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Management of Radioactive Waste in Australia

January 2011

1. Introduction

The application of radioactive materials and radiation provides numerous benefits to people and society, and plays a significant role in everyday life. This includes scientific, medical, agricultural and industrial applications. It is a natural consequence of such applications that waste is generated. The radioactive waste needs to be managed in a safe and secure manner. Radioactive waste management involves treatment, conditioning, transportation, storage and disposal of all categories of radioactive wastes, including administrative, operational and safety-related activities. The primary objective is to isolate the radioactive waste from people and the environment for the period the waste remains hazardous.

The Australian Nuclear Science and Technology Organisation (ANSTO) is Australia's centre of nuclear expertise, and provides advice and information to the government and the public on matters related to the use of nuclear technology. ANSTO has significant experience in managing its own radioactive waste, which has been largely generated from scientific research and nuclear medicine production. It also maintains strong links with counterpart organisations overseas and participates in international forums on radioactive waste management.

This paper describes the current international best practice in radioactive waste management, as defined primarily by the International Atomic Energy Agency (IAEA), and implemented successfully by many countries that utilise nuclear technology. This advice is based on many years of experience and scientific research, for all classes of radioactive waste, including disused radioactive sources and used nuclear fuel. Examples of existing practices are provided. The Australian case is also considered against this international best practice background.

2. Context

Radioactive material, including radioactive waste, contains unstable elements (radionuclides) that decay over time. Radioactive decay causes the emission of radiation in the form of charged particles and gamma rays. For any given mass of material, radioactivity diminishes with time as radioactive elements decay into more stable elements[1]. In some classes of radioactive waste, the radioactivity decays relatively quickly to a level low enough for the material can be reused or disposed of as normal domestic or industrial waste. In this way, radioactive waste differs from some other categories of hazardous waste, such as mercury, heavy metals or asbestos, which remain hazardous indefinitely[2].

Radioactive waste is a subset of the much broader category of hazardous wastes. Current global hazardous waste production is approximately 400 million tonnes per annum. Radioactive waste from nuclear power plants and the fuel cycle support facilities comprises approximately 0.4 million tonnes per annum, or approximately 0.1% of global hazardous waste[3]. Low level and short-lived intermediate level waste is already being disposed of in many countries. Over three quarters of all radioactive waste (on a volume basis) has already been sent for disposal[4].

Because of the wide variety of nuclear applications, the amounts, types and even physical forms of radioactive wastes vary considerably. They include solid, liquid and gaseous

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[1] The decay period is different for each radioactive element; some materials decay in seconds, whilst others take thousands of years or even longer. It should be noted that, in general terms, the decay period is inversely related to the radiation hazard; a material that is decaying slowly is therefore emitting only low levels of radiation.

[2] Based on their chemical interactions with living matter.

[3] Nuclear Energy Agency-OECD, 'Radioactive Waste in Perspective', No 6350, 2010.

[4] Nuclear Energy Agency-OECD, 'Radioactive Waste in Perspective', No 6350, 2010.

wastes. Some wastes (such as the small radioactive sources found in smoke detectors) carry little or no safety or security risk; however, some other wastes are highly radioactive and must be managed appropriately to address safety and security issues.

Internationally, the major source of radioactive waste has been from the development and production of fissile materials for weapons manufacture, especially dating from the cold war period (often referred to as 'legacy wastes'). The major sources of non-military waste internationally are fission products and contaminated and activated materials from nuclear power generation, including various process wastes arising from parts of the nuclear fuel cycle such as reprocessing, and the decommissioning of nuclear facilities.

2.1 The Australian situation

In Australia, radioactive waste is produced from the use of radioactive materials in scientific research, industrial, agricultural and medical applications and the production of radiopharmaceuticals. A large proportion of Australia's current production of radioactive waste comes from the national landmark infrastructure at ANSTO. This includes waste from the operation of the OPAL reactor, the decommissioning of the Moata reactor and in future, the decommissioning of the HIFAR and OPAL reactors. HIFAR operated over several decades and supported research and the production of radioisotopes for medical and other applications.

Naturally Occurring Radioactive Material (NORM) is another source of radioactive waste, and is particularly relevant to the mining and minerals industries. There are also relatively large amounts of 'historic' waste in storage that arose from various activities, such as CSIRO research into radioactive ores, or previously commonly used radioactive materials, such as radium used in luminous dials.

