Nuclear Waste Management in Australia

Submission to the Uranium Mining, Processing and Nuclear Energy Review

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Introduction

Australia possesses a very large proportion of the world's identified reserves of uranium. With three mines in operation, 110,000 tonnes of U_3O_8 have been exported since 1986 and this after enrichment has probably yielded 13,000 tonnes of fuel for nuclear reactors. Current exports at the annual rate of 11,000 tonnes yield 1,100 tonnes of enriched uranium.

The development of laser enrichment by Silex Systems Limited and Synroc, a method of immobilising high level radioactive waste from nuclear fuel, invented by Ted Ringwood and refined by ANSTO, are both local contributions to the technology of the nuclear fuel cycle. However Australia is yet to benefit by developing businesses around these opportunities.

It is clear looking at the added value through the nuclear fuel cycle (Table 1) that mining uranium and its enrichment are significant value added parts of the fuel cycle.

However the great unmet need is the final disposal of spent fuel or the extracted wastes from reprocessed fuel. Many countries are searching for a publicly acceptable system for nuclear waste disposal.

Australia may be in a unique position to offer safe long term burial of waste. This will not only make a substantial contribution to world security but also offer a very large business opportunity. **The key element is the development of an internationally accepted and approved high isolation disposal site that would be unique.**

The waste management system would include a disposal site, a railway and the associated seaport docking facilities.

A repository would establish contracts with waste generators. The contracts would cover:

1. Stable solid waste shipments to the dedicated port of the repository;
2. transport of the wastes to the repository location;
3. encapsulation of the wastes in a disposal container;
4. storage of the wastes at the surface of the repository; and
5. disposal of the wastes.

It should be noted that these operations are not bulk handling but rather special high-tech handling of hundreds of tonnes of material at a time.

The Australian repository may accept title to the materials for disposal at the point of acceptance for shipping or depending on the contractual negotiations at the point where it touches Australian soil. Title will be retained throughout all operations until closure of the repository. Title will then be passed to the national government.

Radioactive Waste Disposal

The problem of long term disposal of radioactive waste affects all developed countries. Even countries with no nuclear power or research reactors use radioactive isotopes for medical and industrial purposes and these isotopes must be safely stored until their levels of radioactivity are no longer dangerous. Countries which produce nuclear energy or have research reactors such as Australia have an even greater challenge, as nuclear reactors produce wastes which have very high initial levels of radioactivity. The time needed for safe disposal is neatly illustrated below. High level waste takes at least 5,000 years before its activity becomes similar to that of a uranium orebody. Thus wastes need to be safely isolated for extremely long times, up to a million years, if the highest standards of radiation safety are to be met.

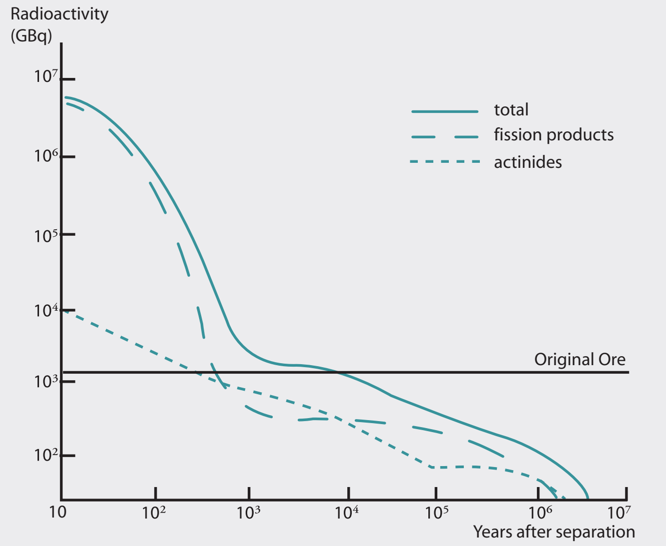
Nuclear power utilities throughout the world have already produced 270,000 tonnes of spent nuclear fuel. During the next 25 years, this inventory will increase by approximately 12,000 tonnes annually, assuming that no new power plants are constructed.

