CHAPTER 5: MANAGEMENT, STORAGE AND DISPOSAL OF NUCLEAR AND RADIOACTIVE WASTE

The activity under consideration is the management, storage and disposal of nuclear and radioactive waste from the use of nuclear and radioactive materials in power generation, industry, research and medicine (but not from military uses).

55. The activity of storing and disposing of wastes produced domestically from industry, research and medicine presents different risks and opportunities than storing and disposing of international waste from power generation. They need to be addressed separately.

The activity of storing and disposing of Australian-origin low and intermediate level waste is to be distinguished from the potential commercial activity of storing and disposing of international used fuel and intermediate level waste. This is because:

- domestic waste produced in Australia is a result of the past and continuing actions of Australians who have derived benefits from nuclear medicine and other industrial and research activities. The current generation of Australians has an obligation to future generations to properly manage and dispose of the waste that it has created
- the receipt of international waste would be a commercial activity that requires a choice by South Australians as to whether they want to engage in that activity
- the nature and level of risk associated with storing and disposing of Australian-origin low and intermediate level waste is different to the nature and level of risk associated with storing and disposing of international used fuel. Low and intermediate level waste is less hazardous as it emits less radioactivity overall and generates low levels of heat.

For these reasons, the application of principles for negotiating social and community consent, as explained in Chapter 6, would differ for different waste streams. The social and community engagement that would be required would be determined by the amount of waste involved, the level of hazard, the timeframes for decision making and the nature of the communities involved. The two activities are discussed in this chapter.

56. The safe management, storage and disposal of Australian and international waste require both social consent for the activity and technical analyses to ensure the waste is contained and isolated. Of the two, social consent warrants much greater attention than the technical issues during planning and development.

There are two broad aspects to the development of a waste disposal project: technical and social. The technical aspects include analyses of geology, engineering, land use, climatic, meteorological and environmental conditions. They require sophisticated planning and scientific work. The social aspects involve developing community understanding, providing information, and obtaining and maintaining community support for the activity. Social issues warrant much greater attention than technical issues during planning and development.[1]

International experience in developing radioactive waste facilities shows that processes that focus on technical issues at the expense of social issues are likely to fail.[2] Examples include the failed process to establish the Yucca Mountain facility in the United States[3], the failed process to establish a facility in Cumbria in the United Kingdom[4] and early approaches to siting facilities in Belgium, France, Germany, South Korea and Spain.[5] Detailed accounts of siting processes can be found in Appendix H: Siting significant facilities— case studies.

Without public and community support, projects typically have not proceeded, irrespective of their technical merits and whether or not the actual risks corresponded with the community's perceptions. Careful, considered and detailed technical work needs to be undertaken to ensure community support. Where social issues have been prioritised, there are international examples of project success.[6]

AUSTRALIAN LOW LEVEL AND INTERMEDIATE LEVEL WASTE

WHAT ARE THE RISKS?

57. Australia holds a manageable volume of domestically produced low and intermediate level radioactive wastes. The wastes result from science, medicine and industry, the products of which have served current and past generations of Australians.

A total of 4250 cubic metres (m^3) of low and intermediate level waste is stored around Australia, awaiting disposal, at many facilities.[7] These low level wastes comprise contaminated soils, decommissioning waste from research reactors, and equipment and laboratory items from the operation of Australia's research reactors and medical facilities.[8] The Australian Government is responsible for 4048 m^3 of this waste (see Table 5.1). The balance, approximately 200 m^3, is managed by the states and territories, with 22 m^3 of South Australian origin.[9]

Australia has 656 m^3 of intermediate level waste in storage, of which 551 m^3 is the responsibility of the Australian Government.[10] This inventory includes operational wastes from ANSTO's radiopharmaceutical production and some materials from the decommissioning of research reactors.[11]

Table 5.1: Current inventory of Australian Government radioactive waste

Waste type	Volume of waste (m^3)	Current storage location
Lightly contaminated soil: a legacy waste from ore processing research in the 1950s–60s	2100	Woomera Prohibited Area, SA
Operational waste from the Australian Nuclear Science and Technology Organisation (ANSTO)	1936	ANSTO, Lucas Heights, NSW
Defence waste: electron tubes, instrument dials, sealed sources, etc.	12	Department of Defence

Data courtesy of Department of Industry, Innovation and Science

Most of that waste (approximately 451 m^3) is held at ANSTO's Lucas Heights facility. An estimated 105 m^3 of intermediate level waste is held by the states and territories. Australia has 394 kilograms of used fuel assemblies from the OPAL (Open Pool Australian Lightwater) reactor[12], all stored at the ANSTO site. All the used fuel from ANSTO's previous reactors has been shipped overseas for either permanent management or reprocessing. Some byproduct materials of the reprocessed fuel were returned to Australia as intermediate level waste in 2015.[13]

The waste products from the reprocessing of Australian used fuel are mixed with molten glass in a process called vitrification, which produces a solid, durable waste form. The vitrified waste is contained in stainless steel canisters that are inserted into specifically designed casks for transport by road, rail or sea. The casks are made from forged steel, have walls that are 20 centimetres (cm) thick and weigh more than 100 tonnes: features that provide the appropriate level of radiation shielding.[14]

58. Low level wastes, typically items contaminated with radionuclides, do not generate heat. They require containment and isolation from the environment for up to a few hundred years. Intermediate level wastes need a greater degree of containment and isolation. The hazard posed by both kinds of waste reduces over time.

Low level waste (LLW) is broadly categorised on the basis that the physical amount of radionuclides contained in the waste 'package' is below levels[15] prescribed in national regulations.[16] Much of the LLW generated in Australia is derived from the manufacture and processing of radioactive products for research, industry and medicine, and this material typically contains radionuclides with relatively short half-lives (about 40 years or less).[17] Other LLW contains small amounts of naturally occurring uranium and thorium and their natural decay daughters—these parent elements have long half-lives.[18] A key attribute of LLW is that it does not require shielding to protect workers from excessive radiation doses during normal handling, transport and storage.[19] Nevertheless, best management practice requires that it be contained and isolated from the environment for up to a few hundred years to reach natural background levels.[20] LLW does not contain enough radioactivity to generate heat as a byproduct of the radioactive decay process.

Intermediate level waste requires a greater degree of containment and isolation than LLW due to its higher radioactivity and possible higher proportion of long-lived radioactive materials. It can be stored in surface facilities with sufficiently protective walls, although disposal of this material is best achieved using geological disposal.[21] Intermediate level waste requires shielding during storage and transport. It does not generate significant quantities of heat.

Both types of wastes should be durable and non-volatile solids at the point of disposal.[22] The risks posed by waste should be assessed based on the measures in place to ensure its containment and isolation. The hazards associated with radioactive material must be managed from the perspectives of both environmental protection and human safety. As the radioactivity increases, so, too, do the containment requirements and the need to isolate the material from the living environment.[23]

Figure 5.1: Storage of drums containing low level waste at ANSTO's Lucas Heights facility

Image courtesy of the Australian Nuclear Science and Technology Organisation

IS THE ACTIVITY FEASIBLE?

59. The federal government controls and manages most Australian low level and intermediate level waste, with the balance managed in the states and territories. There appear to be advantages in terms of managing long-term risks in a purpose-built, centralised facility.

As noted, the Australian Government is responsible for approximately 95 per cent of the nation's radioactive waste inventory.[24]

Australia's two largest stores of LLW are in the Woomera Prohibited Area (WPA) and at ANSTO's Lucas Heights facility.[25] The waste in the WPA is stored in 10 000 steel drums at a location called Evetts Field. The drums contain contaminated soil from CSIRO research in the 1950s and 1960s, and are considered a legacy waste.[26] Under the terms of CSIRO's interim storage licence, the site is inspected annually by CSIRO and the Australian Government's nuclear regulatory body, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).[27]

ANSTO stores its LLW in dedicated buildings on site at Lucas Heights. The waste is reduced in volume and placed on racks, contained in 200-litre steel drums (see Figure 5.1). The drums are scanned to determine their radionuclide content and then labelled, with the relevant information recorded in a database.[28]

The remaining LLW is held in a significant number of facilities dispersed around the country, including universities, hospitals and industry, pending final disposal.[29] While these storage facilities are licensed for this purpose, they are managed by organisations whose primary function is not the storage and disposal of radioactive waste.[30] The waste is often small in volume and held in stores that were not designed for long term storage or are nearing their capacity limits.[31] Radioactive waste is stored at 78 different facilities across South Australia, which are licensed through South Australia's Environment Protection Authority (EPA).[32] The approximate locations of these facilities are shown in Figure 5.2.

Australia does not have a central storage or disposal facility for its low and intermediate level wastes. A central facility offers advantages to the management and storage of radioactive waste. In particular, it would[33]:

- make it easier to impose consistent, stringent environmental, safety and security measures, rather than apply them across a number of individual sites. A central facility would have the potential to benefit from an enhanced safety culture and strong professional relationships with service providers because of the consistency of the management tasks
- likely be more cost effective than storage at several smaller, individual sites. There are potential economy-of-scale benefits, for example, in terms of administration and staffing of waste management tasks, such as reducing the cost of complying with regulatory obligations. It would also reduce costs for the regulator in monitoring compliance
- provide for continuity of control of the waste. This includes both physical control of the material and the retention of information of the waste type and characteristics. In the past, issues have arisen when organisations have disbanded or relocated, and corporate knowledge has been lost. This has resulted in unnecessary waste-handling transportation issues, inadequate control of radioactive material, or 'orphan sources' (sources no longer under proper management)[34]
- allow for the design of a purpose-built facility that includes specific features to provide for monitoring and compliance. A dedicated store would involve engineered facilities and staff who specialise in managing radioactive waste, to ensure continuing safe management of the waste.

Further, and as discussed in Chapter 9, there have been many thousands of shipments of LLW in Australia, without any accident resulting in harm to workers, the public or the environment. As the risks associated with transportation of LLW are low,[35] the benefits of centralisation outweigh any transportation risk. This experience supports the view that the overall risk to the community would be reduced if low and intermediate level wastes were moved from the hundreds of storage locations to one properly engineered waste management facility.

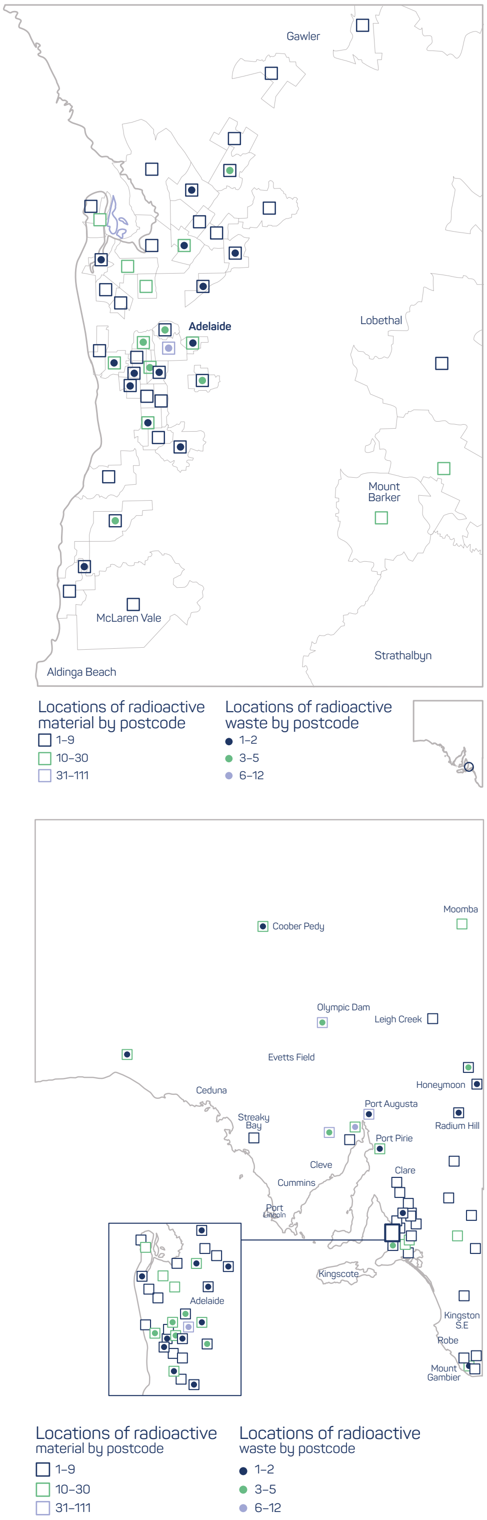

Figure 5.2: Number of locations of radioactive material and waste in the Adelaide metropolitan area (top) and across the state of South Australia

Data courtesy of the Environment Protection Authority, South Australia

60. Many countries, including Finland, France, Hungary, South Africa, South Korea, Spain and the United Kingdom, have developed and operate purpose-built low level waste repositories. These repositories handle volumes far greater than exist in Australia.

Most countries that have longstanding nuclear power or other nuclear fuel cycle facilities also have dedicated facilities for the disposal of LLW.[36] There are more than 100 proposed, operational or closed LLW repositories operating in Asia, Europe and the Americas.[37] A number of these facilities are licensed to handle volumes of waste that are many times larger than Australia's LLW inventory.[38] For example, the Federal Waste Facility in Texas has a licensed capacity of 736 000 m^3 and is one of four operating LLW disposal facilities in the United States.[39]

The characteristics and size of the international facilities vary and many have operated for long periods. Table 5.2 details key international waste facilities by type. Australia already has an established near-surface facility for the disposal of LLW at Mount Walton East in Western Australia. It commenced operations in 1988 and is managed by the state government.[40]

Facilities in other countries are being developed. Belgium is fulfilling its obligation to provide a national solution for disposing of LLW and short-lived ILW with the cAt project in Dessel (see Figure 5.3). After a long public consultation and site selection process, the facility is expected to start accepting waste in 2022.[41] The surface disposal facility is licensed to hold 70 500 m^3 of waste.[42] It will accept waste over an indicative duration of 50 years, followed by 250 years of institutional control (see Appendix H: Siting significant facilities).

61. Overseas waste disposal facilities have been developed on a range of sites and in a variety of climates—many of which are much less favourable for this purpose than conditions in South Australia. There is substantial international experience in their design, management, operation and monitoring.

Climatic and meteorological conditions such as rainfall, temperature, erosional processes and groundwater levels affect a waste disposal facility's ability to isolate the hazardous radionuclides in LLW from the environment.[43] Water is the main potential transport mechanism of radioactive materials from a waste package to the environment.[44] Therefore, characterising the hydrogeological features of a site is critical when designing for long-term containment. Sites with low groundwater flow rates, long flow paths or low water tables are preferable.[45]

Table 5.2: Key international low level waste facilities

Country	Facility name	Capacity (m³)	Waste type	Start of operation
Tunnel-type facilities				
South Korea	Wolsong	214 000	LLW, ILW	2015
Sweden	SFR	63 000	LLW, ILW	1988
Hungary	Bátaapáti	40 000	LLW, ILW	2008
Finland	VLJ	8432	LLW, ILW	1992
Highly engineered surface facilities				
France	Centre de l'Aube	1 000 000	LLW, ILW	1992
Spain	El Cabril	100 000	LLW	1992
Belgium	Dessel (under construction)	70 500	LLW, ILW	2016
Near-surface type facilities				
USA	Federal Waste Facility	736 000	LLW	2013
South Africa	Vaalputs	Not specified	LLW, ILW	1986

Data sourced from KORAD, NEA, NECSA, SKB

Figure 5.3: An overview of the proposed cAt project site in Dessel, Belgium

Image courtesy of ONDRAF/NIRAS

That said, facilities have been developed in places with high rainfall, near-surface water tables, areas potentially affected by permafrost, and even in areas where the accurate characterisation of the local hydrogeology has been difficult.[46] In such cases, the design of the facility and its engineered barrier system must play a greater role than the surrounding geology in ensuring the isolation and containment of the waste while it remains hazardous. For example:

- The French Centre de l'Aube LLW facility is situated in a high rainfall area that typically receives 500–1000 millimetres a year. The geological foundations of the facility contain a water-resistant formation of clay that creates a natural barrier against radioactive elements entering the groundwater.[47]
- The Finnish LLW/ILW disposal facility, VLJ, at the Olkiluoto site, has been built to take into account the local climate, which is characterised by potential permafrost. It uses an underground silo design, consisting of an access tunnel, a shaft and two rock silos at a depth of 60–100 metres where the waste is held.[48]
- The Spanish LLW facility, El Cabril, has been designed to rely completely on engineered barriers to isolate the waste from the environment. The barriers are robust enough that the facility could be located on almost any site.[49]

There is substantial international experience in the operation of low and intermediate level waste facilities. Some have operated since the 1950s, and one has closed, entering post-closure monitoring in 2003.[50] This experience has been used to develop international standards for the design, management, operation and closure of LLW and ILW facilities.[51]

In particular, the ability to assess the performance of these waste facilities through long-term monitoring programs is being built into new facilities. Belgium's cAt facility has developed an extensive long-term site characterisation and monitoring program to verify the performance of the repository during operation. This includes initial site characterisation before operation to establish a baseline for performance. This is followed by continual monitoring of the structure of the repository and the drainage water, and groundwater measurements to predict the potential migration of pollutants. Inspection areas and galleries have been included in the design of the facility at the request of the local community to monitor concrete floors and containment, and detect leaks in the disposal area.[52]

62. The disposal of low level and short-lived intermediate level waste need not rely on the technical characteristics of the site. There is no need for a perfect site; rather, a sufficient one.

