories are derived from years' of operations (assuming 60 years lifetime) and ILW production of 60 m^3 per year per 1 GW unit. This is based on literature data of the AP1000 reactor operation and maintenance of one 1 GW unit will generate around 58.2 m^3 ILW (for modelling purposes this was rounded to 60)[20].

There are large uncertainties in this since the ILW production depends strongly on reactor type and the mode of operation.

2.3 Inventories for selected countries

2.3.1 Spent fuel inventories - current and historic programmes

Based on the sources and assumptions presented above regarding historic, current or planned nuclear power programmes, the following total spent fuel inventories are foreseeable for those countries seeking an international solution to their radioactive waste streams (as light water or heavy water reactors).

Table 2.1 : Light water reactor (LWR) inventories (historic and future to 2080)

COUNTRY	SF amount up to 2014 (tHM)	SF amount from 2015 to 2080 (tHM)	SF amount up to 2080 (tHM)
Armenia	276	550	827
Belarus	0	1,497	1,497
Belgium	4,413	3,045	7,458
Brazil	678	3,022	3,699
Bulgaria	1,589	1,292	2,881
Czech Republic	1,627	3,042	4,668
Germany	15,119	6,667	21,786
Hungary	1,229	1,131	2,359
Iran	29	1,064	1,093
Italy	203	0	203
Japan	23,126	30,337	53,463
Korea	7,699	22,231	29,930
Mexico	634	1052	1686
Netherlands	470	176	647
Pakistan	114	1,399	1,513
Slovakia	1,320	2417	3,737
Slovenia	491	359	850
South Africa	1,075	1,087	2,162
Spain	5,224	4,149	9,373
Switzerland	2,679	1,521	4,200
Taiwan	3517	5048	8565

[20] Legacy nuclear power plants are likely to give rise to greater quantities of decommissioning waste than newer ones, as early fleet designs did not consider ease of decommissioning or waste minimisation to the degree that they are now. As a conservative estimate, this potential reduction has not been taken into account in considering the size of the prospective available market.

COUNTRY	SF amount up to 2014 (tHM)	SF amount from 2015 to 2080 (tHM)	SF amount up to 2080 (tHM)
Ukraine	6,205	11,199	17,404
UAE	0	6,384	6,384
Total LWR (rounded)	**77,717**	**108,669**	**186,385**

Table NOTES:

1) The selection of countries is based on known national policies or on judgment of potential national policies. The list includes Taiwan although shipping to mainland China is perhaps as probable, depending on geopolitical factors.
2) Taiwan data is for June 2015 and for 40 year's operation as provided by the Minister and Chairman of the Atomic Energy Council, in a letter to the RC dated 14 August 2015. These values differ slightly from the IAEA data of 3609 tHM at present and 5664 tHM from 2015 to 2080. These differences are insignificant for the business case being developed.

Table 2.2 : Heavy water reactor (HWR) inventories (historic and future to 2080)

COUNTRY	SF amount up to 2014 (tHM)	SF amount from 2015 to 2080 (tHM)	SF amount up to 2080 (tHM)
Argentina	3,458	4,739	8,197
Korea	6,500	14,102	20,602
Pakistan	208	211	419
Romania	2,096	8,660	10,756
Total HWR (rounded)	**12,262**	**27,712**	**39,974**

2.3.2 Intermediate level waste (ILW) Inventories – current and historic

Based on the assumptions above the following ILW inventories are foreseeable among countries seeking an international solution to their radioactive waste stockpile.

Table 2.3 : Intermediate level waste inventories

COUNTRY	ILW amount up to 2014 (m^3)	ILW amount from 2015 to 2080 (m^3)	ILW amount up to 2080 (m^3)
Argentina	2,348	4,057	6,404
Armenia	1,200	1,738	2,938
Belarus	0	4,727	4,727
Belgium	12,749	9,615	22,364
Brazil	2,482	9,542	12,024
Bulgaria	5,998	4,080	10,078
Czech Republic	5,273	9,606	14,879
Germany	46,378	21,053	67,431
Hungary	3,630	3,570	7,200
Iran	240	3,360	3,600
Italy	1,548	0	1,548
Japan	85,175	95,800	180,975
Kazakhstan	146	0	146

COUNTRY	ILW amount up to 2014 (m³)	ILW amount from 2015 to 2080 (m³)	ILW amount up to 2080 (m³)
Korea	25,119	76,613	101,732
Lithuania	3,510	0	3,510
Mexico	2,113	3,323	5,436
Netherlands	1,406	556	1,962
Pakistan	635	4,514	5,148
Romania	1,143	3,936	5,080
Slovakia	4,362	7,632	11,994
Slovenia	1,483	1,134	2,617
South Africa	3,550	3,434	6,984
Spain	15,745	13,104	28,849
Switzerland	7,744	4,803	12,547
Taiwan	10,605	17,885	28,490
Ukraine	24,889	35,357	60,246
UAE	0	15,120	15,120
TOTAL	**269,471**	**336,674**	**595,540**

2.3.3 Planned reactor programmes

Table 2.4 presents a list of the national nuclear power programmes which are in the advanced stages of planning and are reasonable to include in the wider demand modelling for spent fuel and intermediate level waste. The table presents the key assumptions of 19 tonnes of heavy metal (uranium) equivalent per gigawatt hour equivalent installed capacity, per annum.

Table 2.4 : Planned nuclear reactor programmes and foreseeable waste arising

COUNTRY	Programme power [GWe]	Assumed median start date	SF discharge per GWe installed (tHM)	Assumed SF by 2090 (tHM)	ILW by 2090 (assuming 60m³ / GWe per year)
Turkey	2	2030	19	2,280	7,200
Iran	2	2030	19	2,280	7,200
UAE	5	2030	19	5,700	18,000
Jordan	1	2030	19	1,140	3,600
Egypt	1	2030	19	1,140	3,600
Nigeria	1	2030	19	1,140	3,600
Ghana	1	2030	19	1,140	3,600
Bangladesh	1	2030	19	1,140	3,600
Vietnam	2	2030	19	2,280	7,200
Thailand	1	2030	19	1,140	3,600
Malaysia	2	2030	19	2,280	7,200
South Africa	9	2030	19	10,260	32,400

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COUNTRY	Programme power [GWe]	Assumed median start date	SF discharge per GWe installed (tHM)	Assumed SF by 2090 (tHM)	ILW by 2090 (assuming 60m³ / GWe per year)
Saudi Arabia	16	2030	19	18,240	57,600
Totals	44			**50,160**	**158,400**

2.3.4 Total reference inventories (current, historic and planned)

The total spent fuel inventories derived from sections 4.1 and 4.2 are given below.

Table 2.5 : Total inventories (pre-rounding)

Waste	Available now from current programmes	Available by 2080 from current programmes	Available by 2090 from assumed new programmes	Total available by 2090
LWR spent fuel (tHM)	77,717	186,386	50,160	236,546
HWR spent fuel (tHM)	12,262	39,974	0	39,974
Total SF (LWR+HWR) (tHM)	**89,979**	**226,360**	**50,160**	**276,520**
Total ILW (m^3)	***269,471***	***624,030***	***158,400***	***782,430***

To provide some context, the global stockpile of HLW is of the order of 390,000 tHM (although some of this will have been reprocessed) and so the portion from the potential client countries is less than 25%. By 2090 the global stockpile is anticipated to be just in excess of 1 million tonnes, around four times the stockpile anticipated for the potential client countries: the potential available stock is calculated to be 26% of the global stockpile.

If the simplifying initial assumption is made that the future SF becomes available at a linear rate from 2014 to 2090, then the annual rate for all the countries considered is (276,520-89,979) / (2090-2014) tHM / year, which in rounded numbers is 2,450 tHM / year – to be compared with a global production rate of around 10,000 tHM / year.

For modelling purposes a rate per year that varies over different ranges of years has been assumed, starting at a rate of 2,098 tHM / year with a maximum rate of 2,934 tHM / year between 2031 and 2080 then 836 tHM / year until 2090.

The ILW global stockpile is presently just under 10 million m3 and is expected to be nearly 24 million m^3 by 2090. The potential client countries stockpile is assessed to be 3.3% of this. The lower fraction is due to a preponderance of global ILW that is not associated with civil nuclear reactors.

A similar simplifying initial assumption for ILW to that for SF gives the annual rate for all the countries considered of 6,750 m^3 / year. For modelling purposes a rate per year that varies over different ranges of years has been assumed, starting at a rate of 5,455 m^3 / year, with a maximum rate of 8,095 m^3 / year between 2031 and 2080 then 2,640 m^3 / year until 2090.

2.3.5 Australian market share assumptions

It is unlikely that all of the countries listed would transport all of their wastes to an Australian site. Some might find a national repository less costly if large amounts of funding have already been invested by the time that an Australian facility is shown to be a credible option. It is also possible that serious interest shown by an Australian government in seizing this business opportunity might lead to competitive offers from other countries – obvious candidates here could be Russia and China.

Accordingly for the present business case study, if 50% of the totals shown are taken for the baseline and variants above and below are examined to assess the impacts of the scale of storage or repository projects. In rounded numbers therefore, we have three cases, as shown in Table 2.6.

Table 2.6 : Inventory market share scenarios (rounded)

Scenario	SF inventory (by 2090)	ILW inventory (by 2090)
Upper case (75% of available)	207,000 tHM	585,000 m^3
Baseline (50% of available)	**138,000 tHM**	**390,000 m^3**
Lower case (25% of available)	69,000 tHM	195,000 m^3

To give some perspective on these figures one can examine the inventories being planned for in national waste management programmes. Examples are:

- USA — the Yucca Mountain repository was planned for 70,000 tHM
- Sweden — the spent fuel inventory is 12,000 tHM.

2.3.6 Timing of shipments

For planning the operation of a storage or disposal facility it does not suffice to know the final inventories that will be reached. The delivery times of the wastes are also crucial. The question of when waste producers will transfer their wastes to a centralised storage facility or to a final repository is an important and sensitive point in all waste management programmes. Transporting wastes is expensive. Accordingly, waste owners will tend to delay this step as long as possible unless there are real drivers to moving the material.

The most effective driver in practice has usually been the lack of further storage at the nuclear plant. This could lead to a forced shut-down and major loss of revenue. This is discussed in Section 3. A more general incentive is to demonstrate to the politicians, the public and the national nuclear safety regulator that a permanent solution to the challenge of managing long-lived wastes is available. This is what is driving the most advanced disposal programmes (e.g. those in Finland, Sweden and France) to plan for initiating disposal as soon as the appropriate facilities have been built and licensed.

In the present study, it is assumed that clients of an Australian storage or disposal facility would chose to move their wastes off to the facility as soon as it became possible. In this regard SF has to be stored for five or more years under water before it is in a condition for dry transport. A nominal time of ten years has been assumed in the modelling. In practice, there it might be necessary to provide some incentives to adopt this strategy, e.g. reduced prices for early users, stand-by charges for storage or disposal space that will ultimately be required, etc.

2.3.7 Timing assumptions

The timing and inventory assumptions that are made for this project are therefore as follows:

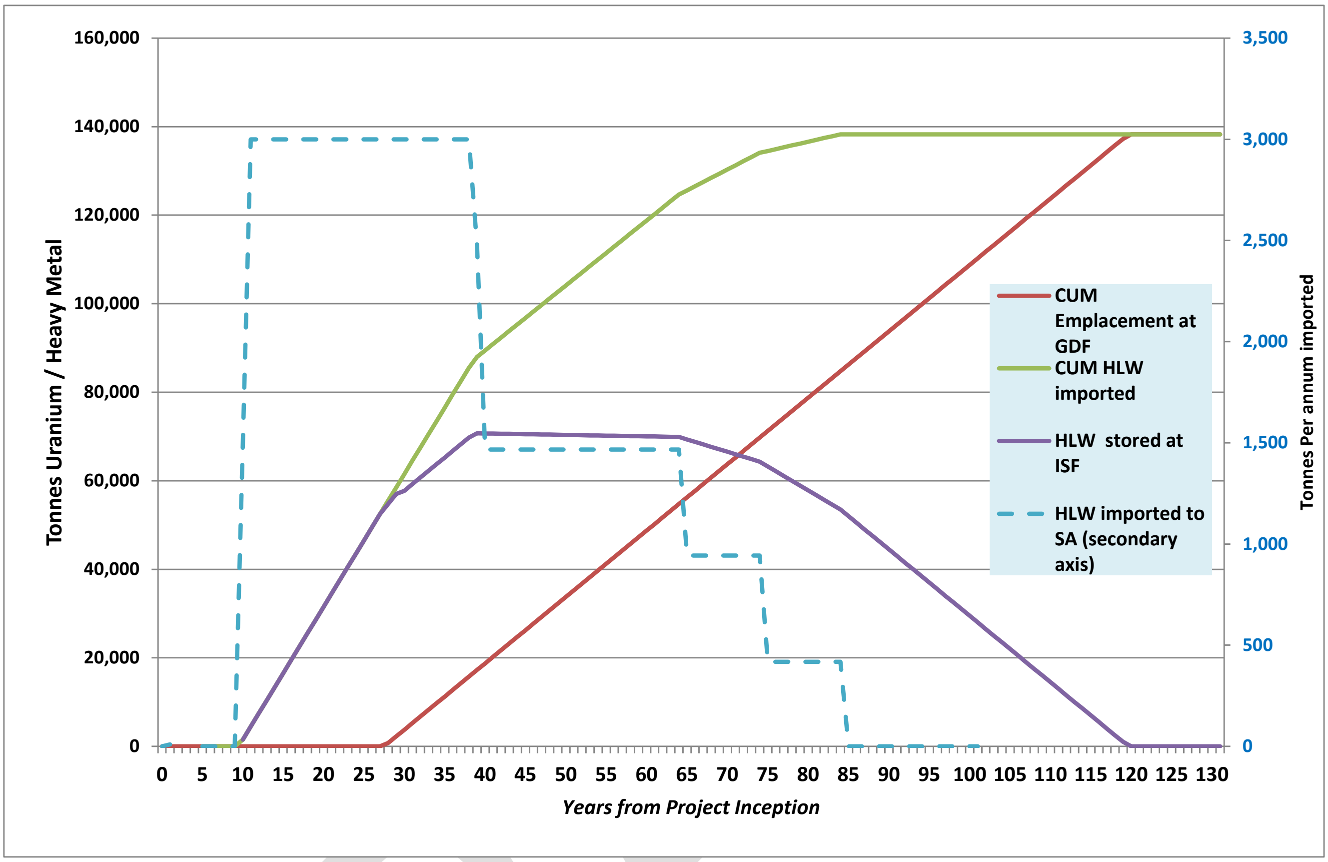
- Clients will start to ship spent fuel to the interim storage facility (ISF) for initial storage in above ground casks as soon as it is commissioned. The timescale for this is discussed in Paper 1, which suggests a decision to proceed in FY22 and shipments commencing in FY27. All the spent fuel available by 2014 in the inventory cases can therefore be assumed to be immediately available for shipment as it will be ten or more years since it was removed from the reactors. At the time of the decision to proceed / financial investment decision (FID) there will be a small additional amount of waste from arisings in 2015 through 2022, conservatively assumed to be at a rate half of that from 2025 onwards, as current programmes progressively go into operation and some waste from fuel that is presently in operating reactors. While this waste will not be ready for immediate shipment it will be suitable for shipment by the time the backlog has been shipped.
    - Baseline SF available at the time of decision to proceed (including fuel that is currently in use in reactors) = 2014 SF inventory of 90,000 tHM + 8,400 tHM arising between 2015 and 2022 plus in-reactor 5,200 tHM totalling 103,600 tHM. The base case 50% of available, i.e. **51,800 tHM** (rounded)

- Upper case SF available = 77,700 tHM (75% of available)
- Lower case SF available = 25,900 tHM (25% of available)

- The clients will ship at the highest rates that can be accepted at the storage sites until such time as their backlog of SF has been shipped. In the US PFR programme a shipping rate increasing up to 3,000 tHM / year was planned. It is assumed that the ISF would accept SF at this rate while the old inventories were being shipped out.
- Thereafter, each reactor would produce and ship at a rate determined by the throughput of fuel – i.e. ~20 tHM / year for a 1000 MWe plant, with this fuel being shipped off in dry casks after 10 years of cooling in locally at the fuel ponds at the reactors. As described above, this gives a transfer rate of circa 1,500 tHM / year. This implies that the 3,000 tHM / year acceptance rate at the ISF is not a constraint for the long term operation in the baseline or even in the upper case.
- SF will start to be transferred from the ISF to the GDF as soon as the GDF is operational. This is assumed to be 24 years after a decision is taken to implement the international project, i.e. in FY44. Thus the ISF must have space for all deliveries for 20 years. The assumed acceptance rate at the ISF, based on estimates from the USA, is 3,000 tHM / year. This would allow acceptance of the baseline inventory in approximately 15 years (8 years in lower case and 23 years in upper case) which are credible timespans for this initial scoping exercise.
- When the GDF opens, the transfer rate of SF to the encapsulation plant which is assumed to be located at the GDF site will be set to match the rate at which finally packaged SF can be emplaced in the repository. The relatively small Swedish programme with shaft access and vertical emplacement of disposal containers assumes an emplacement rate of 1,500 tHM / year at the repository. With a simpler, horizontally accessed facility, the Yucca Mountain repository in the USA was planned to ramp up to an emplacement rate of 3,000 tHM / year. For the present study, we have assumed that the Australian baseline inventory should be emplaced over the nominal 100 year lifetime of the repository, i.e. the average emplacement rate is 1500 tHM / year. A significantly higher rate is feasible but offers little benefit as revenues are driven by imports into the ISF (see Section 3.6).
- If the client has to be able to ship all of the fuel that his reactor(s) will produce, then the Australian repository must be open to accept spent fuel for around 40-50 years after the reactor shuts down since this is the typical cooling time required before SF can be emplaced deep underground. For modelling purposes we have assumed that the spent fuel will be stored for 40 years – nominally 10 years at country of origin plus 30 years at the IFS. However, the far future development of nuclear power world-wide is impossible to predict with accuracy so that details of the final phase of operation are very open.

These assumptions lead to the following profile for the spent fuel imported in Australia, stored at the ISF and emplaced at the GDF. A similar profile is shown for long lived intermediate level waste (ILW) that will be emplaced in the intermediate depth repository (IDR) part of the GDF.

Figure 2.1 : Baseline spent fuel inventories

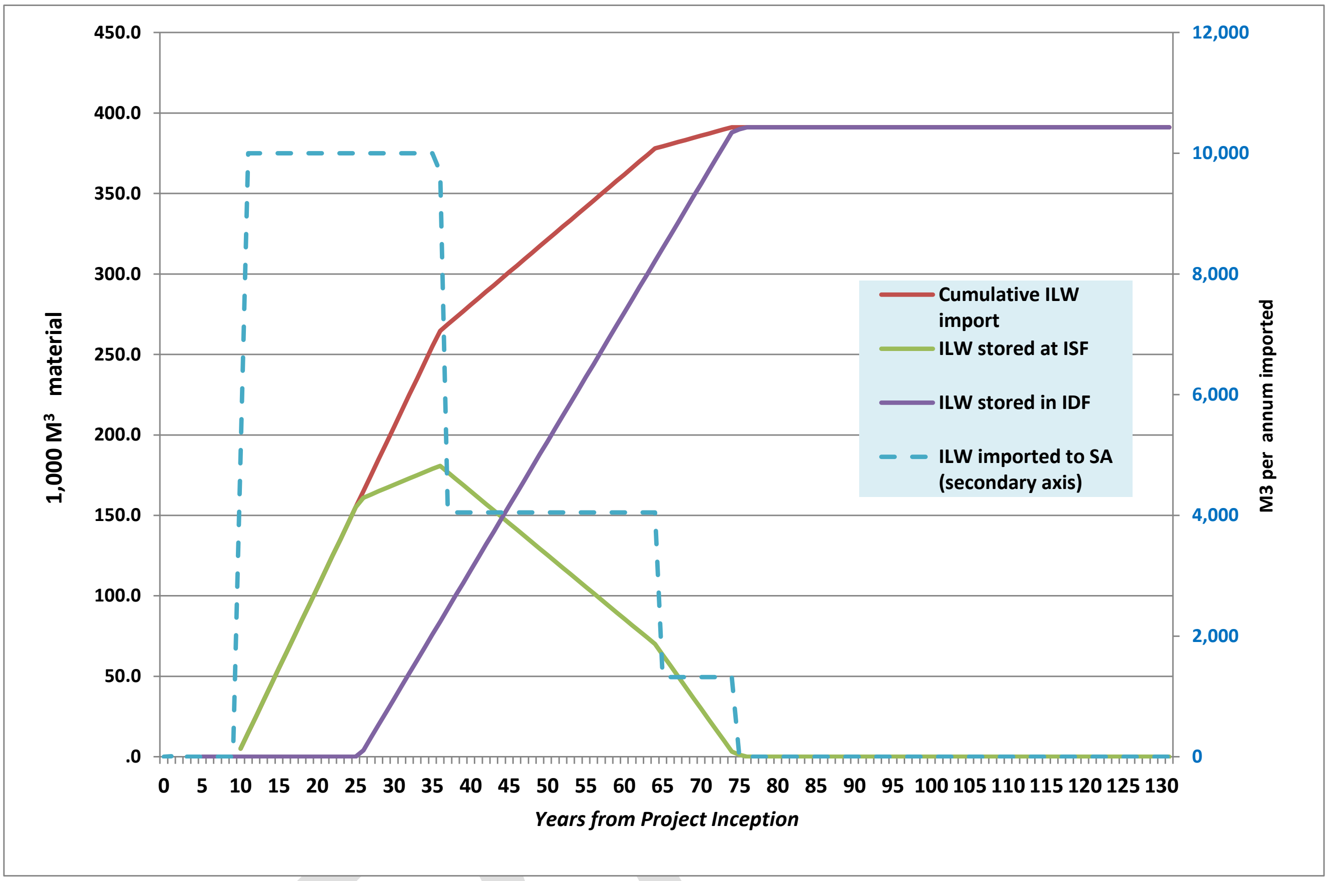


Source: Jacobs and MCM estimates

This figure shows that the ISF would receive used fuel and ILW in project year 11. Receipt of SF and ILW would continue at the ISF until year 83, initially at a rate of 3000 tHM / year for the first 30 years, then at the production rate of approximately 1500 tHM / year or less thereafter.

SF would be transferred to the GDF for disposal in year 28 at a rate of 1500 tHM / year for 92 years. The different timings and transfer rates lead to a maximum ISF storage inventory of 72,000 tHM.

Figure 2.2 : Baseline ILW inventories



Source: Jacobs and MCM estimates

3. Client willingness to pay

From the different waste streams mentioned, the HLW and spent fuel dominate in any commercial analysis since these are the most expensive materials to store and dispose of and they are also the radioactive materials which give rise to the greatest public and political opposition to self-management. Accordingly we focus on the HLW / SF issue when analysing market demand and willingness to pay.

Assumptions regarding the revenue which will accrue from the management of radioactive waste are fundamental to the business case. Since there is no observable market for radioactive waste management, a range for countries' likely willingness to pay for such a service is *inferred* from a range of reliable data sources, including proposed whole of life cost allocations for declared disposal projects, general funding allocations for waste management against nuclear power programmes and costs incurred or forecast for reprocessing of high level radioactive waste.

These data provide a snapshot of a 'bare' or 'minimum' willingness to pay, which is mostly relevant for a select group of countries which either possess well-developed plans for radioactive waste management, or already have some track record in self-management of this waste stream.

For reasons explained in this Section, the willingness to pay among the market which is accessible to South Australia is expected to be distinctly higher, due to a combination of poor or absent local alternative management options, regulatory or other imperatives which place additional time pressure on rapid delivery of permanent disposal options, or other features of an offshore (South Australian) option which are able to fulfil more criteria for a customer and hence able to command a higher fee.

Each of these sources of willingness to pay is described in turn below, and they combine to determine an average willingness to pay in excess of USD1.5 million per tonne of spent fuel (or heavy metal equivalent, "tHM").

3.1 Willingness to pay from published geological disposal costs

As noted in Section 2.6 of Paper 1 (Cost benchmarking for GDF) there is a subset of countries with operating nuclear power programmes which have declared their intention to manage and dispose of their own waste stockpiles, and have published their estimated costs to do so.

These countries, including Sweden, Switzerland, Finland, Canada, France, USA and the UK, all possess a longstanding nuclear power programme, a well-established nuclear safety regulatory framework and an informed, largely supportive social and political environment which has agreed in principle to the permanent disposal of spent fuel from their nuclear programme on their own soil. Data published by the group indicates that the cost to develop, operate and close geological disposal facilities for their own amounts of spent fuel ranges from AUD0.452 to 2.4 million per tonne, with an average of AUD1.2 million / tHM (see Figure 3.4, below).

This observed data, for those countries which may be considered the best equipped technically, geologically and socio-politically to manage the waste, provides a floor level of their willingness to pay for spent nuclear fuel disposal. This is since, if they were unwilling to pay *at least* these amounts, they would not have proceeded with implementation of their plans via legislative change, extensive community consultation, site selection and in the cases of Sweden and Finland, advanced development and construction, respectively.

Nevertheless, given the favourable position that these countries enjoy technically and socio-politically in managing radioactive waste, not to mention the significant sunk costs that they have put into decades of general and site-specific research, these countries may be regarded as occupying the *lower end* of the global willingness to pay spectrum. Countries without these features are at a long term disadvantage and hence faced with paying higher amounts to resolve their legacy and current waste liabilities.

Conclusion – "best equipped" countries have WTP average of at least AUD1.2M per tonne of spent fuel, other countries will be yet higher.

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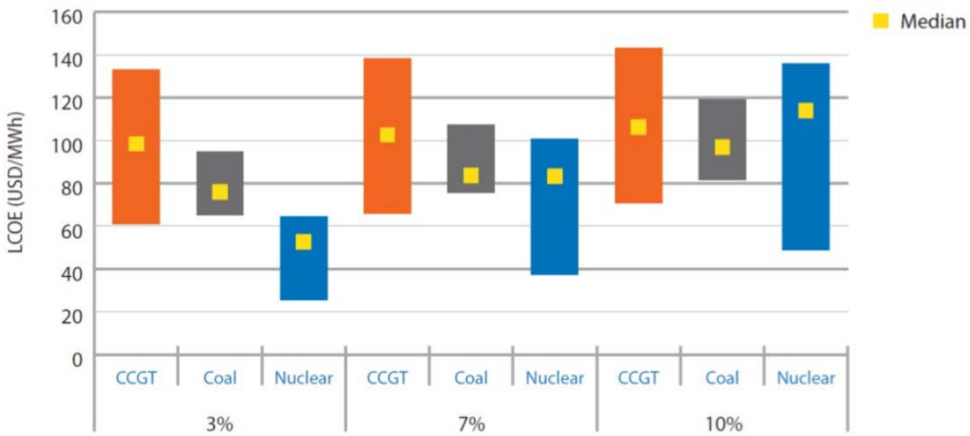
3.2 Baseline worth to utility in divesting itself of nuclear fuel

The cost to a nuclear utility of spent fuel storage and disposal has also been examined as part of several studies of the levelised cost of electricity (LCOE). There have been several influential studies of LCOE, and the example used here is the OECD's 2010 and 2015 publications "*Projected Costs of Generating Electricity*"[21]. These derive LCOE estimates for the various technologies in terms of US Dollars per MWh. The LCOE takes into account discounting of costs over time, and this can have an enormous effect on the results for activities which stretch over decades. Figure 3.1 (below) from the 2015 OECD report illustrates this clearly.

Figure 3.1 Overview of Results from various Technologies - LCOE for different discount rates (Source: OECD 2015)[22]



The breakdown of the LCOE for nuclear power plant is shown in Table 3.1 and Table 3.2 (below) for three interest rates from the 2015 report. The figures average a spread of results for different LWR reactors in nine OECD (and one non-OECD) countries, totalling some 18.6 GWe of installed capacity[23]. An interesting observation is that, in spite of the 2011 Fukushima Daiichi accident in Japan, reported capital costs have not risen since the corresponding report in 2010.

Table 3.1 : Lifetime cost of electricity results for three discount rates

Discount rate	Investment cost (USD / MWh)	Refurbishment and decommissioning costs (USD / MWh)	Fuel and waste costs (USD / MWh)	O&M costs (USD / MWh)	LCOE (USD / MWh)
3%	**26.99**	**0.46**	**10.46**	**13.55**	**51.45**
Percentage of LCOE	52.46%	0.89%	20.33%	26.34%	
7%	**55.43**	**0.29**	**10.46**	**13.55**	**80.53**
Percentage of LCOE	68.83%	0.36%	12.99%	16.83%	
10%	**84.37**	**0.14**	**10.46**	**13.55**	**109.32**
Percentage of LCOE	77.18%	0.13%	9.57%	12.39%	

[21] http: / / www.oecd-nea.org / ndd / egc / 2015 /
[22] Note: figure assumes region-specific fuel prices for US, Europe, Asoa; 85% load factor, CO2 price of USD30 / tonne
[23] The figures quoted in the 2015 OECD report cover a sample of nine OECD countries (Belgium, Finland, France, Hungary, Japan, Korea, Slovak Republic, UK and US) and one non-OECD country, China.

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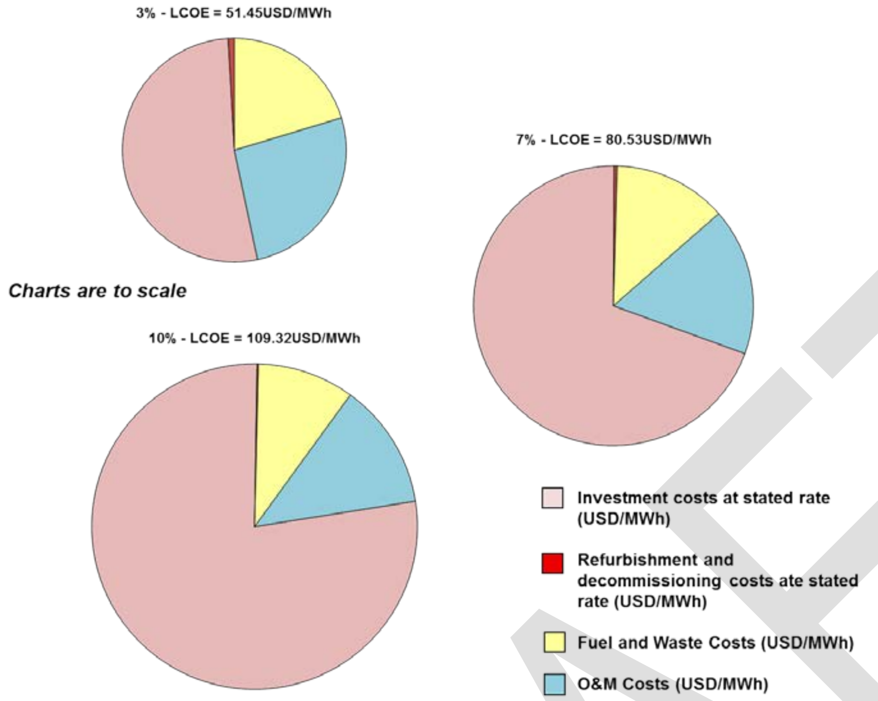
Figure 3.2 : Levelised cost of electricity for 3%, 7% and 10% discount rates



The key observation is that capital and investment costs dominate even at low discount rates, and in particular, the fuel cycle costs are only 10-20% overall, which will include uranium mining, enrichment, fuel fabrication, spent fuel storage and disposal.[24] The fuel cycle cost detail from the report also gives:

> *"Front-end of nuclear fuel cycle (Uranium mining and milling, conversion, enrichment and fuel fabrication): USD 7 per MWh (USD 1.94 per GJ);*
>
> *Back-end of nuclear fuel cycle (Spent fuel transport, storage, reprocessing and disposal): USD 2.33 per MWh (USD 0.65 per GJ).*

Thus the 'back end' is estimated to make up some 25% of the overall fuel cycle cost. As the power output per tonne of fuel is known (at a burn-up of 50 GWd / tHM and thermal efficiency 34%, each tHM produces 408,000 MWh of electricity), it follows that the 'back end' cost to the utility can be calculated in terms of 'expected cost USD per tHM spent fuel'. The results are shown below.

Table 3.2 : Derivation of expected spent costs from 2010 and 2015 analyses

	LCOE (USD / MWh)	% for Fuel cycle	Fuel cycle (USD / MWh)	Fuel storage & transport (USD / MWh) @ 25% of total fuel cycle	Expected SF cost per tHM (USD) at 408,000 MWh / teHM
2010 case with 5%	52.5	17.1	9.01	2.25	918,000
2010 case with 10%	84.5	10.7	9.01	2.25	918,000
2015 case with 3%	52	20.3	10.46	2.62	1,069,000
2015 case with 7%	81	10.5	10.46	2.62	1,069,000
2015 case with 10%	109	9.6	10.46	2.62	1,069,000

[24] Note also that decommissioning costs, often quoted as a real obstacle for nuclear power, account for only 0.1 and 0.9% at the discount rates examined. This is because of the large time delay before disposal is assumed, which means that the 'back end cost' effectively becomes '*the Net Present Cost of spent fuel storage for infinite time at the assumed discount rate*'.

Thus individual utilities will make a provision to spend around USD 1 M / tHM spent fuel on the 'back end', and this represents the baseline or lower estimate for '*willingness to pay'* to rid themselves of this liability.

Conclusion – Levelised cost of electricity (whole of life costs per unit power) indicates expected cost of USD 1M / tonne, ie WTP > $1M USD/t U

3.3 Spent fuel reprocessing costs

Several countries that are without advanced waste management and disposal programmes and have experienced opposition to their declared plans for dry storage are facing considerable pressure to reduce their accumulated SF volumes by other means. Reprocessing of spent nuclear fuel, which is offered by a small number of countries on a fee for service basis, involves the separation of the most active elements of a spent fuel assembly and the immobilisation of the remaining high level waste, typically in vitrified (glass) form. Reprocessing of spent fuel reduces its overall volume by some 80%.[25]

In order to address non-proliferation concerns, countries which send waste for reprocessing generally do not receive the separated fissile elements of the spent (notably plutonium) in return, and the benefit of these potential energy sources accrues to the reprocessing country. The customer countries, however, do have to agree to the return of the highly radioactive vitrified wastes, so that they are still faced with the challenge of finding a disposal option for these.

Taiwan currently has six operating nuclear power reactors which provided 8.3% of its total power output in 2014[26] and over a quarter of its baseload power. Following a series of delays and interruptions to its plans to investigate and develop dry storage and geological disposal of spent fuel, it is now facing a severe shortage of storage at two of its three reactor complexes and in 2014 commenced detailed planning for overseas reprocessing. This decision resulted in a 'pilot tender' for reprocessing of some 300 tonnes of spent fuel[27] being let in February 2015, with an estimated cost to Taiwan of USD356 million. Under the terms of the pilot, separated fissile elements would not be returned to Taiwan, but recycled by third party nuclear reactors at the site of reprocessing and the high level waste products would be returned to Taiwan over a period of 20 years[28] in immobilised (vitrified) form for eventual geological disposal.

The tender was suspended in March 2015 following a ruling that additional budgetary approval was necessary, and remains suspended following a recent change of government in Taiwan.

The recent experience of reprocessing costs faced by Taiwan indicates a willingness to pay for reprocessing at a rate of >US1M per tonne of spent fuel, in essence to 'buy time' for continued nuclear power development and to secure a permanent solution for its high level waste stream. As shown below (Section 3.4.2), the calculated maximum willingness to pay to continue plant operation is perhaps more than 20 times this amount.

Conclusion – WTP in Taiwan for reprocessing and repatriation > USD1M per tonne spent fuel, indicating WTP for a permanent, offshore solution >> USD1M. Note that the repatriation means that a final disposal facility will still be required – and a GDF for vitrified waste is not basically different from a GDF for SF.

3.4 Enhancements of willingness to pay

The observed data points above suggest a willingness to pay for self-management among well-equipped countries of >AUD1 million / tHM to self-manage their radioactive waste streams, and a willingness to pay for temporary/partial removal of waste stockpiles of > USD1 million /tHM in the case of Taiwan.

[25] Modern spent fuel reprocessing involves a hydrometallurgical process which separates the three main streams of nuclides (uranium, plutonium, and waste, i.e. fission products and minor actinides). The prevailing system is known generically as PUREX which utilises the extractant tributyl phosphate (TBP) mixed in an inert hydrocarbon solvent. Source: IAEA (2008) Spent Fuel Reprocessing Options, IAEA-TECDOC-1587, August 2008, Austria.