Table 1: Fuel cycle costs for 1kg of UO_2 reactor fuel in US$, 2006

Process	Amount required	Unit Cost	Cost	Fraction of Total
Fuel Front End				
U_3O_8 :	8 kg	$90	$720	27%
conversion:	7 kg U	$12	$84	3%
enrichment:	4.8 SWU	$122	$586	22%
fuel fabrication:	kg		$240	9%
Total Fuel In			**$1,630**	62%
Fuel Back End				
Reprocessing/Disposal	kg		$1,000	38%
Total Fuel Cycle			**$2,630**	100%

Source: Uranium Information Centre

Figure 1: Decay in radioactivity of high-level waste
from reprocessing one tonne of spent PWR fuel



GBq = 109 becquerel
The straight line shows the radioactivity of the corresponding amount of uranium ore. Both scales are logarithmic
Source: OECD NEA 1996, *Radioactive Waste Management in Perspective*

Every country that has reviewed the problem of long term disposal of their radioactive waste has reached the same conclusion: for the greatest long term security, their wastes should be placed in a geologically stable underground repository (see Table 2). Such a repository is typically designed much like an underground mine, with ramps or shafts and elevators to access the underground workings, and waste packages inserted into the walls or floors of excavated tunnels. The repository protects people against direct exposure to radiation from the unwanted nuclear materials and must be sited and designed so that there will be no transport mechanisms capable of moving significant amounts of radioactivity to the point where humans, or other terrestrial or aquatic animals might be exposed.

Since the 1960s, extensive research programs have been underway to develop the technology required to identify and characterise suitable disposal sites, to encapsulate and store the wastes, and to demonstrate the long term safety of a disposal facility. With few exceptions, the scientists and engineers involved in these programs have concluded that the technology exists to safely dispose of these wastes.

Despite these efforts, however, no repositories for disposal of spent nuclear fuel or high level waste have been constructed. Additionally, the majority of the public believe that the problems of disposing of radioactive waste have not been solved and that radioactive wastes represent a serious threat to the environment. Why is there such a discrepancy between the opinions of informed scientists and those of the public? One reason for this lack of public confidence lies in distrust of the necessarily untried technological solutions that are being proposed for the different disposal programs. While most scientists have confidence that all of the key questions have been answered, the public is not yet convinced. Given a requirement for **engineered** components to survive intact for orders of magnitude longer than any existing human works, the public's scepticism may not be unreasonable.

If the public is sceptical of high technology solutions, why not seek out disposal sites whose geological properties would intrinsically provide reliable long term containment or better isolation of the wastes? There are several geological formations, worldwide, that have been highly stable for hundreds of millions of years. If such geological formations exist, and they support no processes capable of transporting buried wastes to the human environment, it would be possible to avoid reliance on these engineered barriers.

While it may appear obvious that countries should seek the best available sites for radioactive waste disposal, it turns out that essentially all of the countries currently planning for radioactive waste repositories have limited choices in the types of geological system in which they could bury the wastes. Some of these countries are geologically active, with complex and unstable geological structures. Others have older, more stable geology, but have to deal with active groundwater flowing in the rock fractures, which could eventually start to dissolve the radioactive wastes and bring them up to the biosphere. While such sites can be perfectly safe, they require highly effective underground engineered barriers in order to be safe for all time. Lastly, many countries over the time periods that must be considered have regularly experienced periods of glaciation, which can profoundly affect the climate, flow of surface and subsurface waters, and erosion.

A useful approach is to identify the characteristics of '**a high-isolation region**', which could contain one or more repositories, sites that would be intrinsically safe, and to then look for its characteristic signatures worldwide. If such regions could be found, in countries that are politically stable and which have safe transportation routes, they could be a key to solving the world's radioactive waste disposal problem.