The emphasis is placed on a facility design that is engineered with sufficient barriers that, in combination, provide for long-term containment and isolation of radionuclides.

The nature of low level and short-lived intermediate level waste means that such material should be isolated from the environment for up to a few hundred years.[53] Over this time, anthropogenic short-lived LLW radionuclides will fully decay.[54] For LLW containing thorium and uranium, the 'activity concentrations' of these elements are already lower than that of many naturally occurring radioactive ores and materials. Architectural history and expertise suggest it is feasible to build structures that assure containment for this period.[55]

The primary focus in designing a facility for disposing of LLW is to provide sufficient engineered barriers to assure that waste radionuclides do not migrate from their packages into the environment. A facility may rely on both engineered and intrinsic natural barriers at the site. Collectively, the natural and engineered barriers should contain the waste at least until the radioactivity content has diminished to natural levels.[56]

When disposed of in near-surface facilities, the risks of radionuclides migrating from LLW packages into the natural environment are managed by[57]:

- ensuring that the waste radionuclides are in a solid, non-volatile and durable form. This greatly restricts the mobility of the radionuclides. The migration of radionuclides is hindered by binding the waste to an immovable material or reducing their solubility

Figure 5.4: An example of a concrete overpack from the proposed cAt low and short-lived intermediate level waste facility in Dessel, Belgium

Image courtesy of ONDRAF/NIRAS

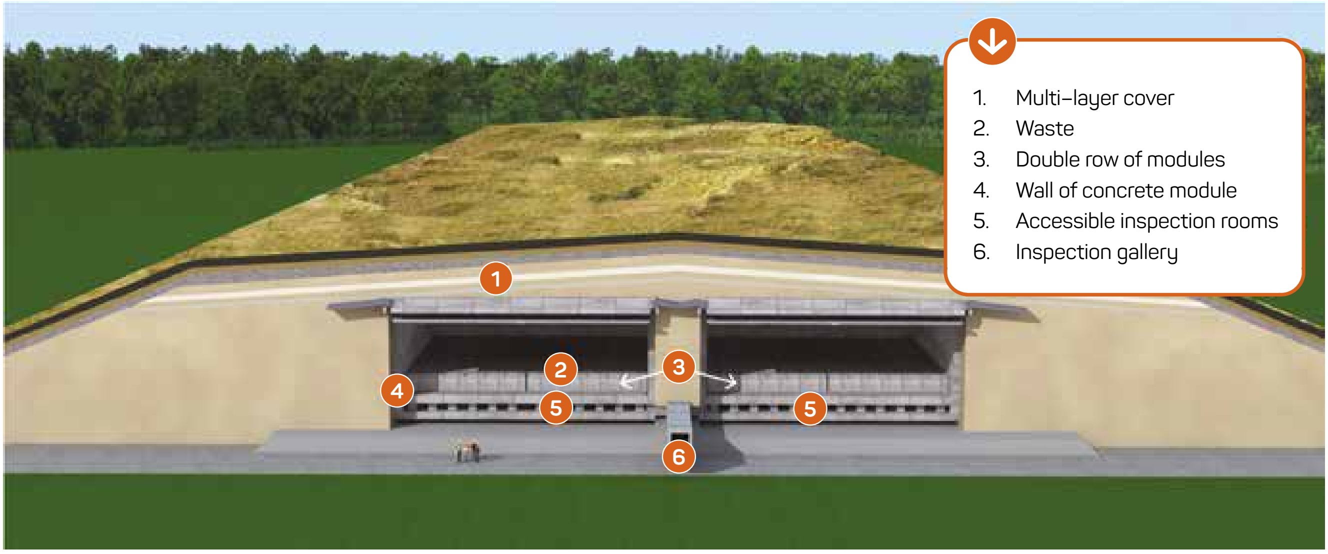

Figure 5.5: A conceptual drawing of the proposed cAt project in Belgium detailing the multiple barriers that isolate the waste from the environmen

Image courtesy of ONDRAF/NIRAS.

- containing the waste in a purpose-built package. The purpose of waste packages is to provide a primary protective layer for the length of time the waste remains hazardous. While the container is intact, the radionuclides cannot migrate from the waste package
- adding, where necessary, a steel or concrete barrier around the primary waste package. The use of such 'overpacks' made from robust materials can extend the duration of containment and increase protection from radiation hazards. Compound waste container systems can be designed to provide containment for hundreds of years. An example of a concrete overpack or 'monolith', is shown in Figure 5.4.
- designing and building the facility in a way that prevents moisture entering from the natural environment. The construction and design of the facility may be such that the site provides a natural barrier. The design and construction of the facility should ensure that operational activities do not compromise site or engineered barriers.

The cAt project in Dessel is an example of a LLW and short-lived ILW waste facility that provides robust isolation of waste using engineered and natural barriers.[58] Figure 5.5 is a conceptual drawing of the proposed site and provides details of the layers of isolation.

63. Key elements of the successful development of a low level and intermediate level waste facility are acceptance by society that it has an obligation to manage the waste it has created, and compensation to communities that host facilities for the service they provide.

The experience of countries that have attempted to site facilities for managing LLW and ILW shows that success is most likely achieved if the affected host community is compensated for the service it provides to the broader society.[59] This is clearly shown in the cases of Belgium and South Korea, which are discussed in further detail in Appendix H: Siting significant facilities—case studies. Both countries initially adopted approaches that did not provide benefits, and which failed to obtain community consent. These approaches were subsequently changed.

It is an international principle of radioactive waste management that the society that generates waste is responsible for managing it.[60] There also is a moral basis for communities that derive a benefit from the use of radioactive materials in science and industry to manage the waste that has been created. This ensures that an unfair burden is not placed on future generations. It is recognised that there may be circumstances in which the management of a country's waste is contracted to another country. This is permissible under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.[61]

IN WHAT CIRCUMSTANCES IS THE ACTIVITY VIABLE?

64. The federal government is currently managing a process to identify a site for the centralised, long-term disposal of its low level and intermediate level waste.

The Australian Government is working to identify a site for a National Radioactive Waste Management Facility for the long-term management of Australian LLW and ILW.[62] The proposed facility would permanently house Australia's LLW and serve as an interim store for its relatively small volumes (656 m^3) of ILW. Australia does not produce high level waste (HLW), and storage and disposal of HLW is prohibited at this facility.[63]

The facility will be owned and managed by the Australian Government and regulated through ARPANSA. The proposed design is a surface-type facility, similar to well-established operations in the UK and Europe.[64] The Spanish facility at El Cabril, built in 1992, is an example of a modern, purpose-built surface facility that uses the multi-barrier approach.[65]

The Australian site is being identified through a voluntary nomination process, where willing landowners have nominated their land for consideration. Phase 1 began in 2015 and involved the consideration of 25 of the eligible nominated sites. Six were shortlisted, based on a multi-criteria analysis of each site.

This was followed in 2016 by a consultation process at the shortlisted sites to engage with the community and provide information on the infrastructure specifics, risks and safety cases, employment opportunities and community benefits measures. The government will then seek broad community support for hosting the facility at one or more of the shortlisted sites before moving on to the next phase.[66] In April 2016, the Australian Government authorised a single site at Barndioota, South Australia, for further community consultation.

Due to the Australian Government's ongoing process to find a storage site, the Commission has not conducted any viability analysis into the proposed storage and disposal of Australian LLW and ILW.

65. In the event that the process currently underway is unsuccessful, there is no reason why such a facility could not be safely developed in South Australia with the support of a host community.

There is no credible evidence on technical and environmental grounds to suggest that a LLW and ILW disposal facility could not be safely operated and in due course closed in South Australia. Indeed, the risks associated with such a facility have been demonstrated to be manageable. Australia has the significant advantage of being able to draw on a considerable body of international experience in developing such a facility (see Appendix H).

Such a process in South Australia would, however, need to address the economic and social justifications for the activity and how the risks would be managed. Were a process to be adopted that drew on the principles outlined in Chapter 6: Social and community consent, there would be no reason for a South Australian community not to consider and learn about hosting a facility. Should a community choose to proceed beyond this initial stage, it would then need to discuss and negotiate the economic benefits for engaging in the activity. The experiences of Belgium and South Korea in engaging with and informing interested communities and, subsequently, developing facilities provide useful lessons in this regard (see Appendix H).

Although social and community consent for establishing a radioactive waste management facility would be required for international HLW, which would be undertaken as a commercial activity (discussed in this chapter), there is a qualification with regard to Australia's own LLW and ILW. The Australian Government has a responsibility to safely manage Australian-origin radioactive waste on behalf of current and future generations.[67] Failure to select a site in the manner proposed by the Commission would not negate the need to find a location for safe long-term storage and disposal.

Countries, including Australia, that are signatories to the Joint Convention recognise their binding legal obligation to manage their wastes safely for the long term.[68] While seeking willing volunteer communities, the UK, for example, has reserved its right to use other approaches should a consent-based approach not result in site selection.[69] Given that, Australia has little choice but to continue to seek a long-term solution for the safe management of its radioactive waste, irrespective of whether a volunteer host community presents itself.

INTERNATIONAL USED FUEL (HIGH LEVEL WASTE) AND INTERMEDIATE LEVEL WASTE

WHAT ARE THE RISKS?

66. Used fuel is hazardous due to its high radioactivity and heat generation.

Used fuel when discharged from a nuclear reactor is a solid ceramic that remains sealed in its metal cladding (see Figure 5.6). It has the same outward appearance as when loaded into the reactor. [70] Inside the fuel rods, the ceramic fuel pellets undergo changes due to the high temperatures and the generation of new radionuclides. They are fission products and heavy by-products (otherwise known as transuranics) (see Figure 5.7). [71]

Used fuel is hazardous mainly because of its radioactivity, but also because it generates substantial amounts of heat.[72] The radioactivity is produced by the many different radionuclides that result from the fission or capture of neutrons by some of the uranium atoms in the fuel pellet.[73] As well as presenting an external radiation hazard, these new radionuclides are highly toxic if inhaled or ingested (see Box: Radiotoxicity). Although these new substances constitute only about 5 per cent of the used fuel (the balance is uranium), they increase the radioactivity of the fuel at the time of discharge by about 100 000 times the level at the time the fuel was loaded.[74]

67. The hazard created by used fuel diminishes significantly over time. Within 500 years the most radioactive elements have decayed. However, used fuel requires isolation and containment from the environment for at least 100 000 years.

The amount of heat and radioactivity produced by a used fuel assembly is determined by the length of time that the fuel has been used in the reactor core (the level of 'burn-up' of the fuel). The longer the period, the greater the amount of radioactivity and heat when it is removed from the reactor.[75]

The scale of the reduction of the hazard through the predictable process of radioactive decay is illustrated in Figure 5.8. Most of the hazardous radionuclides in used fuel are fission products, which include caesium and strontium, which decay within the first 500 years.[76] However, some radionuclides, particularly heavy by-products such as plutonium and americium, will remain for at least 100 000 years.[77] Used fuel therefore requires careful management over a long time to ensure its hazardous contents remain inaccessible to humans and the environment.[78]

As shown in Figure 5.8, the radiotoxicity of used fuel initially declines rapidly and then more slowly until, after about 300 000 years, it reaches the same level as natural uranium ore. The decline occurs because the radionuclides in the used fuel decay into stable non-radioactive elements. In Figure 5.8, the circles show the percentage of radiotoxicity compared to used fuel one month after its discharge from a reactor. The high initial radiotoxicity is associated with fission products. Following the decay within the first 500 years of almost all the fission products, the lower residual levels of radiotoxicity are associated with long-lived heavy by-products.

When managing, storing and disposing of used fuel, the main concerns are to prevent humans and other organisms:

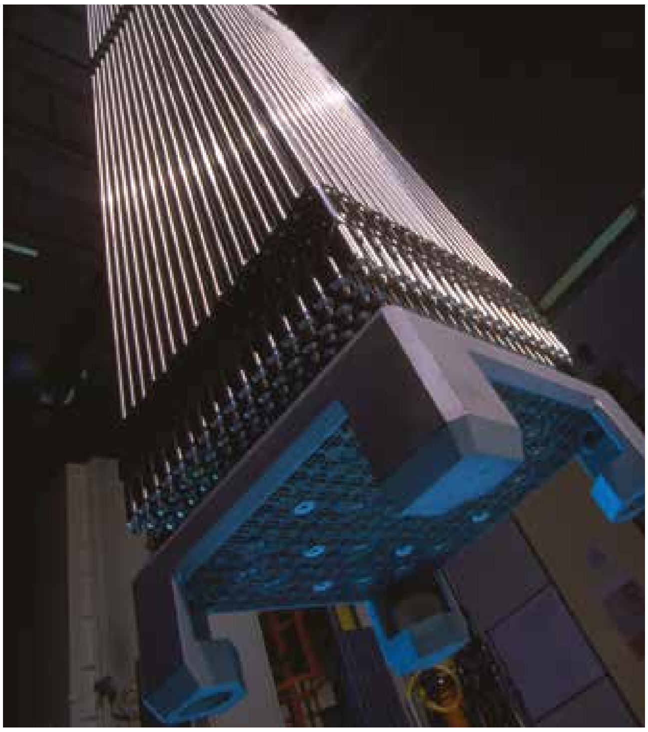

Figure 5.6: Fuel assembly for a commercial light water reactor

Image courtesy of AREVA

Figure 5.7: The chemical make-up of used fuel

RADIOTOXICITY

Radiotoxicity describes the harm which a radioactive substance can cause if people are exposed to it.

It specifically describes the potential for an impact on health where a radioactive substance enters the body, through inhalation or ingestion, and emits radiation there.

As a measure it takes into account both the biochemical nature of the radionuclide, or a number of them, as well as the type and energy of radioactivity it emits. It is measured in sieverts.

Source: Hedin, *Spent nuclear fuel—how dangerous is it?* SKB, Sweden, 1997, p. v

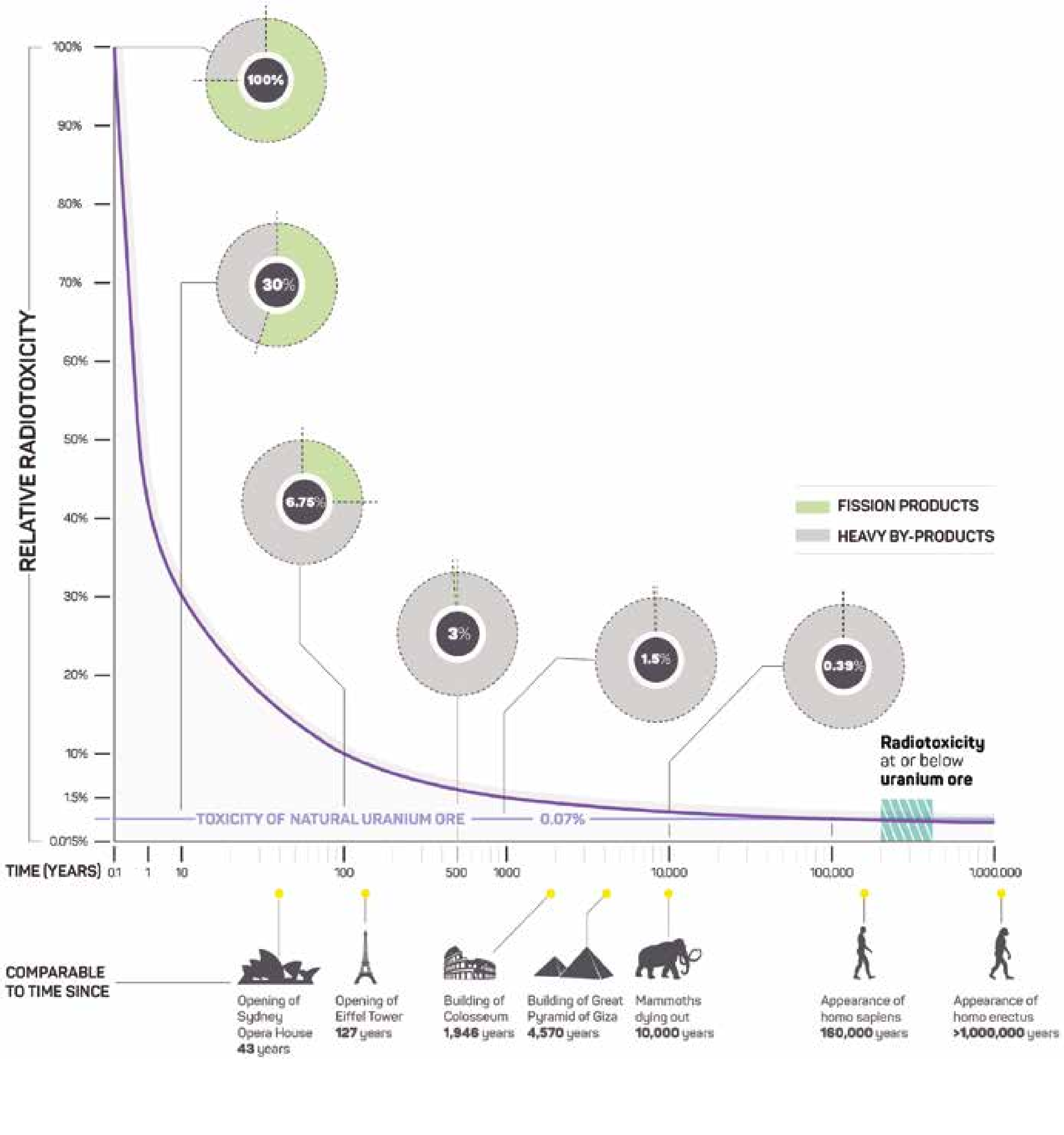

Figure 5.8: Radiotoxicity of used nuclear fuel over time[79]

- being exposed to the external radiation produced. This is primarily prevented by appropriate shielding
- inhaling or ingesting the hazardous radionuclides.[80] This is achieved by isolation and containment to prevent radionuclides migrating from the used fuel into the natural environment.[81]

The diminishing hazard over time means that the approach to managing used fuel can similarly evolve—from wet storage initially to dry storage and ultimately to disposal.[82]

The initial and main hazard following the discharge of a used fuel assembly from a reactor is the gamma radiation produced by the decay of the short-lived radionuclides.[83] A person standing one metre from an unshielded used fuel assembly would receive a lethal dose of radiation in a few seconds.[84] Shielding and remote handling of the used fuel protects people and organisms from exposure to such high levels of radiation.[85]

Similarly, on discharge from a reactor, used fuel assemblies need to be cooled for several years to ensure they remain below melting temperatures by a large margin of safety. This heat is managed in the short term (typically for up to 10 years) in a wet storage pool at the reactor site.[86]

During that time there is both a substantial reduction in the radiotoxicity of the used fuel (see Figure 5.8) and in the amount of heat generated. After removal from the wet storage pools, the used fuel assemblies are typically stored in large, dry storage casks, allowing the used fuel to cool further.[87] A total of about 50 years of storage is required for used fuel to cool sufficiently before it can be permanently disposed of underground.[88]

During that period, the radiotoxicity of the used fuel falls to about 15 per cent of the level one month following its discharge from a reactor.[89] At that time, the rate of heat output (per tonne heavy metal) is comparable to that of a powerful domestic toaster.[90]

Within 500 years, the most radioactive elements in the used fuel will have decayed.[91] At that point the radiotoxicity is dominated by the presence of radionuclides of plutonium and americium, which have very low solubility and mobility when underground, given their strong tendency to adhere to surfaces of rock and clay.[92] After 1000 years, the radiotoxicity of the used fuel is only about 1.5 per cent of initial levels following discharge from a reactor, and the rate of heat output is comparable to that produced by an adult human.