ANSTO conducts extensive research in the area of radioactive waste and has developed wasteforms to treat radioactive wastes using a technology called HIP (hot-isostatic pressing) under the ANSTO Synroc brand. The waste is combined with a ceramic material and using the high pressure and temperature of the HIP, it is compressed and sealed into a ceramic wasteform. This process is designed to safely encapsulate the waste for tens of thousands of years. The product is then stored inside shielded containers. In December 2009, the US Department of Energy made a decision to use HIP technology to process and store 4400m^3 of high level waste stored at the Idaho National Laboratory. Further information can be found at www.synrocansto.com.

Australia has accumulated approximately 4,000 cubic metres (m^3) – less than the volume of two Olympic swimming pools - of low level and short-lived intermediate level radioactive waste from over fifty years of research, medical and industrial uses of radioactive materials. The Commonwealth is responsible for about 3,800 m^3 of this waste. The States and Territories hold the rest (around 200 m^3)[5].

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[5] http://www.ret.gov.au/resources/radioactive_waste/radiation_radioactive/Pages/AmountsofRadioactiveWasteinAustralia.aspx

Figure 1. Storage of low level waste (LLW) at ANSTO. LLW contains low levels of radioactivity, and therefore shielding is not required to protect workers during storage or transportation.

This total does not include uranium mining wastes, which are disposed of at mine sites. Over half the volume of Australia's current low level and short-lived intermediate level waste is some ten thousand drums of lightly contaminated soil - a legacy of CSIRO research into processing radioactive ores during the 1950s and 1960s.

Australia produces a very small quantity of low level and short-lived intermediate level radioactive waste when compared globally. Each year, Commonwealth agencies produce approximately 35 m^3 of such radioactive waste - less than the volume of one shipping container. States and Territories together generate annually another 5 to 10 m^3 of this waste. By comparison, Britain and France each produce annually around 25,000 m^3 of low level waste.

Australia currently holds approximately 535 m^3 of long-lived intermediate level radioactive waste (that is, radioactive waste requiring shielding for handling, transport and storage). This 535 m^3 is equivalent to the volume occupied by a typical house[6]. This includes waste from the production of radiopharmaceuticals, wastes from mineral sands processing, and used sources from medical, research and industrial equipment. Intermediate level radioactive waste contains radioactive material at a concentration that may require shielding for safe handling and transport.

The Commonwealth is responsible for about 430 m^3 of this waste and generates less than 5 m^3 per year. The States and Territories hold the balance (that is, about 100 m^3) and produce about 2 m^3 of this waste annually[7].

2.2 Stakeholders and Accountable Bodies responsible for Radioactive Waste in Australia

The management of radioactive waste arising from Commonwealth activities is governed by rigorous national and international (IAEA) standards.

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[6] 12 metres wide by 15 metres in length by three metres high

[7] These figures include waste held by private entities, which are subject to State or Territory regulation.

All nuclear activities and uses of radiation and radioactivity by Commonwealth agencies are regulated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) in accordance with the *Australian Radiation Protection and Nuclear Safety Act* and *Regulations*. This includes licensing and regulation of the management and storage of radioactive waste by Commonwealth agencies. ARPANSA have adopted the *IAEA General Safety Guide No. GSG-1 Classification of Radioactive Waste* as *Radiation Protection Series No. 20 – Safety Guide for the Classification of Radioactive Waste (2010)*:

http://www.arpansa.gov.au/Regulation/index.cfm

The Department of Resources, Energy and Tourism is responsible for implementing the Commonwealth Government's policy on radioactive waste management, including selection of a site or sites for a central waste management facility:

http://www.ret.gov.au/resources/radioactive_waste/Pages/RadioactiveWasteManagement.aspx.

The management of radioactive waste generated by State or Territory government bodies or by private users is regulated by the appropriate state or territory regulatory bodies – see http://www.arpansa.gov.au/Regulation/regulators/index.cfm.

Specific waste management practices at ANSTO are outlined at:
http://www.ansto.gov.au/nuclear_information/managing_nuclear_materials.

3. Classification of Radioactive Waste

Radioactive waste is defined as 'radioactive material in gaseous, liquid or solid form for which no further use is foreseen, and which is controlled as radioactive waste by a regulatory body'[8].