Table 2: Waste Management for Spent Fuel from Nuclear Power Reactors

Country	Policy	Facilities and progress towards final repositories
Belgium	Reprocessing	Central waste storage & underground laboratory established Construction of repository to begin about 2035
Canada	Direct Disposal	Underground repository laboratory established Repository planned for use 2025
China	Reprocessing	Central spent fuel storage in LanZhou
Finland	Direct Disposal	Spent fuel storages in operation Low & intermediate-level repositories in operation since 1992 Site near Olkiluoto selected for deep repository for spent fuel, from 2020
France	Reprocessing	Two facilities for storage of short-lived wastes Site selection studies underway for deep repository for commissioning 2020
Germany	Reprocessing but moving to direct disposal	Low-level waste sites in use since 1975 Intermediate-level wastes stored at Ahaus Spent fuel storage at Ahaus and Gorleben High-level repository to be operational after 2010
India	Reprocessing	Research on deep geological disposal for HLW
Japan	Reprocessing	Low-level waste repository in operation High-level waste storage facility at Rokkasho-mura since 1995 Investigations for deep geological repository site begun, operation from 2035
Russia	Reprocessing	Sites for final disposal under investigation Central repository for low and intemediate-level wastes planned from 2008
South Korea	Direct Disposal	Central interim HLW store planned for 2016 Central low- & ILW repository planned from 2008 Investigating deep HLW repository sites
Spain	Direct Disposal	Low & intermediate-level waste repository in operation Final HLW repository site selection program for commissioning 2020
Sweden	Direct Disposal	Central spent fuel storage facility in operation since 1985 Final repository for low to intermediate waste in operation since 1988 Underground research laboratory for HLW repository Site selection for repository in two volunteered locations
Switzerland	Reprocessing	Central interim storage for high-level wastes at Zwilag since 2001 Central low and intermediate-level storages operating since 1993 Underground research laboratory for high-level waste repository, with deep repository to be finished by 2020.
United Kingdom	Reprocessing	Low-level waste repository in operation since 1959 High-level waste is vitrified and stored at Sellafield. Underground HLW repository planned.
USA	Direct Disposal	Three low-level waste sites in operation 2002 decision to proceed with geological repository at Yucca Mountain

Sources: Uranium Information Centre, OECD NEA, 1996, *Radioactive waste Management in Perspective*, IAEA, 1992, *Radioactive Waste Management An IAEA Source Book*, & IAEA *Bulletin* 40,1; 1998, OECD NEA 1999, *Geological Disposal of Radioactive Waste - review of developments in the last decade.*

Radioactive Waste Disposal with a High Isolation Site

The concept of a natural site means that the repository must be simple and superior in safety terms to other disposal systems. A high isolation region profile was selected after reviewing geologic formations around the world, and considering the types of natural barriers inherent in the geology and in the present and possible future conditions at or near the surface called collectively the biosphere.

Signatures of a high isolation site are listed in Table 3. The following sections discuss the key signatures selected to identify high isolation regions, and how they contribute to isolation of a repository in the region.

Minimising Groundwater Flow Volumes

The primary driving pressures for groundwater flow come from water's propensity to flow from higher to lower elevations, which is just as significant for groundwater as it is for rivers and streams. Rainfall seeps into the ground at higher elevations, and percolates down to emerge in valley-floors. Thus, a site with very flat topography (Signature 1) has very low driving forces to move groundwater.

Similarly, a flat site with minimal precipitation, and high potential evaporation (Signatures 2 and 3), minimises the amount of water infiltrating into the ground, and reduces the volume of flowing groundwater. Such sites typically have a deep, flat water table, where the small amount of net precipitation which reaches the water table flows along its upper portions to discharge in low-lying evaporative marshes or playas. In a warm, dry climate the air may have the potential to evaporate far more water than the annual precipitation. Also desert plants are very efficient at collecting and using soil moisture, which is then evaporated by the process of transpiration. As a result, very little water actually reaches the water table.

A dense sedimentary formation (Signature 4) may have a very low permeability and few fractures capable of transmitting water, so that even under high pressure gradients negligible flow would occur. (For example, oil and gas reservoirs, which are typically capped by dense sedimentary formations, are able to contain high-pressure fluids for geological times.) Unlike crystalline rocks (such as granites), sedimentary rocks can have a small ability to slowly deform, so that ancient fractures in the rock can be completely healed.