It will take more than 100 000 years for used fuel to reach similar radiotoxicity levels to natural uranium, primarily due to the presence of some of the longer-lived radionuclides that remain hazardous[93], even in trace amounts, to humans and other organisms if inhaled or ingested. Therefore, the potential for these radionuclides to migrate into the living environment must be managed over such timeframes.[94] The rapid decline in radiotoxicity means that the most critical period during which isolation and containment of the used fuel must be assured is relatively short in geological terms (up to 10 000 years).[95] This has important implications for the design of facilities for the disposal of used fuel and the combination of engineered barriers and geology used for isolation and containment.

68. There is international consensus that geological disposal is the best technical solution currently available for the disposal of used fuel. Two countries, Finland and Sweden, have successfully developed long-term domestic solutions.

The geological disposal concept involves placing solid radioactive waste in robust, multi-layered engineered containers that are in turn placed in specifically constructed openings in a disposal facility a few hundred metres or more below the earth's surface.[96] The facility is ultimately closed and sealed. Over hundreds of thousands of years the facility and the wastes decay to become part of the natural subsurface environment.[97]

In a geological disposal facility, the twin objectives of isolation and containment are achieved through a combination of suitable geology and specifically engineered barriers. Engineered barriers initially isolate and contain the waste to restrict the ability of radionuclides to reach people and the natural environment.[98] These barriers will degrade progressively after tens to hundreds of thousands of years, eventually losing their ability to contain the waste.[99] Isolation is then provided by deep, stable geology. At this stage, the remaining long-lived radionuclides have low solubility and mobility, significantly retarding their migration through the natural environment.[100]

The combination of geological and engineered barriers is designed to provide a robust system in which safety is not reliant on the performance of any single item.[101] Each barrier performs a specific, complementary role to ensure that a single failure does not lead to a failure of the system (see Figure 5.9).[102]

Compared to above-ground cask storage, geological disposal via a multi-barrier system is a permanent, passive solution, removing the need for future generations to manage the used fuel.[103] The engineered barriers must be designed and constructed within the subsurface geology to ensure safety after closure, without ongoing maintenance or monitoring.[104]

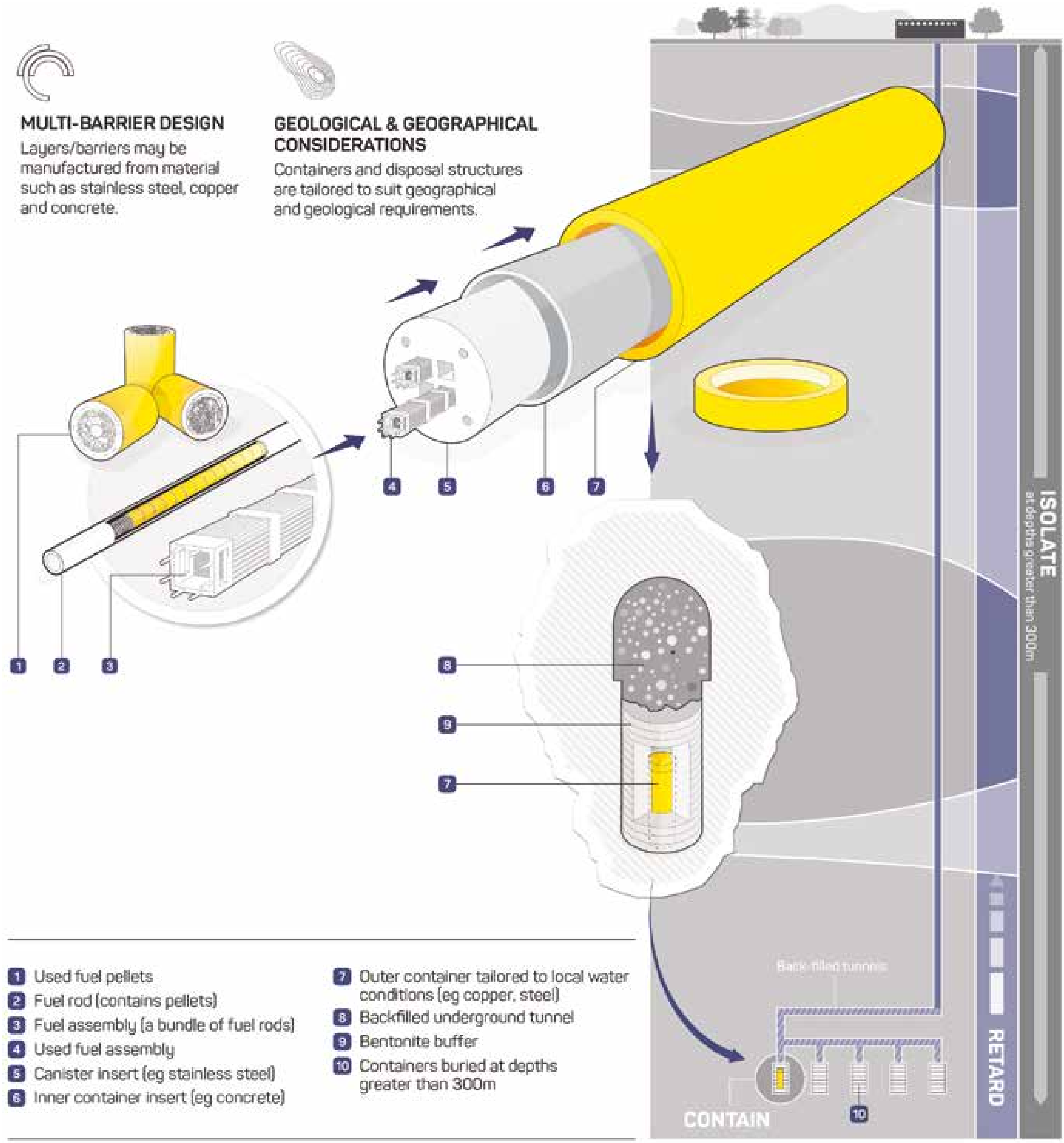

Figure 5.9: Generic multi-barrier system for the disposal of used fuel

Geological disposal research has been conducted since at least the 1950s.[105] There is international consensus that geological disposal is presently the best technical solution for the disposal of used fuel, high level waste and other long-lived radioactive waste.[106] That consensus has arisen following careful reviews of other options for disposal, including used fuel reprocessing, and of the scientific basis for geological disposal in several countries. Although future technological advances may result in new solutions in radioactive waste management, geological disposal is accepted to be the best available option.

Assessments in Belgium, Canada and the United Kingdom have also studied geological disposal from a social perspective, including the distribution of risk, fairness and benefits across generations. They have concluded that it represents the best management option overall.[107] Geological disposal is national policy in many countries including Belgium, Canada, Finland, France, Germany, Sweden, Switzerland, the United Kingdom and the United States of America.[108]

Geological disposal concepts have been developed for a range of host geologies. The two most advanced countries in this area are Finland and Sweden, which have successfully developed the KBS-3 concept for crystalline rock and found host communities for disposal facilities.[109]

Finland has had an underground research laboratory at Olkiluoto for many years. Posiva, the Finnish organisation responsible for used fuel management, was granted a construction licence in 2015 to expand the facility to accept used fuel.[110] A separate licence must be granted before this can occur. Operations are expected to start in the early 2020s.[111] Sweden also has an underground research laboratory.[112] A construction licence application was submitted to the government in 2011, with construction expected to begin in the early 2020s and be completed in about 10 years.[113]

Other countries have different geological disposal concepts. For example, Belgium, France and Switzerland have developed concepts for disposal facilities in geologies with clay.[114] The most advanced of these projects is in France, which has submitted a licence for the construction of a disposal facility near the Meuse/Haute-Marne border.[115] The site, which already hosts an underground research laboratory in the Callovo–Oxfordian formation, is expected to begin operations in 2030.

Some countries are also exploring salt deposits and other geologies for the disposal of used fuel. In the USA, the Waste Isolation Pilot Plant facility in New Mexico, which is a mined disposal facility in a bedded salt layer, has received long-lived intermediate level waste that was produced by the country's defence program.[116] It is proposed that the plant will receive further national wastes later in 2016.[117]

69. Development of a geological disposal concept requires comprehensive identification, understanding and analysis of the physical and chemical processes that may occur over at least 10 000 years and up to a million years.

To assess the safety of a geological disposal concept, it is necessary to demonstrate that the host geological environment that has been selected and the engineered barriers that have been designed will be effective in combination to prevent harmful releases of radioactivity.[118] This will assess the potential for the release of radionuclides, notwithstanding this will not happen for many tens of thousands of years.[119] This is done by constructing a 'safety case' (for examples, see Appendix I: Safety cases for geological disposal facilities).

A safety case is a structured argument supported by evidence to justify that a disposal system is acceptably safe.[120] According to the International Atomic Energy Agency (IAEA), a safety case is

> … *the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal facility, covering the suitability of the site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all the safety-related work associated with the disposal facility.* [121]

The use of safety cases is not unique to the nuclear industry.

The guiding parameters for the safety of geological disposal are often fixed by national regulations, based on international expert consensus. The regulations specify maximum levels of radioactivity to which a person may be exposed were that person, for example, to drink water from a well or aquifer above the disposal facility within 100 000 years following its closure.[122] The upper allowable annual dose limit used in many jurisdictions is 0.1 millisieverts (mSv) from these exposures, which is the equivalent of an arm x-ray. This means that a safety case would need to be developed that demonstrates as far as possible that in at least the first 100 000 years following closure of the facility, the maximum dose of radiation that a human at the surface could expect to experience would be less than 0.1 mSv.[123]

A safety case typically consists of a reference case and alternative scenarios.[124] The reference case comprises the best estimate—based on a range of realistic (albeit conservative) assumptions—of how the used fuel, engineered barriers, geological environment and surface environment will evolve following facility closure.[125] The alternative scenarios consider the system's behaviour and performance under less likely events, such as a fault caused by an earthquake and include pessimistic 'what if?' events[126], such as unintentional human intervention by accidental drilling.[127]

The reference case and alternative scenarios are then analysed systematically to determine the likely range of radiation exposures to humans and other organisms that might result.[128] As the actual events many hundreds of thousands of years into the future cannot be known, safety cases include assessments of a wide range of possible geological and climatic events and performance of the engineered barriers.[129] The objective of the assessment is to account for a range of likely and less likely outcomes.

To achieve this, modelling structured around accepted and testable physical processes is used, based on data gathered over a long time from previous international research at proposed sites. Figure 5.10 shows the relationship between the various inputs for a safety case.[130] Data-gathering occurs during site investigations and continues during construction, operation and even once the facility has closed.[131] The data is used to build, check and refine models of site behaviour, and to confirm the system is behaving as expected.[132] For this reason the safety case will evolve, and will become more detailed and specific as the project progresses through different stages.[133]

Safety case analyses have been undertaken by geological disposal facility proponents at various stages of project development in Belgium, Canada, Finland, Japan, Sweden, Switzerland and the USA, and accepted by independent nuclear safety regulators in Finland, Switzerland and the USA.[134] While each proposed facility and geology differs under each scenario analysed, the doses that might affect hypothetical people only occur in the most distant future and are so small that their effects would be undetectable.[135]

70. The role of the host geology is critical to the long- term safety of geological disposal. The geological conditions therefore need to be thoroughly analysed and understood.

A geological disposal facility for used fuel must be sited in geological conditions that naturally limit the potential pathways for radionuclide migration. Such conditions include a combination of:

- depth: disposal at sufficient depth provides protection against climatic and meteorological conditions, including aridity, fire, sea-level rise, erosion and glaciation. The disposal depth provides a significantly oversized shield from external exposure to gamma rays. Similarly, the depth of disposal removes waste from areas of human activity, reducing the risk of inadvertent intrusion[136]
- low seismicity and low geohazard potential: the host rock should be demonstrably stable to reduce the risk of faulting affecting the facility[137]
- low water flow: the main mechanism for radionuclide transport is groundwater flow. In crystalline rock, groundwater flow is restricted to the fracture network, while in sedimentary formations, groundwater flow occurs slowly through porous and permeable pathways. At depth, groundwater moves even more slowly[138]
- an absence of other mineral resources: this reduces the risk of inadvertent intrusion from exploration and mining[139]
- appropriate host geology: some geologies are better than others at isolating the radionuclides. For example, in salt and other dry environments, there is no groundwater flow. In clay environments, a high degree of sorption (retention) by clay minerals prevents radionuclides from migrating into the groundwater.[140]

Careful characterisation over several decades is required to confirm the suitability of the geological conditions. [141] It is necessary to attempt to assess the full range of possible changes to geological and climatic conditions over time, including likely and more remote developments as a result of climate change, such as sea level rises and glaciation.[142] While this process is complex, sound predictions can be made about the future development of geological formations by studying how those formations have behaved throughout history.[143] For example, the chemistry of the groundwater gives an indication of how slowly it moves, where it originated and, as a result, how it is likely to behave in the future. Similarly, seismic investigation of the local and regional geology allows trends in tectonic processes, such as uplift and compression, to be identified.[144] A phased approach is appropriate for this, starting with surface-based investigation and continuing on to underground investigation if warranted[145], initially via borehole sampling and then moving to construction of an underground research laboratory.[146]

Other considerations are also taken into account to validate the appropriateness of the assumptions made and the calculated results. Much useful scientific information has arisen from studying natural analogues: for example, how naturally radioactive elements in deep geological systems can be mobilised by groundwater, or fixed by interaction with the geology.[147]

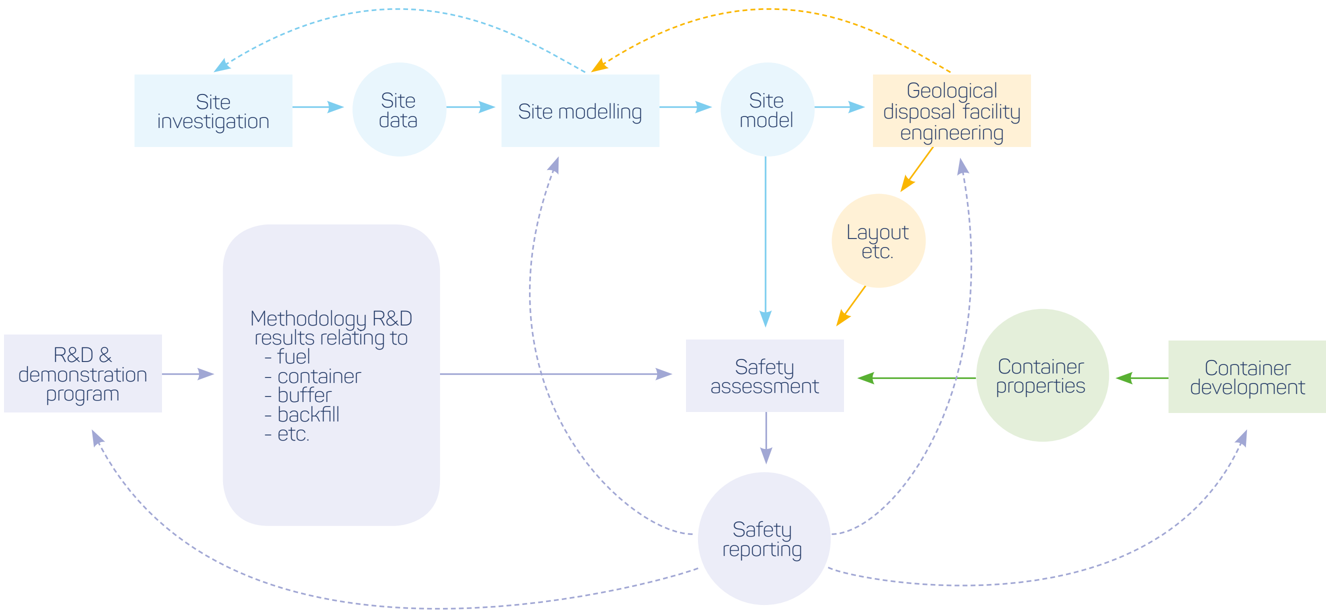

Figure 5.10: The relationship between the safety case, site investigation and other key activities.