The classification of radioactive waste has been defined in international standards developed by the IAEA[9] . There are three general classes of radioactive waste – low level waste (LLW), intermediate level waste (ILW) and high level waste (HLW). A recent review of the waste classifications added two new classes between LLW and exempt waste. The classifications are described below and shown schematically in Figure 2.

- ***Exempt Waste: (EW):*** contains such a low concentration of radionuclides that it can be excluded from nuclear regulatory control because radiological hazards are considered negligible[10].
- ***Very short lived waste (VSLW):*** can be stored for decay over a limited period of up to a few years and subsequently cleared of regulatory control to be disposed of as regular waste.
- ***Very low level waste (VLLW):*** does not need a high level of containment and isolation and therefore is suitable for disposal in near-surface landfill-type facilities with limited regulatory control.
- ***Low level waste*** (***LLW):*** contains limited amounts of long-lived radionuclides. This classification covers a very wide range of radioactive waste, from waste that does not

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[8] International Atomic Energy Agency, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, IAEA, INFCIRC/546, 1997.

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, IAEA Safety Standard Series, No GSG-1, 2009.

[10] Given that virtually everything is radioactive to some extent, it is obviously not reasonable to regulate all materials as radioactive materials. For that reason, international bodies have developed thresholds for regulation.

require any shielding for handling or transportation up to activity levels that require more robust containment and isolation periods of up to a few hundred years. There are a range of disposal options from simple near-surface facilities to more complex engineered facilities. LLW may include short lived radionuclides at higher levels of activity concentration, and also long-lived radionuclides, but only at relatively low levels of activity concentration.

- ***Intermediate level waste (ILW):*** contains increased quantities of long-lived radionuclides and needs an increase in the containment and isolation barriers compared to LLW. ILW needs no provision for heat dissipation during storage and disposal. Long-lived radionuclides such as alpha emitters will not decay to a level of activity during the time for which institutional controls can be relied upon. Therefore ILW requires disposal at greater depths of tens to hundreds of metres.
- ***High Level Waste (HLW):*** has high levels of activity that generate significant quantities of heat by radioactive decay that need to be considered in the design of a disposal facility. Disposal in deep, stable geological formations usually several hundreds of metres below the surface is generally recognised as the most appropriate option for HLW. The two primary classes of civilian HLW are: (a) used fuel from nuclear power reactors; and (b) separated waste arising from the reprocessing of that used fuel.