Saline groundwater (Signatures 5 and 6), which are often associated with desert sites, are denser than fresh water, and tend to collect in stagnant or near-stagnant underground 'pools' beneath shallow, faster moving, fresher waters. Particularly if the salinity increases with depth, such pools may be essentially completely immobile, with no deep groundwater flow occurring at all. Also, a repository in such conditions could be robust even if accidentally drilled into by a future generation, as there would be no driving force to lift contaminated water up

Table 3: Signatures of a High Isolation Site

Signature	Description	Purpose
1	Very flat topographic surface	Low flow, max. travel time
2	Low annual precipitation (desert or near-desert)	Low flow, max. travel time
3	High potential evaporation rates	Low flow, max. travel time
4	Dense sedimentary (clay/shale) formation	Low flow, max. travel time
5	Saline or brackish, un-drinkable groundwater	Low flow, max. travel time, min. exposure
6	No fresh water aquifers	Min. exposure
7	No underlying mineral resources	Min. exposure, long term stability
8	Climate stable for a very long time	Long term stability
9	Low erosion rates	Long term stability
10	Flat geologic units, simple stratigraphy	Long term stability, predictability
11	Low seismicity	Long term stability
12	At least 200 metre thick disposal unit	Engineering requirement
13	Disposal units well below groundwater table	Predictability

Table 4: Isolation Barriers Used in Different Repository Concepts

Site Classification	Engineered Barriers			Natural Barriers See text and Table 3 Signatures			
	Waste Form	Container	EBS	Low	Travel Time	Max. Dilution	Min. Exposure
Swedish (granite)	E	H	E	E		E	
Other European, Canadian, Japanese (granite)	E	Φ	E	E			
Belgian (clay)	E	Φ		H	E		
United States (unsaturated welded tuff)	E	Φ		E	M		M
Sub-seabed (irretrievable)	E	Φ		H	E	H	H
High isolation site	E	Φ		H	H		H

Symbols

H Highly effective barrier (adequate on its own to meet long term safety requirements)

E Effective barrier (two or more, combined, required to meet long term safety requirements)

M Minimal barrier (sufficient on its own to prevent catastrophic releases, but inadequate for long term safety requirements)

Φ A relatively short lived (thousand year plus) container provides a robust package for emplacement operations, and to protect the wastes during their period of most intense radioactivity

(blank) No significant barrier

EBS Engineered Barrier System

the borehole, which would tend to eventually plug itself naturally with filling sediment.

Maximising the Time to Reach the Biosphere

All of the factors that reduce the amount of flowing groundwater also act to increase the time that it would take to transport radioactivity from the repository to the biosphere. In addition, a dense sedimentary formation (Signature 4) may also have chemical properties that act to retard the transport of many dissolved radionuclides. If the groundwater at the site is essentially stagnant, the only significant release mechanism might be the extremely slow process of diffusion through the rock pores.

Minimising the Possibility of Human Exposure

Signatures 5 and 6, requiring saline groundwater, mean that it is unlikely that future generations will utilise the water for drinking, stock, or irrigation. In an arid environment, the ultimate destiny of shallow saline groundwater is likely to be a salt marsh or saline lake bed, where it is highly unlikely that significant human populations would be exposed to radioactivity.

Signature 7, requiring that there be no underlying mineral resources, serves to minimise the potential for accidentally drilling through the repository in the distant future. Such drilling would not destabilise a high-integrity site, but could result in accidentally exhumed wastes creating a local area of higher radioactivity.

Other Factors

Most of the other signatures sought relate to ensuring that the site will be stable for at least a million years, and to 'predictability', which refers to having a simple, testable geology and being controlled by simple geological/ hydro geological processes that are well understood. As discussed below, geological simplicity may be an essential prerequisite for successfully proving a site's safety.

High-Isolation Site Concept Compared to Others

Different countries have selected different geologic media, and engineered barrier systems, to evaluate for potential repositories. The Table 4 indicates the level of reliance on the different types of barriers for some of the major national repository programs, and compares them to the High Isolation site.

World Wide Locations of High Isolation Regions

A preliminary global survey points to several regions that may contain sites matching the high isolation signature. However, many apparently promising areas do not meet all of the criteria. For example, the Sahara desert is flat and dry, but is geologically very young, does not offer long term climatic stability, and contains fresh water aquifers. The only extensive areas that appear to have the potential for high isolation sites are in Australia, Namibia/South Africa, the Terim Basin (in China), and in southern Argentina.