Notes: Activities are shown in rectangles and outputs in circles. The dashed lines represent feedback loops
Data sourced from SKB

The overall impacts to humans and the environment are not evaluated based on geology alone, but on a combination of geological and engineered barriers.[148] This is explained in Finding 71.

GEOLOGICAL BARRIER FOR THE DISPOSAL FACILITY AT OLKILUOTO, FINLAND

Finland's deep geological disposal facility will be located at Olkiluoto in crystalline rock. The site, which has been investigated for 25 years, has been shown to have naturally isolating characteristics (Appendix I: Safety cases for geological disposal facilities) including:[149]

- a tectonically stable location in the Precambrian Fennoscandian Shield, away from active plate margins. Super blocks, of some several kilometres squared in size, formed in the region a long time ago and move separately from each other.[150] Consequently, the blocks are not susceptible to internal fracture by seismic activity.[151]
- groundwater flow conditions that will limit the movement of radionuclides. This includes naturally slow flow between sparse fractures in the rock, with a hydraulic conductivity of 3×10^{-11} m/s (which equates to 1 mm a year) at the disposal depth.[152] It also includes chemically reducing conditions that will limit the movement of radionuclides—these chemical conditions are not particularly corrosive.[153] Furthermore, multiple ore bodies in equivalent geology in the Fennoscandian Shield have been isolated over long periods in the past, indicating that used fuel emplaced in engineered barriers can also be isolated over the long term.
- no natural resources, reducing the risk of future human intrusion.

GEOLOGICAL BARRIER FOR A DISPOSAL FACILITY IN OPALINUS CLAYSTONE, SWITZERLAND

Switzerland is planning to locate its deep geological disposal facility in claystone, in the Opalinus Clay formation. The formation, which extends over much of Northern Switzerland, has been investigated at the Mont Terri underground research laboratory for more than 20 years.[154] It has been shown to have naturally isolating characteristics (Appendix I) including:

- tectonic stability, with the capability to self-seal in the event of seismic shear
- groundwater flow conditions that will limit the movement of radionuclides. This includes extremely slow flow, which is controlled by the rate of diffusion between pores in the claystone. It also includes chemical conditions that buffer the movement of radionuclides through sorption and other processes
- no natural resources, reducing the risk of future human intrusion.

71. **Engineered barriers are designed to work in combination to greatly delay the exposure of the fuel to groundwater and ensure that if the radionuclides migrate into the natural environment, the level of radioactivity would be below that produced by natural sources.**

Engineered barriers are designed to support the geological barrier in containing and isolating the waste. Their primary functions are to contain the waste for the period of time that its radiotoxicity is greater than that presented by natural uranium, or around 100 000 years (see Figure 5.8). [155]

The host geology plays a large role in determining the types of engineered barriers that might be suitable. Engineered barriers need to be chosen to complement the naturally isolating characteristics of the host geology.[156] For example, the groundwater chemistry in clay geologies may not be particularly corrosive to steels, but the same may not be true for water in crystalline rock environments.[157] Similarly, the materials used for engineered barriers need to be chosen such that the corrosion and degradation products do not adversely affect other barriers, such as by reducing sorption properties.

Using multiple engineered barriers that work in concert with one another and with the host geology provides protection against a single failure severely challenging the performance of all safety barriers.[158] There is significant complexity in analysing the likely interactions between barriers in a disposal environment, but much research has been undertaken around the world in this field.[159]

Engineered barriers include:

- solid form waste, i.e. radionuclides that are fixed within the waste form and not easily released from it[160]
- a purpose-built canister to protect it from mechanical loads[161]
- the canister being deposited inside an additional container to prolong containment. Containers provide a principal protective barrier to the waste—radionuclides cannot migrate while the container is intact. Different materials and different numbers of layers can be used to extend the duration of total containment. Even if a container(s) is perforated by corrosion, the corrosion products might limit radionuclide migration, thus still acting as a partial barrier. Containers have been assessed as being capable of providing containment for tens to hundreds of thousands of years[162]
- a buffer to impede moisture entry and thereby reduce corrosion. Buffers can work in three main ways: some buffers such as bentonite clay swell on contact with water, reducing the flow through porosity and permeability pathways[163]; some buffers provide sorption, limiting the ability of radionuclides to move through the buffer; some buffers are chosen to provide chemical conditions that are not particularly corrosive to the waste containers, packages and waste form.[164] Buffers can provide isolation for hundreds of thousands of years, and can also be used to limit movement from seismic activity
- backfill and plugs to provide structural support to the tunnel and impede groundwater flow.[165]

UNDERGROUND RESEARCH LABORATORY

The construction of an underground research laboratory is a key step in understanding the suitability and performance of the geological conditions for prospective sites or geology. An underground research laboratory is situated several hundred metres underground and is accessible by tunnel or shaft. It is important that it is located in geological conditions similar to those being considered for the disposal facility itself. This allows an accurate characterisation of the geological and groundwater properties at depth. It also allows experiments to be undertaken that provide realistic results on the performance of the engineered barrier system, including corrosion rates of the selected materials. Some countries have subsequently chosen to locate their disposal facility at the same location as their underground research laboratory, while others have chosen or will choose other sites.

Further, the facility must be designed and constructed in a way that acts as a geological barrier, such that construction and operations activities do not compromise the performance of the geological or engineered barriers.

THE ENGINEERED BARRIER SYSTEM FOR THE DISPOSAL FACILITY AT OLKILUOTO, FINLAND

Finland's deep geological disposal facility will use an engineered barrier system at the Olkiluoto site. This concept, which has been developed and refined in conjunction with Sweden for more than 30 years,[166] has features that support containment and isolation, including:[167]

- used fuel, in solid, ceramic form[168]
- a cast-iron canister inside a copper container, providing containment over very long timeframes. Copper is not

easily corroded by conditions in the Fennoscandian Shield.[169] Evidence of the long term behaviour of copper in the Fennoscandian Shield is provided by native copper deposits, which have retained their elemental form for over a billion years[170]

- compacted bentonite clay, which surrounds the container.[171] The clay restricts moisture entry by swelling on contact with water.[172] It also makes the local chemistry less favourable for corrosion, reducing the mobility of radionuclides. The function of the clay is to provide isolating properties over hundreds of thousands of years [173]
- backfill of underground openings to help restore the site to natural conditions.[174]

THE ENGINEERED BARRIER SYSTEM FOR A DISPOSAL FACILITY IN OPALINUS CLAYSTONE, SWITZERLAND

Compared to the Finnish concept, the geology of Switzerland requires less reliance on the engineered barrier system. Switzerland's deep geological disposal facility will use an engineered barrier system that has been tailored to their geological conditions. This concept has features that support containment and isolation, including:

- high-level waste immobilised in a solid glass (vitrified) matrix and used fuel in solid, ceramic form
- a steel container, providing containment for several thousand years.[175] If, after 10 000 years or more, the containers are penetrated by corrosion, the corrosion products would further isolate the waste by helping to provide a reducing chemical environment that limits the solubility of the radionuclides, and by reacting with and thus further binding them
- compacted bentonite clay which surrounds the container. The clay has similar properties to the host rock. The bentonite restricts moisture penetration by swelling on contact with water. It also makes the local chemistry less favourable for corrosion, reducing the mobility of radionuclides. The function of the clay is to provide isolating properties over hundreds of thousands of years.[176]

IS THE ACTIVITY FEASIBLE?

72. For the management of used fuel and intermediate level wastes, South Australia has a unique combination of attributes that offer a safe, long-term capability for the disposal of used fuel in a geological disposal facility.

The attributes that offer a long-term capability for the disposal of waste include the physical attributes of the state—underlying geology, low seismicity, an arid environment— as well as social attributes including a mature and stable political, social and economic structure, and sophisticated pre-existing frameworks for securing long-term agreement with rights holders and the broader community. Each of these is discussed below.

THE UNDERLYING GEOLOGY OF SOUTH AUSTRALIA

The underlying geology of South Australia is old and stable. It encompasses different geological environments that are suitable for the disposal of used fuel, namely, hard crystalline rock and appropriate sedimentary formations, including clay.[177] This means that there are various disposal concepts that could be employed, depending on the site.

The fundamental geological building blocks of South Australia are the Gawler Craton and the Curnamona Craton.[178] This geology is composed of hard crystalline rock, which formed about 2.5 billion to 1.5 billion years ago.[179] There have been several episodes of volcanic activity, beginning around 1.6 billion years ago, shown in the connecting material between the cratons.[180]

The more recent erosion of the geology of South Australia has resulted in a thick accumulation of retained sediments within basins that overlie hard crystalline rock in various locations across the state.[181] These sedimentary sequences extend more than a kilometre in depth[182], and are characterised by siltstone, sandstone, shale, limestone and conglomerates.

LOW SEISMICITY

Although South Australia is the most tectonically active state or territory in Australia, on a global scale that activity is very low. This is especially when compared to countries in the Pacific 'Rim of Fire', including Japan and Indonesia, and in zones in parts of Asia, such as the Himalayas, Iran and Turkey, which are located on active plate boundaries.[183]

A prominent fault system extends from the Mt Lofty Ranges to the Flinders Ranges, and remains active.[184] The highest risk area in South Australia is the Adelaide Geosyncline (the Adelaide Hills and Flinders Ranges).[185] The largest magnitude earthquake in South Australia was 6.5 in 1897 at Beachport near Mount Gambier.[186] The state has recorded about 40 earthquakes over a magnitude of 4.5 since 1872.[187] By way of comparison, Japan routinely records more than ten of these magnitude earthquakes in a month.[188]

AN ARID ENVIRONMENT IN MANY PARTS OF THE STATE

The climate in South Australia is considered to be arid, with annual evaporation exceeding rainfall. For example, in Adelaide, the mean annual rainfall is about 540 mm and the annual mean evaporation is 1460 mm per year.[189] In the central northern regions of South Australia, at Woomera for example, the annual mean rainfall is 182.2 mm and annual mean evaporation is 3139 mm.[190] However, the arid climate does not preclude flooding due to short duration heavy rainfall, or from floodwaters migrating towards South Australia from other states, including waters migrating from Queensland towards Lake Eyre.[191]

There are two major freshwater aquifers in South Australia, the Great Artesian Basin and the Murray–Darling Basin. Aside from these aquifers, groundwater exists at varying salinity, volume and depth across South Australia. At depth, the hydrogeology of the majority of the state would support further consideration for hosting a geological disposal facility.

A MATURE AND STABLE POLITICAL, SOCIAL AND ECONOMIC STRUCTURE

The planning, development and construction of a geological disposal facility would take several decades. By the time of closure, about 100 years would have passed. Stable and consistent management of such a project would be required for this duration.

South Australia has a stable representative democratic political system that has not significantly changed since Federation in 1901. Under this system, there are established processes for debating and passing legislation and budgets, and addressing issues of public importance before the parliament. As a result, significant public and private sector projects have been successfully undertaken.

SOPHISTICATED PRE-EXISTING FRAMEWORKS FOR SECURING LONG-TERM AGREEMENT WITH RIGHTS HOLDERS

The nature and longevity of hazards associated with a geological disposal facility raise complex and intergenerational issues that require social and community consent (see Chapter 6: Social and community consent). This requires sophisticated and respectful engagement with all stakeholders.

There are frameworks for securing long-term agreements with rights holders in South Australia, including Aboriginal communities. These include Indigenous Land Use Agreements, Cultural Heritage Management Plans, mining agreements, land access agreements and exploration permits. These frameworks provide a sophisticated foundation for securing agreements with rights holders and host communities regarding the siting and establishment of facilities for the management of used fuel.

73. The storage and disposal of international used fuel and intermediate level waste in a South Australian location are likely to be technically feasible. However, detailed investigations to demonstrate suitability would be required once prospective sites were identified as part of a wider consent based siting process.

Above-ground radioactive waste storage has been undertaken around the world for decades. Such facilities are already in use in other countries in a range of environments. These facilities, in which the used fuel assemblies are stored in large steel and concrete casks placed in above-ground structures or buildings (see Figure 5.11), are largely independent of site conditions. A number of types of casks can be employed for both the transport and storage of used fuel. During storage, casks weighing more than 100 tonnes are typically positioned on concrete pads for storage and monitoring until they are transported to a geological disposal facility. The casks allow for the safe containment of radioactive materials, continuous transfer of heat out of used fuel by natural ventilation, and minimisation of occupational and general public exposure to radiation both during normal operation and in the case of accidents or other malevolent acts (as discussed within the Transport section of Chapter 9: Transport, regulation and other challenges). Such dry cask systems have now been commercially licensed to operate for 100 years or more.

In the case of geological disposal, and as discussed above, concepts have been developed over many decades in other countries covering a range of geologies. These are at varying levels of regulatory approval. The technology for the construction of a geological disposal facility is not new, and is similar to that already used in South Australian mining operations. Furthermore, the geologies being considered have similarities with those found in South Australia, making it highly likely that technically suitable sites can be found. While cask and facility designs continue to be refined, there are few characteristics that would make a prospective site unsuitable.

It must be acknowledged that poor planning and implementation, and lack of a strong safety culture, can result in unintended releases of radioactivity from radioactive waste disposal facilities. This has been borne out at both the geological disposal facility for low level waste at Asse, Germany, and the Waste Isolation Pilot Plant (WIPP) for intermediate level waste in Carlsbad, New Mexico, USA.

The low and intermediate level waste facility at Asse in Germany received waste from 1967 for research purposes. Before this time, the disposal facility was mined for potash

Figure 5.11: Dry cask storage facility, depicting casks stored in horizontally configured modules (left) and in a vertical configuration (centre)

Image courtesy of AREVA.

salt and rock salt. As the disposal of radioactive waste in the mine was not originally envisaged, some chambers were mined until they reached the edges of the salt layer, compromising the ability of the geology to effectively isolate and contain the waste. At the time disposal ceased in 1978, no formal assessment was undertaken as to the measures required to safely close the facility, and the chambers and tunnels were not reinforced or sealed. Pressure from the overhead geology has allowed pathways for groundwater penetration. It is planned to retrieve the waste and manage it at a separate location where long-term safety can be assessed.[192]

The operation of the WIPP facility in New Mexico is currently suspended following an accident in February 2014. The accident was caused by a failure to follow strict protocols in packing a waste drum. Incompatible materials were packed together, which caused a chemical reaction that opened the lid of the drum. The accident resulted in the exposure of 21 employees to small doses of radiation (equivalent to a chest x-ray) following its release to the environment.[193] It is planned to reopen in late 2016.

Given the different type of waste disposed of at Asse and WIPP, neither of these examples has direct technical relevance to the storage and disposal of used fuel. However, they are salient reminders that, despite broad international scientific consensus that geological disposal of used fuel can be achieved safely, it can also be implemented poorly. The consequences of human error and 'normal' accidents must be anticipated, expected and planned for in system design and operation.

An authoritative decision on the suitability of a disposal site, and on the disposal concept for that site, cannot be made without detailed site investigations.[194] Such site investigations, which should be transparent and open to scrutiny, are part of the process for characterising the geology of a proposed site, as discussed at Finding 70. The identification of prospective sites is not part of the Commission's Terms of Reference. Any future siting process would require sophisticated planning and consent-based decision making outlined in Chapter 6: Social and community consent.[195]

74. The timeframe for the development of a geological disposal facility for used fuel on the Finnish and Swedish models is long. Any future proposal could draw on these experiences to reduce licensing and construction timeframes.

By the time used fuel is received at the Finnish and Swedish facilities in the 2020s, these projects will have taken more than 40 years to develop.[196] As used fuel needs to cool for several decades prior to disposal, the facilities were not required earlier.[197] Nevertheless, the timeframes have been dominated by the need to concurrently develop the disposal concept, design new equipment, test disposal methods, and identify and characterise prospective sites.[198] The development of concepts for the disposal of used fuel in other geological environments has been similarly long.

Any site investigation and characterisation program for a geological disposal facility could take around two decades.[199] However, any future proposal could draw on the concepts, methods and technology developed in Finland, Sweden and other countries with underground research laboratories to reduce overall licensing and construction timeframes.

IN WHAT CIRCUMSTANCES IS THE ACTIVITY VIABLE?

75. Globally there are substantial quantities of used fuel from nuclear reactors in temporary storage awaiting permanent disposal.

Internationally, there are significant quantities of used fuel discharged from nuclear reactors. While this waste is safely and securely stored in wet storage within nuclear reactors, or in dry cask storage in purpose-built facilities, in many countries there are no facilities available for its permanent disposal.[200]

The reasons for this vary. In some cases, it is a result of governments delaying development of permanent disposal until there are sufficient quantities of fuel available for disposal, and in others, it is a result of the failure of earlier processes to secure societal and community consent to develop a domestic disposal facility.[201] Further, some countries, including those with challenging geological conditions unsuited to a disposal facility, intend to develop programs to reuse the fuel by developing reprocessing (although wastes from reprocessing also contain highly radioactive materials which themselves require disposal).