[26] Source: MOEA (2015) Taiwan Ministry of Economic Affairs, Bureau of Energy. Energy Supply and Demand Situation of Taiwan in 2014. https://web3.moeaboe.gov.tw

27 This pilot tender amount was comprised of 1200 boiling water reactor (BWR) fuel assembles (each with an average mass of 275kg) from the Taiwanese reactor complexes at Chinshan (480 assemblies or 132 tonnes) and Kuosheng (720 assembles or 198 tonnes), (WNA 2015).

[28] World Nuclear Association (WNA) 2015. http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx

While the *actual* willingness to pay for SF and ILW management and disposal may never be known empirically, even after contract close (since a remaining element of consumer surplus may remain), there are a variety of reasons to expect that the value of an offshore, reliable and permanent service, would be above its direct financial benefit / saving as estimated above. Five of the key additional *material* benefits to an NPP of upfront SF and ILW disposal for which they will be willing to pay an additional premium, are as follows:

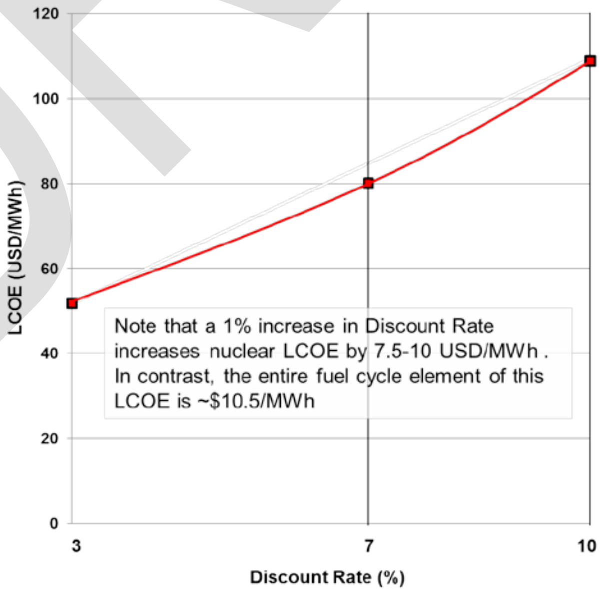
1) At the initial project stage, the availability of a reliable, fixed-cost waste disposal option may reduce the perceived risks of a NPP project and allow financing at a lower interest rate
2) The availability of a reliable, fixed-cost waste disposal option to a stable offshore recipient may reduce opposition to the introduction or expansion of nuclear power plants
3) The availability of a reliable, fixed-cost waste disposal option may have a beneficial effect upon the attitudes of local stakeholders at existing national NPP or national storage sites, enabling faster project approvals or review of excessive restrictions (such as setback distances)
4) The availability of a reliable, fixed-cost waste disposal option may remove risks to continued plant operation associated with the waste stream, including dry storage bottlenecks, regulatory and / or policy challenges
5) The availability of a reliable, fixed-cost waste disposal option may enable the more rapid removal of "orphaned fuel" from shut down plants and therefore allow sites to be released for other purposes which themselves offer a net benefit to the landholder or local community.

All of these five these considerations may justify payments over and above the '*SF Divestment Baseline'* described above in the LCOE data. They may derive from pressure on the spent fuel producer from the community or region hosting an NPP or storage site, or from national policy, driven by the need to honour international conventions and agreements. Points (1) and (4) are examined in further detail below.

3.4.1 Reduction of perceived risk at project inception

As has been shown in Figure 3.1, the interest rate on capital has a very strong effect on the LCOE of any nuclear project. The strength of the effect is emphasised by Figure 3.3, below.

Figure 3.3 : Nuclear LCOE variation with discount rate



With a USD 7.5-10 / MWh increase for every 1% rate rise, and using the 'power from 1tHM fuel' as in Table 3.2, a reduction of 0.5% (ie 50 basis points) in the interest rate for a reactor project would be worth around **USD1.5 to 2 million per tonne of heavy metal (spent fuel).**

Thus if the lack of 'back end liability' led to even a relatively small reduction in rate at the inception of a project, this should add very significantly to the 'willingness to pay' for spent fuel and ILW management. While the empirical financial advantage to a new operator (or one seeking project refinancing at a market rate) is unclear in the absence of an actual market quotation, this equation demonstrates the clear potential financial advantage in securing a low risk, long term waste management option, well above baseline willingness to pay.

3.4.2 Risk to continued plant operation

The income of a reactor is dependent on the amount of electricity it produces; any threat to its ability to generate threatens the entire income side of the project. A 1,000 MWe power plant must be able to offload around 20t of SF per year. In extremis, a reactor could be facing a shortage of spent fuel storage capacity caused by delay in expanding or implementing dry cask storage, possibly through regulatory problems or public opposition.

In this case the price being paid 'to remove the spent fuel' must be viewed against the loss of income which would attend shutting down the reactor. If the entire LCOE of, say 80 USD / MWh is projected onto the spent fuel arising which is, ultimately, causing the reactor to shut down, this 'spent fuel key enabler', can be valued at around USD 33M / tHM. The actual income, and therefore the potential payment to achieve '*SF divestment break-even'* would of course, generally be larger (see Table 3.3, below).

Table 3.3 : Loss avoided by availability of international spent fuel transport, storage and disposal

Loss avoided by the availability of fuel storage and transport (USD / MWh)	Burnup (GWd / teU)	Thermal efficiency (%)	Output (MWh / teU)	Expected SF cost per teU (USD millions)
80	50	34%	408,000	32.64

Such '*distressed payments'* will, of course, depend on the SF solution being available when it is needed i.e. the solution must be operable and in place before such opportunities could be realised. Such drivers have manifested themselves in the past, and in fact formed one of the powerful background drivers to the offshore reprocessing contracts obtained by the UK and France since the 1970s.

3.5 Structured country programme opportunities

Larger, more structured opportunities can arise from emerging nuclear programmes, especially when viewed against the long times, high expenditure and immense stakeholder effort involved in even the current 'successful' country programmes. An examination of the activities in nuclear programmes over the last 50 years makes it clear that the challenges of providing a convincing final disposal route have been large and the lack of such a route has been repeatedly raised as a fundamental objection to nuclear power.

The advantages of an international solution to an emerging nuclear programme will include:

- Avoiding most of the spent fuel and ILW storage infrastructure cost plus all the time / effort / cost of finding a GDF solution. This will take account of the fact that, though the funding of the actual GDF may be distant in time and negligible in discounted terms, the cost, effort and (in some countries) stakeholder engagement involved in setting up a disposal infrastructure and siting process will be large, immediate and long-lasting.
- The removal of the 'back end problem' will definitely reduce the perceived risk for potential investors in a new nuclear programme or a debt provider for a mid-project refinancing
- Willingness to participate in an international back-end solution in a country with impeccable safeguards and security standing can demonstrate to the national population and to the international community[29] that a new nuclear nation is taking its responsibilities seriously.

In '*willingness to pay*' terms, the overall '*SF divestment payment'* could therefore conceivably be far greater than the typical USD 1M / tHM, by an amount that will vary with the perceived difficulty of successfully pursuing alterative options for spent fuel storage and disposal in a timely manner.

[29] Note that Australian possession of a large spent fuel inventory with its attendant plutonium content will inevitably lead to suggestions of 'closing the fuel cycle'. This debate needs to be held early and a fixed policy position arrived at.

3.6 Programme financing at willingness to pay baseline level

While the '*willingness to pay baseline*' can be relatively well established, and its magnitude refined by further study, there is a clear difficulty estimating the overall sales income of the Project because virtually all of the '*enhanced payments*' are very country- and situation-specific and must be negotiated and agreed as they occur.

The accessible market of some 35 countries' spent fuel (listed above) will encompass a range of willingness to pay points. None of these countries currently has a credible permanent waste management pathway for their spent fuel, due to a range of factors, including unsuitable geology/physical geography, dense population coverage, social or political opposition or other reasons. **All of these countries may be considered as sitting above the baseline willingness to pay measure** to one extent or another. Some will be towards the extreme upper end – facing interruptions to their nuclear power output, and others faced with other suboptimal management of new or existing plants which they are willing to pay to remove or avoid.

Should South Australia decide to pursue plans for hosting an international storage and disposal service, one of the immediate tasks will be to have specific discussions with potential client countries in order to clarify their requirements and assess demand on a country by country basis, including their timing and volume requirements as well as their willingness to pay level.

Revenues accruing to South Australia from the provision of this service into such a diverse market may be maximised via a tender or similar 'capacity auction' process, whereby waste services are offered to those with the highest willingness to pay or greatest need before others.

3.7 Achievable 'willingness to pay' over a programme

It has been seen that '*perceived risk at project inception*' and '*risk to continued plant operation*' can offer large multipliers over the WTP baseline. It is difficult to estimate what proportion of these 'increased expectation' fees might materialise, but when it is realised that the saving from a 1% rate reduction to 10 GWe of reactor projects destined to produce 200 tHM / year would amount to a 'willingness' increase of over USD 620-820 M / year then the potential is clear.

Similarly, if 5 GWe of reactor capacity were threatened with shutdown unless the 100 tHM they were producing per year[30] could be exported, then the power plant owner might be expected to have a willingness to pay of 30% of the income safeguarded, which at USD 33 M / tHM would amount to around USD 1 B / year.

For a 3,000 tHM / year programme, the inclusion of 5 GWe of '*risk to continued plant operation'* fuel plus 10 GWe of '*perceived risk at project inception*' fuel would add some USD 2B to the annual revenues, increasing the average price over the 3,000 tHM to USD 1.7 M / tonne. Against this background a range of willingness to pay assumptions from the USD1M / tHM baseline to at least USD 2M / tHM appears amply justified.[31]

The suggested conservative 'most likely' estimate for use in comparisons with calculations in the business case is the average of two values, the 'likely minimum baseline' of USD 1M provided by well-equipped countries (noting these are not the likely client countries), and USD 2M which reflects a foreseeable baseline willingness to pay for a superior service with transfer of all risk and liability for waste storage and disposal for countries without a realistic programme in place. This average is USD 1.5M and takes no account of the potential upsides described in this section. The range is summarised in the following figure:

[30] Based on a typical rate of 20 tonnes / GWe per annum
[31] Recent informal exchanges (not related to the present project) with representatives of a small European nuclear programme have indicated that internal discussions have indicated that 1M USD / tHM would be very acceptable and prices up to 3M USD / tHM may be contemplated, depending on the details of any specific offers.

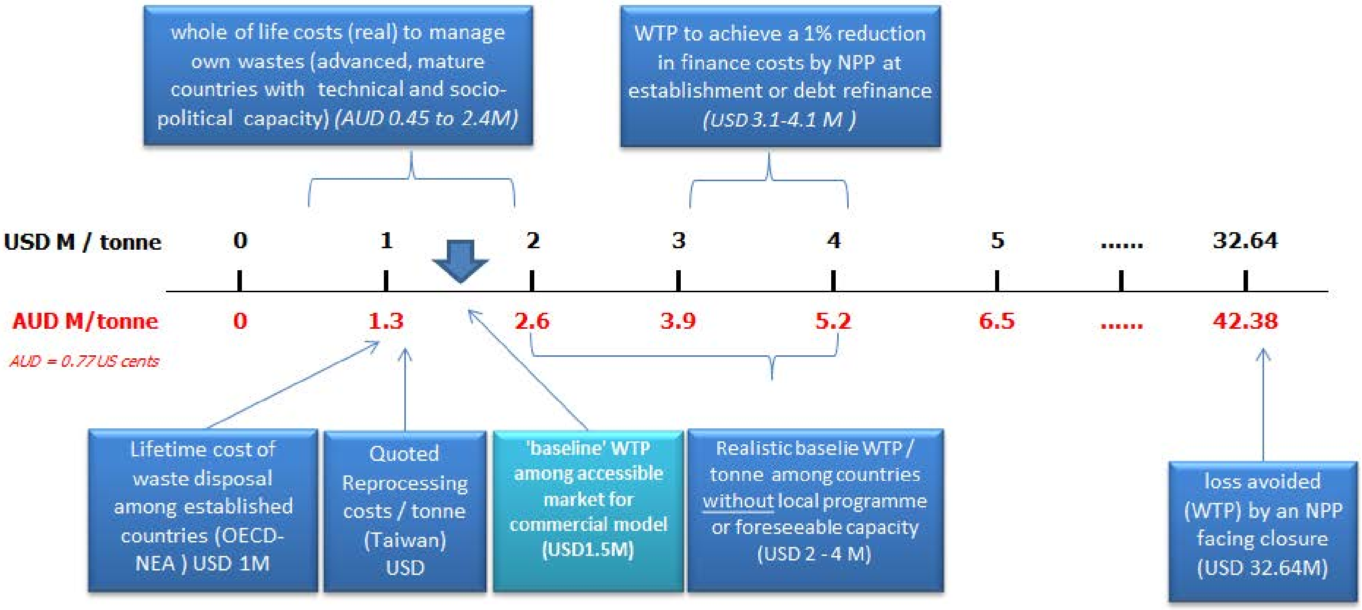


Figure 3.4 : Summary willingness to pay (USD/tonne) based on published data and likely 'enhancements'

3.7.1 Price to charge v willingness to pay

It is noted elsewhere that the Project will receive a 'price to charge' (PTC) alternatively described as a transfer of liability cost' (TOLC) on receipt of the waste in South Australia. This will correspond with transfer of ownership, noting that if ownership remained with the consigning country, with the potential 'risk' of repatriation, this would clearly influence willingness to pay until the point of irreversible disposal in a GDF (this scenario has not been considered in this paper). The actual PTC will be lower than the baseline willingness to pay, corresponding to the costs incurred by the client countries in preparing and delivering the waste to South Australia. These "pre-delivery' costs (including onsite cooling/pond storage, transportation packaging and shipping), which are within the overall WTP but which don't accrue to South Australia, are estimated to total USD 0.15 million / tHM on average.

Hence a baseline WTP of USD1.5 million / tHM corresponds with a PTC for revenue purposes of USD1.35 million / tHM. If these are converted to AUD at the long term exchange rate of 0.77 the value becomes AUD1.75 million / tHM **this is the baseline price to charge which is included in the commercial model** (see Paper 5, below).

3.7.2 Revenue modelling

As noted above in Table 2.6, the three inventory cases for spent fuel are:

- **Baseline SF inventory 138,000 tHM (50% of total accessible market)**
- Upper case SF inventory 207,000 tHM (75% of accessible market)
- Lower case SF inventory 69,000 tHM (25% of accessible market)

At a '*willingness to pay baseline*' of USD1.5 M / tHM overall, PTC is USD 1.35 M / tHM. Therefore Project income from spent fuel management would translate to:

- **Baseline USD186 billion**
- Upper case USD279 billion
- Lower case USD93 billion

The accumulated backlog of spent fuel could be shipped and received at a maximum rate of 3,000 tHM / year which gives annual revenue from spent fuel of USD 4.05 billion over a period of 30 years. Subsequently the income stream would reduce, being then generated by the 1,500 tHM (+ or – 50%) being shipped per year, corresponding with the rate of production from customer NPP programs. It is recognised that by this time, the annual SF production from countries wishing to use the Australian disposal service could be different, depending on how nuclear power develops globally.

The other quantities of interest will be the amounts of spent fuel that is available at the time of the decision to build the facilities, and which could therefore be shipped (and paid for) as soon as the ISF was operational. These give confidence of a minimum quantum of revenue regardless of future unforeseen events. In this scenario it is worth considering both the waste at the time of the decision and also the waste arising from fuel within the reactors. A typical reactor's fuel will last for five years before becoming waste so the fuel complement is equivalent to 5 years' arisings. These quantities and prospective incomes are:

- Baseline 47,500 to 51, 800 tHM – payment at baseline willingness to pay USD64 to 70 billion
- Upper case 73,800 to 77,700 tHM – payment USD99 to 134 billion
- Lower case 24,600 to 25,900 tHM – payment USD33 to 35 billion

3.8 Timing of revenues

The baseline modelling of revenues from SF management and storage have them commencing at the point at which the materials are transferred into the ownership of the waste manager (and the simultaneous transfer of liabilities). For the sake of simplicity, this is taken to be the point at which they are delivered ashore at a South Australian port.

While this scenario is the simplest, it is also conceivable that income could flow before the initial facilities (port and ISF) are completed. In the case of reprocessing where France and the UK established facilities that were desired by foreign customers, the plants were actually pre-financed by a 'base-load customer group' which agreed to this procedure in order to assure themselves early access to the completed facilities.

The commercial modelling of the radioactive waste management scenarios has considered various forms of pre-payment in order to demonstrate the impact that this would have on key financial metrics.

3.9 Willingness to pay for ILW management and disposal

The management and disposal of independent level waste commands a far lower willingness to pay than for spent fuel. This is due to countries' ability to stockpile ILW arising from nuclear power plants or other sources (such as decommissioned nuclear facilities) within shielded containers far more readily than spent fuel, and the absence of threshold limits for ILW storage at NPP sites which applies to spent fuel. Where there is a lesser imperative for a permanent solution, so too there is a lower willingness to pay.

The most reliable, recent evidence for willingness to pay for ILW management comes from DECC (2011), quoted above in the previous Paper. That report explained ways to levy a transparent cost on nuclear power operators for eventual ILW management and disposal. It showed that a cost per m^3 of £25,900 reflected both the anticipated base cost and a risk factor to account for foreseeable cost increases which may arise in future. This equates to some AUD66,000 per m^3. On the assumption that other countries would face a similar cost profile to dispose of their future ILW in the same manner, a WTP of AUD66,000 per m^3 is considered appropriate. In the interests of conservatism, and to address the costs of packaging and transport (which are not as well defined as for spent fuel) a price to charge of AUD40,000 per m^3 is proposed.

It is also notable that the revenues over the life of the programme are dominated by spent fuel management, which accounts for some 94% of all revenues (in real, undiscounted terms)[1] under the baseline scenarios. Despite this, a conservative price to charge for ILW is proposed, with the expectation that those countries which send SF for disposal will be countries who send their (corresponding) inventories of ILW.

3.10 Conclusions

The willingness to pay estimate and the judgement on the potential spent fuel inventories from clients are two critical factors influencing the attractiveness of a business case for accepting foreign spent fuel in Australia. Both are subject to significant uncertainties. For the inventory numbers this has been taken into account by

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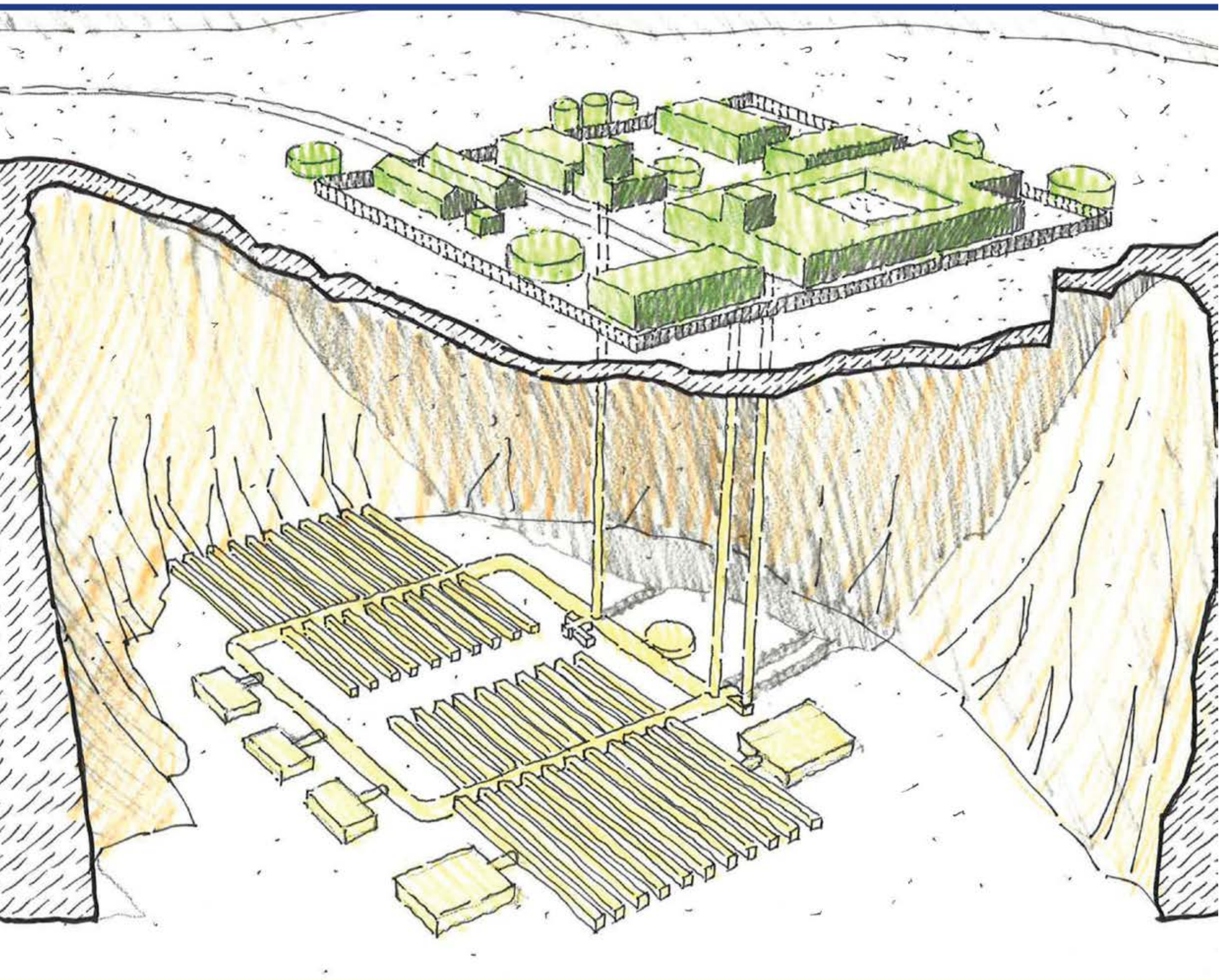
using a range of assumptions on the fraction of the accessible market for spent fuel that could come to Australia. The willingness to pay of any potential client will depend on:

- the estimated cost of national storage and disposal
- the sunk funds in the potential client country
- the importance and urgency (for technical, societal or political reasons) of identifying a credible disposal route
- the timing of ownership transfer and of payment of the PTC, where different timeframes are used.

The estimates derived when taking all these factors into account range from around USD1 million / tHM up to tens of millions of USD / tHM for countries which face steep cost penalties from a lack of credible waste management options for existing nuclear power plants.

Overall, a baseline PTC of AUD1.75 million / tonne is applied for HLW and AUD40.000 per m^3 of ILW, with sensitivity testing both above and below this amount, as described in Paper 5.



PAPER 3
BASIS OF CAPITAL COST ESTIMATES

Paper 3 – Basis of capital cost estimates

1. Introduction

This document describes the process that was used to determine capital cost estimates in accordance with AACE Category 5 for the four facilities both individually and in various combinations (the configuration scenarios). The outputs from this work are capital cost values over time that are used in the commercial model.

Initially four waste management facilities options were to be considered and are outlined as follows

- **W1 LLWR /** Surface / near-surface low level waste management facility (e.g. El Cabril Spain (vault))
- **W2 IDR /** Tunnel low and intermediate level waste management facility (e.g. VLJ Finland)
- **W3 ISF /** Dry cask storage of spent fuel at a centralised site
- **W4 GDF** / Staged development of a deep geological disposal repository for radioactive waste forms underground (greenfield site with no connectivity (radius <200 km) to HV electrical network, water supplies, road and rail).

No determination on specific location(s) for these facility types has been made. For the purpose of this report the estimates were developed based on the following simple site definitions;

- costal access location (approximately 5 Km from a coastal seaport)
- an inland location (semi-rural) (approximately 50 km from an established town / permanent labour force)
- inland locations (approximately 200 km from an established town / permanent labour force)

Following the development of the whole of life capital costs for the four facility types as potential ‘standalone’ facilities (configuration scenario 1) additional scenarios were developed with alternative locations and combinations for some or all of the facilities.

2. Basis of estimate

2.1 General

The objective of this basis of estimate (BoE) report is to provide the framework of how the cost estimates have been prepared and developed for the preliminary concept study capital cost estimates.

The four facility types which are estimated may be divided into two groups – surface and underground facilities. For the surface facilities, structures are relatively simple (albeit of significant scale) and there are a small number of well-reported international examples from which to derive concept cost estimates for a South Australian case. For the underground facilities, there are virtually no historic “actual” development costs which have been reported, and in place of actual historic costs, a small number of advanced design and costing studies are applied in order to derive a concept cost.

The estimates developed are conceptual in nature (Class 5 as according to AACE cost accuracy classifications) due to the lack of *project definition* which exists at this stage. At the present time, while design *principles* are agreed actual designs are yet to be prepared and the location of the facilities is as yet uncertain, beyond general agreed preferences. Therefore for the purposes of clarification the overall level of *project definition* should be regarded as in a range of 0-2% and the *level of costing accuracy* should be regarded as no better than -50% to +100%, as for a Class 5 estimate.

2.2 Assumptions

Ultimately, there are many assumptions that need to be developed and tested to prepare an estimate for waste management facilities, particularly when the specific site location is unknown and likely to be a significant distance from any major capital city or connectivity to infrastructure such as; rail and road, water supplies and electrical supplies.

The location of any underground radioactive waste disposal facility, whether for intermediate level waste (ILW) or high level waste (HLW), is highly dependent on physical factors including geology and hydrology, as well as demographic factors including proximity to population centres and available labour force. These factors can influence the process of site selection and therefore significantly influence the capital cost requirement.

The lead time required to select an radioactive waste management site, and particularly an underground repository for ILW or HLW is significant and therefore the ultimate “out-turned” capital cost requirement will be significantly influenced by inflation and other cost escalation factors. This rate has historically has been in the order of 5.0% per annum. As the estimate is in real dollars (2015 Australian dollars) escalation has not been considered in the numbers presented in the cost estimates, but is applied as a factor in the commercial model which takes the capital costs as an input.

Unlike the majority of overseas examples, the facilities being investigated for SA are likely to be located in locations which are some distance from established population centres, due to the large proportion of the state which has low population density. Rather than presume that such remote locations will provide transport and other connections (which would be optimistic), the capital cost estimates have included significant, detailed provision for *enabling infrastructure* such as port facilities, railway connections, road connections, airfield facilities and other utility infrastructure such as power and water service connections.

Construction in remote locations in Australia is common practise (i.e. resource projects) and the method of construction of a waste management facility in a remote location doesn’t significantly differ from this aspect of construction (i.e. working camp for both construction and operational phases of works). As the GDF will be operational for a considerable period of time (50+ years) and will require staff numbers in excessive of 200 people. Further investigations may determine that a small township with appropriate social facilities be established, further influencing the capital cost beyond construction, this type of requirement has not been considered in the current cost estimates.

2.3 Estimate classification

The capital cost estimates have been prepared generally in accordance with the requirements of Jacobs' estimating procedures, which are aligned to AACE standards.

The capital cost estimate has been prepared in accordance with an AACE Class 5 estimate classification.

In general, Class 5 estimates are prepared for strategic business planning purposes, such as but not limited to market studies, assessment of initial viability, evaluation of alternate schemes, project screening, project location studies, evaluation of resource needs and budgeting, long-range capital planning, etc.[32] The expected accuracy for a AACE class 5 estimate is within -50% / +100%.

Table 2.1 : Cost estimate classes (after AACE)

Description	Class 5	Class 4	Class 3	Class 2	Class 1
Description / estimate type	**Order of magnitude / conceptual**	**Prefeasibility study (PFS)**	**Feasibility study (FS)**	**Detailed estimate / control estimate**	**Definitive estimate**
Typical purpose of estimate	Concept / screening	Pre-feasibility	Funding decision	Control / tender	Close out / contract variation
Definition					
Engineering definition %	**0 - 2%**	**2-5%**	**15-30%**	**30-50**	**50-100%**
Project definition %	**0 - 2%**	**10 – 30%**	**30-50%**	**50-70%**	**70-100%**
Accuracy of estimate					
Expected contingency range	20-25%	15-20%	10-15%	5-10%	0-5%
Expected accuracy range (final built cost vs estimate)	-20 to -50% / +30 to +100%*	+ / - 25%	+ / -15%	+ / -10%	+ / - 5%
Inputs					
Accuracy development	Judgement	Evaluated	Probabilistic basis	Probabilistic basis	Probabilistic basis
Geography / location	General assumptions	General location(s)	Actual location(s)	Actual location(s)	Actual location(s)
Equipment lists	Theoretical	Preliminary	Optimised	Finalised	Finalised
Typical estimating methods	Analogy (historical costs), capacity factored etc. and adjusted for location, cost escalation etc.	Preliminary civil, structural designs, factored labour and utility costs (factored on previous)	Budget quotes. Detailed opex budgets, detailed equipment lists, detailed civil, structural design	Budget quotes. Actual opex budgets, detailed equipment lists, detailed civil, structural designs	Actual market quotes. Detailed opex budgets, detailed equipment lists, detailed civil, structural designs

*See Contingency Section 2.12, page 132.

2.4 Methodology

Various estimating techniques have been employed to ascertain the cost estimate values including experience and judgment, historical values, benchmarks, cost guides, factoring and simple mathematical calculations.

[32] The cost estimate classification is based on AACE International (Association for the Advancement of Cost Engineering). Recommended Practice 18R-97 (2011), Cost Estimate Classification System - As Applied in Engineering, Procurement and Construction for the Process Industries

Some estimate values have been derived from the cost of a similar facility or facilities with a similar production process though not necessarily the same capacity. Differences in the scope of works have been identified and adjusted, actual historical costs or previously detailed estimate were updated into current dollars and capacity factored for the new facility. Where overseas examples have been used the values have also been naturalised to take into consideration the difference between locations.

2.5 Direct and indirect costs

The estimate includes both direct and indirect costs. The direct costs relate to the cost of built structures, infrastructure, plant and equipment, including temporary works, consumables, transport, handling, construction, installation, contractors' dry testing / commissioning.

The indirect costs generally include contractor costs (i.e. management, overheads, profit, insurances, and site construction facilities), Design consultants, owner's costs and contingency.

2.6 Work breakdown structure (WBS)

A work breakdown structure (WBS) is used to define and group a project's work elements in a way that helps organise the total scope of the project. The WBS provides the necessary framework for detailed cost estimating and control along with providing guidance for schedule development and control.

A basic WBS has been developed for this project with the following major elements:

Table 2.2 : Work breakdown structure

Description	Comments / inclusions
Project costs	Includes siting, licensing and permitting design costs, construction management costs, land purchase costs, pilot testing and facility closure / decommissioning
Enabling infrastructure	Off-site infrastructure required to receive or transport product to facility location. This may include railway connections, HV electricity connections, potable water connection, road connections
Site enabling infrastructure	On site infrastructure
External works	Site preparation, perimeter fence and security system, batching plant, internal access roads, car parking,
External services	Electrical supply, communication services, water supply, storm-water management.
Buildings	Various administration, technical, warehouse / storage, maintenance, and materials handling buildings
Specialist equipment	Various warehouse logistics and handling equipment
GDF below ground requirements	Core underground facilities such as transportation, workshops, labs and offices. Deposit chambers for waste.
Other capital costs	Renewals (replacement of buildings or whole components in future years)

2.7 Base date

The base date for the estimate is September 2015. All construction pricing relates to this date.

2.8 Escalation

No forward escalation is included in the base estimate. Cost are presented as 2015 real costs and are escalated (via a cost inflation index factor) within the commercial business case model.

2.9 Locality factor

A locality factor takes into consideration the additional costs of delivering a capital development project in a remote location such as additional labour and material costs.

As indicated above the site location is unknown therefore for the purposes of the cost estimates the following locality factors have been assumed;

Location	Locality factor (base = 100)
Coastal access	100
Inland location (50 km to services)	100
Inland location (200 km to services)	130

2.10 Estimate currency and exchange rates

The estimate is reported in Australian dollars (AUD). Exchange rates for the trading currencies in the estimate and foreign currency exposure of equipment are shown in the following table:

Table 2.3 Foreign exchange rates (2015)

Country of origin	Native currency	Value of AUD
Euro	EUR	1 AUD = 0.6355 EUR
Swedish Kroner	SEK	1 AUD = 5.91834 SEK
Swiss Franc	CHF	1 AUD = 0.68751 CHF
Great Britain Pound	GBP	1 AUD = 0.46001 GBP
United State Dollar	USD	1 AUD = 0.71291 USD

In instances where historical data has been used the rates relevant to that date have been used.

2.11 Price indices

The ABS historical consumer price index (all groups) has been applied to bring historic prices up to date. It has been compared to two other relevant indices in the following diagram the ABS Producer Cost index for Mining (Coal) and the ABS Producer Cost index for mining equipment manufacturing (all). The CPI (all groups) proves to be an almost exact average of the two and hence is applied. The following diagram illustrates the behaviour of the three indices since December 1992, showing an increase of 74.4% over that time.

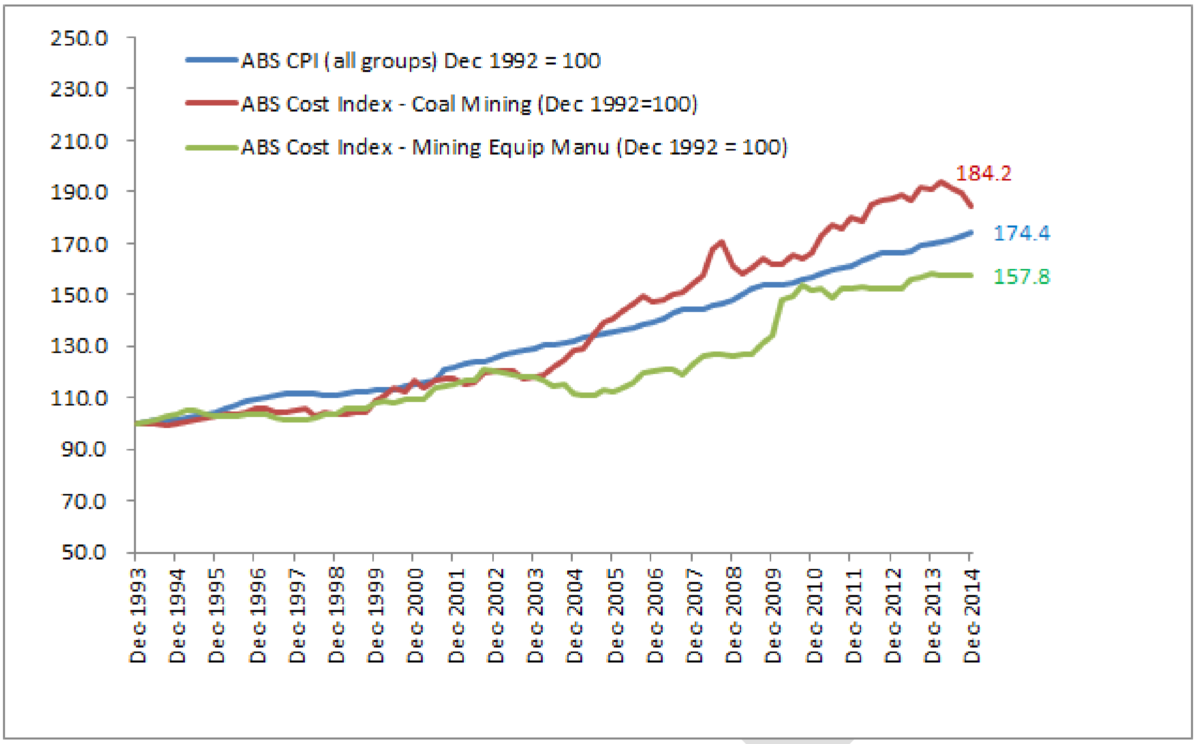


Figure 2.1 : Historic price indices. Source: ABS References 6427.0 (Price Indices); ABS 6401.0 (Consumer Price Index)

2.12 Growth allowance and scope contingency risk allowance

The growth allowance is a standard item added to the project base estimate to account for foreseeable increases in material quantities or unit costs owing to typical project discoveries in construction or market movement. In this estimate no separate provision has been included for the growth allowance, which is accounted for in the overall contingency risk factor

As noted above (in Section 2.3, Table 2.1), the capital and operating cost estimates prepared are considered Class 5 or concept level, and contain a significant degree of inherent uncertainty, due to the lack of design or siting input, among other factors.