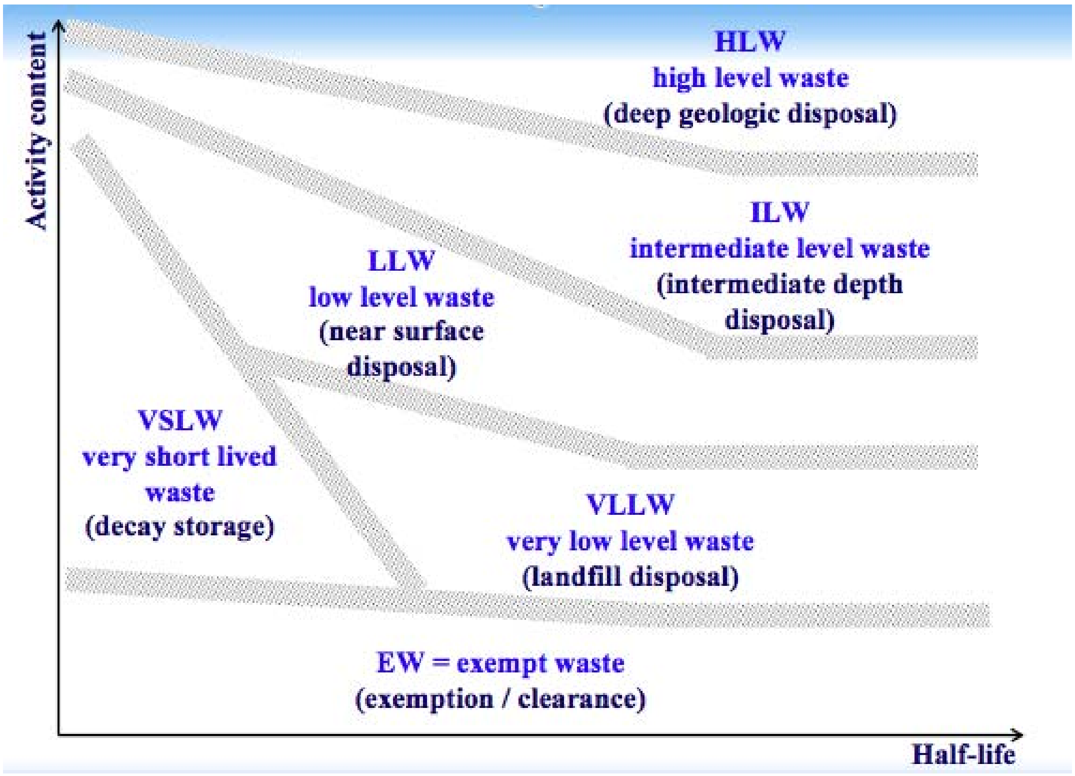

Figure 2. Conceptual illustration of the waste classification system and relevant disposal options[11]

Under the current international guidance, there is not a precise boundary between each of the waste categories, as limits on the acceptable level of activity concentration will differ between individual radionuclides or groups of radionuclides. Waste acceptance criteria for a particular near surface disposal facility will be dependent on the actual design of and planning for the facility (e.g. engineered barriers, duration of institutional control, site specific

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[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, IAEA Safety Standard Series, No GSG-1, 2009.

factors)[12]. Previously, a contact dose rate of 2 mSv/h was generally used to distinguish between LLW and ILW. While this is still an important consideration, long-term safety is the primary basis of the present classification system, and thus short-lived materials are generally classified differently to long-lived materials.

3.1 The Australian situation

The ARPANSA Safety Guide for Classification of Radioactive Waste (2010)[13] largely reflects the international guidance referred to above. As such, it does not include quantitative values of allowable activity content for each significant radionuclide, which ARPANSA indicate will be specified on the basis of the safety assessment for individual disposal sites.[14]

The *Commonwealth Radioactive Waste Management Act 2005* defines “high level radioactive material”, as “material which has a thermal energy output of at least 2 kilowatts per cubic metre”[15]. That definition was replicated in the *National Radioactive Waste Management Bill* introduced into Parliament in early 2010.

Radioactive waste generated in Australia generally falls within the VSLW, VLLW, LLW or ILW classifications. Australia does not generate any electricity from nuclear power and therefore does not generate any used fuel that would be classified as HLW.

4. Management and Disposal of LLW (including VLLW)

These types of wastes are often treated to achieve volume reduction and/or conditioned (waste immobilisation) prior to disposal. Examples of LLW are lightly contaminated laboratory items such as paper, clothing, plastic and glassware, soil, smoke detectors, medicinal and industrial materials. A variety of safe and effective treatment options are available, including chemical precipitation, incineration and compaction. These may be followed by immobilisation in materials such as concrete, bitumen, or polymers.

The types of disposal currently used internationally for low level wastes are:

- Near surface non-engineered disposal (e.g. unlined shallow trenches);
- Near surface engineered disposal; and
- Subsurface disposal facilities.

The isolation period is usually up to 300 years, thus requiring institutional and administrative control for that period. The majority of the world’s LLW has been safely disposed of (Table 1) in near surface disposal facilities which have been operated in numerous countries such as France, the UK and the USA for over 30 years.

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[12] Whilst this approach is appropriate for developed countries with long experience in radioactive waste management, ANSTO considers it is unhelpful for developing countries which lack such experience. In our view, such countries would benefit from clear boundaries, as such boundaries would assist them in deciding upon appropriate waste management strategies for different types of waste.

[13] http://www.arpansa.gov.au/Publications/codes/rps20.cfm.

[14] See page 9 of the document referenced in the previous footnote (page 17/42 of the PDF on the web).

[15] The definitions effectively act to prohibit the storage or disposal of “high level material” at the proposed Commonwealth Radioactive Waste Management Facility.

4.1 The Australian situation

In Australia, low-level waste is generated in industry, hospitals and nuclear facilities. It typically comprises paper, plastic, gloves, clothing and filters.

Australia does not have a central storage or disposal facility for low-level wastes (except for the Mt Walton Intractable Waste Disposal Facility, in Western Australia, used for the disposal of low level waste produced in that state), and as a result Australia's low level waste is held at a host of widely dispersed locations across the country. In 2002, an audit of radioactive waste in South Australia found that there were 80 sites where radioactive waste was held[16].