In addition to the signatures discussed above, there are a number of non-geological criteria that limit the number of possible locations for a repository site. For example, suitable transportation corridors must exist. Also, the host country must be politically stable, must accept the presence of a repository, and must have the necessary institutions and technology to safely oversee its development and operation. After considering all such considerations, truly ideal high-isolation sites are very rare, and in their own way represent a geological resource of great value to humanity.

National and International Political and Commercial Consequences

The political and commercial consequences of a repository in Australia are potentially far reaching. The public and political hurdles that must be overcome are well known and have been delineated by opinion polls over many years.

International security considerations

Those countries that have produced nuclear weapons must deal not only with the reactor wastes, but also with quantities of plutonium and highly enriched uranium, which, while not themselves highly radioactive, are the essential components for creating nuclear explosives. (The US spent fuel standard calls for spiking plutonium with high level waste in preparation for burial.) With the waning of the global nuclear arms race, and inventories of tens of thousands of nuclear bombs, the risk of nuclear weapons and the fissile materials necessary to make them falling into the hands of terrorists or rogue states is alarming. The problem of safely protecting for the indefinite future materials coming from the disassembly and destruction of these weapons is one of the most urgent international issues of our time. Geological disposal into a secure Australian repository has been identified as one of the few promising ways to solve this problem. While other countries might be politically stable no other countries with 'high isolation characteristics' would meet the mandatory test of political stability.

Anything that will rapidly improve the ability of responsible governments to remove these dangerous materials from inadequately protected and unguarded sites will be regarded as a significant step forward in world security.

International validation of the disposal of commercial fuel in regional or international repositories for environmental and efficiency reasons has been validated by the recent completion of negotiations of a Vienna Convention on the safe management of radioactive wastes and spent fuel (IAEA). This convention, supported by Australia contains provisions for the transfer of radioactive wastes across international boundaries for disposal. It is likely that at least two international repositories will be required. This means that Australia would not be the only international repository for the nuclear waste products from commercial nuclear power production.

National Considerations

The greenhouse debate has heightened the view that the world should be searching for sources of energy that do not generate greenhouse gases. Australia will be making a substantial contribution to this search by encouraging the nuclear power option to be responsibly considered.

Market for Waste Disposal

The amount of material available for disposal and the pricing of its disposal are key elements in the development of a repository and are discussed below.

i) Market Size

Data for the amount of spent fuel discharged and forecast to be discharged until the year 2025 yields the following conclusions:

- There are about 270,000 tonnes of spent fuel and its derivatives (from reprocessing) in inventory throughout the world.
- Until the year 2020, about 12,000 tonnes will be discharged annually,
- Omitting the US, Russia and the fuel sent to reprocessing accounts for a reduction of 4,500 tonnes annually leaves an effective annual market of 7,500 tonnes.

Considering the amount of fuel in inventory today as well as the annual discharge rates for the foreseeable future there is ample market for a high isolation site. Even restricting the inventory to Australian sourced uranium would be a substantial market.

ii) Pricing

An industry estimate at a price for disposal is $1M per tonne of spent fuel. This price is comparable to the cost of nuclear fuel reprocessing. There are, however, estimates of the burial cost available in most countries that have repository programs. These estimates range from $0.56M per tonne in Sweden to $0.39M per tonne in the United States. It should be noted that these costs have been revised significantly upward on a regular basis in recent years, further there is some evidence that the present sites will be found to be unsuitable, and that no one is utilising a high isolation site

It should be noted that the projected price corresponds to a cost of approximately 0.4 cents per kwh for a light water reactor plant.

Conclusion

Australia may be in a unique position to offer safe, long-term burial of spent fuel and high level waste given the geology of our continent. Even restricting the waste to Australian-sourced uranium would be a substantial market of 1,000 to 2,000 tonnes of spent fuel annually. The repository, which is essentially a deep underground mine, would cost between $1.5 billion and $2.5 billion. There are very good reasons to host waste from any source. Australia's twin stabilities, geological and political, offer splendid advantages. Both Indonesia and Japan lack our geological stability and providing a repository would enable their sensible development of nuclear energy.

The disposal of spent fuel and high level waste in Australia is a major opportunity. It is not only a significant business but also a major enabling step for the use of nuclear power, an important contribution to nuclear safety, countering proliferation and a major contribution to our region.

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