AACE International[33] recommends the application of a 20-25% contingency or risk factor to Class 5 base estimates, to arrive at a median or P50 cost estimate. It notes that a typical low estimate, *after* the application of this risk or contingency factor, is -20 to -50%, and the typical upper estimate after contingency is between +30 and +100% above.

For the purposes of our analysis, we have applied a contingency/risk factor of 25% to our base capital cost and, as noted in Paper 4, operating cost estimates, and then an overall accuracy range of +50% to both capital and operating costs, to demonstrate the likely foreseeable range of costs.

As discussed in the following section, this approach is also designed to address ‘optimism bias’ in the development of cost estimates for major infrastructure projects.

2.13 Optimism bias

Major public projects have been found to be susceptible to optimism bias reflected in under estimation of total costs when projects are announced, relative to the final cost of delivery. This is often a result of external factors, including the costs and delays induced through regulatory approvals processes not being taken into account.

[33] AACE (2011). AACE, previously the Association for the Advancement of Cost Engineering, is a non-profit, professional certifying association concerned with the enhancement of Total Cost Management techniques and practices throughout industry.

The costs that have been estimated for the development of a geological disposal facility for radioactive waste in South Australia are based on a bottom-up methodology where the conceptual level of project definition outlines requirements for:

- Enabling infrastructure (port facilities, rail, airport, road, electricity and water);
- Site preparation, site services and Buildings for onsite facility requirements and staff;
- Underground excavations and facilities and
- Capital renewal at various stages of project life.

The nature of the engineering required for the development of these facilities were localised to SA using realised costs for the specified infrastructure (i.e. transport, buildings, staffing). The deep excavation costs further reflect escalation benchmarks reported by the Australian Institute of Mining and Metallurgy. The development of quantities using this methodology enables the definition of the estimates as a Class 5 cost estimate. The expected accuracy range for an Association of Cost Engineering Class 5 estimate is -50% to +100%.

While the Class 5 estimates are based on considerable Australian experience in both engineering, procurement and construction, they do not take into account regulatory risk. This risk was accounted for as part of the addition of a 25% contingency to the *base* Class 5 estimate and reflects the actual measured difference in cost performance in Australian PPP projects between the time of original announcement to the point of actual final project delivery[34]. This uplifted figure was assumed to be the *Central* cost estimate upon which all assessments of the project's financial performance were undertaken.

The Commission also evaluated methods proposed in other jurisdictions to account for optimism bias in public engineering projects. An analysis of public engineering projects in the UK proposed a contingency of 66% for Non-Standard Civil Engineering projects[35]. However, a comparative analysis undertaken by Duffield et al. (2008) showed that Australian traditional projects have better cost performance than UK projects, with 43% of *Traditionally* procured Australian projects being completed within 5% of the expected cost but only 27% of similar projects in the UK being completed within the same budget. This suggests that a baseline contingency of 66% is overly conservative and unrepresentative of Australian conditions.

Nevertheless, a sensitivity analysis was undertaken to reflect the upper end of the range for the Class of estimates made by increasing the *Central* cost estimate by a further 50% (~87% above the *Base* Class 5 estimate) to reflect conservatism in the financial analyses. The range of costs assessed as part of the commercial analysis business case is reflected in the table below relative to the base estimate.

Table 2.4 : Range of costs assessed under commercial business case modelling assumptions

	Base Class 5 Estimate (P25)	Expected Final Cost: Central Class 5 Estimate (P50)	Conservative Class 5 Estimate (P90)
Difference Relative to the Base	1	1.25	1.87

[34] Duffield C, Raisbeck P, Xu M 2008. National PPP Forum – Benchmarking Study, Phase II. Report on the performance of PPP projects in Australia when compared with a representative sample of traditionally procured infrastructure projects. The University of Melbourne MERIT Report. Available at http://infrastructureaustralia.gov.au/policy-publications/publications/files/PC_Submission_Attachment_K.pdf

[35] UK Government. Supplementary Green Book Guidance Optimism Bias. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191507/Optimism_bias.pdf

3. Project capital costs

The following paragraphs provide brief descriptions of what has been included in each section of the capital cost estimate for the various WBS sections.

3.1 Detailed design

This is the cost of the consulting engineering and associated cost that will be required to provide a fully documented design for the facilities. As noted in Table 2.1 (above) a class 5 estimate is prepared without a specific design. A nominal allowance of 10% has been applied as a percentage and intended to cover the cost of the various consultants that will be involved during the design and construction phase of the project.

3.2 Overhead and margin

As expected for a project at this early stage of project definition the alternative forms of construction delivery method (e.g. lump sum, EPCM, etc.) have not been compared and a preferred approach has not yet been formally selected. The intent of the 'Overhead and Margin' is to include the estimated cost that a managing contractor will apply to manage the various construction components.

For the purposes of the estimate a 10 % allowance for overhead and margin based on the estimated cost of construction components has been used. The percentage used is consistent with large scale engineering projects in Australia (as in AusIMM 2012 benchmark costs).

3.3 Commissioning

This has been calculated as a percentage of the capital cost components. A rate of 2.0% for commissioning related costs has been applied in line with common industry practice.

3.4 Construction contingency

This factor is included in the growth and contingency risk allowance of 25%, as noted above.

3.5 Siting, site characterisation

One of the significant aspects to determining an appropriate site location is to undertake significant investigations to obtain site characterisation information such as geological conditions. Given the proposed purpose of the facilities, significant time and cost will be involved in this aspect of the project. For the purposes of the estimate, preliminary cost advice has been obtained from specialist consultants familiar with the scale and methods of site characterisation for the development of radioactive waste management facilities. The allowances (referred to in section 2.3.12 on page 32– Paper 1) are as follows:

Facility type^	Siting / Characterisation (excluding land purchase, permitting and licensing) $AUD2015
Low level waste facility	$30M
Intermediate level waste facility (underground)	$300M
Interim storage facility	$100M
Geological disposal facility	$750M

^The allowances for these facilities include siting for enabling infrastructure, such as a port, road / rail alignments and utility connections.

The amounts proposed for siting and site investigations are intentionally conservative (high) given the uncertainty regarding the number of regions, localities and sites which will be the subject of initial and more detailed investigation over several years.

3.6 Licensing / permitting requirements

This is a notional amount expected to be spent on obtaining various licensing and permitting approvals.

3.7 Pilot testing

This is a notional amount of 2% of build capital cost (ie excluding land purchases) which is expected to be spent undertaking various facility pilot-testing requirements, in line with industry benchmarks.

3.8 Decommissioning or closure

This is allowance is intended to account for the costs involved in closure and decommissioning of the various facilities. This involves demolition and removal of buildings and site infrastructure and backfilling of underground excavations, prior to commencement of the post-closure monitoring and surveillance phase. Decommissioning has been calculated using a notional percentage (30%) applied to the construction costs, derived from international experience.

This rate is intentionally conservative (high) given the inherent uncertainty of planning decommissioning prior to the development of a concept design.

3.9 Land purchase costs

Following a detailed site selection process, the land for each facility will be purchased. The land area for each facility will be the proposed final (maximal) size required for waste management and storage, as well as a further buffer to separate an internal and external security perimeter.

As the location of each facility is unknown, any market testing of land values was not feasible, and so regional and state-wide average values for broad acre land parcels were applied as a proxy.

The ABS *Land Account, South Australia (Experimental Estimates*[36]*)* provided total land value and areas for regions across South Australia, with an overall average market value per hectare of $1,400 (total land value of $19.58Bn over 13.98 million hectares).

Government acquisitions of land do not always reflect prevailing market value alone, and there is a precedent for some multiple of market value being paid. The rate applied for potential land purchases modelled in the commercial analysis was a multiple of four of the state-wide land value rate, or $5,602 per hectare.

In scenarios where roads and / or railways are required, land beneath these connections is also presumed to be purchased. Easements on either side of road and railways were also included (see next section), and a higher multiple of average value (total multiple of 20 times) was applied to reflect the additional compensation payable to landholders owing to the additional disruption from linear infrastructure bisecting their land holdings.

These rates are intentionally conservative (high) given the uncertainty of siting of any of the proposed facilities.

[36] ABS Catalogue reference 4609.4.55.001 - Land Account: South Australia, Experimental Estimates, 2006 - 2011

4. Enabling infrastructure

No existing enabling infrastructure is presumed to be in place prior to the development and depending on the facility development scenario being considered, various forms of enabling infrastructure will be required. Enabling infrastructure can be defined as the infrastructure required enabling a selected site to be suitable and functional. Across the various scenarios modelled, the following were included:

Table 4.1 : Forms of enabling infrastructure

Item	Comment / Specification
Roads	Rural highway standard road. Seal and shoulder width of 10m.
Rail	Standard gauge rail with 30t rated sleepers to suit 30t axle loads
Airport	Sealed runway 2000m long x 30m wide and basic regional airport facilities
Sea port	10 ha wharf space and suitable to vessel size of 120M length overall, draft of 7.5M
Electricity supply	22Kv overhead power supply (50km length)
Water supply	250mm diameter in-ground water pipe (50km length)
Port crane	Up to 200t lifting capacity port crane system (2 cranes)

Generally the extent of the enabling infrastructure (i.e. Km of rail) will depend on the scenario being considered and proposed location of the site.

4.1 Port facilities

It has been assumed that the material arriving from overseas will be supplied in transport canisters and will require a dedicated port facility specifically developed to transfer the canisters for the delivery ship to rail for transportation to the facility site. A greenfield port is proposed, rather than an existing one, and development costing for a port has therefore been included in the estimate.

The location of the port is unknown and therefore site specific requirements such as the type of wharf construction and need for dredging is unknown. Port requirements, as developed via review of current shipping and handling practices, nominated the following design features:

- ability to handle vessels up to 120 m LOA
- ability to accommodate vessels requiring draught up to 7.5 m
- ability to dredge to 10.0 m without structural change to wharf, piles, dolphins or other infrastructure
- shore based craneage to lift 140 tonne indivisible units
- sufficient wharf space to accommodate 28 casks received from a single ship without the need to rearrange casks of the wharf and providing adequate space for mobile harbour cranes to manoeuvre around the wharf (estimated to be a total of 10 hectares).

Given prior experience, and benchmarks from AusIMM (2012) and elsewhere, an allowance of $100M has been made for the development of a dedicated port facility.

4.2 Rail

No determination for specific location(s) within South Australia has been made for any of the facilities proposed, however several scenarios propose location of the interim storage facility at a coastal location (within 5km of the coast) and geological disposal facilities farther inland – to be connected by rail.

For those scenarios where rail is required to transport the materials from the coastal interim storage facility to the three disposal facilities (with counter-flow materials also being moved by rail) allowances have been included for construction of the rail infrastructure. Recent and historical rail cost estimates have been used to estimate typical cost per km for rail infrastructure connecting remote locations (i.e. mining and other resource development sites). It is anticipated that one major rail crossing will be required and that has been included in the cost estimate. *(Typical rate allowance $0.6 M / km).*

4.3 Road

It has been assumed that the various site locations will require a portion of dedicated road to be constructed. The quantity will depend on the location of the site (i.e. port 5 km, Inland 200 km, etc.) The road will generally follow the rail line and will be used for general site access during construction and operation phases. It has been assumed that the road will be similar in design to a heavy haul road as used for a mining project.

4.4 Airfield

For the inland locations (200 km) it has been assumed that an airfield will be required to provide efficient access for personnel and time-sensitive freight to service operations. For the purposes of the cost estimate the airfield has been assumed to similar to a small regional airport (i.e. Roxby Downs, Onslow) with a 30 m x 2000 m runway capable of taking a F100 plane (as operated by Qantas / Virgin). It has been assumed that the site location for the airfield will be 3000 m x 500 m with fairly flat topography requiring minimum site clearance and levelling.

While an airfield is not necessarily required as the locations for various facilities is yet to be determined, a capital cost allowance of some $7M for a basic facility (excluding land purchase costs) has been made as an intentionally conservative measure.

4.5 Power supply

For the purposes of the estimate it has been assumed that a dedicated HV power supply connection of some 50km in length will be required and therefore an allowance has been included in the cost estimate for a 22Kv overhead power supply. *(Typical rate allowance $1.5 M / km).*

4.6 Water supply

For the purposes of the estimate it has been assume that a potable water supply will be required to service the site. The amount of water used has not been determined therefore the cost allowance is based on a ~250 mm diameter pipeline for a length of some 50 km. It is assumed that site infrastructure will include adequate water storage facilities. *(Typical rate allowance $0.5 M / km).*

5. Site construction costs

5.1 Site preparation

This is the cost of preparing the site to receive the various building paved areas, etc. It is assumed that the site preparation will not require significant site clearance (i.e. removal of trees) or earthworks to achieve the required benching levels for the buildings. *(Typical rate allowance $25 / m^2).*

5.2 Access roads and car parking

This is the cost of internal site roads, vehicle parking and hard standing areas. The quantity and rate allowance is based on previous project experience for similar scale facilities *(Typical rate allowance $58 / m2).*

5.3 Boundary (perimeter) fence

This is the cost of a standard chain mesh fence to the property boundary of the ‘owned’ site. The rate allowance is based on previous project experience *(Typical rate allowance $64 / m).*

5.4 Security (operating area perimeter) fence

This is the fence surrounding the working facility area and has been assumed to comprise two fences with a sterile zone in between, as is practice for sensitive sites of various types. The rate allowance is based on previous project experience *(Typical rate allowance $400 / m).*

5.5 Security system

This is a lump sum allowance of $17.1M (excluding locality factor) and is based on the design and costing information in the EPRI, 2009 Generic Interim Storage Facility (GISF) report.

5.6 Dry cask storage pads

At the interim storage facility, each storage cask rests upon a hardstand concrete pad capable of hosting a cask weight of approximately 140t.This is an allowance for the hard standing paved areas on which the casks are stored. The size and design of the pads is based on the information in the EPRI, 2009 Generic Interim Storage Facility (GISF) report. A typical pad is 129m x 64m x 1m deep (8,256m2) and can accommodate 300 casks. *(Typical rate allowance ~$6000 / pad).*

5.7 Concrete batching plant

This refers to the cost of a concrete batching plant for the production of concrete both for the construction of the facilities and the future potential operational needs for concrete (such as for potential future production of concrete storage casks under license from Holtec or another provider). *(Typical rate allowance ~$4.25m per complete plant).*

5.8 Site services

This is an allowance included in the cost estimate for the various site services required to service the site and connect the buildings as no site specific specifications are available the nominal lump sum values included are based on previous experience for projects of a similar scale (Site area) and typically include the following services;

- electrical services (i.e. power, communications, lighting)
- hydraulic services (i.e. sewer, water, storm-water, tank storage, sewerage treatment plant)
- desalination plant (back-up to mains supply)

- generators (back-up to mains supply)

5.9 Specialist equipment

This includes the cost of site specific specialist equipment such as canister transporters and the encapsulation automation system.

5.10 Building costs

The costs of the buildings servicing each facility, comprising rates and quantities, have been derived from various sources (details in the following section). In general, quantities have been derived from existing, relevant waste management and disposal facilities (overseas published sources), and cost rates have been taken from Australian cost benchmark publications (such as Rawlinsons, 2015). The key sources for each facility are described below.

Low level waste facility

Building description	Quantity	Qty type	Rate	Primary source (design Qty)
Administration / security building	2,000	m^2	3,200	ENRESA (2013)
Buffer storage facility	2,000	m^2	3,194	ENRESA (2013
Disposal cells (multiple phases)	16	no.	1,500,000	ENRESA (2013), NDA 1999, Rawlinsons 2015
Operation building (general services building)	1,250	m^2	3,200	ENRESA (2013)
Workshop	2,000	m^2	1,500	ENRESA (2013)
Concrete laboratory building	300	m^2	2,800	ENRESA (2013)

Interim storage facility (dry cask storage facility)

Building description	Quantity	Qty type	Rate	Primary source (design Qty)
Administration building	1,500	m^2	$3,200	EPRI, 2009
Security building	1,650	m^2	$3,209	EPRI, 2009
General services building (O&M)	5,000	m^2	$2,729	EPRI, 2009
Concrete batching plant	1	item	$4,250,000	Previous project experience.
Canister transfer building (excluding specialist equipment)	10,000	m^2	$3,092	EPRI, 2009
Storage cask fabrication facility	1	item	$16,069,486	EPRI, 2009
Cask maintenance facility	1	item	$20,890,331	EPRI, 2009
Waste management facility	1	item	$48,208,457	EPRI, 2009
ILW storage facility (multiple phases)	14,650	m^2	$3,194	EPRI, 2009

ILW facility (standalone)

Building description	Quantity	Qty type	Rate	Primary source (design Qty)
Administration / security building	2,000	m^2	$3,200	ONKALO, 2003
Operation building	1,250	m^2	$3,200	ONKALO, 2003
Workshop building	4,000	m^2	$1,500	ONKALO, 2003
Ventilation building	1	item	$4,551,975	ONKALO, 2003
Provisional sum for services including Generator	4,000	m^2	$3,194	Previous project experience.
Waste encapsulation / box plant	1	item	$28,469,301	ONKALO, 2003
Permanent Camp	100	pax	$150,000	Budget pricing from similar remote location permanent camp accommodation

GDF facility (as standalone)

Building description	Quantity	Qty type	Rate	Primary source (design Qty)
Permanent camp (400 pax)	400	pax	$150,000	Budget pricing from similar remote location permanent camp accommodation
Encapsulation facility	1	item	$647,029,570	ONKALO, 2003
Administration building	2,700	m^2	$3,200	ONKALO, 2003
Operation building	1	item	$11,569,299	ONKALO, 2003
Research building	1	item	$3,048,002	ONKALO, 2003
Tunnel technique	1	item	$736,379	ONKALO, 2003
Workshop	1	item	$5,243,875	ONKALO, 2003
Ventilation building	1	item	$4,551,975	ONKALO, 2003

Where necessary for the facility / scenario being considered the sourced information has been further adjusted by factors to take into consideration the quantities of materials being processed, stored, etc.

5.11 Underground excavations

The capital cost estimate for the underground excavation for both the HLW and ILW geological repositories is derived from the cost estimation which has been applied to the POSIVA GDF at Olkiluoto, Finland, and compared against high level mining industry benchmark estimates in AusIMM (1993).

The underground portion of the Olkiluoto facility comprises two main capital elements,

i. a central core (which also served as an underground rock characterisation facility to confirm the status of rock through stratigraphic layers). This central core comprises a central shaft and a "corkscrew" of declines around it with a total excavated volume of some 395,000 m^3.

ii. a series of deposition or disposal galleries for emplacement of the spent fuel, with a total volume of some 505,000 m^3 (for the emplacement of 9,000 tU). Two design options for the emplacement galleries was prepared for Olkiluoto – one with vertical emplacement and another with horizontal emplacement of the spent fuel (SKB, 2008). The horizontal method[37] was proposed on account of its lower total volume of excavation required.

The Olkiluoto facility proposed expenditure of EURO 119M (in € December 2003) to construct the central core which was to serve the entire SF disposal facility. This core would extend to a depth of 520 metres, which is some 50-100 metres below the planned layer of encapsulated SF , and would also incorporate a main access tunnel, ventilation shaft, various underground rock characterisation facilities (short tunnels and technical rooms for investigation) and various life support (water, lighting), emergency and other systems.

The central core is not a limiting factor on the scale or extent of the disposal galleries for SF, and would be appropriate as enabling infrastructure for geological disposal of either spent fuel or ILW (at some 400 m-500 m and 200 m depth, respectively). The core design, as one of the most developed in the world, and including inherent capacity for underground rock testing, is appropriate as a benchmark for the South Australian GDF of any conceivable size. A direct conversion from 2004 EURO (the cost estimates were produced in 2005 based on December 2003 Euro is AUD357 million, including a locality conversion factor from Finland to semi-remote Australia. AusiMM (2003) and AusIMM (2012)

The disposal galleries for 9,000 tonnes of SF in the Olkiluoto facility, via copper canisters, was calculated to cost EURO 241 million, and involved a program of continual development / expansion throughout the ~80 year operational life of the facility, with nine expansion phases commencing roughly every nine years, and lasting ~2 years each. Based on this model, we have proposed a simple linear expansion of this variable cost amount, to reflect the larger volumes of SF proposed to be hosted at the South Australian GDF, under the 'baseline' (130,000 tU), for an estimate of AUD10.411 billion in underground construction costs.

Table 5.1 : Derivation of volumes from Olkiluoto (Posiva 2003; POSIVA 2013; SKB, 2008)

Element	Olkiluoto^	South Australia
Central access shaft and rock characterisation (ONKALO)	395,000 m^3	390,000 m^3
Tonnes SF emplaced (over entire life)	9,000	138,000
Volume of storage galleries and access shafts required (KBS-3H method)	505,000 m^3	7,294,444 m^3

^note the final estimated excavation volumes of the Olkiluoto ONKALO facility declined by some 15% to 337,921 m^3 and the main emplacement galleries to 497,000 m^3, respectively in a detailed 2013 review (Posiva 2013). Despite this, the higher (original) figures are intentionally used as a mark of the conservative nature of the cost estimation.

This cost estimate was comparable with a raw estimate for excavation for a hard rock underground mining operation (AusIMM, 1993, 2012), which produced an estimate of AUD10.2 billion in underground development costs (with a 30% locality factor and before ancillary underground development, mobilisation and other costs).

5.11.1 ILW

In the scenario that ILW disposal was collocated at the same facility, it is recommended that no additional expansion of the central core is required to accommodate ILW delivery and emplacement, but that additional disposal galleries would be developed to suit the ILW, at a depth of ~200 m below surface level (ie, at shallower depth than the spent fuel disposal level). The cost of excavating space for ILW is taken from a Swedish example, where underground disposal space for 16,000 m^3 of material was costed at a total of AUD143 million, or an average cost of ~AUD9,000 per m^3. Extrapolating this cost to the quantum required for the foreseeable

[37] This is the method referred to as KBS-3H in SKB (2008).

Australian baseline volumes (377,000 m^3 ILW) gives an order of magnitude cost estimate of AUD3.369 billion over the operational life of the project (real dollars, undiscounted).

If the underground ILW repository (IDR) was established in a location which was separate from the geological disposal facility for spent fuel, a number of additional costs would be incurred, most notably a second central access and core (which also serves as a ‘rock characterisation facility’, used to prove the geology of the local environment). A standalone facility would also require its own transport connections (road, rail, airstrip), utility connections and several generic surface buildings including stores, administration, security and workers’ accommodation. Again, the Finnish example provides a cost benchmark for best practice for this scenario with an independent geological disposal for ILW, though since ILW deposition is 50% shallower than spent fuel some cost savings are expected. Given that some mobilisation and other site related costs will be fixed regardless of scale, a cost saving of 35% is anticipated. Hence AUD357 million x 65% or AUD232 million is the estimated cost of an ILW central shaft.

5.12 Construction workforce

The current preliminary level of project definition does not allow a detailed assessment of the construction workforce employment numbers to be ascertained to a high level of accuracy. However using the anticipated capital expenditure values, indicative cash flow and a rule of thumb for the labour and material ratio it is possible to determine a broad order of magnitude estimate of FTE’s (full time employees) required for the project.

The GDF (In particular core underground facilities) will not be completed until approximately year 25 from the commencement of the project. The deposit chamber construction continues well beyond the initial year 25 as material is gradually delivered and placed into the GDF therefore a construction workforce will remain on site to cater for this need.

It is a normal profile for a construction project that there is a gradual increase in FTE requirements which eventually peaks and then declines as the amount of work gradually decreases as the works are completed.

On this basis the construction project is estimated to generate between 1,500 jobs through the establishment phase, to a peak of 4-5000 full time positions through the initial establishment of the underground facilities in years 2021 through 2025.

6. Other capital costs

6.1 Capital cost renewals

The capital cost estimate includes capital renewal costs which are applied to extend the technical life of project elements, or to expand its capacity / capability, throughout the project life[38] but does not include any allowance for other life cycle costs such as maintenance or other repair / upkeep costs which are incorporated into the analysis as operating expenses.

As the facilities are modelled to operational for a considerable period of time (ie more than 20-30 years) there is asset renewals (e.g. replacement of buildings and building systems) are necessary to provide a realistic estimate of the capital costs to continue operations. (These are in addition to planned and reactive maintenance costs such as scheduled or unscheduled minor repairs to floor coverings, fencing or a roof).

At this stage of project definition it is not possible to identify specific requirements therefore a nominal allowance has been applied to the capital cost estimate values for renewals throughout the facility life, on a typical rotation of every 25 years. As renewals expenditures are significant, they are modelled to be delivered over several years. Capital cost renewals were applied in the commercial cost model according to the following cycle / allowance;

Table 6.1 : Capital renewals allowances

Year (since commencement)	Renewals allowance
25	10% of capital cost
50	25% of capital cost
75	15% of capital cost
100	15% of capital cost

6.2 Operational costs excluded

The capital cost estimates do not include any allowances for operational costs such as labour, materials, energy usage and operational plant and equipment (e.g. computers, laboratory equipment, furniture, vehicles). These are assessed in Paper 4.

6.3 Owner's costs

The capital cost estimation has not included the costs incurred by the Owner in undertaking environmental impact statements and gaining approvals, managing the procurement, monitoring the implementation of the works, legal fees and initial spares and consumables. Typically these costs can range from 5 to 15% of the capital cost depending on the size and nature of the project. In general larger projects lead to a smaller factor and we have taken 7% as a reasonable assumption for these costs.

[38] Project renewals are also referred to as sustaining capital, as compared with initial capital which is spent to achieve initial operating capability.

7. Overall costs and comparison with benchmarks

Summary overall capital costs have been derived for the four facilities individually and for various combinations as shown below. For the base case sizing described in Paper 2 the following apply.

Facility / configuration	Total cost AUD2015, million, undiscounted and rounded^^	Nominal size of facility (total waste capacity)	Normalised cost AUD2015 thousands per unit
LLWR	820	81,088m^3	10.1
ISF	2,200	72,000 tHM	30.63
IDR	14,300	390,000 m^3	36.67
GDF^	33,400	138,000 tHM	242.02
GDF and IDR co-located	38,000	138,000 tHM, 390,000 m^3	
Base case configuration: LLWR, ISF plus co-located IDR and GDF (see Paper 5)	41,010	NA	NA

^GDF includes encapsulation plant

^includes contingency risk allowance, locality allowance, owners costs and others.

This table clearly shows the large benefit in co-locating the deep GDF and the intermediate depth IDR, using common transportation and utility connections, surface infrastructure and the main access tunnel. The cost savings for other combinations are far smaller. This is discussed further in Paper 5.

The comparison of the capital costs (in 2015AUD) derived from planned developments overseas indicates the overall similarity in terms of overall cost magnitude. The advantages of the economies of scale for a far larger South Australian development are also evident.

Table 7.1 : Benchmark capital costs, different facility types, baseline costs for business case modelling

Facility type, location	Benchmark facility / reference	Capital cost per storage unit (2015 AUD, thousands)	Relevant comparison capital cost for business case modelling and % of estimate (rounded)
Low level waste repository	El Cabril, ENRESA (2015)	8.9	10.1 (base modelling input is 113% of estimate)
Interim storage facility^	USA generic, EPRI, 2009	28	31 (107% of estimate)
	USA Generic, US DoE, 2013	34	31 (91% of estimate)
IDR (as standalone)	Forsmark, Sweden (SKB, 2003)	13	37 (284% of estimate)
	Swiss (Nagra)	26	37 (142% of estimate)
GDF^^	Olkiluoto, Finland Posiva (2003, 2005, 2012)	176	242 (137% of estimate)
	Forsmark, Sweden (SKB, 2014)	430	242 (56% of estimate)

Facility type, location	Benchmark facility / reference	Capital cost per storage unit (2015 AUD, thousands)	Relevant comparison capital cost for business case modelling and % of estimate (rounded)
	SwissNuclear, 2011	1,300	242 (19% of estimate)
IDR plus GDF	*No comparison*	NA	38,000 (*NA comparison*)

^Interim Storage facilities were taken as "bare facilities" without 'hot cell laboratories' for rehousing spent fuel on site (as the operational model presumes no removal of fuel from the MPC until the encapsulation plant). Capital expenditure on rolling stock was also excluded, to prepare a more direct comparator.

^^GDF costs include encapsulation plant, where specified.

The table above indicates that the cost estimates developed for the South Australian commercial model are comparable with advanced examples taken from international experience.

Overall, benchmark cost comparisons may also be misleading, particularly against facilities which are relatively small in scale (such as the Swiss GDF at Forsmark, which will host some 3,850 tonnes of heavy metal compared with 138,000 modelled for South Australia) or are intended to have only a brief operating life (the Forsmark facility is expected to receive waste over only 15 years) which may mean their design is less efficient from a capital perspective than if the facility were run over a longer campaign.

The purpose of the benchmarking exercise was to support the development of cost estimates for an analogous South Australian facility, by illustrating the relationship between fixed and variable capital costs (quantities or rates) for various facilities and enabling capital cost estimates to be prepared 'from the ground up'.

8. Source documentation

The cost estimates, comprising rates and quantities, have been derived from various sources.

In general, quantities have been derived from existing, relevant waste management and disposal facilities (overseas published rates), and cost rates have been taken from Australian cost benchmark publications (such as Rawlinsons 2015 and AusIMM 2012). While a large number of reports and other publications were reviewed to develop the capital cost estimates, the following list presents the key references which were applied in the development of the Class 5 estimates for the four main facility types.

Table 8.1 : Key information sources utilised to develop the capital cost estimates

Source	Full title	Relevant waste facility type	Key inputs
AACE, 2011	Cost estimate classification system – as applied in engineering, procurement, and construction for the process industries. AACE International practice note 18R-97	All facilities	Cost estimation principles for Class 5 estimates
AusIMM, 1993	Cost Estimation handbook for the Australian Mining Industry. Australian Institute of Minerals and Metallurgy Monograph 20. (1993)	Underground disposal facilities	Capital cost of underground mining development and labour categories
AusIMM, 2012	Cost Estimation handbook for the Australian Mining Industry. Second Edition, Australian Institute of Minerals and Metallurgy Monograph 27. (1993)	Underground disposal facilities	Capital cost of underground mining development and labour categories, various industry benchmarks
DoE, 2013	A project concept for nuclear fuels storage and transportation. Prepared for US Dept of Energy Nuclear Fuels Storage and Transportation Planning Project (Techsource PL) June, 2013	Dry cask storage (above ground)	Scale and design of key features of dry cask storage facility, with operational similarity to South Australian proposal.
ENRESA, 2013	Conceptual Design for a Near Surface Low Level Waste (LLW) Disposal Facility and Collocated Above Ground Long-Lived Intermediate Level Waste (LLILW) Storage Facility in Australia.	Low level waste repository	Scale and design principles of key features of scalable engineered near surface low level waste repository to suit Australian conditions.
EPRI, 2009	Cost estimate for an away from reactor generic interim storage facility (GISF) for Spent Nuclear Fuel. Report 1018722. EPRI, Palo Alto.	Dry cask storage (above ground)	Scale and design of key features of dry cask storage facility, with operational similarity to South Australian proposal.
NDA, 2010	NDA, 2010. Geological Disposal: Summary of generic designs. UK-NDA report NDA / RWMD / 054	Underground disposal facilities	Scale and design principles for aspects of underground disposal facilities (both above ground buildings and underground excavations / structures)

Source	Full title	Relevant waste facility type	Key inputs
OECD-NEA, 1999	Low Level Radioactive Waste Repositories – An Analysis of Costs	Low level waste repository development costs	Scale and design of key features of the ENRESA El Cabril facility not detailed in ENRESA reference. Global Benchmark costs
Posiva, 2003	ONKALO Underground Rock characterisation facility – main drawings stage. Posiva Working Report 2003-26.	Main shaft and rock characterisation facility for GDF / ILW facility	Scale and design principles for main shaft to suit underground GDF or ILW facility
Posiva, 2005	Cost Estimate of Olkiluoto Disposal Facility for Spent Nuclear Fuel. Kukkola and Saanio, Posiva Working Paper 2005-10 (March 2005). Authors: Kukkola and Saanio.	Geological disposal facility	Detailed scale and design, through life costs of geological disposal facility. Suitable for extrapolation to South Australian case.
Posiva, 2012	Encapsulation Plant Design 2012. Posiva Working Report 2012-49, December 2012. Author: Kukkola	Encapsulation plant for GDF	Scale and cost principles for encapsulation plant
Rawlinsons, 2015	Australian Construction Handbook	All facilities	Benchmark costs for construction in Australia (both buildings and associated infrastructure) Locality factors for locations Australia-wide.
SKB, 2008	KBS-3H layout adaptation 2007 for the Olkiluoto site. Johansson et al. R-08-31. Swedish Nuclear Fuel and waste management Co (SKB), Authors: Johansson, Hagros et. al May 2008	Underground repository	Scale and design principles for main shaft to suit underground GDF or ILW (or combined) facility
SKB, 2007	Encapsulation at Forsmark. Swedish Nuclear Fuel and waste management Co (SKB), 2007. Authors: Nyström and Kärnbränslehantering.	Encapsulation plant for GDF	Scale and design principles for encapsulation plant
SKB, 2014	Plan 2013. Costs from and including 2015 for the radioactive residual products from nuclear power. Basis for fees and guarantees for the period 2015–2017. Svensk Kärnbränslehantering AB, Stockholm. Report TR-14-16, May 2014.	Underground disposal facilities	Principles for site selection costs

Source	Full title	Relevant waste facility type	Key inputs
SwissNuclear, 2011	Cost Study 2011 (KS11) – Estimate of the cost of disposal of the Swiss nuclear power plants. Swiss Nuclear nuclear energy section of the Swiss Electric [Company], Olten, Switzerland39.	Underground disposal facilities	Principles for site selection costs, Swiss GDF development costs.

[39] Taken from the original German language document: Kostenstudie: Schätzung der Entsorgungskosten der Schweizer Kernkraftwerke. Swissnuclear Fachgruppe Kernenergie der Swisselectric, Olten, Switzerland.

9. Qualifications, assumptions and exclusions

9.1 Qualifications

- This estimate is based on the engagement of a head contractor management team
- All construction work is based on a planned continuous flow of work and any significant disruption may require changes to the programme and / or additional costs
- Works relating to the sites geotechnical characteristics are based on the assumptions of project specific geotechnical information
- No significant change in land prices.