All countries are required to periodically report the quantities of used fuel and intermediate waste they have in storage as part of their obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Joint Convention).[202] In total, the IAEA reports that there were global inventories of 390 000 tonnes of used fuel and reprocessed waste and 9.9 million cubic metres of intermediate level waste in storage as at 2015.[203]

76. International conventions require that countries generating used fuel must address its management domestically; however, the development of international or regional solutions for disposal are permitted.

The international management of used fuel is governed by the Joint Convention. That agreement, to which Australia is party, dictates countries' responsibilities for managing their radioactive wastes, including used fuel.[204] The Joint Convention stipulates that while responsibility to develop arrangements for domestic management rests with the country that created the waste, in some cases international or regional facilities may be beneficial.[205] Some countries such as Switzerland and the United Arab Emirates are investigating a domestic option for disposal of their used fuel, while keeping the international option open.[206] Other countries have not defined their position.

There are international models that address the transfer of waste between countries. The Basel Convention, which applies to hazardous wastes other than radioactive waste, imposes requirements upon the transfer of hazardous wastes between countries; namely the transfer shall only take place where prior informed consent has been received and only if the transfer represents an environmentally sound solution.[207] Hazardous wastes are commercially transferred under this regime. While the Joint Convention applies equivalent requirements to transfers of radioactive waste between countries, there are no operating models for the commercial transfer of used fuel for disposal.[208]

Various organisations have looked into potential concepts.[209] There are, however, commercial models for the transfer of used fuel between countries for reprocessing, as well as the take-back of fuel from reactors built by Rosatom, the Russian state nuclear corporation.[210] Similarly, the United States had a program to take back research reactor fuel of US origin as part of its non-proliferation policy.[211] The United Kingdom has reprocessed used fuel for many countries but does not accept the waste products for disposal. In all cases, transfers can only take place if the recipient country has the capacity to manage the waste safely and where such transfer has been agreed between the countries concerned.[212]

Under the Joint Convention, any proposal to store and dispose of used fuel in South Australia would require agreement between the countries concerned.[213] In Australia, treaty level agreements would need to be developed between the federal government and the relevant overseas government. An agreement would also need to specify arrangements between the Australian Government and the Government of South Australia, to ensure these commitments were fulfilled. Further agreements may be required with third party countries: for example, if they have supplied uranium to the country wishing to store and dispose of used fuel in South Australia.

77. Used fuel management is an issue of global concern and, like other countries that participate in its supply chain, Australia has a direct interest.

Used fuel management is an issue of global concern for several reasons. As a supplier of uranium, Australia has special interests in ensuring it is used for peaceful purposes. In addition to the IAEA safeguards[214], Australia requires further assurance on the peaceful uses of Australian obligated uranium material.[215] This includes accounting for material through the whole fuel cycle.[216] As a result, Australia has an interest in how and where radioactive waste is managed around the world.

Similarly, Australia has an interest in ensuring that nuclear materials are securely handled for both Australian obligated uranium and other radioactive materials used by Australia in industry and science.[217]

As Australia is a net exporter of energy, it has a significant role to play in assisting other countries to lower their carbon emissions. This includes countries with less opportunity for large scale renewable energy deployment than Australia, for whom nuclear power makes a substantial contribution to their production of low carbon energy. For new nuclear entrants or countries with little prospect of siting their own used fuel disposal facilities, an international solution would remove a significant impediment to the new or ongoing use of nuclear power as a low carbon technology. As a result, Australia would derive a reputational and financial benefit by hosting a facility for the disposal of international used fuel.[218]

78. Given the quantities of used fuel held by countries that are yet to find a solution for its disposal, it is reasonable to conclude that there would be an accessible market of sufficient size to make it viable to establish and operate a South Australian disposal facility.

The current global inventory of used fuel is estimated to be in the order of 390 000 tHM. By 2090 this global inventory is anticipated to be in excess of 1 million tHM, based on existing reactors and new reactors in the advanced stages of planning. The ILW global stockpile is presently just under 10 million m³ and is expected to be nearly 24 million m³ by 2090.[219]

To make a conservative estimate of an accessible market for a disposal facility in South Australia, it is necessary to exclude used fuel and intermediate level waste stored in the United States, France, the United Kingdom and Canada, as they are committed to developing national solutions or already have structured programs leading to a domestic facility.[220] Countries which have national laws that prohibit their export of waste, such as Sweden and Finland, should also be excluded.[221]

Other than those countries, the overall current and forecast quantity of used fuel and intermediate waste which is not committed to a national solution is presented in Table 5.3.[222]

The forecast includes only quantities of used fuel and intermediate level waste from existing reactors and from those that are currently under construction, such as in the UAE, or are in the advanced stages of development. To ensure the figure is conservative, no account has been taken for any new reactors being constructed beyond 2030 and the waste they would produce.[223]

In response to the Tentative Findings, comment was made concerning the inclusion of some new entrants in the forecast.[224] First, their combined contribution to the figure is small, meaning that if none ultimately developed programs, it would make no material difference to the conclusion that there is a large accessible market. Second, their inclusion is more than counterbalanced by two potential sources excluded from the analysis: used fuel from a new nuclear reactor developed after 2030 and used fuel from countries with domestic programs that might pursue an international disposal arrangement if it became available.

To provide some context, the current and forecast figures in Table 5.3, comprise about 25 per cent of current and forecast global used fuel inventories.[225]

Bearing those matters in mind, the Commission considers this estimate of a potentially accessible market to be conservative.

79. There is no existing market to ascertain the price a customer may be willing to pay for the permanent disposal of used fuel. However, willingness to pay may reasonably be inferred from analysing, in combination:

a. the costs that the customer might avoid in receiving the service

b. the costs of disposal estimated in countries with domestic permanent disposal programmes

c. the costs associated with reprocessing, being the only alternative long-term used fuel management strategy

d. the savings in capital costs for new nuclear power plants that might be enjoyed where access to permanent used fuel disposal reduces project risk and therefore lowers the cost of finance

e. distress costs, being the costs a nuclear utility may be willing to pay to avoid plant shutdown due to a lack of used fuel management options.

Countries with domestic nuclear power programs, and their nuclear power utilities, incur real costs associated with the storage and management of used fuel, such as developing and operating temporary storage, as well as identifying and developing options for long term permanent disposal domestically.

Because those entities and governments have an incentive to reduce expenditure where they can, such costs indicate what they might pay to avoid incurring their current liability for storage and disposal.[226] Rationally, they would be expected to be willing to pay an amount up to the present value of these future liabilities. This allows for a reasonable

Table 5.3: Total current and forecast used fuel and intermediate level waste inventories excluding countries committed to a national used fuel disposal solution

Total	Currently available	Forecast growth from 2015 to 2090 (current and declared new programs)	Total (2090)
Used fuel (tHM)	89 979	186 541	276 520
Intermediate level waste (m³)	269 471	512 959	782 430

Source: Jacobs & MCM

estimation of willingness to pay in the absence of an existing market for international used fuel disposal. This approach is not unusual: for any new service that is proposed to be offered by a commercial entity, this is precisely the question it must contemplate in fixing a price for its service.

It has been suggested in a response to the Tentative Findings that such an approach seeks to price an environmental externality.[227] Externalities are the costs, for example, that emitters of pollutants impose on the wider community at large but do not bear themselves. The cost of used fuel management and disposal is not an externality—it is a cost actually incurred by those utilities that must fund used fuel storage and disposal.

COMPONENT OF LCOE OF NUCLEAR ASSOCIATED WITH WASTE DISPOSAL

In analysis undertaken for the Commission, the relevant costs incurred by utilities were estimated based on the fraction of the levelised cost of electricity (LCOE) that can reasonably be attributed to used fuel storage and disposal. From this analysis it was estimated that the cost of transport, storage and disposal of used fuel was just under A$1.4 million per tonne, based on LCOE estimates used in the OECD's 2015 publication entitled *Projected costs of generating electricity*.[228] That LCOE estimation is robust because it averaged a spread of results for different reactors in nine OECD and non-OECD countries.

In a response to the Tentative Findings it was suggested that the analysis should have been based on the LCOE estimated by the Electric Power Research Institute.[229] Because the LCOE estimate used in the Institute's analysis is higher, it results in a higher estimate of inferred willingness to pay for waste disposal than that stated above—in fact more than 50 per cent higher as set out in Table 5.4.

The same response asserts that this approach is 'speculative' because the share of disposal costs for used fuel that forms part of LCOE remains unknown, given that no geological disposal facility has yet been constructed.[230] However, geological disposal projects are currently under construction in Finland, and there are others at an advanced stage of development elsewhere. The reported costs associated with such projects offer a valuable guide, and have been incorporated into recent LCOE analyses. As various projects advance, such costs will become more certain. There is sufficient information available to ensure that the approach used by the Commission is not speculative.

As part of seeking to determine a sound indication of willingness to pay, the Commission has considered that information in combination with other independent sources.

ESTABLISHED WASTE FUNDS

Along with costs to nuclear power utilities for used fuel disposal which might be avoided, the Commission has also considered the amount of funds held, and provisions made, for the future management, storage and disposal of used fuel by countries with nuclear power plants.

This approach takes advantage of the fact that in most countries with nuclear power programs, funds are put aside to address the costs of used fuel management, storage and disposal. The amount held in those funds is determined within those countries on the basis of domestic estimates of the future liability for used fuel storage and disposal. The additional benefit of utilising this approach is that such funds already exist. A reserve fund has been established sourced from a small margin on the cost of electricity sold. Those funds can only be used for the dedicated purpose of used fuel storage and disposal.

Detailed analysis undertaken for the Commission reported on the cost estimates used by a number of countries with domestic nuclear power programs for their domestic

Table 5.4: Calculation of used fuel storage, transport and disposal cost from the levelised cost of energy

	Levelised cost of electricity ($A/MWh)	Combined costs of fuel production and long-term management (A$/MWh)	Fuel storage, transport and disposal (A$/MWh)	Expected cost per tHM (A$ million)
OECD (2015)	147	9.6	3.40	$1.39
EPRI (2015)	180	21.3	5.33	$2.18

Notes: EPRI = Electric Power Research Institute, MWh = megawatt hour, tHM = tonne of heavy metal
Data sourced from OECD, Electric Power Research Institute

Table 5.5: Costs for used fuel disposal in countries with advanced projects

	Whole of life disposal costs (A$ million per tHM)
Finland	$0.65
Sweden	$1.13
Switzerland	$2.43

Note: tHM = tonne of heavy metal
Source: Jacobs & MCM

used fuel storage and disposal. That analysis arrived at an average disposal cost of about $A1.2m/tHM as an illustrative benchmark.[231] The Commission considers the most relevant and robust cost estimates are those from countries most progressed with geological disposal facility projects, including those which have constructed underground research laboratories. Costs estimated in those countries are set out in Table 5.5.

The key point to be drawn in Table 5.5 is not any single cost, but the range of costs for the advanced programs. Though the costs for the Finnish geological disposal facility are lower, they are not representative of the costs of advanced programs in Switzerland, Sweden and the United States. The Finnish costs are unlikely, for reasons of geology, to be representative of costs in other countries which require a domestic disposal capability. Therefore a median price for willingness to pay has been used.

REPROCESSING COSTS

The Commission has also considered the cost other countries are prepared to pay to manage waste, as such costs are an indicator of what they might pay for a permanent used fuel disposal service.

A tender was issued by the government of Taiwan to reprocess 1200 fuel assemblies (330 tHM) for an announced cost of US$356 million. This tender was later suspended by the Taiwanese parliament, which required approval of the budget and development of guidelines for the use of the Taiwanese fund for managing the disposal of used fuel. Though suspended, the arrangement was the policy of the utility and government and reflected the likely cost of that activity. That price represents, when converted, a willingness to pay $A1.54 million per tHM to manage its used fuel.[232] This is significant given that reprocessing does not eliminate the highly radioactive material, and it is still necessary to dispose of the immobilised vitrified high level waste.

This means that Taiwan would, in addition, still face disposal costs for the waste remaining after reprocessing. This suggests its willingness to pay for disposal for used fuel is higher.

A response to the Tentative Findings claimed that the reprocessing cost could not be used without offsetting the value derived from 'the sale of the reclaimed fuel'.[233] It was said this might mean the activity was cost neutral or 'could even have been a net profit'. This is incorrect. Reprocessing does not produce usable nuclear fuel. Rather it would be necessary to re-enrich the uranium and to undertake a further specific fuel fabrication process (to produce mixed oxide fuel), in addition to reprocessing, to make usable nuclear fuel. This additional process is itself very costly, and more expensive than the cost of fabricating fuel from natural uranium.[234] Furthermore, mixed oxide fuel, once used in a reactor, creates its own used fuel burden.

Moreover, the Taiwanese price has independent support. The quoted price for reprocessing is consistent with the fees charged to Japanese power companies under the Spent Nuclear Fuel Reprocessing Fund Act (Japan). The fee is ¥0.5 kWh generated (A$0.0055 kWh). This equates to A$2.24 million per tHM. [235] The total of secured funds held was reported to total ¥2.4 trillion (around A$26 billion) in March 2015.

REDUCED CAPITAL COSTS

A further approach in considering willingness to pay can be drawn from reductions in project risk and the resultant cost of capital by having reliable, fixed-cost waste disposal.[236] Nuclear power plant projects, as explained in Chapter 4, have high upfront capital costs and associated costs of finance. The cost of finance takes account of project risk, a component of which is the availability of a disposal solution for used fuel. If that risk can be reduced, or eliminated, it could lower the costs of finance.[237]

The significance of a lower rate of interest on debt to the ultimate cost of electricity generated is shown in Figure 5.12. It shows that the cost of electricity increases by US$7–$8 per MWh (about A$9–$10) for every additional 1 per cent increase in interest rates.

If a secure, waste disposal solution was able to reduce project risk and the cost of finance by the relatively small amount of 0.5 per cent, then it would have a value to the project developer equivalent to A$1.9m to $2.6m/tHM of used fuel. This would have a significant bearing on willingness to pay to secure such a long term arrangement.[238]

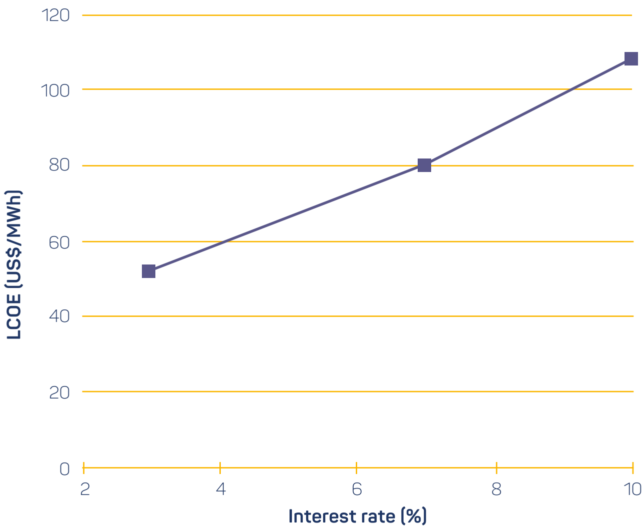

Figure 5.12: Variation in nuclear power LCOE with cost of capital

Note: LCOE = levelised cost of electricity.
Source: Jacobs & MCM.

DISTRESS PAYMENTS

A further approach is to consider distress payments or the payments that a nuclear utility may make to move used fuel to avoid unscheduled plant shutdowns. Given their capital intensity, nuclear power plants are required to operate for as much of the year as possible in order to be commercially viable. One potential reason for plant shutdowns is that the used fuel pools associated with those reactors are full and cannot be expanded, so options are not available to move fuel into dry storage. In that circumstance, the plant would have to shut down until a solution could be found. Plant operators would be willing to pay an amount up to or equal to the cost of the shutdown to avoid that outcome. Estimates based on the levelised cost of electricity suggest that this could be up to A$42m/tHM.[239]

80. A conservative baseline price for permanent disposal is A$1.75m/tHM for used fuel and $40 000 per m³ for intermediate level waste. These figures are not recommended prices. A higher figure could be negotiated in a range of circumstances.

Based on detailed analysis, the Commission considers that a reasonable baseline price for the purpose of assessing viability would be A$1.75m/tHM for used fuel. This is based on a reasonable baseline 'willingness to pay' estimate of A$1.95m/tHM, less A$0.2m/tHM to account for costs incurred by customers in preparing and delivering the waste to South Australia.

The financial modelling derived the baseline 'willingness to pay' figure of $A1.95m/tHM as a mid-point between the estimated highest and lowest willingness to pay.[240] Willingness to pay varies depending on a country's domestic circumstances. The lowest figure, being A$1.3m/tHM, represents the willingness to pay from countries with advanced programs for the disposal of domestically generated used fuel.[241] The highest willingness to pay figure was taken at A$2.6m/tHM, based on the position of countries without domestic disposal programs and/or with unfavourable domestic circumstances, such as small volumes of used fuel which would adversely affect economies of scale, and those nations with unfavourable geology.[242] For such countries, A$2.6m/tHM falls at the lower end of the range of benefits that are estimated to accrue if safe and secure used fuel disposal services were available.

The Commission considers this baseline 'willingness to pay' figure is reasonable based on the combined force of estimates derived from the range of sources explained earlier, many of which are higher, as shown in Figure 5.13.