9.2 Assumptions

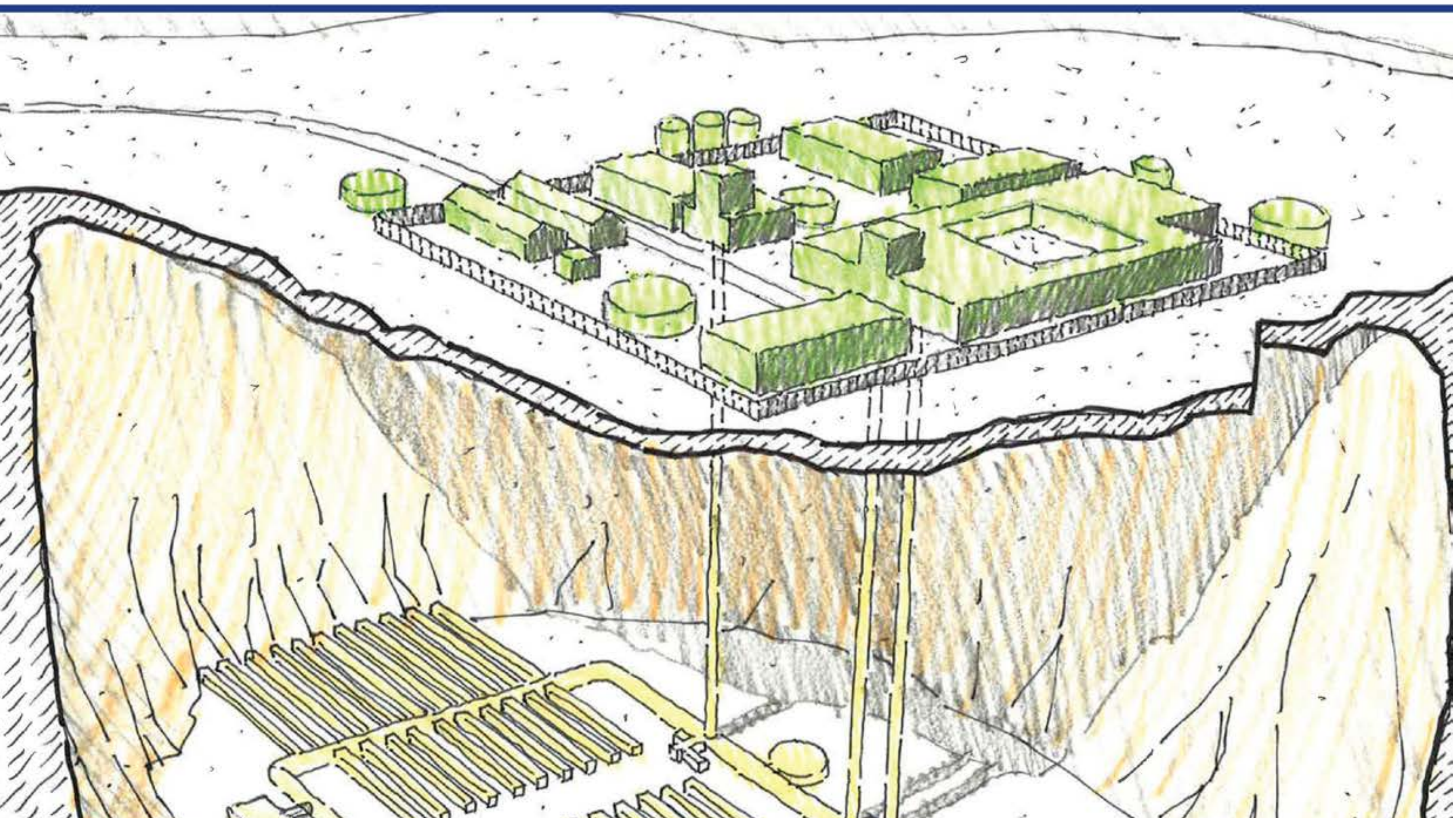
The following assumptions have not been included within the cost estimate:

- It has been assumed that sufficient labour resources would be available to perform the works

9.3 Exclusions

The following costs have not been included within the capital cost estimate:

- operating cost estimates
- foreign exchange hedging allowances
- escalation beyond the estimate base date
- project risk allowance for discrete risk events
- financing charges and interest during construction
- project insurances
- performance bond premiums
- all taxes and duties including sales taxes and GST
- costs associated with previous studies
- community consultation and engagement allowances
- public relations allowances
- compliance allowances
- residual value of temporary equipment and facilities
- unexpected & unidentified site conditions
- force majeure
- extreme weather interruptions to project works
- extreme events.



PAPER 4
TRANSPORT, LOGISTICS AND OPERATING COSTS

Paper 4 - Transport, logistics and operating costs

1. Introduction

This paper describes the typical transportation and logistics arrangements which are in place in Europe, Asia, US and elsewhere for the management and disposal of radioactive waste.

The logistics chain which is modelled in South Australia involves receipt by sea of both high level waste and intermediate waste (no low level waste is presumed to be sent internationally) and then transfer to an interim storage facility for a period of time before underground disposal.

The requirements for each form of movement are described, and cost estimates prepared, as well as other operational costs for each of the facilities which form part of the management chain.

The annual operating costs for each facility, including direct and contact labour, equipment and property leases, utilities and materials and other consumables are then described for each facility type, and under different operating scenarios.

The paper concludes with an estimate of the total annual cost for each facility, which is applied in the commercial model and business case analysis.

2. Transport and logistics

2.1 International practices for transport and storage of radioactive materials

2.1.1 Regulatory environment and safety

The International Atomic Energy Agency (IAEA) regulations for the safe transport of radioactive materials[40] set recommended regulatory standards for international transport activities. The basic concept is that safety is achieved by the properties of the packaging containing radioactive materials. This must provide shielding to protect workers, the public and the environment against the effects of radiation; to prevent an unwanted chain reaction; to prevent damage caused by heat, and to provide protection against release of radioactive materials. This must be achieved under normal conditions, but also under accident conditions which could occur during transport of materials.

The World Nuclear Association in its September 2015 article on transport of radioactive materials[41] opens with the following comments about transport of radioactive materials: There are some 20 million consignments of radioactive substances worldwide each year on public roads, railways and on ships. Since 1971 there have been more than 20,000 shipments of used fuel and high-level wastes (over 80,000 tonnes) over many million kilometres. Although there have been transport accidents involving radioactive materials, there has never been one in which a container with highly radioactive material has been breached, or has leaked.

This article discusses transport of spent nuclear fuel, commenting: Since 1971 there have been some 7,000 shipments of used fuel (over 80,000 tonnes) over many million kilometres with no property damage or personal injury, no breach of containment, and very low dose rate to the personnel involved (e.g. 0.33 mSv / year per operator at La Hague). This includes:

- 40,000 tonnes of used fuel shipped to Areva's La Hague reprocessing plant
- at least 30,000 tonnes of mostly UK used fuel shipped to UK's Sellafield reprocessing plant
- 7,040 tonnes used fuel in over 160 shipments from Japan to Europe by sea
- over 4,500 tonnes of used fuel shipped around the Swedish coast
- routine rail movements of naval spent fuel to Idaho National Laboratory
- some 300 sea voyages have been made carrying used nuclear fuel or separated high-level waste over a distance of more than 8 million kilometres
- the major company involved has transported over 4000 casks, each of about 100 tonnes, carrying 8,000 tonnes of used fuel or separated high-level wastes. A quarter of these have been through the Panama Canal
- in Sweden, more than 80 large transport casks are shipped annually to a central interim waste storage facility called CLAB. Some 6000 tonnes of used fuel had been shipped to CLAB by mid-2015, much of it around the coast by ship
- shipments of used fuel from Japan to Europe for reprocessing used 94 tonne Type B casks, each holding a number of fuel assemblies (e.g. 12 PWR assemblies, total 6 tonnes, with each cask 6.1 metres long, 2.5 metres diameter, and with 25 cm thick forged steel walls). More than 160 of these shipments took place from 1969 to the 1990s, involving more than 4000 casks, and moving several thousand tonnes of highly radioactive used fuel – 4,200 tonnes to UK and 2,940 tonnes to France. Within Europe, used fuel in casks has often been carried on normal ferries, e.g. across the English Channel.

[40] http: / / www-pub.iaea.org / books / IAEABooks / 8851 / Regulations-for-the-Safe-Transport-of-Radioactive-Material-2012-Edition-Specific-Safety-Requirements Accessed 23 September 2015
[41] http: / / www.world-nuclear.org / info / Nuclear-Fuel-Cycle / Transport / Transport-of-Radioactive-Materials / Accessed 18 September 2015

2.1.2 Packaging

The design of packaging containing radioactive materials is the principal assurance of safety in the transport of nuclear materials. The consignor bears primary responsibility for the safety of the transportation, including allowance for very low probability or unforeseen events. Many different nuclear materials are transported on a routine basis and the degree of potential hazard from these materials varies considerably. Various transportation and packaging standards have been developed by the IAEA according to the characteristics and potential hazard posed by the different types of nuclear material, as well as to address different modes of transport.

There are five classifications for packaging of radioactive materials:

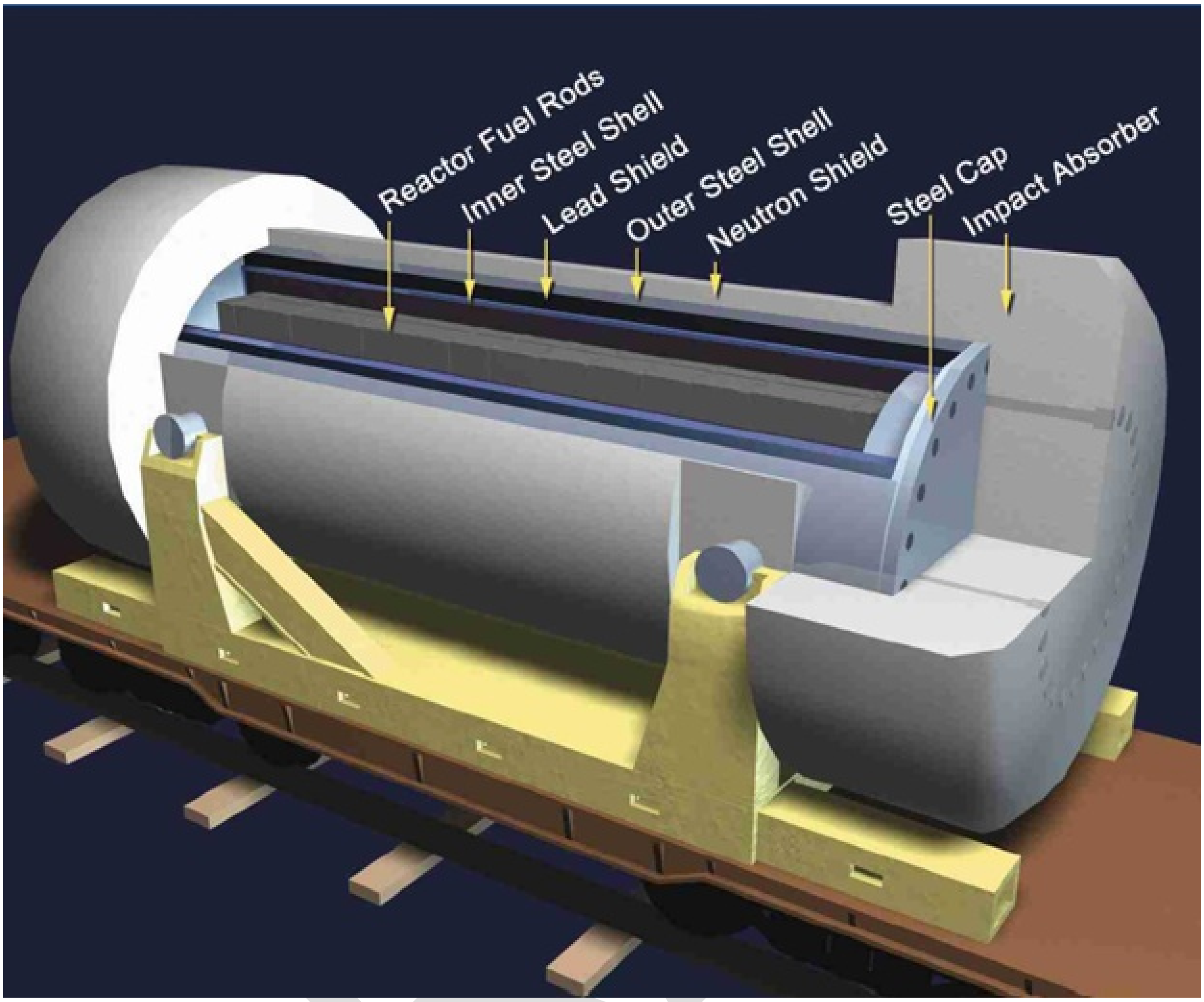
- **Excepted:** for radioactive materials posing insignificant levels of hazard
- **Industrial:** commonly steel drums and ISO shipping containers, used for materials with low specific activity (LSA) such as hospital waste and non-radioactive materials having low levels of surface contamination by radioactive materials. 36 standard 205 l drums fit into a standard 20' ISO shipping container.
- **Type A:** used for low level radioactive materials such as medical isotopes
- **Type B:** used for transport of highly radioactive materials. This is the primary class of container likely to be used for most ILW, HLW and SF.
- **Type C:** packages with similar properties as Type B, but designed for air transport, and able to withstand conditions which could be experienced in air crashes.[42]

Uranium fuel for power station and other reactors is formed into standard sized **assemblies**, with different sizes for pressurised water reactors (PWR) and boiling water reactors (BWR). After removal from the reactor, these assemblies are placed into cooling ponds at the reactor for at least 5 years to allow decay of the heat emitted. Originally, these assemblies were typically intended to go then to a re-processing plant or else to long term storage facilities in which the remain for some decades until they are cool enough to allow them to be placed in a geological disposal facility (DGF). In practice, the high costs of reprocessing and the unavailability of any GDF has often led to pond stores being expanded and filled up and subsequently to the fuel being moved into dry cask storage. The fuel is easier to handle when being transferred if it is encased first in sealed **canisters** (but bare fuel can also be handled). There are various types of canister, but dual purpose canisters (DPCs), suitable for both storage and transport are now the most common, as they reduce need and risk from subsequent handling. DPCs are also referred to as multi-purpose canisters (MPCs), possibly emphasising that these canisters are suitable for both interim and long term storage. Canisters are placed inside **casks** (also referred to as **flasks**, particularly in Europe) which provide greater shielding and physical protection during transport. Once casks reach sites for longer term storage, they are placed inside **vertical storage casks** or horizontal concrete storage modules which provide greater shielding and are designed to manage the heat which continues to be released.

There are some 150 approved designs for Type B casks, but for the purposes of this analysis, the Holtec International HI-STORM system has been assumed, as it is widely used, particularly in USA and provides an integrated set of canisters and casks accommodating a wide variety of SF assemblies and other radioactive materials in a single overpack by using various DPCs[43]. A typical Type B cask design is shown in Figure 2.1.

[42] http: / / www.wnti.co.uk / media / 31575 / FS2_EN_MAR13_V2.pdf
[43] http: / / www.holtecinternational.com / productsandservices / wasteandfuelmanagement / hi-storm / Accessed 23 September 2015

Figure 2.1 : Type B transportation cask (generic design on a rail bogie)



Source: An overview of dry cask storage R McCullum, Nuclear Energy Institute 19 October 2012 http: / / line.idaho.gov / pdf / Overview%20of%20Dry%20Cask%20Storage.pdf p 32 Accessed 29 September 2015

Information on Holtec International's range of nuclear storage containers published by EPRI[44] on system components, capacities, dimensions and masses is shown in Table 2.1. For transport movements, the largest and heaviest dimensions that must be considered in designs are:

- 5.12 m long
- 2.4 m outer diameter
- 111.13 tonne

This makes them slightly smaller than 20' ISO shipping containers, but nearly four times heavier.

Each cask can hold a maximum of 10 tonne of SF. A comparison between 10 and 13 tonne casks was included in ESRI's 2009 investigation into costs for provision of SF storage remotely from reactors[45] which commented: "EPRI also evaluated the impact of using canisters with a capacity of 13 MTU, which is more representative of the capacity of dry storage canisters currently in use at the reactor sites". On this basis, it appears defensible to use a higher average SF contents greater than 10 tonne for storage analysis purposes. However, 10 tonne has

[44] http: / / www.epri.com / abstracts / Pages / ProductAbstract.aspx?ProductId=000000000001021048&Mode=download Accessed 1 October 2015
[45] EPRI, 2009. Cost Estimate for an Away-From-Reactor Generic Interim Storage Facility (GISF) for Spent Nuclear Fuel. Electrical Power Research Institute Report 1018722. EPRI, Palo Alto. http: / / www.epri.com / abstracts / Pages / ProductAbstract.aspx?ProductId=000000000001018722 Accessed 4 October 2015

been used in this analysis to retain a conservative approach. An average capacity of 12 or 13 tonne would seem reasonable which suggests 12.5 tonne could be used as an alternative conversion factor.

Table 2.1 : Holtec International dry storage system parameters

Description	HI-STAR 100		HI-STORM 100			HI-STORM 100U		
Fuel Type	PWR	BWR	PWR		BWR	PWR		BWR
# Assemblies	24	68	24	32	68	24	32	68
Maximum Heat Load (kilowatts)	19	18.5	27	36.9	36.9	27	36.9	36.9
Minimum Cooling Time (Years)	5	5	3					
Maximum Fuel Burnup (GWd/MTU)	42.1	37.6	68.2 (PWR), 65 (BWR)					
Dual Purpose Canister Length [m. (in.)] Outer Diameter [m. (in.)]	4.83 (190.3) 1.74 (68.5)							
Transfer Cask Length [m. (in.)] Outer Diameter [m. (in.)] Loaded Weight [t. (lbs)] (with water) HI-TRAC 100 HI-TRAC 125 HI-TRAC 125D	4.98 – 5.12 (196.25 - 201.5) 2.32 – 2.4 (91.25 - 94.625) 87.09 – 90.26 (192,000 -199,000) 107.23 – 111.13 (237,500 - 245,000) 103.65 – 107.05 (228,500 - 236,000)							
Storage Cask Length [m. (in.)] Outer Diameter [m. (in.)] Loaded Weight [t. (lbs)]	5.87 – 6.17 (231-243) 3.37 (132.5) 163.29 (360,000)					See note 1. 5.79 (228) minimum 2.18 (86) 66.68 (147,000)		
NRC Part 72 Docket	72-1008		72-1014					
Note 1: The HI-STORM 100U utilizes a Vertical Ventilated Module for underground storage. The dimension length dimensions provided are the minimum dimensions of the Cavity Enclosure Container (CEC) plus the approximately length of the closure lid above the CEC. A general licensee may increase this length provided that a 10CFR72.48 analysis is completed and documented. For more detailed information refer to the licensing dockets associated with these storage systems.								

Source: EPRI Industry Spent fuel storage handbook, p 4-10[46]

Other assessments of transport casks for SF have suggested greater masses, such as the ESRI 2004 review[47] which stated a typical gross weight of “250,000 pounds (125 tons)”. 250,000 lb converts to 113.4 tonne. These casks were stated as having typical dimensions of length 25 feet (7.62 m) and diameter 11 feet (3.35 m). These are about 1.5 m longer than a standard 20’ / 6.1 m ISO container, but more than four times as heavy.

IAEA’s 2007 report on the operation and maintenance of spent nuclear fuel casks[48] provided a table of characteristics of a number of SF casks, reproduced in Table 2.2. It can be seen that most are in the range 100 – 115 ton with fuel (equivalent of 90.7 to 104.3 metric tonnes), with the heaviest 140 tons (127 tonnes).

On this basis, designing to accommodate casks weighing up to 140 metric tonnes seems appropriate.

[46] http: / / www.epri.com / abstracts / Pages / ProductAbstract.aspx?ProductId=000000000001021048&Mode=download Accessed 1 October 2015
[47] http: / / www.epri.com / abstracts / Pages / ProductAbstract.aspx?ProductId=000000000001009226 Accessed 19 September 2015
[48] http: / / www-pub.iaea.org / MTCD / publications / PDF / te_1532_web.pdf Accessed 1 October 2015

Table 2.2 : SF cask characteristics

Cask designation	nr of SF assemblies (PWR)	mass in tons, with fuel, rounded	type	fleet used in Europe (Dec. 2003)
TN™12/1	12 PWR	100	transport	55
TN 12/2	12 PWR	105	transport	
TN 13/1	12 PWR	105	transport	
TN 13/2	12 PWR	115	transport	
TN 17/2	7 PWR or 17 BWR	80	transport	
TN 9/4	7 PWR	40	transport	2
TN 52L	52 BWR	115	dual-purpose	61
TN 97L	97 BWR	135	dual-purpose	
TN 24 D	28 PWR	115	dual-purpose	
TN 24 DH	28 PWR	125	dual-purpose	
TN 24 XL	24 PWR	120	dual-purpose	
TN 24 XLH	24 PWR	125	dual-purpose	
TN 24 SH	37 PWR	105	dual-purpose	
TN 24 G	37 PWR	135	dual-purpose	
TN 24 BH	69 BWR	135	dual-purpose	
TN 24 E	21 PWR	140	dual-purpose	

Source: http: / / www-pub.iaea.org / MTCD / publications / PDF / te_1532_web.pdf p 71

2.1.3 Materials handling, lifting and transport issues

Materials handling and transport issues arise from the cask mass, which is substantially greater than normal road transport limits, from issues of lifting and positioning casks as desired, and from the risks posed by the hazardous nature of the contents. The weights are within common limits for specialist over size over mass (OSOM) road transport, commonly used for large, heavy indivisible items such as power station generators and transformers, mine mills and large plant modules. They can be moved by specialist OSOM carriers, but this requires individual planning and management of each transport movement if on public roads. A typical road movement of SF is shown in Figure 2.2. Lifting casks between storage sites and transport vehicles requires adequate capacity cranes with size and manoeuvrability to access required locations.

Figure 2.2 : Road movement of SF in Japan

Source: http: / / www.wnti.co.uk / media-centre / nuclear-fuel-cycle / spent-fuel-reprocessing.aspx Accessed 27 September 2015 Both images courtesy of Nuclear Fuel Transport Co. Ltd. (NFT)

Most land transport of SF in heavy casks worldwide over distances exceeding a few kilometres is undertaken by rail, from a combination of greater ability to cope with such heavy weights, lower accident risk and greater ability to achieve a high level of security. Nearly all SF movements by rail are undertaken in special purpose single commodity trains, such as that shown in Figure 2.3.

Figure 2.3 : Typical rail movement of SF – United Kingdom

Source: World Nuclear Transport Institute http: / / www.wnti.co.uk / media / 4334 / 42.jpeg Accessed 28 September 2015

2.2 International practices for transport of SF

2.2.1 Specialist nuclear fuel ships

The International Maritime Organisation (IMO) introduced a voluntary code for the safe carriage of irradiated nuclear fuel, plutonium and high-level radioactive wastes in flasks on board ships (INF Code) in 1993. This code became mandatory in January 2001 and introduced advanced safety features for ships carrying used fuel, MOX or vitrified high-level waste[49].

There are at least five small purpose-built ships ranging from 1,250 to 2,200 tonnes (DWT), and four purpose-built ships of 3,800 to 4,900 tonnes (DWT), which are able to carry class B casks and other materials. They conform to all relevant international safety standards, notably INF-3 (irradiated nuclear fuel class 3) set by the IMO. This allows them to carry highly radioactive materials such as high level wastes and spent nuclear fuel, as well as mixed-oxide (MOX) fuel and plutonium.

The three largest ships belong to a British-based company Pacific Nuclear Transport Ltd (PNTL), now owned by International Nuclear Services Ltd (INS, 68.75%), Japanese utilities (18.75%) and Areva (12.5%). INS is owned by the UK's Nuclear Decommissioning Authority. These vessels offer nuclear fuel sea transport services to approved customers, and are typical of the vessels which could be involved in bringing SF to Australia.

The three PNTL vessels all have double hulls with impact-resistant structures between the hulls, together with duplication and separation of all essential systems to provide high reliability and also survivability in the event of an accident. Twin engines operate independently. Each ship can carry up to 20 or 24 transport casks. The three vessels now in service, Pacific Heron, Pacific Egret and Pacific Grebe, were launched in Japan in 2008, 2010 and 2010 respectively[50]. Key parameters for the Pacific Grebe are shown below in Table 2.3 and a schematic of the vessel is in Figure 2.4.

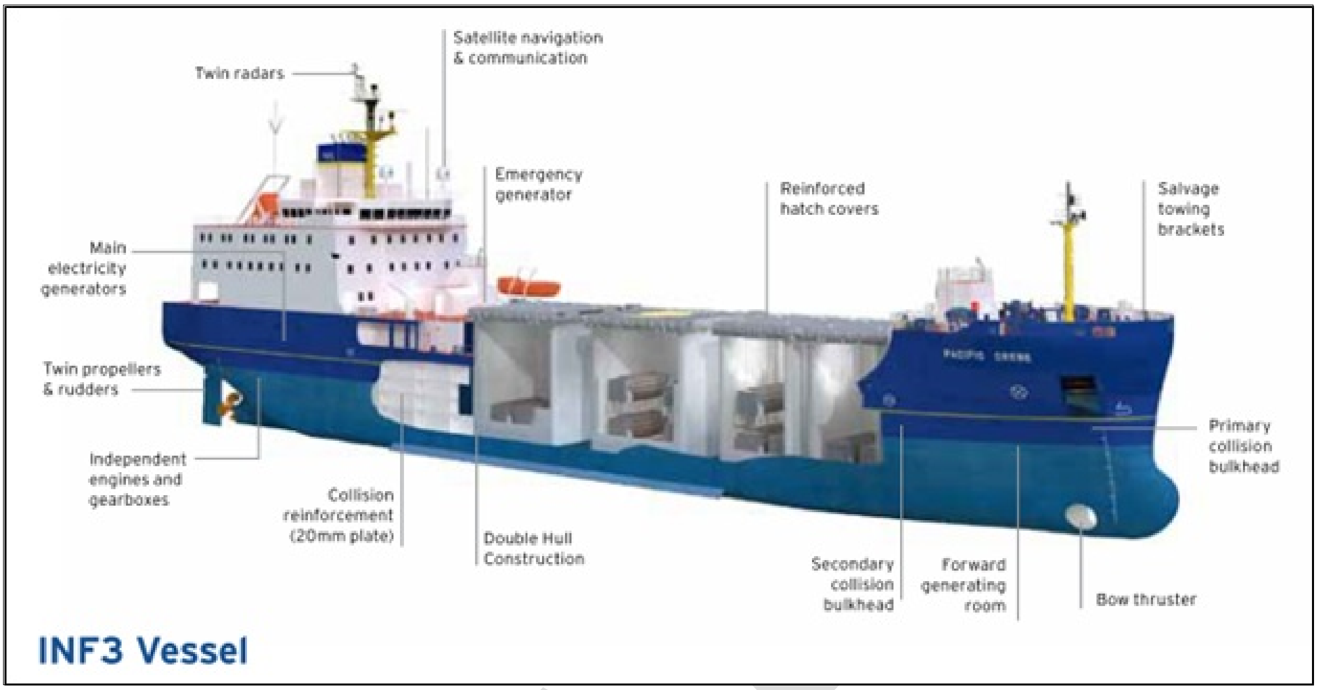
Table 2.3 : Example vessel the "Pacific Grebe" - high level parameters

Specification	Measure
Length overall	103.92 m
Breadth	17.25 m
Draft	6.75 m
Number of holds	4
Capacity	20 flasks
Design speed	14 knots
Deadweight max	4,916 tonnes
Principal cargo	High level waste / compacted waste

Source: http: / / www.pntl.co.uk / wp-content / uploads / 2012 / 09 / PNTL_Grebe_01.pdf Accessed 23 September 2015

49 http: / / www.imo.org / en / OurWork / Safety / Cargoes / Containers / Pages / Default.aspx Accessed 23 September 2015
50 http: / / www.pntl.co.uk / our-fleet / Accessed 24 September 2015

Figure 2.4 : Pacific Grebe schematic view



Source: [http: / / www.pntl.co.uk / wp-content / uploads / 2012 / 09 / PNTL_Grebe_01.pdf](http://www.pntl.co.uk/wp-content/uploads/2012/09/PNTL_Grebe_01.pdf) Accessed 23 September 2015

Other specialist SF carrier vessels are owned by governments operating nuclear facilities, and mostly perform work to meet these countries' needs. Sweden's SKB has commissioned a slightly larger replacement for its 1982 Sigyn, the Sigrid, launched in Romania in 2012 and designed by Damen Shipyards in Netherlands. It is used for moving used fuel from reactors to Sweden's interim waste storage facility. Sigrid is equipped with a double hull, four engines and redundant systems for safety and security, was commissioned in 2013 and carried its first shipment in January 2014. Sigrid is 99.5 metres long and 18.6 metres wide, 1,600 deadweight tonnes (DWT) and capable of carrying twelve nuclear waste casks. Sigyn was 1250 tonnes deadweight and carried ten casks. The current status of the Sigyn is unclear, but it appears scrapping may be under consideration.

Rosatomflot operates the 1,620 DWT Rossita, built in Italy and completed in 2011. It was designed for transporting spent nuclear fuel and materials from decommissioned nuclear submarines from Russian Navy bases in north west Russia. It has been used on the northern sea route, between Gremikha, Andreyeva Bay, Saida Bay, Severodvinsk and other places hosting facilities which dismantle nuclear submarines. Spent fuel has been delivered to Murmansk for rail shipment to Mayak. Rosatomflot has the Serebryanka (1,625 DWT, 102 m long, built 1974) already in service. The Imandra (2,186 DWT, 130 m long, built 1980) is described as a floating technical base but is reported to be already in service transporting used fuel and wastes from the Nerpa shipyard and Gremikha to Murmansk. Andreyeva Bay is the primary spent nuclear fuel and radioactive waste storage facility for the northern fleet, some 60 km from the Norwegian border. It has about 21,000 spent nuclear fuel assemblies and about 12,000 m^3 of solid and liquid radioactive wastes.

Rossita is an ice-class vessel and is designed to operate in harsh conditions of the Arctic. The ship is 84 m long and 14 m wide, with two engines, and has two isolated cargo holds holding up to 720 tonnes in total. On board, the radiation monitoring is carried out by both an automated multi-channel system and a set of portable instrumentation. The €70 million vessel was given to Russia as part of Italy's commitment to the G-8 partnership program for cleaning up naval nuclear wastes, and is designed to cover all needs in spent nuclear fuel and radioactive waste shipments in northwest Russia throughout the entire period of cleaning up these territories.

International shipping costs for nuclear wastes

Order of magnitude shipping costs were sought from a major international supplier, modelled on charter of a vessel such as the Pacific Grebe to bring an entire shipload of HLW / SF and / or LILW to Australia from logical source locations in Europe and Asia. The HLW / SF would be in Holtec International HI-STORM or TN81 casks, and the LILW in various ISO and non ISO containers. INS's general response (which should not be characterised in any way as a quotation) made the following points:

Based on information received, it is estimated that that costs for a single voyage of 20 SF casks to Australia is likely to be in the order of £3 million, once costs for time required for loading and unloading, and country specific requirements are factored in. This converts to AUD6.4 million for the voyage, based on UKP£1.00 = AUD2.14[51]. This is the equivalent to AUD321,000 per cask and AUD32,100 per tonne of SF assuming 10 t per cask.

A recent analysis by the Global Nuclear Future initiative (GNF) of the American Academy of Arts and Sciences[52] estimated international shipping costs at USD1.8 million for a 10,000 mile journey of 40 containers in a specialist 5,000 DWT vessel (p 34). This converts to a daily rate of $61,000 per ship day, based on 30 – 35 days to sail 10,000 miles at 14 knots, the cruising speed of PNTL's Pacific Grebe. Ship cost in port is typically 60 % of sailing cost, so this implies a per day cost in port of around $37,000.

This shipping cost converts to:

- USD76,333 per cask if 24 casks can be carried
- USD91,600 per cask if only 20 casks can be accommodated
- USD5,872 to 9,160 (average $7,516) per tonne of SF (assuming a range of 10 – 13 t SF per cask and 20 – 24 casks per shipment).

This conversion assumed land miles – it is unclear from the GNF report if land or nautical miles were intended. If nautical miles were assumed, these costs would reduce by around 15% as nautical miles are longer.

The main difference between these cost estimates relates to the likely requirement for empty vessel repositioning from UK home port to SF source and to return to UK after delivering the SF cargo in Australia.

2.2.2 Port requirements for these ships and SF cargo format

Based on the young age of the PNTL specialist nuclear carrier vessel fleet and this company's dominance of the third party SF and MOX ship charter provision market, it appears very likely that vessels of this size and requirements will be commonly used for many years to come. On this basis, it is concluded that these vessels provide a good template to define port concept design and evaluation of the suitability of existing ports. To provide some provision for future proofing, some allowance for accommodating larger ships with more SF casks would be prudent.

It is suggested port design and assessment parameters should include:

- ability to handle vessels up to 120 m LOA
- ability to accommodate vessels requiring draught up to 7.5 m
- ability to dredge to 10.0 m without structural change to wharf, piles, dolphins or other infrastructure
- shore based craneage to lift 140 tonne indivisible units
- sufficient wharf space to accommodate 28 casks received from a single ship without the need to rearrange casks of the wharf and providing adequate space for mobile harbour cranes to manoeuvre around the wharf.

Harbour cranes with these lifting capacities are available, but are large and are significant capital items in their own right. One example is shown in Figure 2.5

[51] http: / / www.xe.com / currencyconverter / convert / ?From=GBP&To=AUD Accessed 19 November 2015
[52] Robert Rosner, Lenka Kollar, and James P. Malone (2015) the Back-End of the Nuclear Fuel Cycle: Establishing a Viable Roadmap for a Multilateral Interim Storage Facility. http: / / www.amacad.org / content / publications / publication.aspx?d=21694 Accessed 9 October 2015

Figure 2.5 : Terex model-8 harbour crane with lifting capacity 200 tonne

Source: http: / / www.terex.com / port-solutions / en / products / harbour-cranes / mobile-harbour-cranes / model-8 / index.htm Accessed 01 / 10 / 15

2.2.3 Port requirements for ILW

Demand for receipt, processing and disposal of ILW is less clear, but an estimate of 300,000 m^3 over the 45 year receival time frame has been suggested, averaging 6,667 tpa, and would equate to approximately 18,000 x 20' ISO shipping containers, based on typical volume of 32-34 m^3 per container and 66% volume utilisation by ILW, based on a ratio of waste volume to gross storage volume of 1.5. If this waste was received evenly over the 45 year receival time, this would equate to 400 containers per annum. Another suggestion was 10,000 m^3 ILW per annum, this would equate to approximately 600 ISO TEU shipping containers per year, with a 50% volume utilisation assumption, or approximately 12 TEU per week.

There are two main options for receiving these wastes:

- They could be received at the same port as used for HLW / SF
- If IMO DG regulations permit, and exposure risks / doses were within acceptably low limits, it could be received on regular container vessels at the nearest container. This would almost certainly be a far cheaper international shipping alternative.

If the ILW were received at the same specialised port as used for HLW / SF, it could be received on the same vessels as the HLW, or on small container or multi-purpose vessels able to fit at the port. 600 TEU per annum is around 12 per week, and monthly shipments of around 50 TEU on a small multipurpose vessel chartered for the purpose would be feasible.

If 20' containers containing this waste were received at a major port on regular liner vessels, shipping and land transport costs are estimated at USD2,500 per TEU. Sea transport on a chartered multi-purpose vessel is estimated at USD6,000 per TEU, based on 30 day voyage including ship repositioning, 50 TEU and USD10,000 per day. Land transport to ISFS from the port is assessed in section 2.4 on page 167, and is estimated at AUD $3,000 per TEU.

2.3 Land transport

Available evidence suggests that most land transport of SF is undertaken by rail[53], with the following trip statistics collated by the Canadian Nuclear Management Organization:

- Canada: 5 per year by road
- USA: 3000 up to 2013 by road, rail and ship
- UK: 300 per year by rail
- France: 250 per year by rail, and
- Germany: 40 per year by rail.

The popularity of rail over road is generally understood to be a combination of:

- greater ability to more easily handle the substantial masses involved
- greater security and ability to exclude the general public, and
- greater safety and lower risk of accidents and collision.

2.3.1 Rail transport

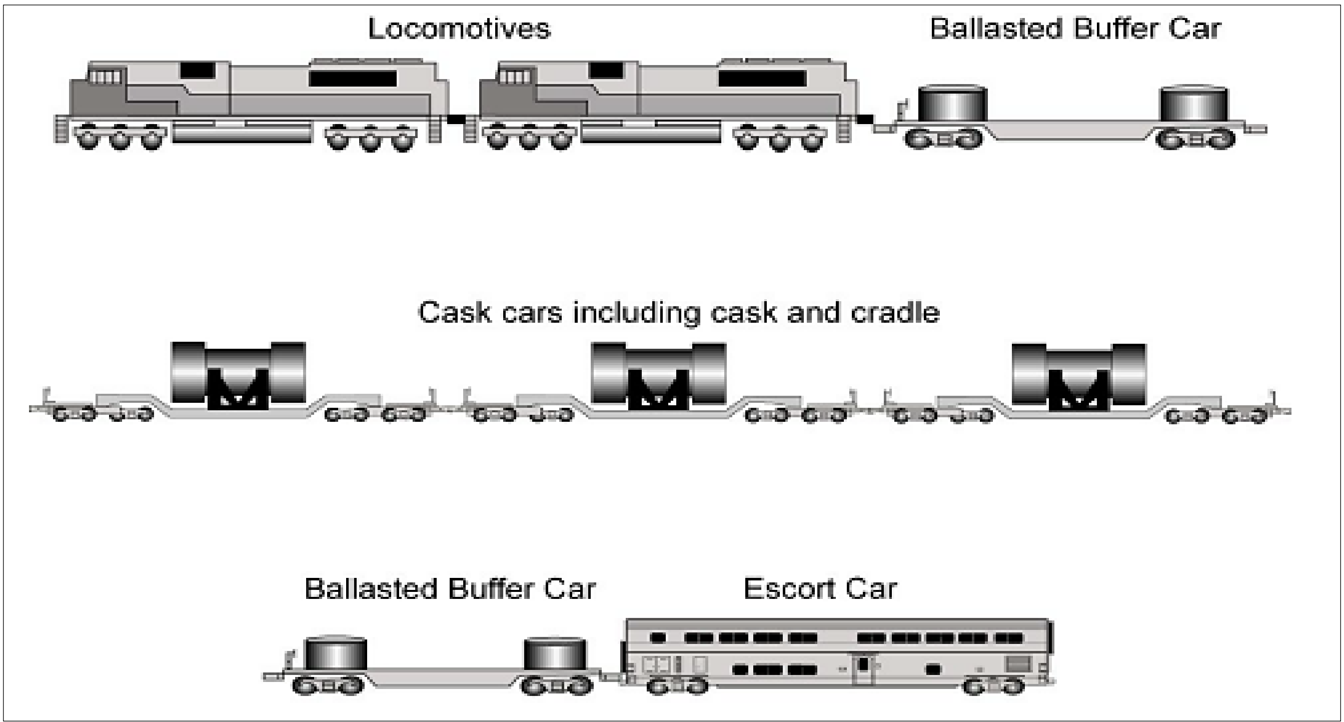
Rail transport of heavy nuclear fuel casks is relatively common, with dedicated trains specifically for the purpose. Rail movements of nuclear materials are not mixed with other rail movements of other commodities. Typical arrangements consist of trains with one or two eight axle (four bogie) wagons for the casks with two locos, one at each end. This arrangement removes the need for locomotive run around tracks and for breaking up and reassembling trains with the lost time this requires to undertake and test brakes etc. It also provides redundancy in the event that one of the locos breaks down. Figure 2.6 shows two typical movements. Figure 2.7 shows a nuclear fuel train arrangement proposed for by the US Department of Energy. It includes a buffer car between nuclear fuel carrier cars and other rolling stock types, and a crew carriage, and has both locomotives at the front of the train.