The Commission does not consider that A$1.75m/tHM represents a price that any future program should charge any particular customer. It is simply a reasonable estimate for the purposes of viability analysis. As discussed above, there may be considerable opportunity for negotiating a higher price based on local circumstances in a customer country. A lower price may also be negotiated in return for the willingness of that customer, by pre-commitments or through finance, to assist in the development of the overall program.

The management and disposal of intermediate level waste commands a far lower willingness to pay than for used fuel.[243] This is due to a country's ability to stockpile intermediate level waste arising from nuclear power plants or other sources (such as decommissioned nuclear facilities) within shielded containers far more readily than used fuel.[244] Unlike used fuel, there are also no maximum limits for intermediate level waste storage at nuclear power plant sites.[245]

However, a 2011 report from the UK Department of Energy and Climate Change has suggested that £25 900 per m³ (in current terms, A$66 000 per m³) represents a levy that ought be imposed on nuclear power plant operators to reflect current costs and the potential for future increases.[246] In the interests of conservatism, and to address the costs of packaging and transport (which are not as well defined as for used fuel) a price to charge of A$40 000 per m³ is considered appropriate for the purposes of a viability analysis. It does not represent a recommended price for the same reasons explained in relation to used fuel.[247]

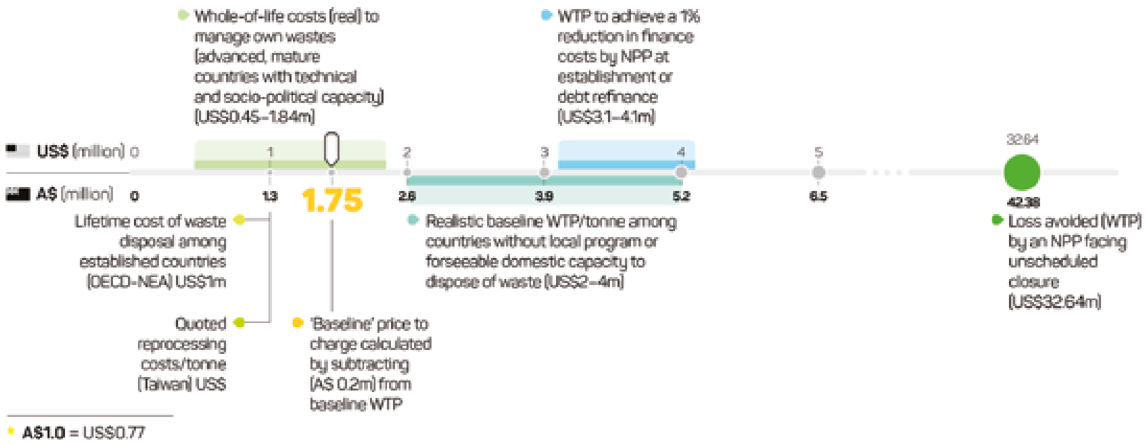

Figure 5.13: Summary of willingness to pay (A$ and US$ per tHM) based on published data and enhancements.

Notes: NPP = nuclear power plant, WTP = willingness to pay
Source: Jacobs & MCM

COMPETITION

It has been suggested in a response to the Tentative Findings that the estimated price has not taken account of currently non-commercial competition from other countries.[248] The Commission has taken account of the potential for competition in considering the necessary market share that would need to be captured for a proposed disposal facility in South Australia to be viable. Based on the financial analysis undertaken for the Commission, and assuming a range of prices charged per tonne of heavy metal received (including as low as $A1m), the facility would be viable if it received only 25 per cent of the accessible market discussed in Finding 78. It should be underscored that there is significant potential for other countries to develop a domestic solution, and for the project to still remain viable.

However, something more should be said about the claimed competition from Russia or China. Australia offers a unique political arrangement given its economic and political structures and international confidence in its non-proliferation credentials, as discussed in Chapter 8. This would make it an attractive disposal site to other countries.

That response to the Tentative Findings also suggests that competition might come from borehole disposal, which would be cheaper—asserting a cost of A$200 000/tHM from a single source.[249] That technology is, however, unproven. Recent reports suggest that substantial efforts towards demonstrating technical feasibility remain to be made (including in the report cited by the response for the cost estimate).[250] Recent analysis suggests the timeframe for implementing a borehole disposal facility is similar to those for a mined disposal facility.[251] Finally, there is no basis for the claim that interim storage facilities would be in competition with geological disposal. They are not regarded by any country as a long-term disposal arrangement.

It was also suggested that advanced reactor designs, such as fast reactors, might also compete with international used fuel disposal services[252], given that some designs can utilise reprocessed used fuel. Significant barriers to commercial deployment of fast reactors remain, as explained in Appendix E: Nuclear power—present and future. They have not been demonstrated to be cost competitive with conventional light water reactor designs. This suggests it is implausible that a fleet of fast reactors could be rapidly deployed internationally with the ability to consume existing and future inventories of used fuel. This is consistent with the findings of the Blue Ribbon Commission on America's Nuclear Future, following consideration of fast reactors as a means of recycling used fuel, that geological disposal is the best long-term solution for the United States.[253]

81. The project concept analysed comprises an integrated above-ground interim storage facility as well as an underground disposal facility.

Detailed analysis undertaken for the Commission assessed the viability of a proposed project for the storage and disposal of used nuclear reactor fuel and intermediate level waste based on the construction of both an above-ground interim storage facility and a separately located underground disposal facility. As discussed at Finding 84, an above-ground interim storage facility is required to generate sufficient cash flow to allow for construction of the underground disposal facility.

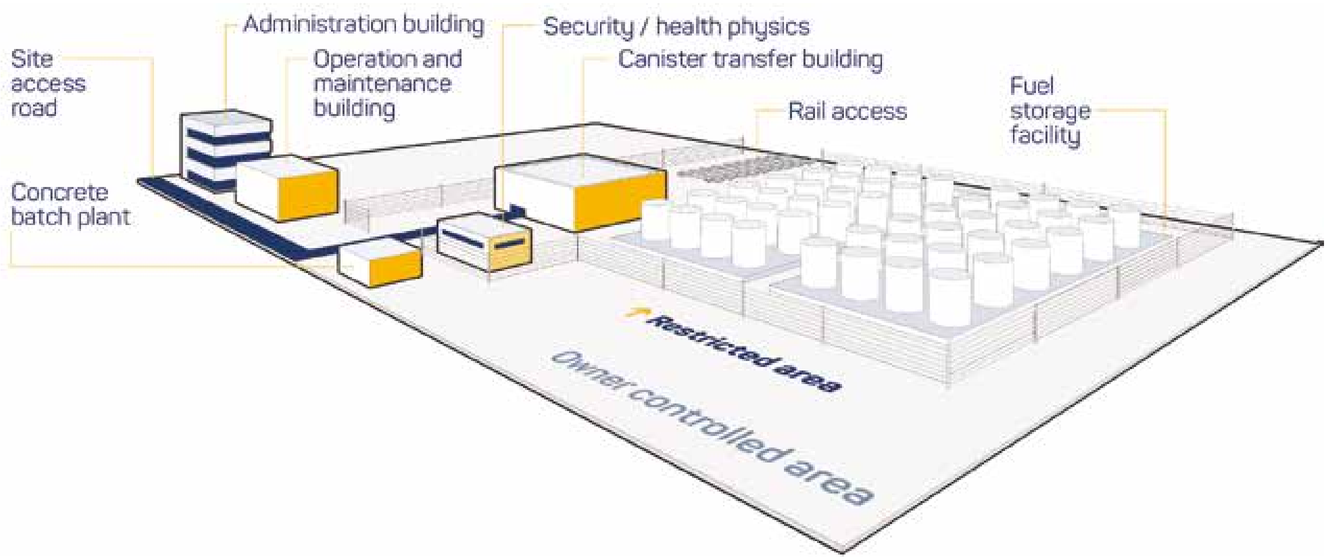

Figure 5.14: Conceptual layout of an interim storage facility

Image adapted from Jacobs & MCM

The viability analysis required assumptions to be made with respect to facility capacity. As a baseline scenario, it was assumed that a South Australian facility would be able to capture 50 per cent of the assessed accessible market discussed at Finding 78.[254] On that basis, the projected final capacity of the proposed geological disposal facility and intermediate depth facility would be 138 000 tHM of used fuel and 390 000 m^3 of intermediate level waste.[255] That figure does not represent a recommended capacity for a facility—nor the profit maximising capacity. Rather, it was a reasonable basis around which profitability could be assessed. Sensitivity analysis was undertaken on smaller and larger quantities. The results are explained later in Finding 83 and in further detail in Appendix J: Radioactive waste storage and disposal—analysis of viability and economic impacts.

INTERIM STORAGE FACILITY

An interim storage facility enables the safe above-ground storage of used fuel inside heavily engineered, purpose-built casks, as discussed at Finding 73.[256]

There are a number of conceptual designs for a used fuel storage facility. The design used for the costings in the financial analysis is based on a proposed facility in the United States shown in Figure 5.14.[257] This facility design has been subject to a comprehensive environmental impact assessment in the United States and two independent cost studies. With capacity to handle a volume of 4000 casks, the facility has a total footprint of 3.3 km^2, with the inner 0.4 km^2 designated as restricted-access to be used for used fuel storage. The facility would be directly accessible by road and rail, with cranes used for the transfer of casks.

DEEP GEOLOGICAL DISPOSAL

The disposal of used fuel in a geological disposal facility comprises two elements: a system of tunnels mined deep underground into geology designed to isolate the waste, and the containment of waste in specially designed containers, as discussed at Findings 70–71.

The financial analysis was undertaken on the basis of a design similar to the disposal facility on which construction has commenced at Olkiluoto in Finland at 400–450 metre depth.[258]

In the analysis, the geological disposal facility for used fuel is notionally collocated with an intermediate level waste facility, where those packages are placed in medium-depth vaults of 50–250 m.[259] A conceptual model for the intermediate level waste facility comprises medium-depth concrete caverns with overhead crane structures for the placement of waste packages, as illustrated in Figure 5.15.

The actual size of any facility underground depends on its design. This is affected by the heat emitted from the emplaced waste and by properties of the host geology. For the purposes of the viability analysis, horizontal emplacement caverns were assumed to be spaced apart by approximately 30 m and are accessed from parallel service tunnels. To deal with the quantities modelled, a total length in the order of 10 km would be required.[260]

Figure 5.15: Schematic illustration of a medium-depth ILW disposal facility, with artist's rendering of a disposal vault with overhead crane for ILW disposal

Note: ILW = intermediate level waste
Images courtesy of Jacobs & MCM and Radioactive Waste Management

The surface footprint would be comparatively small, with land area needed to accommodate road and rail access, underground access headers, waste reception and other supporting infrastructure, such as a site security and an administration building, as illustrated in Figure 5.16. Upon final storage and completion of underground backfilling, the surface facility would be removed and the land remediated.

82. Integrated facilities with the capacity to store and dispose of used fuel would be viable. They would be highly profitable at the target price of A$1.75m/tHM capturing only a relatively small share of the global inventory.

Integrated facilities with capacity to store and dispose of used fuel would be viable. On a number of realistic scenarios, such a facility would be highly profitable.[261]

The Commission draws that conclusion as a broad implication of financial analysis undertaken at its request. The critical significance of that analysis is not the conclusion that any particular concept is viable—rather it is the scale of the profitability and the wide range of scenarios under which a facility would be viable.

Forming a view about viability required estimations to be made as to the timeline over which facilities would be developed, the capital and operating costs, and revenues. It is important that those estimates be comprehensive and as far as possible be based on realised costs.

ESTIMATED TIMELINE FOR CONSTRUCTION AND OPERATION

The necessary steps of conceptualisation and planning, regional area surveys, detailed site investigations, site confirmation, facility design and construction were estimated to take between 20 and 30 years for the geological disposal facility and intermediate depth facility. This includes development of legislative and regulatory frameworks, and establishment of an underground research laboratory. [262]

That schedule is consistent with a program that capitalises on international experience in siting, designing and constructing geological disposal facilities and associated supporting infrastructure.

On that basis the conceptual timeline for the operation of those facilities involved:

- establishing an interim storage facility and associated transport infrastructure, including harbour, port and rail—11 years after project commencement[263]
- transferring used fuel and intermediate level waste from the interim storage facility to the geological disposal facility and intermediate depth facility—28 years after project commencement[264]
- ending the import of used fuel and intermediate level waste to port and interim storage facility—83 years after project commencement

Figure 5.16: Illustration of the surface facility for a geological disposal facility

Image courtesy of Radioactive Waste Management

- decommissioning and backfilling of geological disposal facility, triggering the commencement of the post-closure monitoring phase—120 years after project commencement.

ESTIMATED CAPITAL COSTS

To form a view about the full life cycle of costs, it was necessary to estimate the costs of the preliminary concept development, construction, operation, decommissioning and monitoring. Costs for enabling infrastructure (port facilities, rail, airport, road, electricity and water), site preparation, site services and buildings for onsite facilities, underground excavations and facilities and capital renewal also had to be included in the estimates.[265]

Capital costs were estimated as summarised in Table 5.6. The estimated capital cost of the integrated facilities was A$41 billion (current dollars, real and undiscounted).[266]

The capital costs estimated for individual facilities can be compared with the capital costs from similar completed or more advanced planned international waste disposal projects, as set out in Appendix J: Waste storage and disposal—analysis of viability and economic impacts.

The cost estimates in Table 5.6 include a projected additional contingency of 25 per cent to account for potential optimism bias.[267] This contingency takes account of external factors that might affect costs such as the potential for delays associated with regulatory approvals. The figure chosen reflects the measured difference in costs between the time of original announcement and the point of final project delivery for Australian public–private partnership projects. While a recent analysis conducted in the United Kingdom proposed a contingency of as much as 66 per cent,[268] a comparative Australian study showed that Australian projects outperform UK projects on the basis of cost.[269]

ESTIMATED OPERATIONAL, DECOMMISSIONING AND MONITORING COSTS

Operational costs were estimated from the detailed modelling that has been undertaken for the Olkiluoto facility in Finland and are summarised in Table 5.7. More than half of those costs were attributable to the waste encapsulation facility required for the purpose of containing the waste for long-term disposal.

Although the project is assumed to be closed and decommissioned 120 years from the year of commencement,

Table 5.6: Estimated capital costs for used fuel storage and disposal under the base case scenario

Facility	Capital costs (A$ 2015 million)	Size of facility	Cost per unit waste stored (A$ in 2015)
Low level waste disposal facility	820	81 088 m^3 (LLW)	10 100 per m^3
Interim storage facility	2200	72 000 tHM (used fuel)	30 600 per tHM
Geological disposal facility and intermediate depth disposal	38 000	140 000 tHM (Used fuel) 400 000 m^3 (ILW)	-
Total capital cost	41 020	N/A	N/A

Note: ILW = intermediate level waste, LLW = low level waste, N/A = not applicable, tHM = tonnes heavy metal
Source: Jacobs & MCM

Table 5.7: Estimated operating costs for all facilities

Operating costs	Consumables, equipment leasing, land transport and utilities (A$ million per annum (2015)	Labour (A$ million per annum (2015)	Facility maintenance and upgrades (A$ million per annum (2015)
Combined facilities (before Year 40)	673	125	80
Combined facilities (Years 40 to 120)	560	125	80

Source: Jacobs & MCM

a provision was made in the form of a reserve to fully fund the costs of decommissioning, remediation of surface facilities, closure, backfill of underground facilities and the ongoing, post-closure monitoring phase. That reserve fund is funded from the operating revenues of the facility. Estimates of its growth are based on a low risk investment strategy.

On a baseline scenario, where the funds were drawn from operating revenues so as to maximise the profitability of the facility, the reserve fund would generate about $32 billion by year 83.[270] The criterion that it be profit maximising means that funds begin to accumulate in year 45 of the project, just under four decades before they are required.

The costs that a reserve fund would finance include an annual surveillance allowance of $550 000 for 1000 years for both an interim storage facility and a geological disposal facility.[271] Such funds are necessary at disposal to assure both the community and the monitoring staff that the passive safety features of these facilities are functioning as expected. However, it is important to note that a contingency for surveillance and possible intervention is not an alternative to developing a geological disposal facility that is passively safe.

Responses to the Tentative Findings suggested that the Commission give consideration to the effect of resourcing the fund as soon as revenues are received and without discounting some future liabilities. Taking account of those responses, the Commission considered an alternative scenario for the reserve fund, with 10 per cent of annual operating profits being collected from year 11 and put into a reserve fund. Further, ongoing operating costs were assumed to be undiscounted and equal to A$5.5 million per year, growing at 1 per cent per year in real dollar terms for 1000 years. The reserve fund on that alternative scenario basis would accumulate approximately A$46 billion (in current dollars) by year 60. That amount would significantly exceed estimates of future liabilities.

ESTIMATED REVENUE

The Commission analysed the stream of revenues that would be earned on the basis that it received 138 000 tHM of used fuel over 70 years. It was assumed that the facility would have the capacity to receive and handle the annual rate of imports presented in Table 5.8.

Estimated revenues have been assessed on the basis that payment in full would be made upfront on delivery of fuel to a South Australian port. As discussed in Finding 86, a pre-commitment before project commencement would provide added assurance that capital costs are fully covered before construction began.