[53] For example http: / / www.nwmo.ca / uploads_managed / MediaFiles / 471_NWMOTR-2009-14_TransportationofUF-CanadianandInternational_R0d.pdf but inaccessible quoted in http: / / www.world-nuclear.org / info / Nuclear-Fuel-Cycle / Transport / Transport-of-Radioactive-Materials / Accessed 23 September 2015

Figure 2.6 : Typical spent fuel train

Image sources: http: / / davemcalone.zenfolio.com / p375993654 / h574E9EA#h574e9ea and http: / / davemcalone.zenfolio.com / p375993654 / eb737ed2 Visited 21 September 2015

Figure 2.7 : Proposed US train consist for SF movements



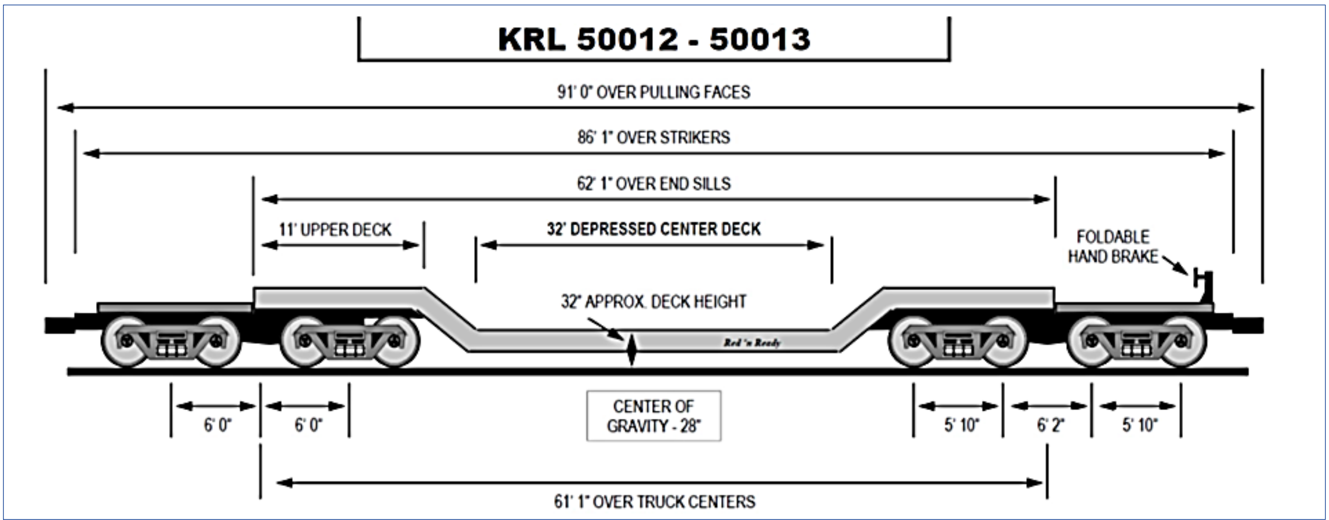
Source: US DOE A project concept for nuclear fuels storage and transport June 2013, p 25[54]

The four bogie, eight axle wagons are required in order to accommodate the substantial mass without exceeding railway axle load limits or requiring exceptionally heavy duty track. For the maximum anticipated weight per cask of 140 tonne, a heavy load drop deck wagon with tare weight around 70 tonne would be required, giving a total wagon weight of around 235 tonne, and axle loading of around 29.4 tonne, just within the heavy haul standard adopted by BHP Billiton and Rio Tinto for their Pilbara iron ore operations. This makes the construction standards well known, but costs are estimated at around 20% more expensive than for normal freight lines of 23-25 tonne.

There are specialist rail freight wagon manufacturers that can provide such wagons to existing designs or purpose design new ones for specific requirements. A typical eight axle four bogie wagon with carrying capacity 175.4 tonne, tare 63.5 tonne gross 238.8 tonne is shown in Figure 2.8 (below).

[54] https: / / www.hsdl.org / ?view&did=739345 Accessed 29 September 2015

Figure 2.8 : Typical eight axle drop deck rail wagon design



Source: http: / / www.kasgro.com / specs.asp http: / / www.kasgro.com / cars / SPEC%20A19636.pdf

Rail costs

Rail capital and operational costs are modelled in the absence of detailed benchmark costs to derive a top-down cost from for South Australia. Track cost will be a major component. Critical track requirements include:

- standard gauge
- 300 mm deep ballast under track and 400 mm deep shoulders
- 30 tonne rated sleepers at 600 mm centres (compared with 650 mm standard)
- 30 tonne rated track fasteners
- head hardened rail of at least 60 kg / m compliant with AS 60.

Bridge requirements include:

- design to the maximum full train mass in accordance with AS5100.

If it is planned to use existing normal freight track (<25t axle load), this track is likely to be damaged by the higher axle loads, unless the rail is 60 kg / m or heavier and heavy sleepers have been used. The fastening system would also be highly stressed and determining the best speed around curves will require careful consideration of the existing cant on the tracks to avoid overstressing the lower rail.

In practice, it is likely that the following will be required:

- virtual full rebuilding, retaining existing ballast if in good condition and topping up by an additional 150 mm on top of typically 200 mm to give finished 300 mm profile with 400 mm shoulders
- replacement of sleepers, fasteners and rail
- assessment of bridges and culverts to determine if the heavy load wagon trains can proceed over the existing structures at controlled speed, or if strengthening works are required
  - on ballasted deck multi-track bridges it is possible that the load could proceed provided there was no traffic on the other tracks
  - single track ballast deck bridges or transom bridges will be the most likely to require strengthening

It is suggested that the organisation operating the nuclear fuel receipt, storage and processing facility should own the specialist wagons to carry the casks, and obtain quotations from established rail operators for 'hook and pull' services. This will enable potentially low levels of loco utilisation to be supplemented with other duties and also mean that the nuclear waste company does not have to deal with the administrative and regulatory issues of becoming a certified rail operator. The rail operator is probably better placed to provide flat or skeletal rail wagons for containers of ILW. If a crew car for guards or other personnel is required, the rail operator should provide this also.

Costing suggestions:

- construction of new 30 tonne axle load rail track as above: AUD2 million / km
- bridges: individual assessment
- culverts: AUD0.5 million
- turnouts: AUD1.5 million each
- rebuilding existing < 25 tonne axle load limit rail track: AUD1.5 million / km
- other items as above
  - 2 x eight axle four bogie wagons: AUD1 million for two
  - locomotives: obtain from rail operator on tendered 'hook and pull' basis

Costs for acquisition of land for the rail corridor would be in addition to this. It is suggested that a corridor width of 10 m would be adequate for a single track rail line, providing space for the track and an adjacent track for road access when required. Provision should be made for passing loops requiring a 1,000 m length of double track section on an alignment 15-20 m wide in suitable locations each 100 km on average.

Rail operations:

- suggest initial cost at AUD0.20 / net tonne kilometre (based on gross mass of loaded sf casks and ISO or other containers exceeding 34 tonne gross)
- equivalent to AUD22.65 / kilometre per cask of 113 tonne
- suggest AUD0.15 / net tonne kilometre (ntk) for ISO and other containers within normal rail loading limits of 34 tonne gross
- thus AUD7.50 / km for a 50 tonne ILW container

2.3.2 Road transport

Road transport of SF is possible using specialist over size over mass carriers and equipment, but is generally confined to short distances between ports and initial storage facilities. The disadvantages over rail include lower perceived level of security, higher risk of accident and the challenges of specialist organisation of each movement. If undertaken on public roads, large heavy OSOM movements cause delays and inconvenience to other road users.

Road costs

Cost approximations were received in September 2014 for specialist OSOM movement of TN-81 casks from Lucas Heights to Northern Territory locations, a distance of just under 3,000 km. These casks are 6.5 m long, 3 m in diameter and weigh approximately 100.5 tonne loaded, consisting of 100 tonne cask empty weight + 500 kg loaded fuel canister). The high level rates offered (not quotations) were AUD25 / km for loaded movements and AUD15 / km for empty return of the trucks and specialist trailers. Rates for shorter moves would be proportionately more expensive per kilometre, due to fewer kilometres over which fixed costs such as movement planning and permitting could be spread.

Road construction costs

If new roads were to be constructed as an alternative to a heavy haul rail line, these roads would need to be designed and specified to accommodate routine movements of over-size over-mass transport equipment, such as that shown in Figure 2.9.

Figure 2.9 : Typical over size over mass road transport movements in Australia

Key requirements include:

- sealed width at least 8 m
- gravel shoulders on similar subgrade structure as for the sealed road of at least 1.5 m both sides
- strength to accommodate multi axle trailers with eight tyres on each axle with axle loadings to 16 tonne and axle spacing as short as 1.5 m
- gradients not exceeding 1:40
- curves suitable for swept paths of triple road trains
- good sight lines around curves from adequate vegetation clearance, particularly on the inside of curves
- alignment to avoid towns, settlements and other developments as far as possible.

For budgetary purposes, a cost allowance for design, construction and commissioning of AUD $3.0 million / kilometre is suggested. Costs for acquisition of a reserve of at least 15 m width would be in addition.

2.4 Road transfer from port to ISF

This transfer is assumed to be over distances less than 10 kilometres, and undertaken by road using equipment similar to that shown in Figure 2.2 and Figure 2.9 on specific purpose non-public roads as specified in section 2.3.2. A distance of 5 kilometres has been used for this assessment.

Costs for relocation of HLW / SF in casks weighing in the vicinity of 100 tonne are estimated at AUD11,500 per cask, with assumptions as detailed in the separate opex cost model. Cost per TEU of ILW is estimated at AUD3,000,.

2.5 ILW packaging and transport containers

There is a range of packaging arrangements for storage and transport of lower level radioactive waste. The range of primary packages includes drums, commonly 200 - 1500 litre with 500 litre being common, which may be packed in stillages of four drums. There are steel, iron and concrete boxes of various sizes, typically of the order of a few cubic metres.

While some of the lower activity ILW could be transported and disposed in 10’ and 20’ ISO shipping containers, the higher activity ILW will be transported in shielded transport containers. The various drums and boxes are packed inside these containers, which are reusable.

For the higher activity ILW, the UK concept is to use a set of standard reusable transport containers with different levels of shielding. They are all about the same size (about 2 x 2.5 x 2.5 m) and weigh between 16 and 53 tonnes empty, depending on the level of shielding. They are all limited to holding 12 tonnes of ILW, giving them maximum shipping weights of between 28 and 65 tonnes. Figure 2.10 shows some examples of typical ILW containers and Table 2.4 provides typical dimensions and weights.

Figure 2.10 : Examples of LLW and ILW packaging containers

Source: NDA (2013) Geological disposal: Operational aspects of waste transport figure 3 p 8

Table 2.4 : Dimensions and weights of typical ILW packaging containers

Waste container	External dimensions (m)	Handling features (m)	Maximum weight[1] (kg)
500 litre drum variants	0.8 diameter 1.2 high	Drum flange, 0.8 diameter, 0.02 wide	2,000
$3m^3$ box variants	1.72 × 1.72 plan, 1.245 high	4 mid-side twistlock apertures, 1.5465 centres Corner twistlock apertures, 1.517 centres	12,000
$3m^3$ drum	1.72 diameter 1.245 high	4 twistlock apertures, 1.5465 centres	8,000
4 metre box	4.013 × 2.438 plan, 2.2 high	4 corner twistlock apertures, 3.809 × 2.259 plan	64,000
2 metre box	1.969 × 2.438 plan, 2.2 high	4 corner twistlock apertures, 1.765 × 2.259 plan	40,000
MBGWS box	1.85 × 1.85 plan, 1.37 high	4 corner twistlock apertures, 1.65 centres	11,000
WAGR box	2.21 × 2.438 plan, 2.2 high	4 corner twistlock apertures, 2.108 × 1.96 plan	50,000

Note: 1. The maximum weights quoted are for transport by rail; other weights may apply for transport by road.

Source: NDA (2013) Geological disposal: Operational aspects of waste transport p 7

Currently, the breakdown of the many ILW activity streams in the model inventory is unknown, so it is difficult to separate volumes by the style and size of shipping container that would be used. The transport system should be defined so that it can handle a range of sizes from 20' ISO containers with gross weights up to 28 or 34 tonnes, down to small, heavily shielded containers, with a gross weight range up to 65 tonnes. These will be well within normal axle load limits for typical two bogie, four axle wagons.

There will be a wide range of waste densities (resins, metals, cemented components etc) and the empty drums and boxes have a wide range of weights, but it is expected that these transport containers would carry between two to 10 m^3 of packaged waste. If 10,000 m^3 per year were received, that would imply between 1,000-5,000 transport container movements a year, which would increase if higher acceptance and disposal rates were implemented.

In the UK most rail lines have 90 tonne gross limit for a four axle wagon, giving a 65 tonne payload limit. However, in the South Australian situation, higher limits would apply assuming the same rail line is used as for the heavy SF casks. In practice, it is likely that train size would be set at the size that the locomotives specified for the HLW / SF cask movements could pull – probably around 50 x 12.2 m flat wagons giving a train of around 650 m. The wagons should ideally have solid (rather than skeletal) floors, ISO twist locks for 10', 20' and 40' containers, and a range of tie down options to give a flexible train able to carry a wide range of containers and packages.

There are many ILW package types, even within a single country, and packaging is evolving, so any customer is likely to have different packages for the same materials accumulated over the years. A range of different types would arrive, although it would be necessary to set waste acceptance criteria (WAC) that would govern what would be accepted, as well as confirmation that consigners of waste had appropriate procedures and quality assurance / quality control (QA / QC) to send the packages in the first instance. An alternative may be use of pre-licensed standardised transport overpacks, or some other form of repacking design standard which much be applied prior to shipping.

The range of package types makes it difficult to give a precise ratio between conditioned waste volume (the ILW figures in assessed inventory quantities) and packaged volume indicating the quantity of space required for storage and disposal. UK data for a range of package types[55] can be interpreted to suggest that a range of 1.5 - 2.0 would be appropriately conservative and this is proposed for use in the current study.

2.6 Interim storage

2.6.1 Immediate port receival laydown area

Port facilities virtually always require interim storage facilities for cargoes awaiting loading onto ships and received from vessels, in order to minimise ship holding times in port. In the case of likely nuclear fuel and waste carriers, which can carry 20-24 casks, the minimum storage at the port would be the maximum 24 casks from a ship, plus an allowance for carry over from the previous vessel that may not have been removed from the interim port storage area when the next ship unloads.

Modelling of potential volumes of SF which could be received and disposed into a GDF in Australia estimated receivals of 3,000 tonne of SF per year. With typical capacity per cask of 10 tonne, this translates as 300 casks per year, requiring 12-15 sailings per annum, meaning one ship call each 24-30 days on average.

In order to assess the minimum immediate storage area required, the following assumptions are suggested:

- most SF would be delivered in via vessels which were functionally similar to PNTL's Pacific Grebe (described in Section 2.2.1, above)
- average delivery 20 casks
- ship unloading time per cask 1 hour
- time in port 24 hours
- time to remove each cask from wharf to adjacent ISF is 4 hours – two casks per 9 hour shift per day
- time to clear 20 casks = 10 days, and
- thus, the minimum immediate port storage capacity for casks unloaded from ships is suggested as 28 casks (25 from shipment + 10% carry over allowance (2.5 rounded to 3)).

2.6.2 Interim storage facility (ISF)

As noted above (Paper 1, Section 3) an integrated nuclear fuel receival, storage, treatment and disposal solution, will involve an ISF to form a key link in the waste management supply chain between port receival and the long term geological disposal facility (GDF). As the siting and complexity and scale of construction for an ISF is lesser than for a geological facility, they will typically be developed faster and may accumulate spent nuclear fuel over a period of time until the GDF is ready and the fuel is sufficiently cooled to be deposited underground.

When not located immediately adjacent to the NPPs which first gave rise to the spent nuclear fuel, the most logical locations for an ISF to be located are

- immediately adjacent to a port (but separate and in addition to the immediate receivals storage capacity discussed above)
- at or adjacent to the GDF
- at some convenient location between the two.

An ISF either at or near a receiving port has the advantages that the initial transport move will be short, and facilities can be established as part of the port / ISF development. Movements between port and a nearby ISF are typically undertaken by road, similar to the approach shown in Figure 2.2 on page 157. Employment costs

[55] UK Nuclear Decommissioning Authority, Radioactive Waste Management. Geological Disposal – the 2013 Derived Inventory. NDA Report no. NDA / RWM / 120, July 2015. www.nda.gov.uk / publication / 2013-derived-inventory / ?download Accessed 5 October 2015

increase as working locations become more distant from population centres, and so a port location is likely to be relatively near to population centres and hence less costly to operate.

Establishment of ISFs as part of an integrated SF and radioactive waste facility including GDF has the advantage of keeping all storage related facilities together, albeit this is likely to be at a distant inland location with suitable geology for deep disposal, and hence more costly facility to staff.

Establishment of an ISF at an intermediate location is likely to be more expensive due to the need for two land transport legs with intermediate handling costs, requiring lifting and materials handling equipment in three locations rather than two (port and GDF). However, if suitable land is not available adjacent to the port, there may be no alternative to ISF at an intermediate location.

2.7 ISF capacity and size

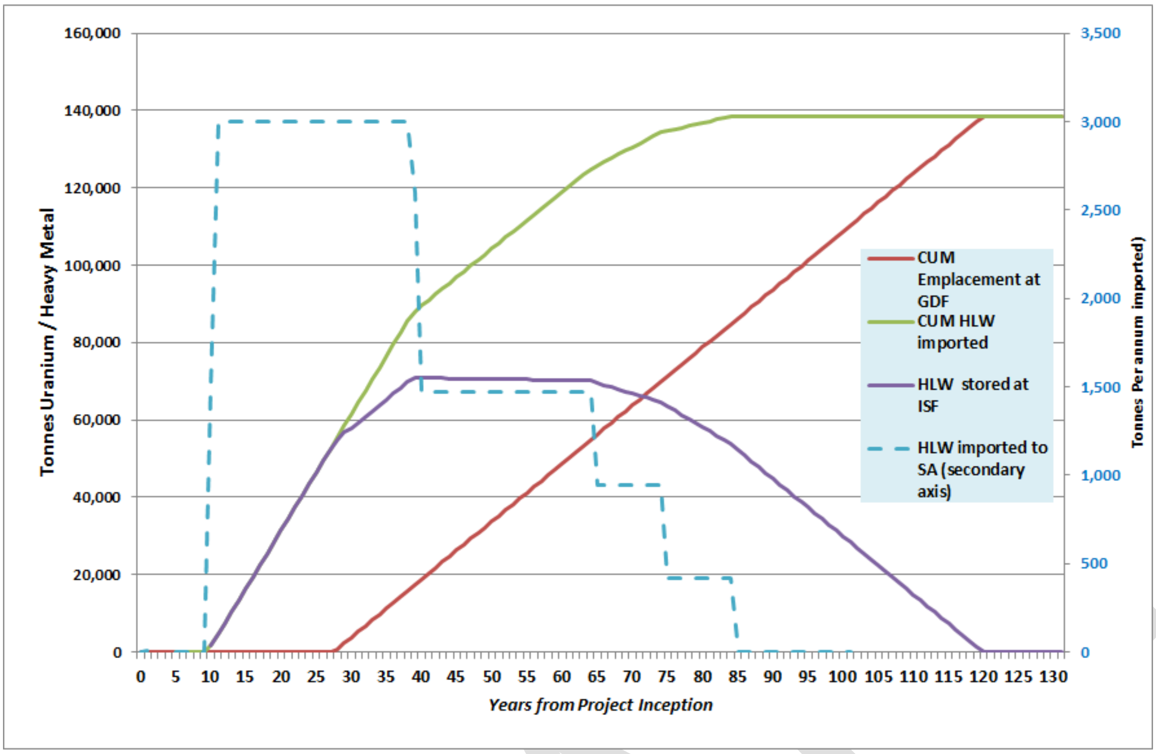
The required storage capacity for ILW and HLW / SF at the ISF is a function of the rates at which both HLW / SF and ILW are received into and despatched from the ISF, and the time delay between the commencement of ISF operations and establishment of a GDF for either waste type. The key assumptions about each form of waste are discussed below.

2.7.1 Interim storage HLW / SF capacity

Demand and capacity modelling undertaken for this project – see Paper 2 –, gives a maximum storage requirement for the ISF of 71,000 tonnes in year 67. On the assumption that HOLTEC HISTORM casks with a capacity of 10 tonnes are applied, this would indicate a total of 7,144 casks at the maximal extent of growth.

The pattern of receipts and outgoings of spent fuel / high level waste in cask form from the ISF is summarised below in Figure 2.11.

Figure 2.11 : ISF storage quantities – SF / HLW level waste, annual arisings and cumulative movements



2.7.2 Interim storage capacity for ILW

As for the SF, the foreseeable required capacity for interim ILW storage at the ISF is a function of several factors, in particular the rate of waste arising (arriving), the time delay between the ISF becoming operation and a final disposal facility being operational, and the rate at which ILW can be transported and received at the final disposal facility.

The proposed project timeline has the ILW underground disposal facility operational at year 24, 12 years after the ISFS commences operations, so storage capacity would need to accommodate whatever was accepted over the 12 years before GDF disposal commenced. Unlike for HLW / SF, there is no 'waiting period' needed before disposal of lower level wastes and in principle, the ILW GDF could receive waste at a higher rate – limited only by optimised underground excavation rates rather than the necessity to reach a latent heat output or similar. It might be reasonable to assume an emplacement rate of around 10,000 m^{3}/year (approx 30 m^{3}/day), but with parallel operations in multiple caverns, this could be increased.

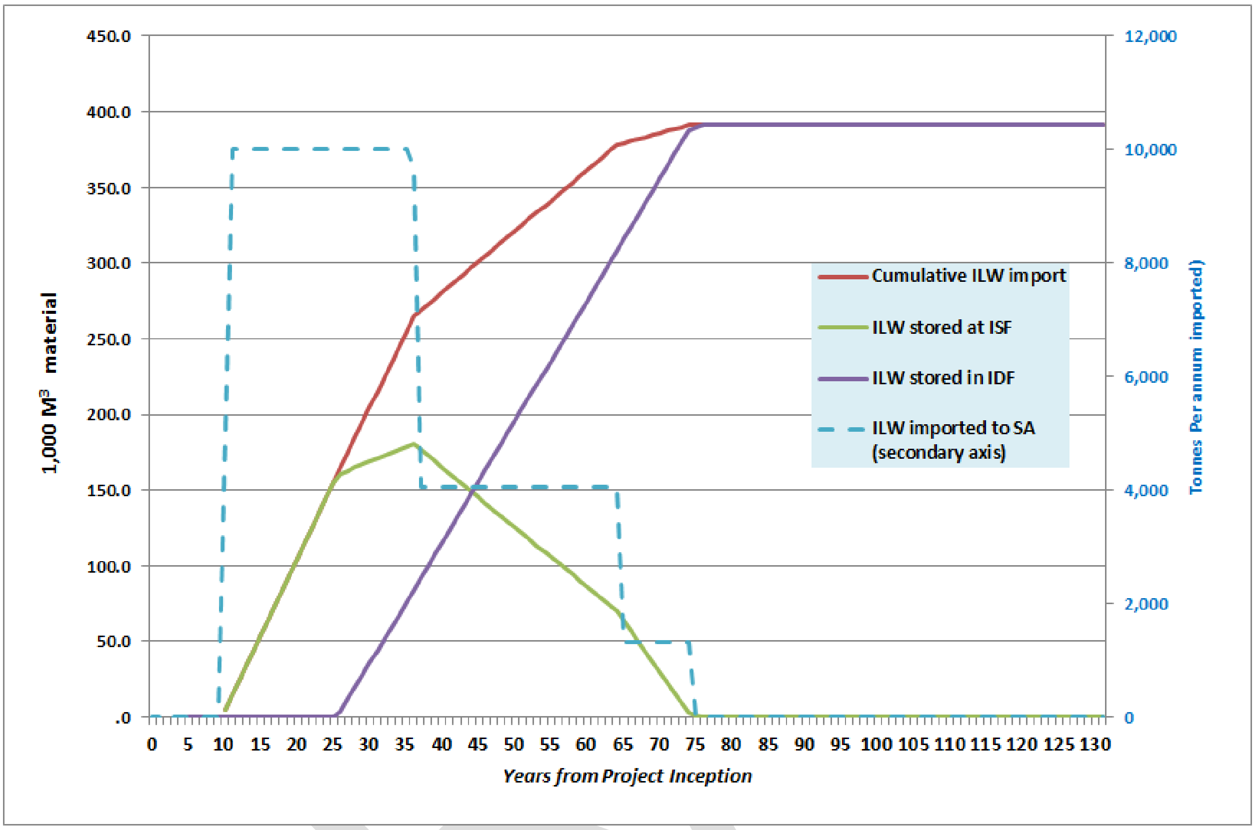
If 390,000 m^3 was received over the 62 year receival time frame (between year 11 and year 73), this averages 6,222 m^3 per annum, or 285 ISO shipping containers, based on typical volume of 32-34 m^3 per container and 65% volume utilisation by ILW, based on a ratio of waste volume : gross storage volume of 1:1.5.

However rather than this estimation of average annual ILW importation over the operating period a stepwise function is more likely, with an initial backlog of material being shipped and then a gradual decline over time. It is likely that there would *not* be great urgency from most customers to ship their entire ILW backlog at the start of the project, as most would have adequate storage already. Those who might want to ship early would be driven by avoiding the need to build additional storage capacity for NPPs with extended lifetimes, or by the need to decommission a NPP and its stores. A maximum of 10,000 m^3 ILW per annum is modelled for 28 years, (equating to 454 ISO TEU shipping containers or 7 per week at the same packing ratio as above) and then stepping down to 4,047 m^3 per annum for 24 years and then 1,320 m^3 per annum for 10 years (183 and 60 containers, respectively). The overall movement of ILW is summarised in Figure 2.12, below.

Jacobs estimates that the maximum ILW storage capacity at the ISF could be about 175,000 m^3 (unpackaged waste volume), based on receiving 50% the conditioned waste backlog and arisings from the customer countries – the same share of the total accessible market as for spent nuclear fuel (see Paper 2, Section 2.3.5). This will be multiplied by the same packing factor of 1.5 to 2.0 to give the total packaged volume (262,000 to 350,000 m^3).

Given substantial uncertainty about demand for lower-level waste disposal, it is suggested that construction of the Interim store should be staged, providing capacity slightly in advance of actual shipping rates.

Figure 2.12 : ISF storage quantities for ILW (annual arisings and cumulative movements – unpacked)



2.7.3 Interim storage ILW design elements

Experience suggests that package types make little difference to the ISFS storage requirements. The same type of structure would hold any / all of these containers. This would be a warehouse type structure, with different levels of structural shielding (concrete walls, essentially) to house packages with different levels of shielding (e.g. some concrete / steel packages are already well-shielded; others require shielded handling when moving them about and in storage). Fork-lift and or overhead gantry crane handling would be used.

The larger or more heavily shielded boxes would be transported and stored as they are. Most containers could be sent for direct disposal to the GDF; others would need additional conditioning, such as grouting of voids in boxes and stillages.

2.8 Spent fuel encapsulation plant

The encapsulation plant, co-located with the GDF facility, is a critical link in the overall supply chain of radioactive waste management services. At this stage of the waste management chain, spent fuel is transferred from a multi-purpose cask (MPC) located inside a transport cask which has hosted it on its journey from the ISF into final disposal canister (composed of either copper or steel for HIC or BRC, respectively) prior to emplacement into the GDF. The process is designed to stabilise the material and reduce potential for leakage of material and radiation after emplacement in disposal vaults or tunnels.

The disposal canisters each hold some 2 tonnes of spent fuel, and so for each transport cask of material, approximately 5 canisters will be required for final disposal. Each canister is handled into position to receive the spent fuel via a series of cranes and trolleys in an airtight environment and after receiving its contents, is welded closed via a suitable process (either electron-beam welding[56] or friction-stir welding[57]) before being assessed via a series of non-destructive tests (ultrasound, xray and other non-invasive, competent methods). The key operational expenses associated with the encapsulation plant are the final disposal canisters themselves (estimated to be AUD320,000 per two-tonne (copper) canister) and associated labour costs.

The Finnish encapsulation plant under development at Olikuluoto (Posiva, 2005) which is planned to manage the emplacement of up to 41 canisters per annum (80 tHM)[58] also provided a detailed set of assumptions and specifications which has informed the high level cost estimate for the Australian model.

The Australian GDF is modelled to emplace 1,300 tonne of processed HLW / SF per year, or around three times the volume of the Swedish encapsulation plant and 15 times the average annual volume of the Finnish plant (or 6.5 times the maximum *design throughput* of the Finnish plant)[59]. These ratios have provided the basis of the personnel number estimates in the opex cost model, recognising that some functions are proportional to volumes handled, and others, particularly management and administrative support functions, are relatively fixed above a the threshold capability described in the European examples.

2.9 GDF SF emplacement arrangements

Following treatment and conditioning of HLW / SF at the encapsulation plant, waste would be enclosed in indefinite term storage / disposal canisters and placed in deep geological emplacement tunnels in either a horizontal or vertical orientation.

There are two methods commonly set out for (horizontal) emplacement[60]:

- using an emplacement base, which is removed from under the disposal canister after emplacement, with the canister resting on bentonite blocks
- mounting disposal casks on either steel or compacted bentonite “plinths”, which are placed in the disposal tunnels by retractable trolleys

For the purposes of this report, the assumption is made that the casks are rested on an emplacement base, as in the first of three options described above. The advantages of this approach are the removal of a potential additional source of corrosion (leading to decay of the canisters themselves) as well as the logistical complexity and higher per-unit cost of this approach. The cost of these supports is included within the per-canister emplacement cost as described in Table 2.8, below.

2.10 Assumptions for facilities required for a South Australian nuclear fuel receipt, storage, transport and disposal industry

The baseline set of facilities consists of:

- port, able to:
  - berth typical nuclear waste carrier vessels
  - lift ILW and SF casks weighing up to 140 tonne using shore based equipment between ships, land based transport and the storage areas
  - lift ISO shipping containers between ships, land transport and storage areas

[56] Electron-beam welding is the preferred method for the Finnish encapsulation plant at Olkiluoto (Posiva, 2005)
[57] Friction-stir welding is the preferred means for the Swedish encapsulation plant at Forsmark (SKB, R-07-36, 2007
[58] The encapsulation plant was intended to manage a peak of 41 canisters per annum however its maximum design capacity was noted as 100 canisters per annum (POSIVA 2012).
[59] Ibid.
[60] See Kawamura et al, 2008 (Prague) for a discussion of the approaches http: / / www.iaea.org / inis / collection / NCLCollectionStore / _Public / 41 / 025 / 41025024.pdf

  - accommodate and move heavy indivisible loads of up to 140 tonne on specialist heavy lift transport platforms with gross mass up to 215 tonne on wharf and roadway structures
  - provide short term storage of up to 28 storage casks of up to 7 m in length, 3 m in diameter and up to 140 tonne
  - provide short term receival storage for 50 ISO and non ISO containers of LLW and ILW ISO after receipt from the same specialist nuclear waste carrier vessels.
- heavy haul roadway enabling road movement of casks up to 140 tonne on specialist OSOM trailers to nearby ISF. Distance expected to be a few kilometres at the most.
- interim storage facility (ISF), including capacity for storage of HLW / SF and ILW, as close as practical to the port, ideally immediately adjacent, providing:
  - storage for up to 7,000 SF storage casks (each holding 10 tU) and
  - ultimately, storage for up to 300,000 m^3 ILW wastes in a variety of ISO and non ISO containers. This would be constructed in stages, according to demand. It is suggested that 33% of this could be constructed up front and the remainder constructed on demand.
    - the ultimate requirement would be for the equivalent of around 14,000 x 20' standard ISO shipping containers, assuming an average waste capacity of 21.45 m^3, 65% of the standard 32-34 m^3 capacity of standard 20' containers.
    - if it is assume these could be stored four high (the maximum storage height in shipping operations is 10 high, limited by wall strength to support the mass of containers above) and 1 metre space between containers, this would require an area of 93,000 m^2. (20' containers are 6.06 m long, 2.35 m wide thus 6.16 x 2.35 m = 14.77 m^2 footprint each = 51,710 m^2 for one layer of 3,500 containers.
    - if we assume that these would be stored in warehouse buildings with two bays each 35 m wide with gantry cranes, this would require buildings totalling 70 m x 328 m – say four buildings each 350 m long allowing for receipt and despatch space and some general working areas.
    - initially, one half of the first building, 70 m x 175 m could be constructed.
  - facility for conditioning / overpacking SF and HLW ready for emplacement in the GDF.
  - transport facilities for receipt of ILW and SF casks from road, rail or other transport method and lifting casks into interim storage location
  - lifting facilities for removing casks from interim storage locations and placing them on rail cars for transport to the GDF.
- heavy haul railway from the ISF to the GDF facility assumed to be 200 km or more distance from the ISF
  - single track, standard gauge, 30 tonne axle load limit
  - train stabling and wagon maintenance at port / ISF
  - potentially train stabling at GDF, if a return trip between ISF and GDF is not possible in one day
  - no requirement for passing loops or run around tracks, as a single trainset and push pull operation (loco at both ends) is anticipated
  - fencing and security controlled for at least those parts of the corridor likely to be relatively easily accessed, and potentially the whole corridor
  - lifting equipment able to handle casks up to 140 tonne, smaller and lighter casks, ISO shipping containers and a variety of smaller containers
- co-located GDF for HLW / SF and intermediate depth repository (IDR) for ILW in geologically suitable, location, including:
- SF encapsulation plant at the GDF – capable of processing contents of 1,500t HM from 150 x 10tU transport casks per annum or 750 final disposal canisters each of 2 tU on average.

- low level waste repository (LLWR) a surface or near surface store for low level waste (LLW) arriving predominantly in ISO shipping containers, but able to accommodate a range of container styles, shapes and sizes, either located near to the ISF or to the GDF

2.11 Operational costs

The operating costs for the set of facilities defined as the receival, storage, treatment and disposal program under consideration for SA involve labour, contracted services, facility maintenance, equipment lease costs, industrial consumables and utilities. These cost factors have been derived from reported international experience in radioactive waste management and costs proposed in well - developed national programmes, as well as analogous industrial applications in the mining and resource sector, for example.

2.11.1 Lifecycle operational cost phases

These high level operating costs are based on typical annual costs for three lifecycle phases per facility, namely the ramp up establishment phase ('start'), full operations, ('full') and the closedown end of operations ('cease'). Following the 'closure' phase, there is an ongoing period of site surveillance for each facility (for a nominal period of 1,000 years). The timing and duration of each facility phase differs (apart from the duration of the surveillance), owing to the various lead-up and construction programmes for each facility, the expected rates of incoming and outgoing material through each facility, and closure times. The timing of the operational cost phases for each key facility are modelled as shown in the following table:

Table 2.5 : Operational timelines, by facility (years since decision)

Facility Name / Element	Timing of costs (years)				
	Start	Full	MS1 (50%) Cease	MS2 (25%) Cease	MS3 (75%) Cease
Head office	4	6	120	120	156
Port	9	10	84	84	84
Transport from port to ISF (W3)^^	10	11	84	84	84
ISF (W3) and handling (phase 1)	7	8	40	28	78
ISF (W3) and handling (phase 2)	41	41	120	120	156
Rail from ISF to GDF	21	25	120	120	120
IDR for ILW (W2) standalone	23	24	76	76	76
IDR for ILW (W2) within GDF	23	24	76	76	76
LLW (W1) near surface repository	10	11	120	120	120
Encapsulation plant (W4)	26	27	120	120	156
GDF for HLW (W4)	26	27	120	120	156

Source: Jacobs estimates

The operating years presented in Table 2.5 (above) refer to the years since the formal decision to proceed with development of the radioactive waste management sector according to the scenario assumptions described above. They reflect the timeline assumptions (See Paper 5, Section 3.2 pp. 200-202) for each facility, noting the first to become fully operational are the low level waste facility (LLW, W1) and the interim storage facility (ISF, W3) which commence full operations in years 10 and 10, respectively.

The date for the close of operations will differ based on the expectations about market share for spent fuel (and ILW) that the South Australian offer will attract from international customers. The MS1 (market scenario 1) is the 'baseline' or 50% market share which corresponds to closure of operations in year 120. market scenario 2 (25%) and market scenario 3 (75%) move most timelines to the left or right, respectively.

2.11.2 Labour costs

The direct-hire personnel requirement for the project is predicated on a model whereby each facility is part of a single entity, with shared head office and administrative functions at a central hub in Adelaide. Each facility has its own operational requirements and throughput rates, and therefore a unique blend of personnel roles and numbers.

The costs of labour for each facility have been estimated on a per annum basis, using the bottom-up approach, drawing from examples and experience with similar industrial facilities (including resource developments) in similar areas of Australia.

Three key forms of labour are proposed, management, technical / supervisory and operative, each covering a number of roles at various places in the management chain. It is presumed that those locations which are more distant from population centres (such as the ILW repository and the GDF repository) will command a wage premium, in line with experience in inland mining camps in SA and elsewhere.

Estimated direct salary cost benchmarks are presented in Table 2.6 below, showing a range of salary for base level through to senior management, across each of the nine key functional areas, head office to GDF repository. These costs are analogous to benchmarks presented in AusIMM (2012) for onsite resource-sector roles.

Table 2.6 : Direct salary benchmarks (baseline –on-costs and contingency risk factor) in AUD2105

Employee salary scale	Base level	Skilled	Technical, Supervisory	Management	Snr Man	CEO
Head Office	$ 75,000	$ 85,000	$ 125,000	$ 150,000	$ 300,000	$ 500,000
Port	$ 85,000	$ 100,000	$ 125,000	$ 150,000		
W1 LLW Repository	$ 85,000	$ 100,000	$ 125,000	$ 150,000	$ 175,000	
W3 ISFS and transport	$ 85,000	$ 100,000	$ 125,000	$ 150,000		
Rail - ISFS based	$ 85,000	$ 100,000	$ 125,000	$ 150,000		
Rail - GDF based	$ 100,000	$ 125,000	$ 150,000			
W2 LILWS Repostory	$ 100,000	$ 125,000	$ 150,000	$ 150,000	$ 200,000	
W4 Encapsulation plant	$ 120,000	$ 150,000	$ 150,000	$ 150,000	$ 225,000	
W4 GDF Repository	$ 120,000	$ 150,000	$ 150,000	$ 150,000	$ 250,000	

Source: Jacobs estimates

In addition to the above raw staff costs, on-costs of 33% are applied, to account for typical indirect staff costs such as leave entitlements and other overhead costs.

Some of the key sources of uncertainty in predicting wages and salaries for the radioactive waste workforce are the expectation that many of the nuclear-related technical roles are virtually absent in the Australian workforce, given the small size of the nuclear sciences sector in general. At the establishment phase, it is anticipated that a significant premium may be required to entice qualified personnel to migrate to South Australia, particularly to the more inland locations, to support the development of the sector, and wages may only reach a new equilibrium some 5-15 years after the establishment of the industry, as a locally sourced workforce becomes available.

The number of staff required to manage each individual facility on an ongoing basis, at their mature state, and the years at which the labour needs will ramp up and then decline, are as presented in Table 2.7. Here the '% Labour' colum shows the labour cost as a percentage of the total facility cost. At the maximal state, direct employment of almost 600 staff is anticipated, excluding operations-phase contractors (such as security guards and specialist transport service providers). These numbers also exclude direct employment associated with ongoing capital expansion of the facilities (such as expansion of the storage "footprint" at the ISF and excavation of the storage galleries / vaults within the HLW / SF GDF and ILW storage facilities).

Table 2.7 : Direct labour force totals – radioactive waste management value chain

Facility Name / Element	Annual costs, AUD		Headcount			
	Labour ($M p.a)	% Labour	Management	Technical / supervisory	Operative	Total
Head office	$26.2	69%	15	1	102	***118***
Port	$3.8	48%	1	3	9	***13***
Transport from port to ISF (W3)^^	*see (4)*	0%	0	2	0	***2***
ISF (W3) and handling (phase 1)	$10.5	7%	4	16	37	***57***
ISF (W3) and handling (phase 2)	$10.5	25%	4	16	37	***57***
Rail from W3 to GDF W4	$2.3	11%	1	5	5	***11***
IDR for ILW (W2) standalone	$24.5	23%	10	25	85	***120***
ILW repository (W2) within GDF	$15.4	20%	*5*	*13*	*60*	***78***
LLW (W1) near surface repository	$4.2	32%	2	4	15	***21***
Encapsulation plant (W4)	$33.5	9%	12	28	110	***150***
GDF for HLW (W4)	$29.2	14%	12	39	75	***126***
Total (withstandalone IDR)	**$134.1**	**$2.1**	**57**	**123**	**438**	**618**
Total (IDR combined with GDF)	**$125.1**	**14%**	**52**	**111**	**413**	**576**

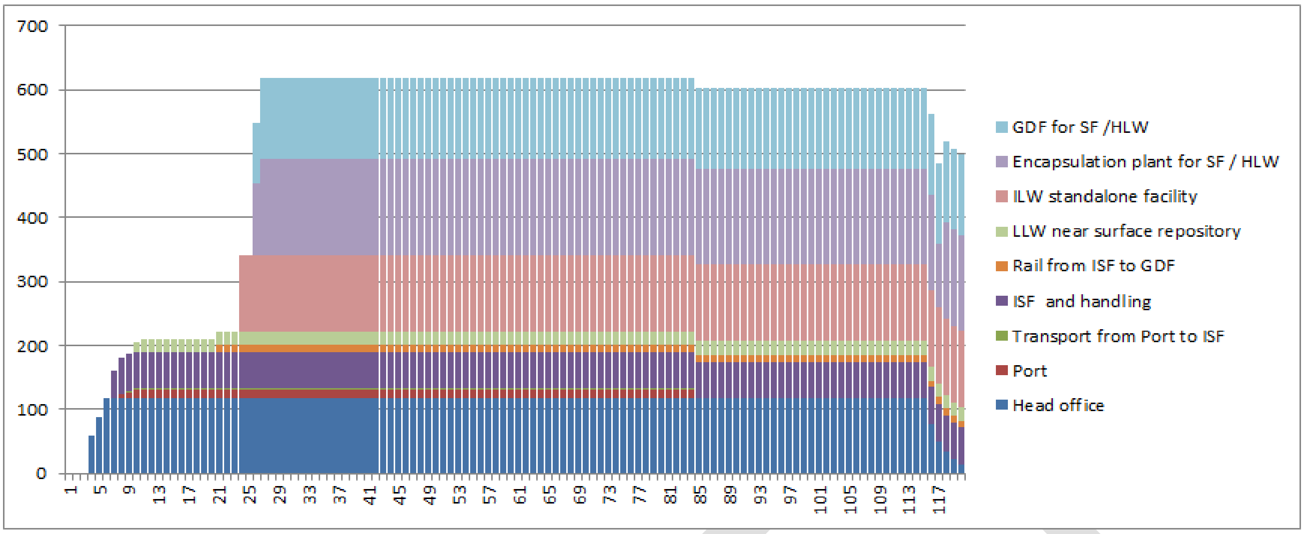
Table 2.7 presents both the number of staff who would be involved in the operation of the facilities as *independent* operations, and if the underground ILW Repository and the HLW / SF GDF repository were developed in tandem and collocated – showing some 42 staff *less* not be required, due to reductions in management and planning staff and some surface building maintenance activities which could conceivably be combined across the two facilities. Overall cost savings of $9M per annum would also be available ($125.1M compared with $134.1M).

The overall project labour costs (direct and indirect) reach an average of $210,000 in direct salary (including on costs) per FTE. This amount reflects the prevailing standard of care and training required to operate at each facility, as well as an additional loading associated with working some significant distance from population centres areas for the geological disposal facility, intermediate waste facility and encapsulation plant.

Total employment would be a significant multiple of this amount, given the employment involved in construction (excluded) as well as indirect and induced employment associated with the flow on consumption and investment effects which would accrue.[61] A summary figure of direct operating employment is presented below.

[61] The macro economic impacts of this project, including statewide and national employment impacts, are discussed in a separate report.

Figure 2.13 : Direct operating employment (ex contractors) through main operating period to year 120.



A breakdown of the roles proposed for each facility type is presented at Appendix B, below.

2.11.3 Inland area staffing (loading)

As noted above and in accompanying papers, a key operating assumption in the business case model is that the long-lived intermediate waste repository (ILW) and the GDF / encapsulation plant are located in the interior, while the interim store and low level waste repository are situated at a coastal location, possibly near the receival port. The relative remoteness of the interior facilities may necessitate a predominantly fly-in-fly-out (FIFO) workforce and given a region for situation of these facilities has not been determined, a 'worst case' operating (and establishment) cost scenario of FIFO has been presumed.

To accommodate the FIFO workforce for both the construction / development and operational phases, a locality factor has been applied for the construction workforce (to take account of an isolated inland construction camp as well as additional costs to deliver construction materials and utilities) and a series of FIFO loadings has been applied to the workforce at these locations.

The FIFO loadings include a per person / day loading of $100, and 13 return flights to Adelaide per FIFO worker per annum. These allowances are commensurate with costs incurred in small-medium resource development sites in SA and interstate in Australia.

Other costs associated with a FIFO workforce include the capital expense of establishing air links (via an airfield with a 30m x 2000m runway capable of accommodating F100 aircraft or similar as used by resource companies), a working camp for the operations phase of work and the associated maintenance of the facility on a per annum basis.

2.12 Underground operations

The cost of underground options not otherwise captured on a per unit basis is derived from the Olkiluoto model which presents a list of materials and activities which are involved in the emplacement of spent fuel underground. The underground operations include tunnel backfilling, bentonite blocks, dismantling of temporary shotcreting to walls, emplacement of concrete plugs at tunnel front, tunnel maintenance and repair and (additional) provision for underground geochemistry, and other investigations as follows:

Table 2.8 : Additional underground operations costs

Activity / cost item	GDF ($AUD2015 per tonne / ½ 2 tonne canister)	ILW ($AUD2015 per m^3)
Underground operations	60,000	8,000

The other underground operational costs which are addressed elsewhere include labour, utilities, site monitoring, equipment and the like, these costs are additional.

2.13 Utilities (power, water)

2.13.1 Annual power consumption

The consumption of power at the various sites has been derived from detailed plans of similar facilities overseas and industrial benchmarks within Australia.

The power consumption is highest at the encapsulation plant, where the load is derived from detailed modelling undertaken for the Finnish GDF and encapsulation facility at Olkiluoto which is in the advanced stages of development. The Olkiluoto facility was designed for a maximum production rate of 100 canisters per annum (or 82 tU) but was typically expected to operate at a maximum of 41 canisters. The 41 canisters / pa figure is taken as the basis of our power consumption benchmark.

The cost of power presumes a direct high voltage connection to the grid[62], with power costs (wholesale + network and connection charges) at an average of AUD130 / MWh and an average of 52,184 MWh / annum above ground (GDF facilities including encapsulation and 19,134 MWh / annum below ground in the repository space.

Power consumption for the underground LILW repository is 4,374 MWh / annum above ground (if separate from the GDF) and 500 MWh / annum for underground activities (lighting, active ventilation and pumps).

Power consumption for the other two facilities, the low level waste store and the interim store are far lower than for the deep repository facilities, owing to the lack of need for active ventilation, lighting and other safety systems which are essential underground. Heavy duty craneage is the key source of power demand. Gantry bridge cranes, rated at 10kw and operating for 8 hours a day, 365 days of the year, one at the LLWR and two at the ISF will consume a total of 80 MWh / annum alone. Total power consumption at the two facilities is estimated to be 1,000 MWh, 400MWh at the LLW and 600 MWh per annum at the ISFS facility.

2.13.2 Water consumption

The consumption of water at the facilities is a combination of industrial demands at the underground sites, and other personal consumption of potable water at the isolated inland sites. Potable consumption per person is anticipated to consume 120 litres per person / day at the working accommodation camps and with total complement of staff at the inland remote sites of some 350 people (presuming ILW repository and GDF / encapsulation are collocated), consumption just for their needs before industrial requirements of some 15.3 ML per annum.

Consumption at the GDF, encapsulation plant and ILW is derived from detailed modelling undertaken for the Finnish POSIVA facility at Olkiluoto. Factoring water consumption by the scale of the proposed South Australian repository facilities (which are 18.3 times larger in terms of average SF throughput and hence variable costs) the industrial consumption above ground (at the GDF surface facilities and encapsulation plant) is estimated to be 72ML per annum and 170ML for the underground facilities (including water involved in vault excavation). With the delivered cost of water modelled at $5.00 per KL (or AUD5,000 per ML) an annual cost of AUD1.2

[62] The development cost of a high voltage grid connection over a nominal distance of 200km has been included in the capital cost estimate for the combined GDF/IDR scenario, and for each of the GDF and IDR separately for the scenarios where they are independent.

million for these industrial purposes would be incurred when at full production across the GDF and encapsulation plant.

The consumption of water arising from the underground ILW facility is estimated to be 50% of the underground amount of the GDF (presuming collocated surface facilities), or 84 ML for an annual cost of AUD0.42 million.

Water consumption at both the LLW and the ISF is presumed to be far lower, with no dedicated workforce and working accommodation and no water requirement arising from ongoing excavation. The estimated consumption for those facilities is presumed to be 5 ML per location per annum.

There is little surface water in most likely remote locations in remote South Australia. Most remote mine sites rely on underground sourced water from artesian basin reserves. This water is frequently high in dissolved minerals including salt and frequently requires treatment for industrial as well as human consumption. Environmental approval for extraction can be challenging to obtain. Costs for coastal desalination and long distance pumping can be substantial.

2.14 Licensing fees

Under the terms of the ARPANS Act, all nuclear installations, including radioactive waste facilities, are subject to a strict licensing regime which involves paper based audit and visual inspections of facilities to ensure compliance in various forms. In addition to these administrative duties, license fees are payable on an annual basis. The current ARPANS Act specifies the annual payment for a nuclear reactor to be AUD945,000 per annum, and a rough multiple of two times this amount has been proposed in theory for each facility to give a benchmark cash cost of AUD2 million per annum per premises for the commercial model.

2.15 Leases

2.15.1 Equipment leases

The business model has presumed that generic industry equipment such as forklifts and commercial vehicles will be leased on an annual basis, rather than purchased as capital items and depreciated. Rates are as presented in the following table:

Table 2.9 : Equipment leases (per annum)

	Lease cost per unit per annum (ex GST)^, AUD
Site vehicles (utility vehicles, 4WDs, small mini buses)	18,000
Heavy duty forklifts	50,000
Xray inspection machine	440,000
Cask inverter cranes (to suit 10 metric tonnes)	200,000
Hi-rail vehicles	25,000
Electron beam weld machine (encapsulation)	920,000
Milling machine	230,000

^note these costs are prior to the application of a 25% contingency risk factor.

2.15.2 Property leases

The only site which is expected to be leased (rather than purchased freehold) is the corporate headquarters / administration site, likely in Adelaide CBD. The size of this lease is modelled on a rate of 15m^2 per person, across some 120 people in various commercial, legal, marketing, engineering and compliance roles. A flat rental rate of AUD550 / m^2 has been modelled, intended to address both recurrent rental costs and fitout installation and renewal throughout the 120 year life of the project. In addition, facility outgoings of 20% to cover utilities, site security, car parking and other typical items has been incorporated.

2.16 Consumable materials

There are various materials which are consumed on a continual basis associated with the packaging, encapsulation, emplacement and disposal of the various forms of waste. Materials include concrete (in shielding LLW boxes) and copper or steel canisters for emplacement, as well as bentonite clay which is typically interred underground with HLW.

The costs of these materials is quite variable, and has been estimated on a per annum, operating basis as a function of the volume (for LLW and ILW) or mass (for SF) of waste materials which are handled. Some benchmark costs applied are as follows:

Table 2.10 : Selected consumable materials included in operational cost estimate

Consumable / material	Basis of cost	Estimate (AUD2015)^
Concrete for LLW containment / disposal	Quantities for LLW containment from El Cabril (ENRESA, 2013)	150 / m^3
Copper canisters for SF emplacement (BRC)	Derived from POSIVA 2004	320,000 per unit
Bentonite blocks for SF emplacement	Derived from POSIVA 2004	Included in above
Concrete overpacks for SF MPC containment / storage	EPRI (2009)	250,000 per unit

^note these costs are prior to the application of 25% contingency risk factor.

2.17 Contract labour

As described earlier in this paper, a number of roles at various facilities are modelled as contract labour, rather than as full time or part time employees on payroll. The reason for this is the expectation that for some activities, a superior service will be provided through this labour model, either due to a degree of specialisation required, perceived risks of training and retaining sufficient staff internally, or long term cost saving measures.

General contract labour has been estimated at an average rate of AUD400 / person / day and has been derived from observed labour rates at similar industrial facilities across Australia, including South Australia.

The typical contract labour activities are provision of security services and specialist equipment maintenance. Contract labour numbers are not included in the labour figures above.

2.18 Operating costs - facility maintenance

The timeframe which is presented for this facility extends beyond 120 years, and hence expenditure of various kinds must be included in order to keep the facility up to date and in good working order over its design life.

Facility renewals expenditure, such as replacement or extensive refurbishment of building systems at the midpoint or end of their life, midlife structural or façade upgrades and the like are modelled as part of the capital cost estimate. These renewals, which are explicitly listed in the capital cost estimate, comprise a renewal expenditure roughly every 25 years after their initial completion.

Facility maintenance expenditure is an operational cost which enables the facility to reach its intended renewals cycle without heightened risk to the achievement of its service objectives. Two fixed annual allowances are applied to the cost of installed capital – 2.5% of capital value for aboveground buildings and 1.5% of capital value for below ground structures. This is in line with estimates prepared in the advanced planning stages of other similar facilities internationally.

Maintenance cost factors is applied to the value of capital construction, excluding capital equipment and other capital expenditure which is not the ongoing responsibility of the waste management proponent, such as power and water related enabling infrastructure. Assets such as disposal cells at the low level waste repository, are also not maintained, as once they are filled and covered, their service life is effectively over.

Dedicated ports and railways are subject to this maintenance cost, which retains assets in good working order but does not extend their technical life, nor expands their capacity beyond their original design (such capital renewals, or 'sustaining capital' investments are treated as renewals expenditure and not operational expenses). The results of the maintenance cost modelling at the project's mature state are as follows in Table 2.11.

Table 2.11 : Annual maintenance cost estimates for capital assets (real costs, inc contingency allowances)

	Timing of costs (years)			Annual costs, AUD
Facility Name / Element	Start	Full	MS1 (50%) Cease	**Facility Maint ($M p.a)**
Head office	4	6	120	*NA^*
Port	9	10	84	$1.9
Transport from port to ISF (W3)^^	10	11	84	$0.1
ISF (W3) and handling (phase 1)	8	11	40	$15.4
ISF (W3) and handling (phase 2)	41	41	120	$15.4
Rail from W3 to GDF W4	21	25	120	$13.7
IDR for ILW (W2) standalone	23	24	76	$14.3
ILW repository (W2) within GDF	23	24	76	$1.7
LLW (W1) near surface repository	10	11	120	$1.6
Encapsulation plant (W4)	26	27	120	*inc w GDF^^*
GDF for HLW (W4)	26	27	120	$45.2
Total (withstandalone IDR)				**$92.2**
Total (IDR combined with GDF)				**$79.6**

Facility maintenance costs are a significant part of the overall operating expense profile for the radioactive waste proposal, with some AUD79 to 92 million in annual expenditure across the portfolio, depending on the extent of co-location of two key facilities, namely the ILW repository and the SF GDF repository.

Maintenance of the GDF facility, and the associated encapsulation plant to prepare canisters for disposal, is the highest single feature, and accounts for over some 50% of the total annual maintenance cost.

Table 2.11 also highlights the AUD13 million per annum maintenance saving associated with the co-location of the IDR facility within the GDF – a direct reflection of the lower capital cost / installed value associated with this development option.

2.19 Site monitoring and post closure surveillance

Monitoring of the radioactive waste management facilities and their environs will be required before and during the development of a repository, and also after their closure, for scientific, technical, management, safety, regulatory, legal and public acceptability reasons (SAM, 2007).

It is defined in IAEA (2001)[63] as "a continuous or periodic observations and measurements of engineering, environmental or radiological parameters, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment."

[63] International Atomic Energy Association Technical Document 1208, Monitoring for geological repositories for high level radioactive waste.

Furthermore IAEA (2011) notes that, "A programme of monitoring shall be carried out prior to, and during, the construction and operation of a disposal facility and after its closure, (if this is part of the safety case). This programme shall be designed to collect and update information necessary for the purposes of protection and safety. Information shall be obtained to confirm the conditions necessary for the safety of workers and members of the public and protection of the environment during the period of operation of the facility. Monitoring shall also be carried out to confirm the absence of any conditions that could affect the safety of the facility *after closure*. [64]

The nature and extent of the monitoring tasks evolve throughout the project lifecycle and for an underground facility will typically involve the following stages (see Table 2.12).

Table 2.12 : Repository lifecycle monitoring (adapted from SAM, 2007)

Project Stage	Monitoring requirement / information requirement
Before site selection	Waste characterisation, QA of waste packages, monitoring of conditions in surface stores
Site characterisation from the surface	surface and underground characterisation for safety assessments and preliminary design studies, definition of site models and baseline environmental assurance and liability monitoring
Underground access and exploration (rock characterisation facility phase)	Will include characterisation for repository design and more detailed long-term safety assessment, testing of hydrogeological and geotechnical response to excavation and improved scientific understanding including model validation
Repository design and construction	Detailed examination of rock conditions in the vault locations, testing of vault stability and equipment, assessment of large-scale underground safety issues, ventilation and drainage tests and baseline operational safety monitoring
Waste receipt and emplacement (which will begin in parallel with construction)	Inventory and condition of waste received at the repository, package placement, vault stability, package conditions, vault environment, equipment function and maintenance, operational safety monitoring (for public and workers) and compliance with nuclear safeguards requirements
Monitored underground storage (care & maintenance phase)	Including continuation of monitoring of vault stability, package conditions, vault environment, equipment function and operational safety, nuclear safeguards, plus longer term confirmation of models and observation of vault-host rock interactions.
Backfilling and post vault backfilling	Will include monitoring of backfill quality and placement, geological responses, evolution of backfill conditions and maintenance and safety of the remaining underground openings.
Closure and post-closure	Will include monitoring of seal quality and installation, confirmation of geological stability, monitoring of physiochemical evolution of the repository environment and continuation of environmental and hydrogeological monitoring for reassurance in perpetuity.

Monitoring provides input to safety assessments, continuing assurance of operational safety of the facility and confirmation that actual conditions are consistent with the assumptions made for safety after closure The duration and extent of monitoring for each project phase is generally as finite and defined as the lifecycle phase of the facility itself, with some monitoring phases overlapping in a similar manner at various stages.

Post closure 'surveillance'

In its guidance for radioactive waste management, the IAEA stresses that "for the post-closure period, the geological disposal facility should be of a passively safe design and should not require or rely upon a post-closure monitoring programme to provide assurance of safety. Post-closure monitoring may be performed to

[64] IAEA Safety Standard Requirement - 5 (Safety of Radioactive Waste Disposal Facilities, 2011. STI / PUB / 1449

provide public assurance, if required, by the government or the regulatory body, but should not compromise the passively safe design"[65] – ie should not be understood as an alternative or even a functional complement to a completely safe *passive* design.

'Surveillance' refers to the inspection of a disposal facility in order to verify its integrity to protect and preserve the passive safety features (such as barriers) in the post-closure phase. Surveillance should focus on elements of the performance of barriers that are directly related to key safety functions of the disposal system and as for monitoring during the immediate post-closure phase, surveillance should not be taken as an alternative to a 100% passive design, since any geological disposal facility should not rely on intervention, surveillance or control for the assurance of safety (IAEA, 2011).

Monitoring during the facilities' operational life is included as an operational (labour) cost, as an allowance for environmental scientists of various specialities, and a further allowance for associated laboratory testing and verification undertaken by independent laboratories and record keeping to inform future generations of the performance of the facility over time to inform their own decision making. Allowances are as follows:

Table 2.13 : Allowances for monitoring / surveillance (per annum)

	Operational Phases		Post decommissioning and closure
Facility Type	Operational phase – dedicated monitoring personnel	Additional annual allowance (laboratory testing, etc) (AUD2015)	Annual Surveillance allowance (years) (AUD2015)
Low level waste store	2 dedicated staff	52,000	150,000 (1000)
Intermediate level waste store	3	104,000	250,000 (1000)
Interim storage facility	2	52,000	150,000 (1000)
HLW / SF geological deep facility	3	104,000	250,000 (1000)
Total	**10^**	**312,000**	**800,000 (1000)**

^these dedicated monitoring personnel are separate and additional to any oversight provide by the national radiation safety regulator (ARPANSA) or the state equivalent (EPA South Australia) or other scientific and engineering oversight provided by facility geologists and engineers.

The duration of the post-closure surveillance phase is essentially open ended, and a period of 1,000 years is reflective of essentially perpetual monitoring activity. As noted above, the passive design of the facilities themselves must be inherently safe and secure in perpetuity and hence the surveillance is not *in itself* intended to provide any additional safety margin or risk mitigation. It rather contributes an important degree of public *assurance*, rather than safety, to indicate to both current and future societies that the principles and expected outcomes of the original safety case are and will remain intact through time. The duration of 1000 years for the surface / near surface and the geological repositories, are taken as reflective of the public requirement for assurance and ongoing interest in the facilities (both at the outset and at the actual time of facility closure in some 120 years) and post closure, which may include both passive and active controls.

2.20 Overall operating costs

High level estimation of operating expenses across the four forms of radioactive waste facility presents a picture of significant ongoing costs throughout the project life to maintain the proposed tempo of storage and disposal activity across multiple functions.

[65] IAEA 2011, 6.64

The following table (noting the potential for combination of the underground ILW repository and the GDF) provides the following costs for each facility operating at their maximum levels, as shown in Table 2.14. These costs include a growth and scope contingency risk factor of 25%, as described in Paper 3.

Table 2.14 : Operating cost - summary breakdown (including contingency risk factor)

Facility Name / Element	Timing of costs (years)			Annual costs, AUD			
	Start	Full	MS1 (50%) Cease	Labour ($M p.a)	Other Opex ($M p.a)	Facility Maint ($M p.a)	Total ($M p.a)
Head office	4	6	120	$26.2	$11.6	*NA^*	$37.7
Port	9	10	84	$3.8	$2.2	$1.9	$7.9
Transport from port to ISF (W3)^^	10	11	84	*see (4)*	$3.4	$0.1	$3.5
ISF (W3) and handling (phase 1)	8	11	40	$10.5	$128.3	$15.4	$154.2
ISF (W3) and handling (phase 2)	41	41	120	$10.5	$15.8	$15.4	$41.7
Rail from W3 to GDF W4	21	25	120	$2.3	$4.3	$13.7	$20.2
IDR for ILW (W2) standalone	23	24	76	$24.5	$67.3	$14.3	$106.0
ILW repository (W2) within GDF	23	24	76	$15.4	$58.6	$1.7	$75.7
LLW (W1) near surface repository	10	11	120	$4.2	$7.3	$1.6	$13.1
Encapsulation plant (W4)	26	27	120	$33.5	$327.1	*inc w GDF^^*	$360.6
GDF for HLW (W4)	26	27	120	$29.2	$130.4	$45.2	$204.8
Total (withstandalone IDR) <yr 40				**$134.1**	**$681.8**	**$92.2**	**$908.1**
Total (withstandalone IDR) >yr 40				**$134.1**	**$569.3**	**$92.2**	**$795.6**
Total (IDR combined with GDF) <yr40				**$125.1**	**$673.1**	**$79.6**	**$877.7**
Total (IDR combined with GDF) >yr40				**$125.1**	**$560.6**	**$79.6**	**$765.2**

The overall operating cost is calculated to be in the range AUD877 to908 million per annum for the first 40 years of operation (under the baseline or 50% market share scenario) and AUD765 to 795 million after year 40, owing to the decrease in annual packaging costs at the interim store as packs start to be reused rather than purchased.

Appendix A. South Australian nuclear waste system planned capacities and volumes

The main size and capacity parameters for the South Australian nuclear waste system facilities are:

- **SF and HLW:**
  - inventory: 135,000 tHM
  - average DPC cask contents: 10 tHM
  - maximum HLW / SF cask mass: 113 tonne
  - receival rate for HLW / SF into ISFS: 3,000 tonne / year (300 10tHM transport casks) initially, falling to 1,500 tHM / year once current backlog is cleared
  - GDF emplacement rate: 1,500 tonne / year (150 casks)
- **ILW:**
  - inventory: 392,000 m^3
  - expansion factor net waste volume : gross storage volume: 1.5 to 2 depending on details of waste and transfer containment
  - maximum 20' ISO containers (or equivalents of other sizes): 14,000
  - receival rate: uncertain, but likely to be more in later years. For the purposes of this assessment, it is estimated maximum 10,000m^3 per year.

A.1 Staffing numbers and costs

This assessment provides estimates for operating expenditure for the South Australian nuclear waste management and disposal system described in section 2.8, covering management, supervisory and operational personnel and general expenditure on goods and services anticipated to be procured from suppliers in the course of managing and operating the set of facilities. It has drawn on the following reference publications which have assessed requirements and costs for other nuclear waste facilities with similarities, providing useful comparison points:

- **UK Nirex 2005:** United Kingdom Nirex Limited (2005) Summary note for CoRWM on the distribution of effort and employment profiles for the Deep Geological Disposal and the Phased Deep Geological Disposal options. Number 484479. http: / / www.nda.gov.uk / publication / summary-note-for-corwm-on-distribution-of-effort-and-employment-profiles-for-deep-geological-disposal-and-phased-deep-geological-disposal-option-a-technical-note-2005 / ?download Accessed 1 October 2015
- **US DOE 2013:** Carter, J and S Dam, et al (2013) A project concept for nuclear fuels storage and transportation. For US Department of Energy. https: / / www.hsdl.org / ?view&did=739345 Accessed 1 October 2015
- **Australia ILW 2013:** ENRESA (2013) Conceptual design for a near surface Low Level Waste (LLW) disposal facility and collocated above ground Long-Lived Intermediate Level Waste (LLILW) storage facility in Australia http: / / www.radioactivewaste.gov.au / sites / prod.radioactivewaste.gov.au / files / / Enresa-report.pdf Accessed 1 October 2015 (in particular pp 249-253)

These all assessed aspects of personnel numbers required and in some cases costs for employment and other operational costs of various nuclear waste management and disposal facilities. Table 2.15 shows a comparison of the main characteristics of the facilities considered in each of these reports.

Table 2.15 : Comparison of nuclear waste management and disposal facilities assessed

Dimension	UK Nirex 2005	US DOE 2013	Australia LLW, ILW 2013	SA NFLC
Wastes handled	LLW, ILW, HLW / SF	HLW / SF	LLW, long-lived ILW	ILW, HLW / SF
HLW / SF facility type	Deep geological disposal	Pilot interim storage facility larger interim storage facility (LISF)	Near surface LLW Above ground LLILW	Interim storage, geological disposal facility
Waste volumes: **LLW** **ILW** **HLW / SF**	 Not stated Not stated Not stated	 -- -- 139,384 tonne / 513+ casks	 10,000 m^3 1,500 m^3 / 5 casks Nil	 -- 392,000 m^3 135,000 tonne / 13,500 casks
Typical headcount: **LLW / ILW** **HLW / SF**	227 (range 70-498) 315 (range 70-457)	-- 250 (LISF) 128 (transport to LISF)	25-30 --	Summarised in Table 2.7 : Direct labour force totals – radioactive waste management value chain

Source: Study team

This shows that the estimates from US DOE for HLW / SF should be relevant, but the others have substantial differences or have unknown scale, potentially limiting their usefulness.