A similar profile for importation rates was developed for intermediate level waste on the assumed import rates. The result is that the bulk of revenues are earned over about the first half to two-thirds of the facility's operational life. As can be seen in Figure 5.17, revenues commence being earned a decade after the project begins operation and cease a little more than 70 years later when used fuel stops being delivered.

Given that costs are incurred, and revenues earned, in the future, the value of future revenues and costs needs to be 'discounted' to reflect that a dollar earned a year from today does not have the same value as a dollar today. This assessment was undertaken using a discount rate for project cash flows at both 4 per cent and 10 per cent to reflect discount rates commonly used for investments made by either public or private entities respectively. The effect of the application of each discount rate on project viability is shown in Table 5.9.

83. An integrated storage and disposal facility remains viable even in the event of:

a. large cost overruns

b. the receipt of a significantly lower price for providing a disposal option for used fuel and intermediate level waste

c. smaller market share

d. delays in the development of the facility

An integrated interim storage facility and deep geological disposal facility would be viable in the face of a wide range of more adverse circumstances or market conditions either taken individually, or in combination.

It is significant to appreciate, however, that the risk presented by adverse circumstances or conditions is mitigated by the fact that the proponent has a choice as to whether to proceed with the project. The facility would not be developed unless the proponent could secure a pre-commitment of used fuel volumes at a price to fully fund the development of the project (see Finding 86). This mitigates risks presented by adverse market conditions.

Table 5.8: Annual quantity of used fuel received by South Australia over project life (rounded figures)

Years	Used fuel received (tonnes HM per year)
0–11	0
11–38	3 000
39–64	1 500
65–74	950
75–84	400
85–120	0

Note: HM = heavy metal
Source: Jacobs & MCM

Table 5.9: Project net present value on a real, pre-tax basis under the baseline scenario

Discount rate	Project net present value (A$ 2015)
4%	51.4 billion
10%	14.4 billion

Source: Jacobs & MCM

The project remains viable if costs are significantly higher than estimated. As discussed at Finding 82, cost estimates already include a 25 per cent uplift to account for optimism bias reflecting the potential to underestimate actual project costs. Even when substantial additional margins (50 per cent) representing cost overruns are added to projected costs (either to capital or operating costs, or both), the conceptual facility remains highly viable, as shown in Table 5.10.

The project also remains viable at a significantly lower range of potential prices for used fuel and intermediate level waste than that identified by the Commission as the reasonable baseline (A$1.75 million), including at a price of $750 000 per tHM assuming 50 per cent of the accessible market is secured. This is depicted at Figure J.7 in Appendix J.

The project also remains viable where only a quarter of the forecast accessible market is able to be secured (69 000 tHM).[272] Figure J.6 at Appendix J shows the viability of the project at three assumed market shares at a range of prices. The project is viable, even in the event of both a smaller market share and a lower price than that the Commission considers as the reasonable baseline estimate.

84. In addition to smaller scale integrated storage and disposal facilities, other facility configurations would also be viable provided that they incorporate an interim above ground-storage facility.

An interim storage facility is required as part of any project concept to enable revenues to be secured early so that later investments to develop the capital intensive underground disposal facilities can be financed.

Financial analysis undertaken for the Commission, in addition to assessment of an integrated storage and disposal facility, assessed other facility configurations.[273]

The analysis showed that the collocation of some facilities that make up the integrated waste storage and disposal concept would deliver substantial cost savings by not duplicating common use transport infrastructure.[274] It further showed that if all, and not just some, facilities were located at a single site, some of these benefits would be lost by increases in other costs.[275] This is a result of the challenges and additional time associated with designing, licensing and constructing a range of facilities at one location.

85. Facilities for the storage and disposal of used fuel would need to be owned and controlled by government.

The level of assurance required to secure the long-term trust and confidence of potential customers for such facilities would be more easily conveyed were the proposed facilities to be subject to government ownership and control, as well as independent oversight. Further investigation and development of potential long-term international used fuel storage and disposal facilities would need to proceed over many years. In the early phases of any further and more detailed assessment of the viability of a proposed project, discussions and then negotiations would need to occur between the project proponent and potential customers overseas. Such discussion and negotiation will need to proceed subsequent to, or in parallel with, similar discussions at the nation to nation level, in order to provide assurance as to the credibility of the project, and commitment to compliance with international requirements for safety, security and non-proliferation.

Further, risk and reward should be linked. Assuming responsibility for the safe and secure storage and disposal of international used fuel carries with it significant risks, which, given the long-term radiotoxicity of such high level waste for humans and the environment, potentially affect future generations of South Australians. The potential substantial economic benefits associated with this activity in part result from the complexity and duration of the risk. It is, therefore, appropriate that those benefits are secured for future South Australians.[276]

A response to the Tentative Findings suggested that, given the extent of the risk involved, control and ownership of storage or disposal facilities ought to rest in private hands, along with the associated responsibility.[277] This argument fails to link risk with reward. The public is also more likely to be assured of the safe and effective management of the relevant risks over the long term where the facilities are government owned and controlled, rather than operated by a profit-driven entity whose ongoing presence cannot be guaranteed. A special purpose project company owned by the South Australian government would be able to source and engage appropriate private sector expertise in developing and operating any such facilities.[278]

86. Through pre-commitment from client countries the state would not need to assume significant commercial risks in incurring capital costs to develop the project.

The development of the integrated storage facility would require an initial investment of about $2.4 billion over ten years, in advance of revenues from used fuel being received.[279] Those expenditures would need to be financed. As shown in Figure 5.17, projected revenues received within the first two years of waste being received would repay these costs.

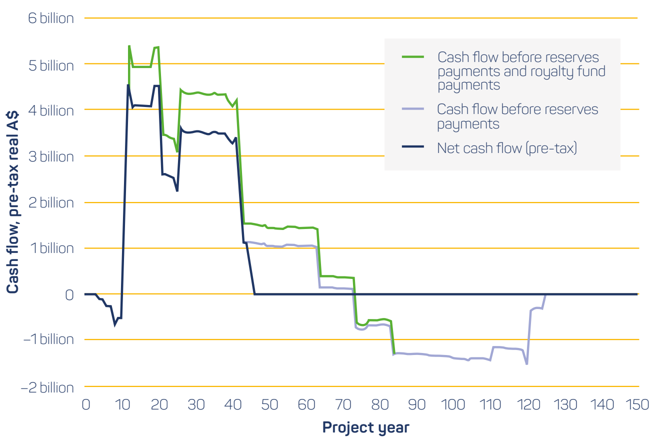

Figure 5.17: Cashflows for an integrated waste storage and disposal facility

Source: Jacobs & MCM

Table 5.10: Sensitivity of project viability to overruns in capital and operating costs, including State Wealth Fund net present value

Discount rate	Project net present value at 10% discount rate (A$ 2015 billion)
Baseline	14.4
Capital costs + 50%	12.8
Operating costs + 50%	13.3
(Capital and operating costs) + 50%	11.7

Source: Jacobs & MCM

However, incurring those costs does not mean that the state should assume significant commercial risk.[280] A prudent operator would not commence construction of the integrated storage facility and initial development of the disposal facility without having obtained sufficient contractual pre-commitment to the disposal of used fuel. In short, because the state has a choice as to whether or not to engage in the development, it need not incur substantial expenses until it is certain that these will be covered by future revenues.

Financial analysis undertaken for the Commission shows that a pre-commitment of 15 500 tHM of used fuel at a price of $1.75m/tHM would be sufficient to meet the cost of developing not only a storage facility but a minimum scale disposal facility based upon the modelled infrastructure.[281] That quantity is equivalent to the used fuel already held by a number of individual countries within the accessible market.[282]

Separate to a contractual pre-commitment there are other means of ensuring that the commercial risk of development can be addressed. One such means would be to secure direct investment in the project by a country seeking to dispose of its used fuel in the facility. Another might be to secure project finance in return for a right to dispose of used fuel.

87. Both an analysis of financial viability, and a risk assessment in the form of a safety case, must be conducted and considered together in order to decide whether to proceed with the development of a disposal facility.

Financial viability and safety of a disposal facility can be assessed in a two-staged approach.

The first step is to prepare a financial assessment of expected revenue and cost flows to determine the profitability of the project.

The second step is to undertake a formal long-term risk assessment in the form of a safety case for a geological disposal facility. As discussed at Finding 69, this requires an objective and detailed consideration of a baseline case and a range of possible alternative future scenarios, based on the chosen geology and engineered barriers.

The results from both stages must then be weighed together, with careful consideration of the nature of institutional arrangements, to ensure that benefits endure and the risks can be managed.

The risk assessment is necessary only for proposals that first pass financial assessment. If the project is not considered profitable, the process goes no further. This is why the risks associated with the construction of a large nuclear power station in South Australia have not been addressed in detail in this report.

In the case of nuclear waste storage, however, the findings from the financial assessment are positive, as explained in Findings 75–86. The financial assessment has assumed the establishment of institutional arrangements, namely a State Wealth Fund and a Reserve Fund, to provide enduring benefits and to cover the cost of post-closure risk management.

The Commission has in Findings 66–74 described the hazards associated with the disposal of used fuel and made a preliminary assessment of the associated long term risks. A more detailed assessment in the form of a safety case would be required before any decision to develop such a facility in South Australia. The significant timeframe over which this would be undertaken and the associated costs are outlined in Appendix J, Table J.9.

This two staged approach takes full account of the long term safety implications of developing a facility. It is not necessary, or meaningful, therefore in the financial analysis to attempt to cost potential adverse outcomes (and in doing so to assess the chance of them occurring far into the future) as has been suggested in one response to the Tentative Findings.[283]

ECONOMIC IMPACTS

88. An integrated interim waste storage and disposal facility has the potential to generate substantial profits and significant direct employment.

An integrated interim waste storage and disposal facility, which received 138 000 tHM of used fuel and 390 000 m^3 of intermediate level waste at the baseline price estimates of \$1.75m/tHM for used fuel and A\$40 000 per m^3 for intermediate level waste, is assessed to generate:

- total revenue (in undiscounted terms) of more than \$257 billion, with total costs of \$145 billion.[284] The undiscounted revenues and costs give a clear perspective on the current dollar costs incurred and revenues earned by the operation. This offers a sense of the substantial scale of the operation, and its potentially significant impact on a small economy.
- total annual revenue of \$5.6 billion a year over the first 30 years of operation and about \$2.1 billion a year until waste receipts were notionally planned to conclude 43 years later.
- over the life of the project, a net present value of profits of more than \$51 billion at a discount rate of 4 per cent.[285]
- throughout the establishment phase of the project, between 1500 and 4500 full-time jobs are estimated to be created, peaking during construction of the underground facilities in years 21 to 25 of the project. About 600 jobs, in operations at both sites, and at a head office, are expected to be created once facility operations begin.[286] In the absence of a detailed construction program, it is difficult to estimate levels of direct employment with any certainty. In the analysis undertaken for the Commission, estimates as to direct employment have been made, based on an allocation of a reasonable proportion of construction costs to labour requirements.

The presence of such a large specialist industry in the state would be likely to support the development of associated industries serving both local and international markets, including: specialist transport and logistics equipment (shipping, rail and road), and possibly including used fuel storage cask design and manufacture for transport and interim storage; and used fuel encapsulation containers for final disposal.[287] The Commission has not analysed the potential development of these ancillary industries in any detail. The Commission did, however, visit the Holtec Manufacturing Division (HMD) plant in Turtle Creek, Pennsylvania. HMD performs heavy manufacturing of dry cask storage systems for used nuclear fuel and ancillary equipment, as well as heat exchanger components for nuclear reactors, using predominantly stainless steel, carbon steel and concrete. The manufacturing plant employs around 400 people, predominantly as welders and machinists, and supplies around 50 per cent of the international market for used fuel transport and storage casks. It appeared to the Commission that this type of activity would be feasible in South Australia.

89. Investing in such facilities would have additional benefits for the whole South Australian economy with:

a. substantial addition to gross state product estimated to be an additional 4.7 per cent by 2029–30 (A\$6.7 billion)

b. substantial contribution to employment of an additional 9600 jobs by 2029–30.

In addition to the revenues that are derived from the operation of facilities to receive used fuel, other benefits flow to the economy.

Those benefits arise from the consequences of expenditures in South Australia to construct and operate the facilities, expenditures by companies and individuals who earn an income from the activities, or by providing services to it, and government expenditure of some of the profits. There are other indirect effects, including those generated from investments made by government in order to grow the funds in special arrangements for the benefit of future generations.

Economic modelling analysis undertaken for the Commission to estimate the potential flow-on benefits across the wider economy of engaging in these activities is described in detail in Appendix J: Waste storage and disposal—analysis of viability and economic impacts.

That modelling estimated that an integrated waste storage and disposal facility would:

- grow gross state product by an additional 4.7 per cent (A\$6.7 billion) by 2029–30[288]
- grow total employment by 1.9 per cent or 9600 full time jobs by 2029–30 (including the direct employment already discussed)[289]
- add \$3000 per person to gross state income in 2029–30 in current dollars.[290]

Those benefits will accrue beyond 2029/30 over the operational life of the facility. Table 5.11 shows the potential benefits to the economy in 2029/30 and beyond 2049/50.

Those estimates were calculated using South Australia's projected share of GST revenue to 2019 released by the Commonwealth Grants Commission. That share was assumed not to change thereafter because the

Table 5.11: Economic benefits of investment in an integrated waste storage and disposal facility

	2029–30	2049–50
Growth in gross state product (A$ 2015)	4.7% ($6699 million)	3.6% ($7367 million)
Growth in gross state income (A$ 2015)	5.0% ($6837 million)	3.6% ($7290 million)
Total employment (full-time jobs)	1.9% (9603 FTE)	1.4% (7544 FTE)

Note: FTE = full time equivalent
Source: Ernst & Young

Commonwealth Grants Commission does not outline a method for determining any state's share of GST revenue over time periods greater than two to three years.[291]

A separate analysis was undertaken to evaluate how the development of an integrated waste storage and disposal facility would affect the South Australian Government's share of GST revenue. While the determination of a state's share of GST revenue is complex and dependent on a range of factors, the greater the level of economic activity in a state, the lower that state's share of GST revenue would be expected to be. The assumptions on which that analysis are based are explained in Appendix J: Waste storage and disposal—analysis of viability and economic impacts.[292]

That analysis showed that South Australia's share of GST in 2050 would be about $1.25 for every dollar of GST generated in the state, which is similar to its present level and slightly above its average over the last decade.[293] That is a result of the fact that South Australia's share of GST revenue is expected to sharply increase in the next two to three years with the further decline of manufacturing, and that revenues from this activity would then return the state's share to about their present level: see Figure J.10 in Appendix J:

90. Given the intergenerational nature of the proposed activity, it would be essential to develop enduring mechanisms to:

a. secure funds to ensure that benefits are shared across the community, in the form of a State Wealth Fund

b. secure funds for decommissioning, remediation and long term monitoring, in the form of a Reserve Fund

c. establish scientific and research capabilities to ensure knowledge and skills are developed which focus on used fuel and its disposal.

The facilities proposed are intergenerational in nature. They would take decades to develop, operate for a century, and be monitored following their closure.

Such a facility would require special arrangements to be established to ensure the benefits of engaging in the activity flow to all future generations of South Australians and that there are resources to manage the risks associated with assuming responsibility for the safe, secure storage and disposal of international used fuel.[294]

STATE WEALTH FUND

A specific, legislated fund would need to be established to secure a proportion of the profits derived from the storage and disposal activities for the benefit of future generations. It would need to be segregated from state consolidated revenue.[295]

Payments out of the fund would need to be restricted and depend upon assessment, by an appropriately expert and independent body, against criteria aimed at securing benefits for current and future generations of South Australians. A portion of the fund might also be quarantined from withdrawal in order to ensure that a predictable level of interest payments might be guaranteed each year, which can be applied for activities of broad public benefit.

Modelling suggests that the value of such a fund could be substantial. For example, based on the project concept and associated revenues discussed at Finding 87, a State Wealth Fund into which all project dividends are deposited and on which interest accrues annually at 4 per cent would, even if half of the interest were withdrawn each year, grow on average at more than $6 billion a year for more than 70 years to reach about $445 billion before notional waste deliveries are planned to cease.[296]

The strategic objectives of the fund would be for the government to develop, in consultation with the South Australian community. Potential options for use of funds could include, for example, projects to advance the interests of Aboriginal communities, the rehabilitation and improvement of the natural environment, and the development of state infrastructure.

RESERVE FUND

Public assurance as to the state's ability to safely manage the long-term risks inherent in used fuel storage and disposal would be enhanced by the establishment of a separate and quarantined fund to finance decommissioning, remediation, closure and long-term monitoring activities.[297] Such a fund, referred to here as a Reserve Fund, would serve a different purpose than, but should be established in addition to, a State Wealth Fund. A Reserve Fund, if properly managed and secured, would guarantee the availability of a reasonable amount of funds to cover both anticipated and unanticipated costs of operating and closing the facilities, and remediating the sites. The proposed scope and operation of a Reserve Fund, as modelled in the financial analysis undertaken for the Commission, has been discussed at Finding 82.

RESEARCH AND SCIENTIFIC CENTRE OF EXCELLENCE

Research capabilities to support the nuclear waste disposal industry would need to be developed in parallel with an education and skills building program.[298] This could involve establishing an associated Centre of Excellence within the state to undertake research focused on long-term characteristics and behaviour of used fuel and high level waste, and its disposal. Research could include, for example:[299]

- alternative forms of disposal including innovations in disposal concepts
- alternative forms of processing and packaging used fuel for storage and disposal
- waste volume reduction techniques
- geological emplacement techniques
- degradation of used fuel while in storage and in a disposal facility
- security and anti-intrusion systems.

A Research Centre of Excellence, based at one of the South Australian universities and modelled on those developed in Australia in relation to other disciplines such as quantum technologies, could be integrated into the existing national nuclear research and expertise capability.[300] It could partner with national and similar overseas institutions and potentially serve a global client base.

Such a Centre of Excellence might also partner with the geological disposal facility proponent to establish and operate an underground research laboratory. The development of such a facility should precede and support detailed site characterisation by allowing for in-situ experiments, so as to inform underground disposal facility design and construction.[301] Many overseas programs for the development of long-term high level waste underground disposal facilities have benefited from the early establishment of an underground research laboratory.[302] For example, in developing the safety cases for their high level waste disposal facilities, the Swiss and French proponents relied heavily on extensive investigations and testing undertaken in their underground research laboratories.[303] The costs of developing an underground research laboratory have been included as part of the project concept which was assessed for viability in modelling analyses undertaken for the Commission.

91. Legislative amendments would be required and regulatory arrangements would need to be developed for the licensing, management and operation of a facility.

The construction or operation of a facility for storage and disposal of nuclear waste, along with the importation or transport of nuclear waste, is unlawful in South Australia.[304] The amendment or repeal of the *Nuclear Waste Storage Facility (Prohibition) Act 2000* (SA) would therefore be required prior to any substantive progress being made in further developing any proposal. Supportive regulatory arrangements are a key component to building confidence in prospective customers.

While not prohibited under federal laws, constructing a facility for the storage or disposal of radioactive waste would require approval under both the *Nuclear Non-proliferation (Safeguards) Act 1987* (Cth), pursuant to Australia's treaty obligations under the Nuclear Non-proliferation Treaty, and the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act), as a 'nuclear action' likely to have a significant impact on the environment.[305] The EPBC Act incorporates a requirement for any proposal to undergo a general environmental assessment, and confers approval authority on the Federal Minister for the Environment. It is not a regime specifically targeted to the regulation of nuclear facilities.

The *Australian Radiation Protection and Nuclear Safety Act (1998)* (Cth) would not apply, given its application only to Commonwealth agencies, entities and contractors as 'controlled persons' under that Act.[306] This means that, based on current federal legislation, the role of Australia's present peak radiation safety authority, ARPANSA, would be limited to providing advice to the Federal Minister in relation to an EPBC Act application and to approving permits for the importation of consigned material.

General environmental assessment requirements would also apply at the state level to the development of these types of facilities due to the application of both the *Development Act 1993* (SA) and *Environment Protection Act 1993* (SA). However, as laws directed to regulating a wide range of activities, neither of these regimes and the regulations made under them contain specific provisions directed to assessing the development of waste facilities.

The radiation protection regime set out in the *Radiation Protection and Control Act 1982* (SA) would apply to any entity wishing to construct or operate a storage or disposal facility, and require a licence from the Environment Protection Authority (EPA). A licence to construct or operate such a facility will only be granted if the applicant establishes it is fit to hold a licence, and that it holds appropriate knowledge and expertise to safely carry out the activities authorised by the licence.[307] As part of this, the applicant must show that the facility it proposes to construct will comply with all regulatory requirements.[308] An applicant must also comply with any conditions imposed on the licence by the EPA, which may be imposed at the time of granting the licence, or subsequently. This regime currently only applies to the storage of low level waste throughout South Australia.

While elements of each of these differing regimes are relevant to the regulation of the development, construction, operation and closure of radioactive waste storage and disposal facilities, new regulatory arrangements would need to be established. Such arrangements would need to provide appropriately stringent and targeted requirements, including a specific licensing regime and the establishment of an appropriately independent and credible nuclear safety regulator at either the state or federal level. Although legislation at both levels is likely to continue to be required, it needs to be developed and implemented as part of a coherent and coordinated regime. A specific regime is also required to provide project certainty to any project proponent, and assurance to the public, potential customers and the international community as to the preparedness and commitment of the state and federal governments to the safe and secure development of the industry in South Australia.

There is significant international guidance available from both the IAEA and overseas regulators charged with overseeing high level waste management in various countries that can be drawn upon.[309] Further discussion as to the regulatory arrangements likely to be required is set out in Chapter 10.

FUEL LEASING

92. Storage and disposal of used fuel potentially offers a pathway to engage in other fuel cycle activities in South Australia through the business model of fuel leasing.

'Fuel leasing' is used to describe a number of commercial nuclear fuel supply arrangements. In this discussion, it is concerned with the sale of UOC or a value-added form of nuclear fuel from South Australia to overseas nuclear power utilities before its return to this state for storage and eventual disposal.[310] It could include, for example, arrangements where a South Australian entity:

- arranges to 'lease' locally mined uranium to a nuclear power utility, on the basis that the resulting used fuel would be returned to South Australia after a certain period of time. The utility would, as per current arrangements, continue to arrange for the conversion, enrichment and fuel fabrication of that uranium with existing service providers
- offers a 'cradle to grave' nuclear fuel service to a nuclear power utility, by arranging for nuclear fuel to be fabricated and delivered to the utility's power plant in its final form, on the basis that the used fuel would be returned to South Australia after a certain period of time.

Fuel leasing has the potential to address the two principal objections to the export of uranium, being non-proliferation concerns, and safe and reliable used fuel management:

- An assured supply of nuclear fuel through a leasing arrangement can potentially discourage the development of domestic proliferation-sensitive nuclear technologies, namely enrichment capabilities.[311] In addition, the return of used fuel for disposal removes the rationale for reprocessing and allows for the used fuel to be consolidated in one location. The siting of that disposal facility in a nation with strong non-proliferation credentials, coupled with appropriate regulatory oversight, would ensure that the material remained accounted for over the long term.[312]
- Given the considerable expense and uncertainty for utilities (and nations) inherent in the long-term storage and management of used fuel, the ability to offer a safe and secure disposal opportunity along with fuel supply services could be of significant value.[313] It may in particular be attractive to nuclear newcomer countries, in terms of offering an acceptable solution to used fuel management, which might assist in achieving and maintaining social consent for new nuclear power facilities. It might also be attractive to nations with relatively modest nuclear

power programs (and without significant market power) to avoid the need to construct domestic geological disposal facilities, or negotiate multiple front-end service contracts in unfamiliar markets.[314] The ability for nuclear power utilities to structure their nuclear fuel supply as a lease rather than a capital acquisition might additionally have positive financing or taxation implications, depending on local laws.[315]

Any fuel leasing arrangement in South Australia would, however, be dependent upon it establishing an international or regional long-term storage and geological disposal facility for used fuel.

The fuel leasing concept is not new and has generated global interest, including endorsement by the International Atomic Energy Agency Expert Group on Multilateral Approaches to the Nuclear Fuel Cycle.[316] While the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management requires countries to manage their own waste, it does not preclude the return of used fuel as part of a fuel leasing arrangement. Organisations such as the International Framework for Nuclear Energy Cooperation continue to explore how such arrangements might be practically implemented.[317] Along with international or regional used fuel disposal facilities, and international fuel banks, fuel leasing services may meet non-proliferation objectives by reducing the need for additional enrichment or reprocessing facilities to be established in multiple countries.[318] Australia's strong non-proliferation credentials, discussed further in Chapter 8, would support its hosting of such international or regional nuclear fuel cycle services and facilities.

Despite significant international analysis and discussion, Russia is the only country to date to undertake a type of fuel leasing service, via the state-owned Rosatom Overseas Inc. (Rosatom).[319] Rosatom offers international customers a variety of integrated services associated with the construction and operation of its nuclear power plants, including guaranteed fuel supply, and take-back of used fuel for storage and eventual reprocessing.[320] Russia, however, does not have a permanent repository for the long-term disposal of nuclear waste.[321]

A number of countries, such as Iran, Turkey and Vietnam, have entered agreements with Rosatom for nuclear power plant construction combined with fuel supply and take-back services, indicating that such services are potentially viable as part of a bundled offering.[322] Other nations have also expressed positive interest in the fuel leasing concept. The 2008 Policy of the United Arab Emirates on the Evaluation and Potential Development of Nuclear Energy states that the UAE would 'prefer to source nuclear fuel via fuel leasing or similar arrangements that relieve it of any of the requirements of safeguarding spent fuel.'[323] The High Level Bilateral Commission established pursuant to the nuclear cooperation agreement signed by the USA and South Korea last year has been tasked with examining the management of used nuclear fuel, the promotion of nuclear exports and assurances of nuclear fuel supply, including the potential for South Korea to participate in fuel leasing services in future.[324] There are a number of other jurisdictions that may be interested in used fuel take-back options in the medium to long term given their domestic circumstances.[325]

As discussed in Chapter 3: Further processing and manufacture, neither the conversion nor enrichment of uranium, nor nuclear fuel fabrication, are likely to be viable as standalone or combined activities in South Australia in the coming decades. However, the ability to combine further processing services with a guaranteed take-back option for the safe and permanent disposal of the used fuel would provide a unique market offering. In this way, the establishment of a used fuel geological disposal facility in South Australia may provide an opportunity to enter new and otherwise closed markets.

At present, a new nuclear power plant is typically purchased by a power utility from a reactor vendor under a 'turnkey contract' whereby the new reactor is delivered ready to operate, and with around a 10 year supply of nuclear fuel. Once further fuel reloads are required, nuclear power utilities operate in a global market for 'front-end' uranium conversion, enrichment and fuel fabrication services, along with the market for the supply of uranium ore. Utilities typically contract with a number of different and competing service providers in procuring each separate step necessary for the supply of nuclear fuel.[326] There are also vertically integrated fuel suppliers, such as AREVA and Rosatom, who offer a fully fabricated fuel service to nuclear utilities. The offering of a 'back-end' solution as part of either a new nuclear reactor development, or ongoing nuclear fuel supply services, would be unique and potentially valuable.[327]

93. A staged process to the development of any fuel leasing service would seem to have the best prospects for success. There are, however, a number of challenges to the implementation of fuel leasing which would need to be overcome.

Potential customers are unlikely to be prepared to seriously consider any fuel leasing proposal until planning and development of a geological disposal facility is sufficiently progressed. Assuming that occurs, the following staged approach to fuel leasing might be explored:

Step 1: the operator of the South Australian geological disposal facility seeks to partner in a fuel leasing arrangement with either:

- a major LWR vendor competing in the market for new-build large nuclear power plants. Such a vendor may be interested in increasing their competitive strength by offering a fuel take-back service along with the construction of, and initial fuel supply for, their plant design.[328] The reactor vendor would remain, as at present, responsible for securing uranium supply, along with conversion, enrichment and fuel fabrication services
- a major SMR vendor competing in the market for new-build small nuclear power plants. Such an arrangement may be particularly attractive to an SMR vendor seeking to enter smaller, nuclear newcomer countries most suited to SMR deployment. The lack of resources and/or suitable geology to support domestic used fuel geological disposal in many such countries, along with proliferation concerns associated with long term storage of used fuel at multiple SMR sites, are seen as impediments to the future commercialisation of SMRs. The ability for an SMR vendor to offer a product that overcomes those impediments could facilitate market entry[329]
- a nuclear fuel vendor, and/or
- large nuclear utilities, which are experienced in obtaining uranium and other front end services as required.[330]

Step 2: If successful over time, sufficient business volume may accumulate to justify investment in multilateral conversion and enrichment facilities in South Australia, the products of which can be integrated into the fuel leasing arrangement.[331] This would include considering partnerships with existing commercial entities engaged in delivering those services, or seeking to commercialise new technologies for the delivery of such services, through new facilities in South Australia.[332]

There are a number of international and commercial considerations that would impact on the feasibility and viability of any fuel leasing proposal based on a South Australian geological disposal facility.

INTERNATIONAL CONSIDERATIONS

As with international used fuel storage and disposal, fuel leasing arrangements would require agreements to be concluded at both the international and commercial level.[333] Support from and via the IAEA could be helpful.[334] Australian Government support to conclude and maintain the necessary international agreements is essential to underpin any fuel leasing arrangements in this state, and would need to progress in advance of any commercial offers or negotiations.[335]

Supportive bilateral arrangements between Australia and a potential customer country, addressing at least regulatory arrangements for import and export authorisations, transport, and applicable liability regimes, would be required to provide the necessary foundation for commercial arrangements.[336] Beyond bilateral arrangements with customer nations, additional treaties may be required with other countries to provide advance consent for the import, export and retransfer of nuclear fuel subject to such consent rights.[337] These arrangements are likely to be significantly simplified where there is an established and operating geological disposal facility in South Australia, which complies with international requirements for safety, security and non-proliferation assurance. It may not be possible to conclude the commercial arrangements necessary to support fuel leasing in the absence of such assurances.[338]

COMMERCIAL CONSIDERATIONS

Assuming the existence of an appropriate geological disposal facility, and the necessary international support, any fuel leasing service would need to be commercially attractive and market-driven to be viable.[339] It would need to be economically attractive for a nuclear utility to enter into a bundled arrangement for their fuel supply, rather than accessing each of the services separately, including long-term storage and disposal of used fuel.[340] This would require detailed market analysis.[341]

Such a bundled service would likely need to be offered in competition with existing 'uranium only' local and international uranium producers, so that Australian uranium would continue to be available on the open market. Australian uranium producers have not been supportive of fuel leasing concepts in the past.[342] Structuring fuel leasing services as an optional market-based offering may overcome the potential difficulties with fuel leasing raised by some uranium producers.[343]

Assuming the existence of commercial customers for a South Australian fuel leasing service, the terms of any lease arrangement with a customer will need careful preparation and negotiation. There may be significant uncertainty surrounding how to appropriately cost and structure payments for fuel leasing services, particularly in advance of the costs of long-term used fuel storage and disposal being well understood.[344] Other complex matters that would need to be addressed include:

- the terms of the arrangement, and related matters including legal title to, and responsibility, liability and insurance for any damage caused by, the uranium or nuclear fuel throughout and at the conclusion of the agreement, including during transit

- warranties as to nuclear fuel quality and composition, and use within a reactor, so as to ensure the resulting used fuel would meet relevant storage and disposal facility waste acceptance criteria
- warranties as to the acceptance by the lessor entity of the used fuel, and as to the construction and operation of relevant storage and disposal facilities consistent with international requirements for safety, security and non-proliferation
- consequences of any failure to secure any necessary export and import authorisations
- how disputes between the parties would be resolved
- taxation and accounting implications.[345]

94. The economic analysis suggests fuel leasing, comprising conversion and enrichment facilities in South Australia, would provide modest additional economic benefits to the conduct of waste storage and disposal activities alone.

Analysis undertaken for the Commission by Ernst & Young has indicated that combining investment in both conversion and enrichment facilities in South Australia with waste storage and disposal has the potential to deliver economic benefits to the state beyond those that might be achieved by investment in waste storage and disposal alone.[346] The modelling suggests the additional benefits would be modest: an addition to gross state product of about 0.5 per cent in 2029–30 ($900 million), and an increase in employment of approximately 1000 jobs by 2029–30, continuing over the life of the conversion and enrichment facilities.[347]

That analysis, along with the analysis undertaken by Jacobs and MCM into the viability of long-term storage and disposal facilities alone, indicates that exploring a fuel leasing concept may provide the ability for South Australia to viably enter the front end of the nuclear fuel cycle. Some of the potential economic returns flagged within the Jacobs & MCM report as a result of developing international used fuel storage and disposal facilities could be directed to support the establishment of front-end facilities and services in this state.[348]

The construction and operation of conversion and enrichment facilities in South Australia would provide broader economic advantages in the form of new highly skilled employment.[349] As discussed in Chapter 3, establishing these facilities would require partnership with existing overseas suppliers in order to transfer the necessary technology for use in local operations.[350] It is conceivable that such technology transfer, and the establishment and operation of such facilities in this state, could foster additional local research and development into advances in front-end nuclear fuel cycle activities.[351] It is also conceivable that South Australia could become an important regional hub for nuclear fuel cycle services, if it is able to viably and securely establish and operate conversion and enrichment facilities, alongside international used fuel storage and disposal facilities.

NOTES

1 H Jenkins-Smith, C Silva, K Ribberger, R Rechard, R Rogers, M Pendleton & L Price, *Summary of approaches for consent-based siting of radioactive waste management facilities: evidenced-based considerations and case studies*, Center for Risk and Crisis Management and Sandia National Laboratories, United States, 2013.

2 Transcripts: Neri, p. 1390; Mallants, pp. 1344–45.

3 Transcript: Jenkins-Smith, pp. 1071–72. Blue Ribbon Commission on America's Nuclear Future, *Report to the Secretary of Energy*, United States, 2012, pp. viii, 23.

4 Transcript: Ellis, pp. 1442–44.

5 Transcript: Neri, p. 1393. Submission: Arius Association, p. 15. The development of the Konrad facility in Germany has proceeded without community consent, as discussed in Appendix H.

6 Jenkins-Smith et al., *Summary of approaches*; C Pescatore & HC Jenkins-Smith, *Reflections on siting approaches for radioactive waste facilities: Synthesising principles based on international learning*, report prepared for the OECD–NEA Forum on Stakeholder Confidence, Radioactive Waste Management Committee, NEA/RWM/R (2012)5, NEA, 2012, p. 10.

7 Department of Industry, Innovation and Science, 'Australia's radioactive waste', Australian Government, 2016, http://www.radioactivewaste.gov.au/radioactive-waste-australia/australias-radioactive-waste

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