Appendix B. Summary staffing model (FTE) for the baseline case

Position / role location	Head office	Port	Rail	W1 LLW	W2 LILW	W2 ILW in GDF)	W3 ISF	W4 Encap	W4 GDF
Board x 8	8	0	0	0	0	0	0	0	0
Certifiers	0	0	0	0	0	0	2	0	0
Chairperson	1	0	0	0	0	0	0	0	0
Chief executive officer	1	0	0	0	0	0	0	0	0
Chief financial officer	1	0	0	0	0	0	0	0	0
Chief regulatory affairs officer	1	0	0	0	0	0	0	0	0
Communications officers	3	0	0	0	0	0	0	0	0
Crane and transport operators	0	0	0	0	0	0	0	15	0
Crane operator	0	3	0	0	0	0	0	0	0
Decontamination operatives	0	0	0	0	0	0	0	9	0
Director communications	1	0	0	0	0	0	0	0	0
Director engineering and operations	1	0	0	0	0	0	0	0	0
Director HR	1	0	0	0	0	0	0	0	0
Electrical, instrument, IT maint manager	0	0	0	0	1	1	1	1	1
Electrical, instrument, IT technicians	0	0	0	0	0	0	0	18	0
Electrician, fitter	0	2	0	0	0	0	0	0	0
Encapsulation plant manager	0	0	0	0	0	0	0	1	0
Engineers	0	0	0	0	4	4	0	10	6
Environmental scientist	0	0	0	2	3	0	2	0	3
Facility development and construction operatives	0	0	0	3	40	30	0	0	0
Facility development and construction super	0	0	0	1	8	4	0	0	0
Finance and accountants	10	0	0	0	0	0	0	0	0
Forklift and general warehouse worker	0	0	0	4	16	6	0	0	16
Fuels manager	0	0	0	0	0	0	1	0	0
Gantry crane operator	0	0	0	2	8	8	2	0	8
GDF and LILW facility manager	0	0	0	0	0	0	0	0	1
GDF development and construction operatives	0	0	0	0	0	0	0	0	30
GDF development and construction super	0	0	0	0	0	0	0	0	20
GDF repository management	0	0	0	0	0	0	0	0	6
GDF repository supervisor	0	0	0	0	0	0	0	0	8
Geologist, geophys, drilling manager,	0	0	0	0	5	3	0	0	6
Harbour master	0	1	0	0	0	0	0	0	0
Health officer	0	0	0	1	3	0	2	2	3
HR officers	5	0	0	0	0	0	0	0	0
Inventory controller	0	0	0	2	5	5	3	0	8
ISF facility supervisor - HLW / SF	0	0	0	0	0	0	2	0	0
ISF facility supervisor - LILW	0	0	0	0	0	0	1	0	0

Position / role location	Head office	Port	Rail	W1 LLW	W2 LILW	W2 ILW in GDF)	W3 ISF	W4 Encap	W4 GDF
Legal and company secretary	1	0	0	0	0	0	0	0	0
LILW repository management	0	0	0	0	4	3	0	0	0
LILW repository supervisor	0	0	0	0	8	3	0	0	0
LILW senior manager	0	0	0	0	1	0	0	0	0
LLW repository management	0	0	0	1	0	0	0	0	0
LLW repository supervisor	0	0	0	1	0	0	0	0	0
Maintenance supervisor	0	1	0	0	0	0	0	0	0
Marine pilot	0	1	0	0	0	0	0	0	0
Material inspectors	0	0	0	0	0	0	5	0	0
Mechanical maintenance manager	0	0	0	0	0	0	0	1	0
Mechanics	0	0	0	0	0	0	4	0	0
Mechanics and fitters	0	0	0	2	4	4	0	15	0
Nuclear and licensing engineers	0	0	0	0	0	0	2	0	0
Office administration and operations	0	0	0	0	0	0	0	10	0
Personal assistant	4	0	0	0	0	0	0	0	0
Port and ISF manager	0	0	0	0	0	0	1	0	0
Radiation protection manager	0	0	0	0	0	0	0	1	0
Radiation safety manager	0	0	0	0	1	1	2	0	1
radiation safety officer	0	0	0	2	5	2	2	5	5
Radiation, chemistry operatives	0	0	0	0	0	0	0	9	0
Rail inventory and operations clerk	0	0	1	0	0	0	0	0	0
Rail operations manager	0	0	1	0	0	0	0	0	0
Rail security officers (on train)	0	0	2	0	0	0	0	0	0
Rail supervisor - GDF	0	0	2	0	0	0	0	0	0
Rail supervisor - ISF	0	0	1	0	0	0	0	0	0
Rail track inspector	0	0	1	0	0	0	0	0	0
Rolling stock maintenance fitter	0	0	2	0	0	0	0	0	0
Rolling stock supervisor	0	0	1	0	0	0	0	0	0
Security *(in contract labour)*	0	0	0	0	0	0	0	0	0
Shift operatives	0	0	0	0	0	0	0	24	0
Stevedores	0	4	0	0	0	0	0	0	0
Technical officers (comm, legal, reg liason, eng, procurement)	80	0	0	0	0	0	0	0	0
Technical support, planning, safeguards	0	0	0	0	4	4	0	4	4
Technicians (various)	0	0	0	0	0	0	0	0	0
Technicians / engineers	0	0	0	0	0	0	25	18	0
Transport	0	0	0	0	0	0	0	4	0
Transport supervisor	0	0	0	0	0	0	2	0	0

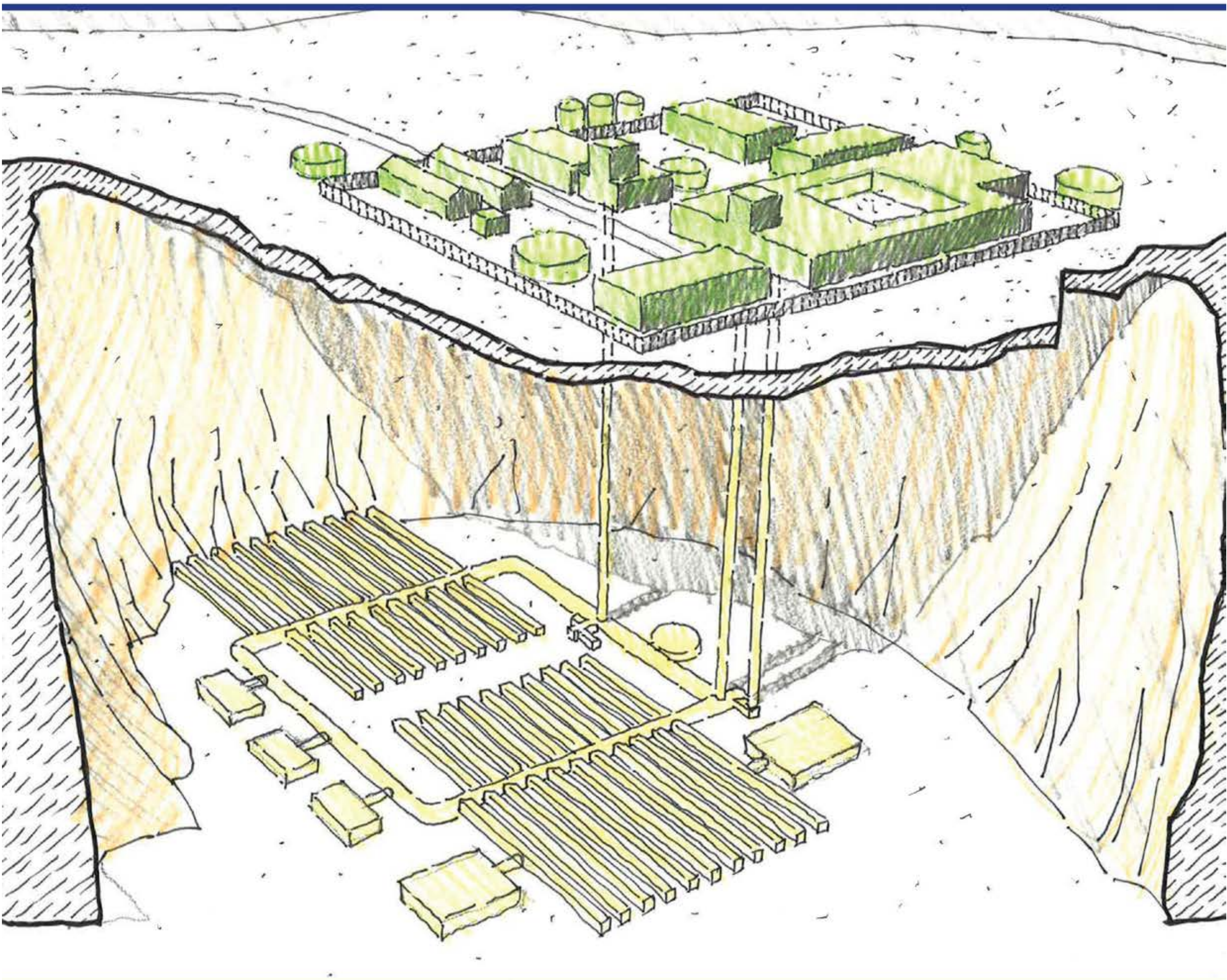
Appendix C. References

IAEA, (2001) Monitoring of geological repositories for high level radioactive waste. IAEA- TECHDOC-1208.

IAEA (2011) Disposal of Radioactive Waste. Specific Safety Requirement Report No. 5 (SSR-5)

POSIVA (2012) Encapsulation Plant Design 2012. T. Kukkola, Working Report 2012-49, Dec 2012.

SAM (2002) *Options for Monitoring During the Phased Development of a Repository for Radioactive Waste.* Safety Assessment Management Ltd, June 2002. Report been prepared for UK Nirex Ltd. by Safety Assessment Management Ltd. in co-operation with NNC Ltd., the National Cooperative for the Disposal of Radioactive Waste, Switzerland and the Centre for the Study of Environmental Change (CSEC), Lancaster University under the terms of Nirex contract SC2803 / 009.



PAPER 5

COMMERCIAL MODEL AND BUSINESS CASE

Paper 5 – Commercial model

1. Introduction

This paper describes the commercial model developed to assess the costs and revenues associated with waste storage and disposal in South Australia. The model is then used to evaluate different operating and market scenarios to demonstrate the robustness of the outcomes with respect to key parameters.

The main elements of the commercial model, revenues and costs, a State Wealth Fund and a reserve or sinking fund are all explained and key outputs presented.

The outcomes from the commercial model then inform the discussion of the business case for storage and disposal of international high and intermediate level wastes.

2. Commercial model

An existing Jacobs cash flow model has been modified and extended to meet the particular requirements of this study. It has the following key assumptions and features.

2.1 Discount rate

The model determines net present value of the income and expenditure streams as a function of discount rate. While different values at discount rates are calculated the baseline assumption, in line with other studies for the NFCRC, is a pre-tax discount rate of 10% pa real.

2.2 Revenue

Revenue is assumed to accrue to the project by means of a 'price to charge' (PTC) alternatively described as a transfer of liability cost' (TOLC) that is charged to customers at the time that the waste arrives at the port of entry in South Australia. Calculations are made at various values for PTC that encompass the best estimate value described in section 3.10 of paper 2.

2.3 Costs

Capital and operating costs are assumed to be met from revenue. In the first few years of the model costs are assumed to be incurred before revenue is received[66]. These upfront costs are assumed to be met by the project owner. In the next phase of the project waste is imported into SA and revenue will exceed costs. After the end of the import phase costs will continue to be incurred and the model assumes that a fund is established to meet these ongoing costs, as described below.

2.4 Reserve account

A reserve account has been determined to provide sufficient funds to pay for costs that exceed revenues throughout the operational phase of the project (that is after waste commences to be imported). These costs include the later transfer, encapsulation and disposal costs at the GDF, the costs of decommissioning and remediating the surface facilities, the costs of closure of the underground facilities and the costs of on-going monitoring.

2.5 State Wealth Fund

In recognition of the long term impacts on South Australia of hosting the storage and disposal of nuclear wastes a State Wealth Fund has been assumed that will provide benefits to future generations. A conservative value of 15% of revenues has been assumed as a baseline: this is not inconsistent with Australian mining royalties. For example the Queensland coal royalty rises to 15% for coal costs above AUD150 / tonne[67]. The fund is assumed to grow at 4% pa real, in line with long term diversified investment funds. Examples include the Australian and Norwegian funds shown below and more general Australian statistics[68].

The net present value has been calculated at both the pre-tax discount rate of 10% pa real and a 'social' discount rate of 4% pa pre-tax real.

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[66] In section 5.3, the possibility of phasing revenue to meet these upfront costs is discussed, but the baseline is that revenue is received at the time of import.

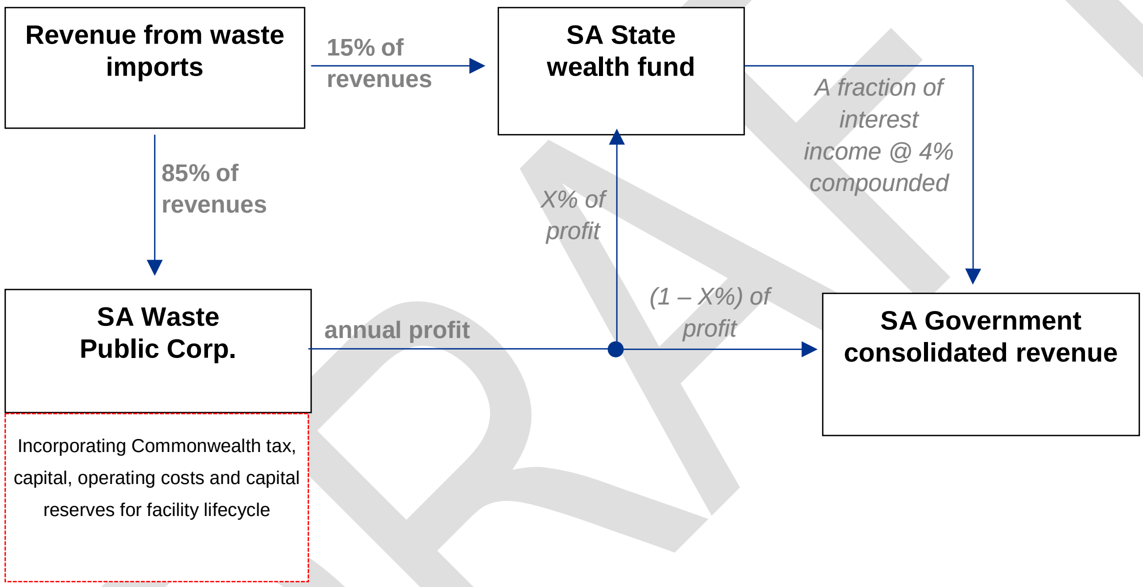
[67] https://www.business.qld.gov.au/industry/mining/applications-compliance/rents-royalties/royalties/calculating-mining/rates

[68] See for example
Long term rates of return (real) in Australia (1991) http://www.rba.gov.au/publications/bulletin/1991/oct/pdf/bu-1091-2.pdf
Last ten year rates of return (nominal) for super in Australia (2013) http://www.superguide.com.au/boost-your-superannuation/performance-history-largest-super-funds
Last ten year rates of return (nominal) for equity in Australia (2013) http://www.asx.com.au/documents/resources/russell-asx-2014-long-term-investing-report.pdf

Sovereign wealth fund	Current value (Real 2015)	Annualised return on investment	Source
Australian Commonwealth Government Future Fund	A$117 billion	4.5% p.a. (since 2006)	http://www.futurefund.gov.au/__data/assets/pdf_file/0013/7015/2014-15_Annual_Report.pdf Page 4
Norwegian Government Pension Fund	A$1.13 trillion at 21 Jan 2016	3.6% p.a. (since 1998) up to 2015 Q3	http://www.nbim.no/contentassets/c241d687f06c4dc498a50407f80f04ca/3q_15_eng_web.pdf Page 15

2.6 Dividends

Annual profits are assumed to be transferred to the project owner. While there are many options for the treatment of dividends (and income from the State Wealth Fund) discussion of these is outside the scope of this report. However one potential model is shown in the following figure.



3. Scenarios modelled

The model has been evaluated for a range of scenarios as described below.

3.1 Configuration of facilities

There is a large number of ways in which the four facilities that provide the waste storage and disposal capability can be grouped. We have identified nine potential configuration scenarios (CS). These are shown in the following table.

Table 3.1 : Facility configuration scenarios

	Costal location	Inland location	Inland location	Inland location
CS 1: standalone facilities	ISF	LLWR	IDR	GDF
CS 2: no ISF		LLWR	IDR	GDF
CS 3: no ISF, co-locate GDF & IDR		LLWR	GDF & IDR	
CS 4: co-locate GDF & IDR, 'baseline' case	ISF	LLWR	GDF & IDR	
CS 5: all facilities at coastal site	All four facilities			
CS 6: co-locate IDR and LLWR	ISF	LLWR & IDR		GDF
CS 7: ISF & LLWR co-located, GDF & UDR co-located, 'optimised' case	ISF & LLWR		GDF & IDR	
CS 8: LLWR co-located with GDF & IDR	ISF		GDF, IDR & LLWR	
CS 9: all facilities at inland site			All four facilities	

Each configuration has potential benefits and drawbacks. A summary of these is shown in the following table.

Table 3.2 : Configuration advantages and drawbacks

	Advantages	Disadvantages
CS 1	Enables independent site selection, licensing and construction - optimal flexibility with respect to approvals (ie simpler facilities not tied to more complex ones), includes ISF enabling faster receipt of revenues .Development of industry base from simpler facility to more complex ones. Spread of construction market impact - more reliable spread of labour market impact	More costly overall, duplication of connecting infrastructure and site infrastructure, higher site characterisation and approval costs and timelines, higher social license burden associated with multiple sites.
CS 2	Operating and capital cost of ISF removed. Opportunity to focus on development of more complex and costly facilities (IDR, GDF)	Division of IDR, GDF far more expensive than collocated; lack of ISF delays revenues out by 15 years (can only accept cool waste).
CS 3	Colocation of IDR, GDF offers significant cost savings and efficiencies in road, rail and shared site infrastructure underground compared with split facilities. Lack of ISF reduces establishment	No ISF means delayed revenue by circa 15 years.

	Advantages	Disadvantages
	costs	
CS 4	Colocation of IDR, GDF offers significant cost savings and efficiencies in road, rail and shared site infrastructure underground	Site characterisation costs of three separate facilities higher than for tighter collocation
CS 5	Removes cost of interconnecting infrastructure, operating cost and perceived risks of transporting waste between facilities; inclusion of ISF enables faster receipt of revenues	Highly unlikely to find suitable geology at coastal site to accommodate both port and underground disposal facilities; delay from co-siting of straightforward with challenging facility types
CS 6	Inclusion of ISF enables faster access to revenue stream, collocation of LLWR and IDR would enable all Australian waste arisings to be managed on a single site with reduced OPEX. Assumes suitable geology etc. for ILW	Splitting of IDR and GDF leads to far higher capex from duplicated onsite and connecting infrastructure.
CS 7	As for CS 4, with lower site characterisation costs given single port site developed, opportunity for opex savings through shared labour pools	Depending on coastal location, siting of LLWR may be more suitable at a site with easier access (for Australian waste).
CS 8	As for CS 4, with lower site characterisation costs given single port site developed, opportunity for opex savings through shared labour pools	Location of LLWR may be more suitable at a site with easier access (for Australian waste).
CS 9	Savings from collocated facilities (especially IDR, GDF) for capital, and some OPEX savings.	Collocation of 'simpler' surface elements (LLWR, ISF) with 'more challenging' elements which require more extensive ground characterisation (IDR, GDF) would delay the establishment of the former well beyond their typical establishment timeframe. Since materials will be landed by ship, a port and transport links inland are still required.

These features influence the modelling of each scenario to the extent that:

- the two scenarios that do not include an interim storage facility (ISF) – CS 2 and CS 3 – will not receive waste until the disposal facilities are operational; and
- the timeline for import of wastes for the two scenarios that co-locate the storage and disposal facilities – CS5 and CS 9 – will be longer than for the other storage and disposal configurations as the decision to commence the construction of the interim storage facility is contingent on the selection of the site for the combined facilities, which has a longer timeline.

From the above analysis CS 4 has been selected as the baseline configuration option.

The baseline costs of each of the options are shown in 2015 real terns in the table below. These costs will vary depending on the other scenarios modelled: a higher capture of wastes will lead to higher costs are more storage and disposal capacity is required. This has been modelled on a case by case basis for the baseline configuration.

Table 3.3 : Capital costs of configuration scenarios, including owner's costs

	AUD billion, real 2015
CS 1	50.6
CS 2	48.5

	AUD billion, real 2015
CS 3	38.8
CS 4	41.0
CS 5	29.6
CS 6	50.2
CS 7	40.2
CS 8	43.3
CS 9	42.3

3.2 Timing of implementation

Timing of implementation has been discussed in Paper 1. A baseline timing leading to import of waste commencing in project year 11 has been developed (TS 1). This shows the disposal timeline to be circa 26 to 28 years. The factors leading to this timeline are discussed further in sections 2.3.10 and 3.7 of paper 1.

In order to demonstrate the impact of timing on the project value an ‘aggressive’ timeline leading to waste imports commencing in year 8 has also been developed (TS 2). These two timelines are illustrated in the following figures

Figure 3.1 : 'Baseline' timescale for import and disposal of wastes

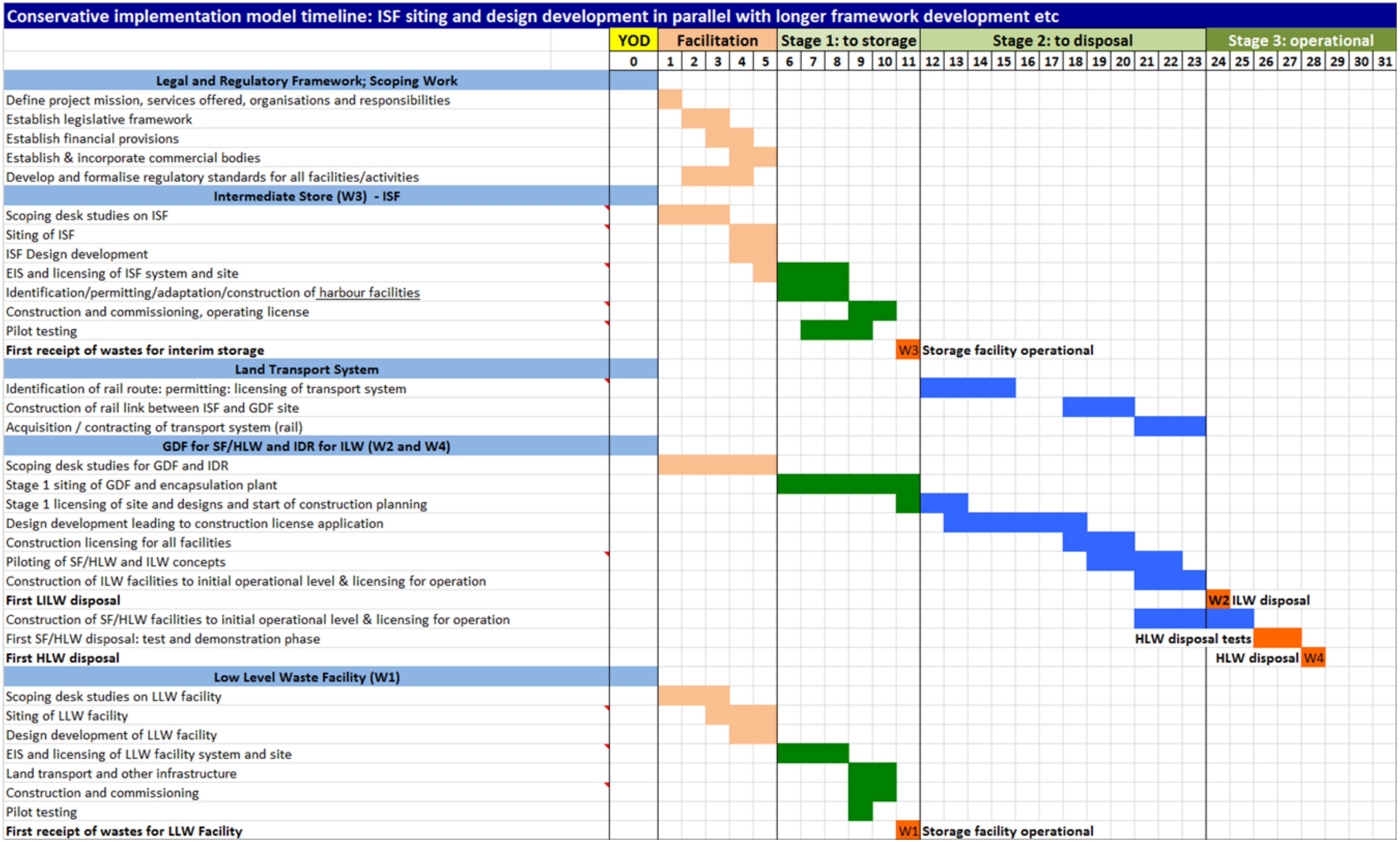
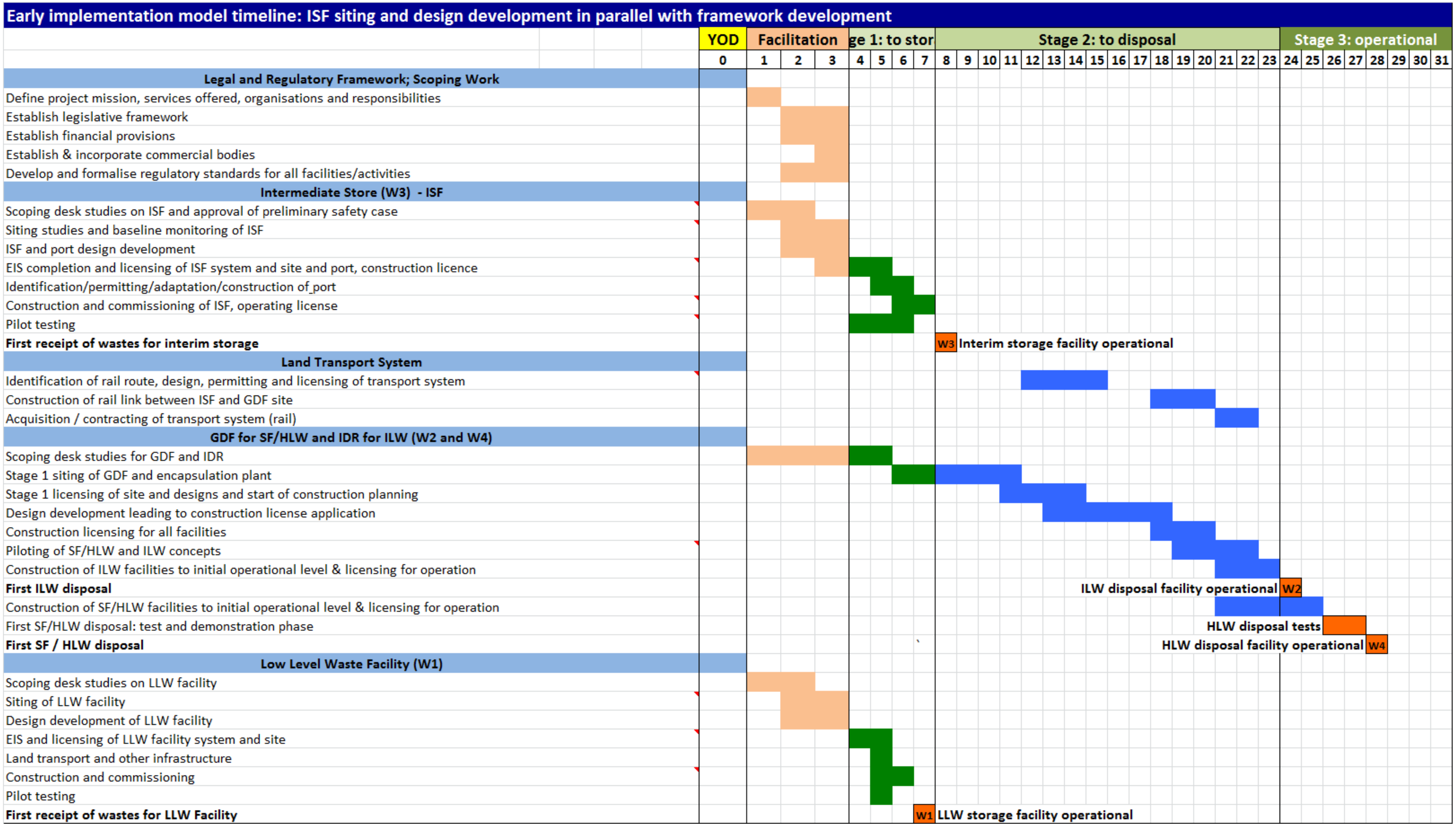


Figure 3.2 : 'Aggressive' timescale for import and disposal of wastes



In both cases the timeline for the construction of the facilities for disposal of high and intermediate level wastes have not been developed to the same degree as these have only a minor impact on the project net present value.

Similarly, a 'conservative' timeline of 15 years to import of waste has been modelled (TS3). This timeline assumes general delays to the baseline timeline but has not been developed any further.

3.3 Market capture

As discussed in Paper 2, three primary scenarios for market capture have been modelled.

- MS 1 – 50% capture of target countries' waste – the baseline
- MS 2 – 25% capture
- MS 3 – 75% capture

In addition, a key factor in the decision to proceed with the construction of the facilities is the certainty of the revenue at the time of the decision. This is described as the financial investment decision (FID) market scenario (MS 4). Here we have assumed that the only wastes that can be confidently assumed to be available are the stockpile at the time of FID plus the waste arising from fuel that is already in use in operating reactors. Sub-scenarios have been modelled to look at varying fractions of this waste that can be contracted by the time of FID.

Depending on the extent of market capture the timescale for the operational phase of the project will vary. The baseline has imports continuing until project year 84 with final disposal continuing to project year 120. For MS2 the timings are little changed from the baseline as they are driven by the time for high level waste from the last operating reactor in the client country to decay to a condition to be disposed of. For the high capture case MS3 while imports cease in project year 84 the disposal of the final high level waste is constrained by the capacity of the encapsulation facility. Presently it is assumed this will not occur until circa project year 166.

By comparison, the MS4 scenarios could lead to final disposal as early as project year 41, if only 10% of the available waste is captured.

3.4 Cost overruns

The CAPEX costs have been estimated to AACE 'Category 5' level. This implies a -50% to +100% level of uncertainty. However many of the larger costs come from imported specialist equipment where the costs are better understood. On this basis we have modelled a CAPEX cost overrun of 50%, although there is no certainty that this will be an upper limit. We note that the baseline costs include a 25% growth and scope contingency allowance.

Similarly OPEX costs have been produced in a detailed 'bottom-up' manner with a 25% growth and scope contingency allowance and a sensitivity case of +50% is considered reasonable.

In addition a sensitivity of +50% on CAPEX and +50% on OPEX has been modelled.

3.5 General

It has been assumed throughout that market capture of ILW will match that of HLW and that the two waste streams will start to be imported at the same time, as soon as the ISF is commissioned.

Model runs have been conducted for a range of PTC values for HLW ranging from AUD 1.0M / tHM to AUD 2.5M / tHM to encompass the baseline to best estimate values of willingness to pay given in Paper 2. Similarly the PTC for ILW has been modelled on a range of AUD 20 k / m^3 up to AUD 100 k / m^3.

4. Model outputs

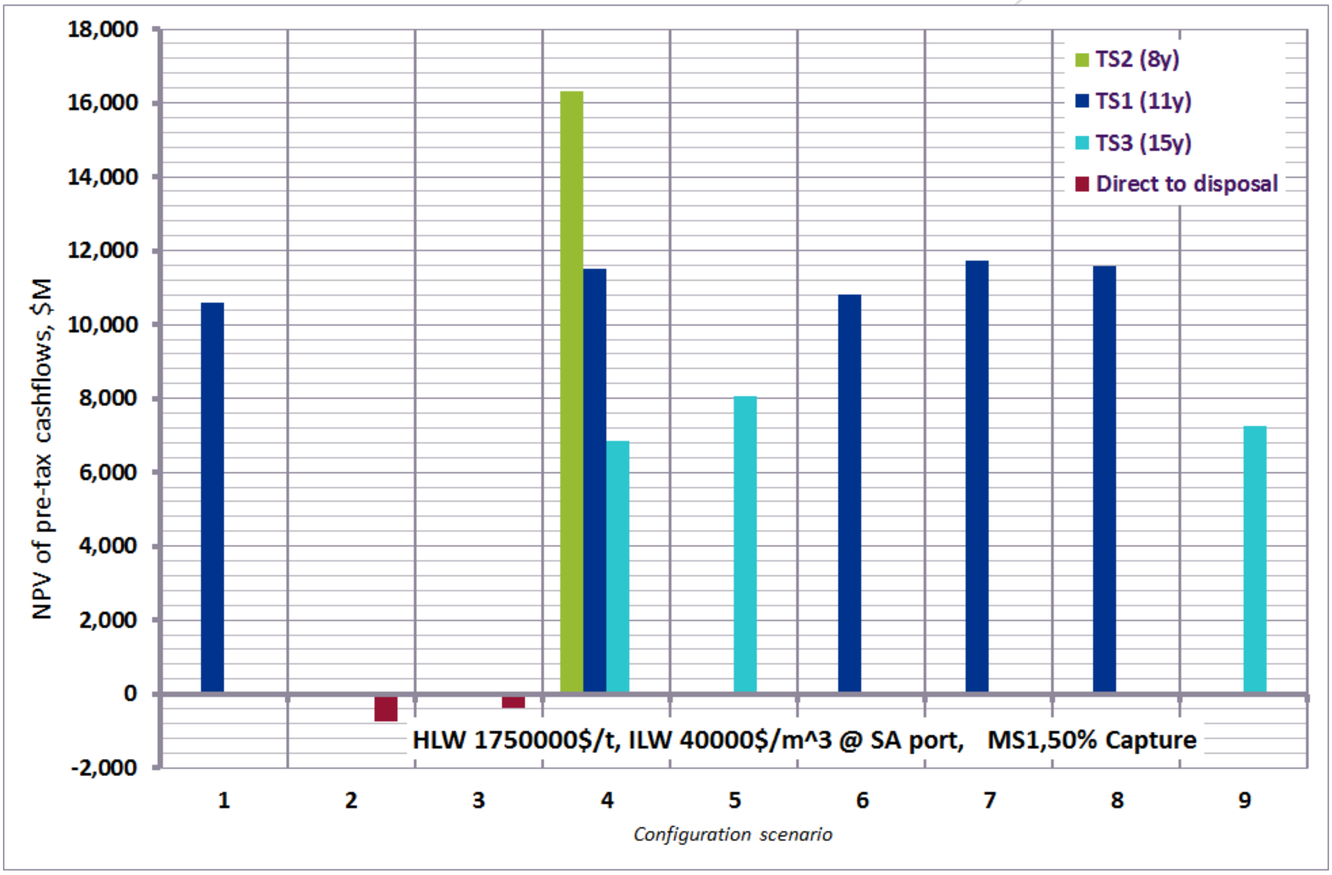
The outputs from the cash flow model are shown in the following series of figures and tables.

4.1 Configuration scenarios

The NPV at the 10% real pre-tax discount rate for the 9 different configurations is shown for the baseline timelines TS 1, 2 and 3 and baseline market capture MS 1, at a typical value for the PTC for ILW. This is shown in Figure 4.1 below for the baseline PTC of 1.75 million AUD per tonne. The differences between the scenarios are not affected significantly by the choice of PTC.

Total international revenue generated under the base-case would be around AUD257 billion (2015AUD real undiscounted) over the 120 year life of the project, with total expenditures of about AUD145 billion (including construction, operating, decommissioning and closure costs, but excluding royalties) over the same period.

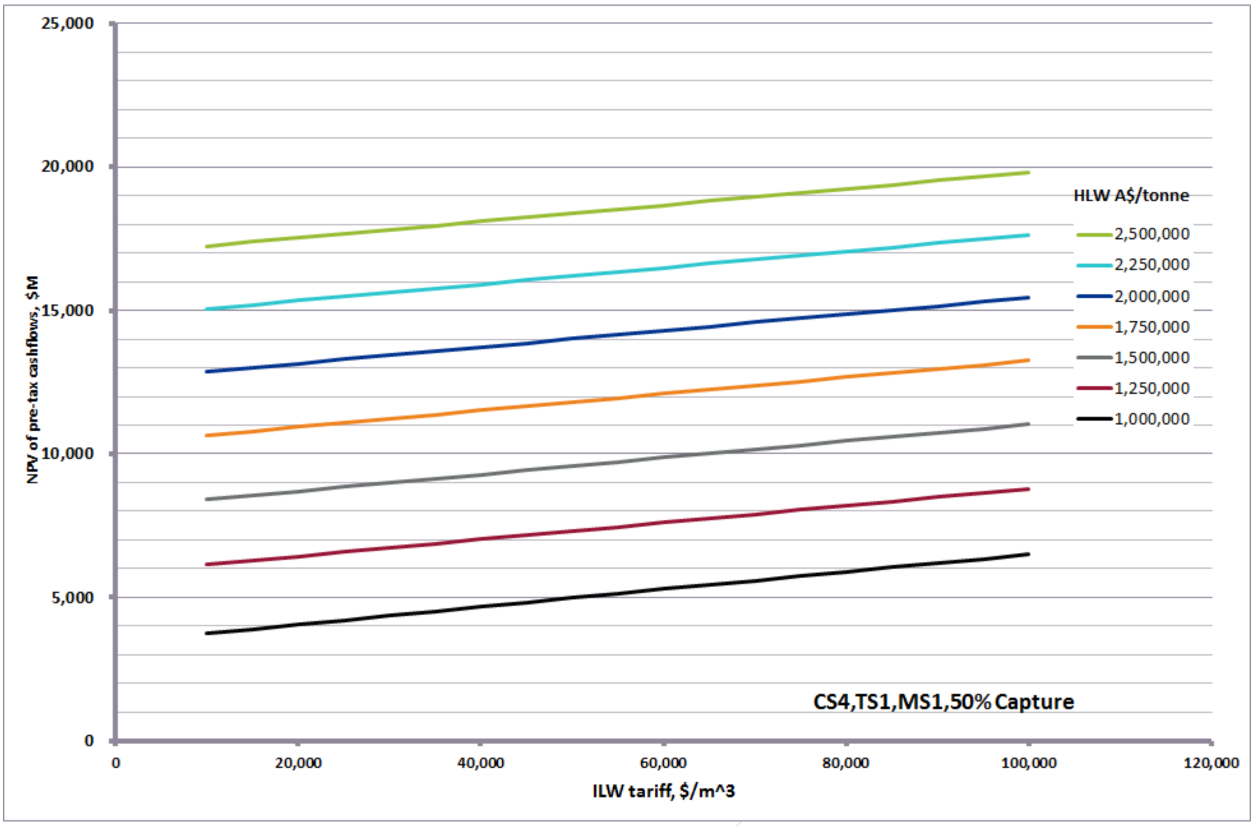
Figure 4.1 : Total project NPV comparison in Australian dollars (AUD) for nine facility configuration scenarios



This figure shows that the NPV for scenarios CS 2 and CS 3 is far below that for the other scenarios and that CS 5 and CS9 that collocate the four facilities is lower than for the remaining 5 scenarios. These differences are driven by the delays in importing waste and receiving associated revenues. The remaining five scenarios show very similar NPVs. The choice of CS 4 as baseline is therefore supported on financial as well as practical grounds.

For CS 4 the impact of varying the value of the PTC for HLW has been evaluated. This is shown in Figure 4.2. In this figure the results are shown for a range of PTC values for ILW. While a higher value for PTC for ILW improves the NPV the impact is, as expected, far less than for varying the PTC for HLW.

Figure 4.2 : Total project NPV (in AUD) of various Prices to Charge for HLW and ILW (otherwise baseline assumptions)



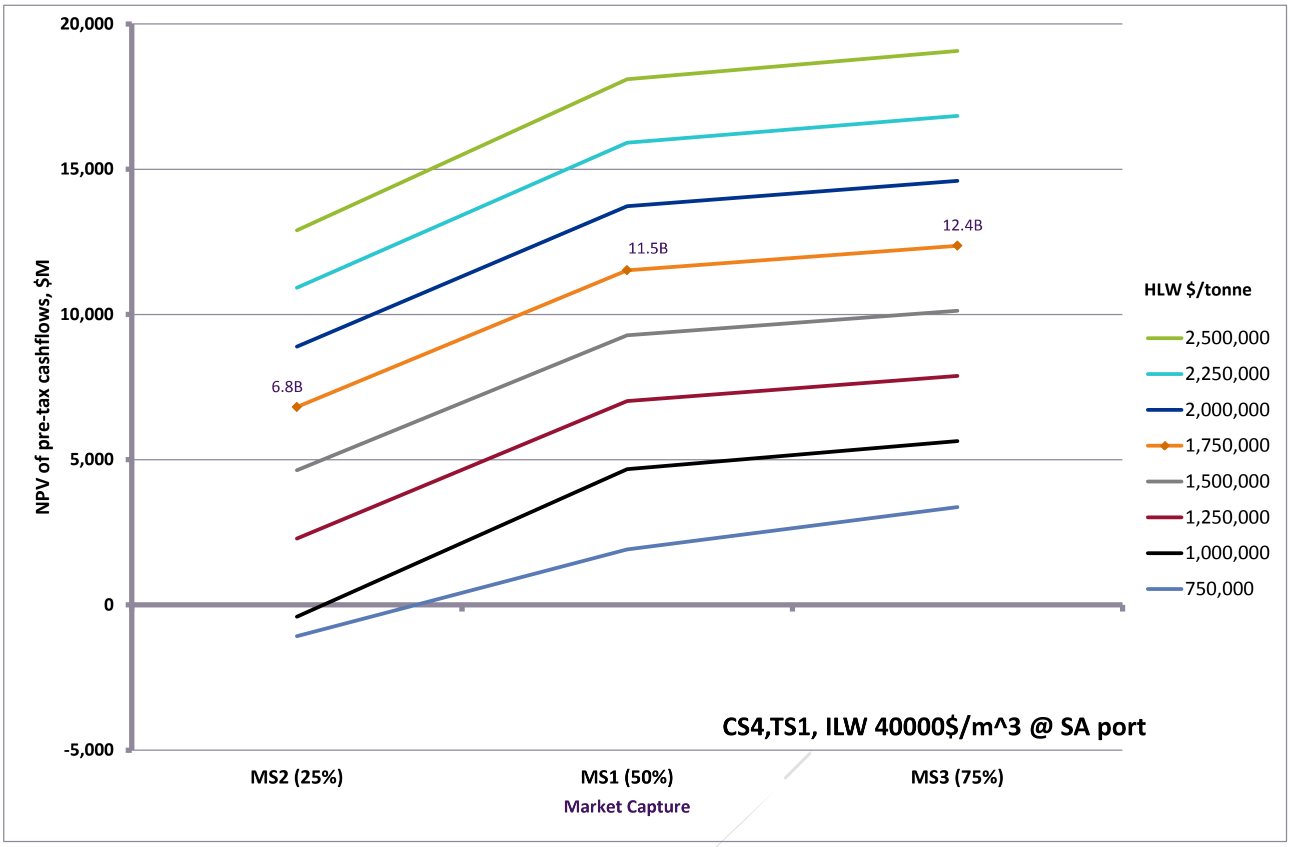
4.2 Timing of implementation

For CS 4 the impact of varying the start year of importing wastes has been evaluated for the three time scenarios. This is shown in within Figure 4.1. Moving from the baseline timescale to the aggressive timeline which sees revenues received earlier, increases the NPV from AUD 11.5 billion to AUD 16.3 billion while the conservative (slower) timeline shows a NPV of AUD 6.85 billion.

4.3 Market capture

For CS 4 the impact of varying the capture of wastes has been evaluated for the three market scenarios. This is shown in Figure 4.3. Again, the results are shown for a range of PTC values for HLW. The high capture scenario (MS3 or 75% market capture) shows a similar NPV to the base-case (AUD 12.5 billion compared with AUD 11.5 billion). This is because the additional shipments occur many years into the future (after the “baseline” 50% market amount is received) and so their impact on NPV is small. By contrast the 25% capture case shows a NPV of about 60% of the baseline level (AUD 6.88 billion compared with 11.5 billion), with all other assumptions held constant.

Figure 4.3 : Total project NPV (in AUD) varying capture percentage of client country wastes and HLW $ / tonne PTC



For the market scenario (MS) 4 which considers the waste available at the point of financial investment decision (FID), shows the NPV as a function of percentage capture for a range of PTC values. This shows a minimum capture to achieve a positive NPV for the modelled range of PTC, with the required capture percentage ranging from around 13% for a PTC of AUD 2.5 million / tHM to 55% for a PTC of AUD0.75 million / tHM.

The available inventory of spent fuel at the FID point is circa 104,000 tonnes (this is comprised of existing stockpile of spent fuel now and fuel which will be in reactors and will certainly require eventual management disposal – ie it is not considered at any risk of a change in future nuclear power developments as it is already 'committed' within our accessible market. Therefore with a PTC of AUD1.75M, some 15,500 metric tonnes of spent fuel is required for commercial feasibility

4.4 Cost overruns

The following table shows the impact of cost overruns. The case where both capex and opex are increased by 50% was found to reduce the NPV of the baseline scenario of AUD 11.5 billion to AUD 8.8 billion. This is since the NPV is driven by revenues which occur some years before the majority of the capex is incurred, and which are therefore discounted to a greater extent.

Note that cost *underruns,* which have not been modelled, would result in a higher NPV than the baseline estimate.

Table 4.1 : NPV in AUD outcomes under various cost overrun scenarios

	NPV of pre-tax real cashflows at 10.0% discount rate, $M
Baseline	11.520
Capex + 50%	9.881
Opex + 50%	10.469
Both Capex +50% and Opex +50%	8.779

According to baseline with facility construction scenario 4 (CS4), time scenario 1 (TS1), market share scenario 1 or 50% (MS1), high level waste revenues of $1.75M (HLW $1.75M)/tonne and intermediate level waste revenues of $40k per m^3 (ILW, $40k), after payment of royalty of 15% revenue.

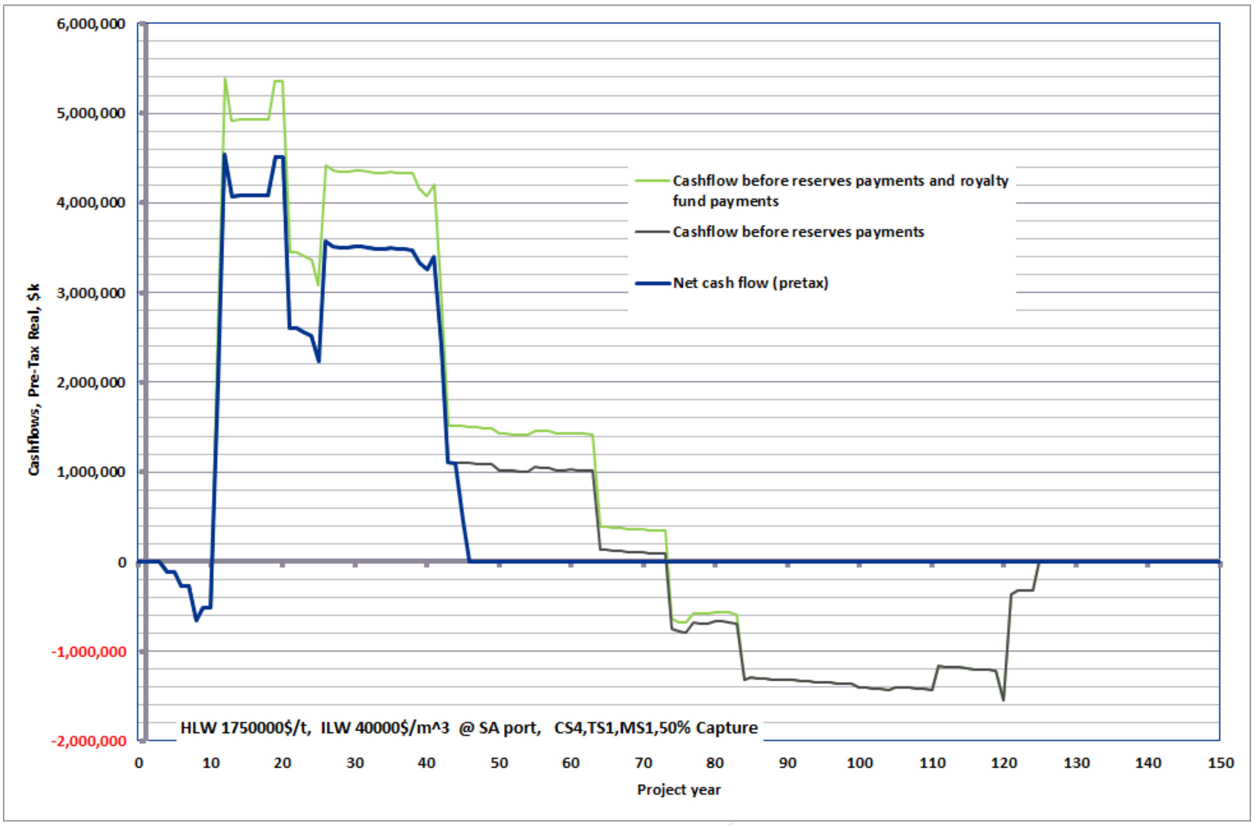
4.5 Cash flow profile for the baseline

Figure 4.4, below, shows the evolution of the project cash flows for the duration of the project, according to the baseline assumptions for market share, revenue, schedule and cost assumptions.

The project is somewhat atypical as significant revenues accrue prior to the main capital outlay. This is because the TOLC revenues coincide with the arrival of the materials at the port, from year 11 onward whereas the main capital expenditure, associated with the development of underground facilities, only commence from year 21 onward. Under the cashflow assumptions of the baseline, where no revenues ahead of delivery are assumed (a deliberately conservative assumption), there is an initial outlay of AUD 2.4 billion (real) in net terms.

After the last receipt of waste, and consequently the last receipt of revenue, significant costs remain to operate the facility to closure (and for ongoing monitoring). As described in the following section, from an appropriate time the net positive cashflows from the early operating phase are set aside into a reserve fund, from which ongoing project expenses through the later operational phase of the project and beyond are met.

Figure 4.4 : Cash flows in AUD over project life (to year 150, baseline scenario assumptions)



Cash flows at ten-year intervals under the baseline assumptions (as points in time, not cumulative) are shown in Table 4.2, below. The table illustrates how revenues commence between years 10 and 20, and peter out before year 80, royalties are paid into a State Wealth Fund over roughly the same period and operating expenses and capex persist to beyond year 120, which is met from drawdowns of the reserve fund - which commences payouts between years 40 and 50 through to the end of the operating period and beyond. For modelling purposes the operating costs for ongoing monitoring beyond the facility closure date are modelled as a net-present-value at the date of closure.

Table 4.2 : Cash flow in AUD breakdown over life of project, $M real

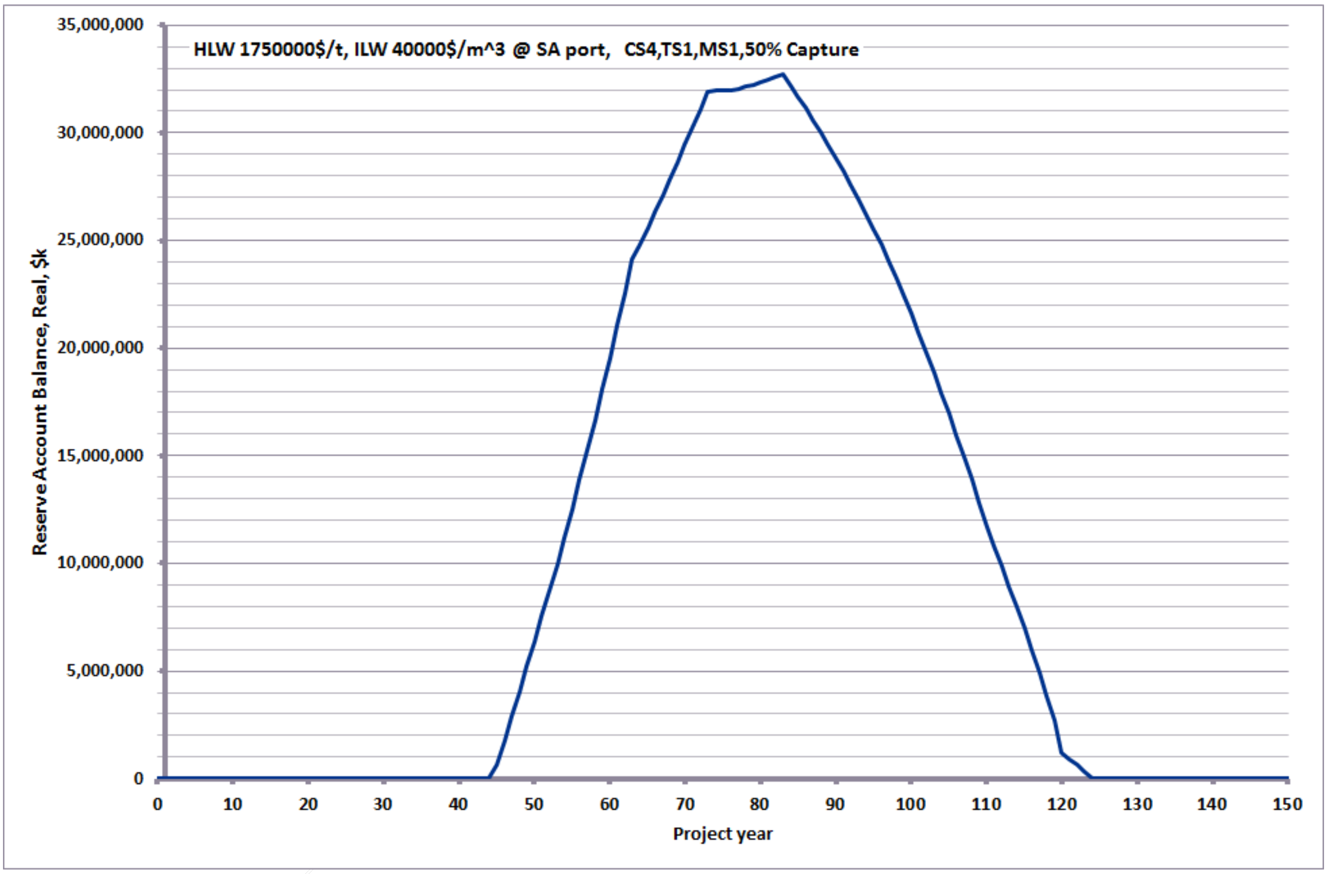
Year	10	20	30	40	50	60	70	80	90	100	110	120
Revenue	0	5,650	5,650	5,412	2,729	2,729	1,702	732	0	0	0	0
Royalties	0	-848	-848	-812	-409	-409	-255	-110	0	0	0	0
Other opex	0	-239	-1,017	-1,071	-977	-1,029	-1,077	-1,022	-1,052	-1,108	-1,160	-1,221
Capex	-510	-53	-267	-267	-321	-267	-267	-267	-267	-299	-267	-319
Reserves transfers	0	0	0	0	-1,021	-1,024	-103	667	1,319	1,407	1,427	1,540
Net cash before tax and finance	-510	4,510	3,518	3,262	-0	0	0	-0	0	0	0	0

4.6 Time profiles of the reserve account and State Wealth fund

The following two figures, Figure 4.5 and Figure 4.6 (below) show the profiles of the reserve funds and the State Wealth Fund through the project timeline.

The role of the reserve or project sinking fund is to meet foreseeable project cash flow requirements beyond the cessation of revenue receipts. Under the baseline project assumptions, the reserve fund, (as shown in Figure 4.5), grows from year 45 to reach a peak of over AUD 32.7 billion (real) in project year 83 and then decays to zero as it is applied to fund the ongoing operations, and then long-term surveillance of all of the facility sites throughout the post-closure phase.

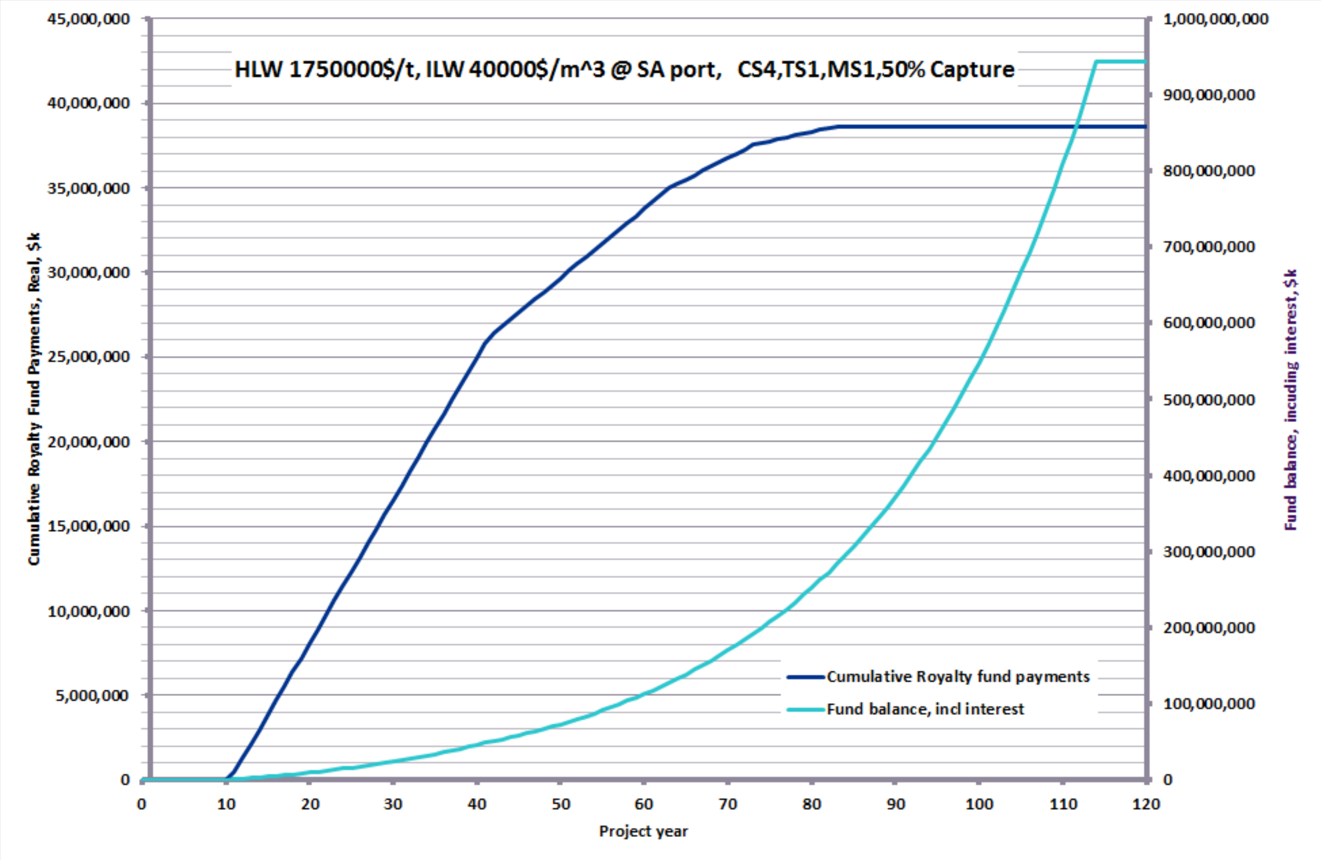
Figure 4.5 : Development over time of the project reserve fund (real, AUD thousands, baseline assumptions)



At the same time, cumulative payments from the project into a separate State Wealth Fund (which is treated as a project expense in the NPV calculations, above) grow to AUD 38.6 billion by year 83, equivalent to AUD2.9 billion at 10% real or AUD11.0 billion at 4% social rate (real).

If it was decided that the State Wealth Fund was not to be 'spent' until year 120 (to coincide with the conclusion of the operational phase of the project) it would have accumulated (with interest compounding at 4% real) some AUD942 billion in undiscounted real terms, as shown on the LHS axis of Figure 4.7, below. In discounted terms, this final amount (in year 120) has a present value of AUD10.6 billion (discounted at 4% real).

Figure 4.6 : Growth profile in AUD of the State Wealth fund with and without investment returns (baseline assumptions)



An alternative approach could be to adopt the model shown in Section 2.6 of this paper. This assumes that a proportion of the dividends are paid into the State Wealth fund and that a portion of the fund's income is paid into State consolidated revenue. If all the dividends are paid into the State Wealth fund which then accrues at a compound return of 4% pa real, then the following result:

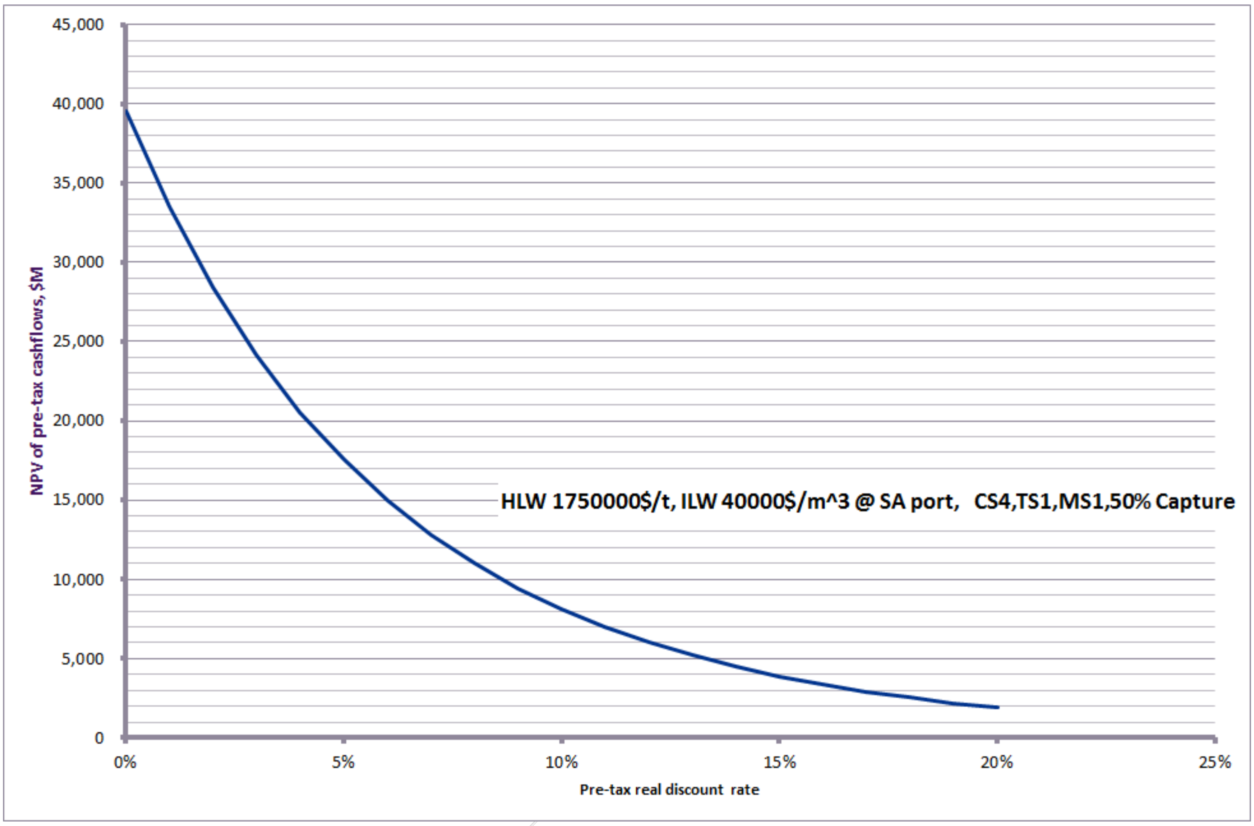
- if 50% of the interest income from the fund is distributed to the State budget each year, interest payments to the State would grow to AUD8 billion per year and the fund would grow to about AUD445 billion (AUD2015 real undiscounted) by the time the receipt of SF/HLW ceased 73 years after the first shipment. The fund grows at a rate of AUD6 billion per annum in the first ten years following commencement of waste imports, AUD6 billion per annum in the ten years following the commencement of GDF operation and AUD8 billion per annum in the last ten years before waste imports are notionally assumed to cease
- if no interest payments were made to the State each year the fund would grow to around AUD1, 364 billion over the same period.

Note that in this analysis it is assumed that the State Wealth fund receives the whole dividend and that no State or Commonwealth tax is deducted.

4.7 Project internal rate of return

An indication of the project internal rate of return (IRR) after diversion of 15% of revenue to the State Wealth Fund is shown in Figure 4.7 below. In this figure the project IRR is the discount rate at which the NPV drops to zero. In this case it is more than 20% (pre-tax, real).

Figure 4.7 : NPV in AUD of the baseline as a function of discount rate



4.8 Overall benefit to the State

The benefit to the State from this project may be characterised in a number of ways, and will depend on its operating and ownership structure (ie whether public or private, Australian or overseas owned, etc).

The impact will include direct and indirect employment, the development and sustainment of supporting industries (not measured in this analysis) as well as significant royalty receipts and net revenues (which may also accrue to the state, depending on ownership) which may together become nothing short of transformational.

The overall cash benefit to the State is the sum of the project NPV plus the royalty payment made to the State Wealth Fund. For the baseline scenario the project NPV grows to AUD11.5 billion by year 50 after which it is essentially flat as there are no further customer payments, based on median cost and revenue assumptions and 10% pre-tax real discount rate. At a social discount rate of 4% this NPV becomes AUD40.4 billion. The NPV of royalty payments that are assumed to be paid to the State at 15% of revenue are an *additional* AUD2.9 and AUD11.0 billion respectively. The project and royalty payments sum to an overall cash benefit to the State of AUD 14.4 billion and AUD51.4 billion respectively for the two discount rates.

5. Business case

This section discusses the key factors to make a viable business case for international nuclear waste storage and disposal in SA.

5.1 Ownership

Ownership of the project is expected to be a special purpose project company that is owned by the SA state. It is feasible for the project company to contract for the majority of the services for construction and operation but it will likely need its own resources to initiate and manage contracts with the client countries. The State Wealth Fund will also need a management company.

5.2 Revenue requirements, market capture and willingness to pay

The commercial model outcomes show that both interim storage and disposal is required for a viable project. The revenue requirements (PTC or TOLC) for the baseline and the modelled variants to show a positive NPV are significantly below the anticipated willingness to pay less transfer and other sundry costs so it should be possible to negotiate sufficient contracts to achieve a reasonable market share from the prospective client countries. There are many ways to arrive at TOLC and it may well be that TOLC has a country specific value as different countries' needs – and hence willingness to pay – vary widely.

The modelled project assumes fixed maximum rates of import of waste to SA and of transfer from the ISF to the GDF. Early discussions with potential client countries will be required to quantify the likely take-up of transfer of liability services from SA and hence the need to revisit the fundamental sizing of the project to optimise the design. In this regard the modelling suggests that a higher uptake will provide more benefit to SA with phasing of expenditure possible to minimise or avoid the need to borrow money or provide equity after the first few years leading to first imports.

5.3 Upfront costs and timing of revenue

The modelling assumes that revenue for storage and disposal of radioactive waste material is received at the time of transfer of the liability for the waste - which occurs at the moment of transfer from ship to shore in SA. In the run up to the commencement of imports there will be an accumulated cost to the project of AUD 2.4 B. While this should not be outside the capability of the state to finance there is also undoubted potential to negotiate advance reservation fees with some prospective client countries to offset at least a portion of this cost. Project cash flows revert to a cash surplus soon after commencement of imports.

5.4 Development activities

The modelling shows that there is an advantage in completing the development activities to achieve commencement of imports as early as is feasible. This will require both early regulatory changes e.g. to allow discussions and negotiation with prospective client countries and for project work to identify and licence the site for the port and interim storage facility. The main tasks associated with the regulatory and project development streams are shown in Figure 3.1 and Figure 3.2. Once a decision to commence formal development of the project is taken a key first step is to revisit and review this programme and establish a base development programme. The challenge is to get to a defined project with appropriate approvals in place at a similar time to establishing contracts ready for execution for sufficient existing waste to cover the project costs. This will allow a financial investment decision for a project that will still be profitable even if further, future waste streams not materialise.

5.5 Reserve account

The reserve account is anticipated to be established and grown from the midlife of the project for drawdown over the following decades. There is a large capital requirement for decommissioning and remediation of the aboveground equipment and buildings and for closure of the underground disposal sites, should it be required by nuclear licensing or social licensing conditions. Funds must also be set aside for many hundreds of years of ongoing monitoring of these underground sites (it is assumed that the above ground sites will be remediated so that no further monitoring is needed). Therefore prudent management and oversight is required to make sure that the account is adequately provisioned and managed to produce market level returns.

The case for a contingency fund to cover unforeseen expenditure both pre and post closure should also be evaluated on a risk basis.

5.6 State Wealth Fund

The State Wealth Fund, drawn from the net margin from management operations, is intended to provide a source of wealth for SA in return for the state taking responsibility for the radioactive wastes and the associated risks. As such it should be completely separate from the project company and managed for the benefit of the state as a whole. There are a number of such funds in existence including those in Norway and some of the 'petro-states' that can be reviewed for examples of good practice. The strategic objectives of the fund would be at the discretion of the South Australian government to determine, and could include direct funding of social and economic development, budget stabilisation, increase savings for future generations among others.

5.7 Treatment of dividends

As it is envisaged that the project company will be a state-owned enterprise, any dividends payable after transfers to the reserve account and to the State WealthFund will be paid to the state as part of consolidated revenue. The modelling has been prepared on a pre-tax basis and so no consideration has been made regarding tax treatment of dividends or capital allowances. This should be undertaken at or before the beginning of the development phase.

5.8 Flexibility of operation

The provision of the interim store (IFS) allows considerable flexibility of operation. The rate of imports can fluctuate as can the rate of transfer to the GDF. By allowing a margin of storage space the impacts of temporary cessation of either imports or transfers can be managed. However redundancy of transfer and logistics arrangements within the ISF will require evaluation so that the likelihood that the store itself will become a bottle neck.

5.9 Potential re-sale of spent fuel

As noted above, transfer of ownership and responsibility for all spent fuel occurs at the point of receival into the country. Since spent fuel is stored at the ISF for several decades prior to underground disposal, and could be recovered from the GDF after encapsulation and underground emplacement but before final sealing into the disposal galleries, there is potential for re-sale should spent fuel attract a value for re-use in new generations of nuclear reactor. This could both provide an income stream and avoid some significant costs, particularly if the transfer was from the ISF not the GDF. This potential upside has not been modelled.

5.10 Sundry industries

The scale of the 'baseline' proposal for receival, management and disposal of radioactive waste in south Australia would be by far the largest such operation in existence. The presence of such a large and long-lived specialist industry would support the potential development of ancillary industries in South Australia and throughout the country in support of the local radioactive waste management sector and provide a platform for future export markets. Such industries include

- specialist (high security) shipbuilding,
- specialist transport and logistics equipment (rail, road, handling, craneage)
- spent fuel transport / storage cask design and manufacture, and
- spent fuel encapsulation containers

Given likely economies of scale achievable from the scale of local operations, it is conceivable that any of the above could grow to serve offshore markets (ie beyond customer countries) rather than only South Australian requirements.

The commercial modelling undertaken has not included the potential development of these ancillary markets, which could be the subject of further detailed analysis.

5.11 Closure and monitoring

A nominal sum of 30% of the upfront CAPEX has been allocated to each facility for decommissioning and remediation or for closure as appropriate. While this value is in line with normal practice it has not been verified in practice – and old waste handling and re-processing facilities elsewhere have led to larger end of life costs. It is important therefore that the initial design decisions explicitly consider the end of life activities and associated costs.

Monitoring of the disposal sites has been allowed for in the model for an indefinite period: it is assumed that the growth in the residual value of the reserve account will match or exceed the cost of required surveillance.

5.12 Risks and mitigation

Major risks to the project include:

- A disruption to the supply / import of waste
- A significant cost overrun on the GDF (in particular) that comes to light after the financial investment date
- An incident either to the facilities or elsewhere that causes a disruption to operations , a requirement to rectify or re-engineering of the storage facilities, or all three.

These are discussed in turn below.

Disruption to import of wastes – the project is fairly robust to the delay, reduction or complete cessation of imports. Provided the financial investment decision (FID) market requirement is met, later disruptions should not cause the NPV to become negative at 10% real. This is because following the upfront capital investment to achieve initial operating capability and commissioning, all of the types of the storage and disposal facility are expanded in a phased fashion which will mitigate the commercial consequences of to market slowdown or cessation at later stage.

Cost over-run for GDF – much of the GDF development cost is within established mining practice as has been implemented in SA and elsewhere in Australia for many years. The GDF storage and disposal capacity is proposed to be extended in a continuous fashion in line with previously accepted spent fuel tonnages / volumes which will mitigate cost risks from both over development, and mobilisation / demobilisation cycles.

The (spent fuel) encapsulation plant located near the GDF is a costly facility, with many specific bought in items however there is precedent elsewhere for its cost and method of operation. Research continues to advance in various fields concerning waste encapsulation technologies and the potential application of less expensive materials than the current single-use copper casks for example. Any future development such as that considered for South Australia would also benefit from such advances. The main risk is due to a requirement to re-engineer a segment of the disposal process in light of adverse experiences elsewhere, as covered in the next point.

Impact of an incident – the spent fuel waste is not transferred to the underground storage / disposal GDF until it has cooled for 40 or more years post leaving the nuclear reactor. The risk of a nuclear incident post emplacement is therefore extremely small, given both the condition of the waste and the multiple barriers preventing a release of any consequence. The risk of environmental contamination is addressed directly by the multi-barrier system which is inherent in the above disposal designs, and as detailed in a comprehensive safety case assessment which covers all aspects of siting, design, operations, closure and post-closure. However it is conceivable that standards may become more stringent over time, due to changing technical or social factors such that later encapsulation and disposal is done via a different method, at a higher cost overall. The project's existing contingency risk factors, high NPV and associated reserve account will provide an inbuilt buffer against this. However it may be prudent to maintain a provision in addition to the reserve account to address.

Similarly there is a risk of an incident at the temporary store. The established design of the storage containers and the careful selection of siting and transport connections makes any adverse event highly unlikely. Any incident is likely to be localised (ie will not spread across the facility) and the cost of any clean-up should be covered within the project NPV. There is though, a risk to ongoing operations due to public perception issues and this will require pro-active management to mitigate against.

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6. Conclusions from the commercial model

6.1 Viability

The modelling indicates that the project shows a large NPV when assessed at a 10% pa real pre-tax discount rate. The sensitivities show that the positive NPV is maintained for all of the credible downside scenarios.

6.2 Potential benefits to SA

The benefits to SA comprise direct operational employment of over 600

staff, excluding construction and expansion-related employment and externally contracted services such as site security and transportation of waste materials between sites. Foreseeable indirect and induced employment impacts are covered in another study, but are expected to produce a multiple of several times this amount in ongoing employment. SA will become an established provider of radioactive waste management and disposal services and its skilled and semi-skilled labour force will enjoy the benefit of employment options elsewhere.

The proposed State Wealth Fund will also provide an ongoing benefit to the state. In the baseline case with a 15% royalty on revenue it has a NPV (at a social discount rate of 4% pa real pre-tax) of $11.0 billion..

In addition to the State Wealth Fund there is potential for many billions of operating dividends to accrue into the South Australian consolidated revenue to underwrite the State's credit rating and options for further investment in social programmes, infrastructure and future savings.

As noted above, significant further commercial 'upside' exists from the conceivable development of ancillary industries associated with the radioactive waste industry, as well as the prospect to potentially 'resale' of retrieved spent fuel, both of which could further enhance if not transform the economic fortunes of the state for the better.