Whilst the precise waste acceptance criteria for a particular disposal facility would depend on the characteristics of the site, the general waste acceptance criteria are detailed in the *Code of Practice for the near-surface disposal of radioactive waste in Australia* (1992)[17] originally issued by the National Health and Medical Research Council and now administered by ARPANSA. Those criteria limit the sort of wastes which could be disposed of in any facility in Australia. In particular, they provide that all waste must be in solid form.[18]

5. Management and Disposal of ILW

Intermediate Level Waste (ILW) can be stored in above-ground facilities but requires disposal at a depth between a few tens and hundreds of metres from the surface. This is because some ILW contains long-lived radionuclides in quantities that require a similarly high degree of isolation from the biosphere as high level waste (HLW). Such isolation would be provided by disposal in geologic formations at a depth of several hundred metres. Disposal at such depths has the potential to provide a long period of isolation from the accessible environment if both the natural and engineered barriers (including the matrix[19] in which the waste is encapsulated) are selected appropriately. Furthermore, the likelihood of inadvertent human intrusion is greatly reduced well below the surface. Consequently, long term safety for disposal facilities at such depths will not depend on the application of institutional controls.

5.1 The Australian situation

ILW is generated chiefly from radiopharmaceutical production, the operation of ANSTO's research reactors and the reprocessing of used fuel from those reactors. In order to limit exposure to radiation, intermediate level waste requires shielding during handling, processing and storage, typically by using concrete, steel or lead.

ANSTO has commenced a project to condition the intermediate level liquid wastes from molybdenum-99 production. The decay product of molybdenum-99, technetium-99m, is used in more than 80% of all diagnostic nuclear medicine procedures worldwide, and molybdenum-99 is the primary radiopharmaceutical produced at ANSTO. Whilst liquid wastes have been accumulated and safely stored at ANSTO (and some have been dried into a solid waste), they are not currently in a form suitable for off-site transport or ultimate disposal. ANSTO therefore plans to implement a process to solidify those wastes. The proposal is to use the "synroc" process to produce a wasteform suitable for long-term storage

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[16] Audit of Radioactive Material in South Australia, Environmental Protection Authority South Australia, 2003.

[17] Radiation Health Series No. 35, http://www.arpansa.gov.au/pubs/rhs/rhs35.pdf.

[18] At page 21.

[19] Some possible matrices are cement, glass and synroc.

in an intermediate level radioactive waste store at the proposed National Radioactive Waste Management Facility. Most of Australia's ILW is currently in storage at ANSTO[20].

6. International Experience of Management and Disposal of LLW and ILW

The total global inventory of radioactive waste up to 2008 (including military waste but not uranium mining and milling waste) is presented in

Table 1. It shows that of the approximately 30 million m^3 of radioactive waste that has been generated, approximately 24 million m^3 has been disposed of and approximately 6 million m^3 has been placed in storage. This means that approximately 75% of all radioactive waste created since the commencement of the nuclear industry has already been sent for disposal. Most LLW is typically sent to land-based disposal facilities immediately upon being packaged for long-term management.

Most ILW is currently stored at purpose-built facilities while geological repositories for disposal are being developed. Both Finland and Sweden are well progressed to have geological facilities operational by 2025. In New Mexico, USA a deep geological waste repository has been in operation since 1999. The WIPP (Waste Isolation Pilot Plant)[21] disposes of transuranic[22] waste (essentially long-lived ILW from military operations) at a depth of ~ 650m in a bedded salt deposit.

HLW is addressed in a subsequent section, but it is noteworthy that the HLW from military applications totally dominates the inventory of HLW.

Table 1. Worldwide Radioactive Waste Inventory (2008 data)[23].

Waste Class	In storage (m^3 x 1000)	Disposed (m^3 x 1000)
LILW-SL*	2,300	24,000
LILW-LL*	3,200	200
HLW	400	
TOTAL	5,900	24,200

* The IAEA revised its radioactive waste classification system in 2009. It now does not include LILW-SL (low and intermediate waste-short lived) and LILW-LL (low and intermediate waste-long lived). Under the new classification, they are broadly equivalent to LLW and ILW, respectively.

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[20] http://www.ret.gov.au/resources/radioactive_waste/radiation_radioactive/Pages/AmountsofRadioactiveWasteinAustralia.aspx.

[21] http://www.wipp.energy.gov/

[22] Transuranic elements are created in the fission process, and are heavier than uranium. They do not occur naturally on Earth. Examples are americium, neptunium and plutonium.

[23] International Atomic Energy Agency, 'Net Enabled Waste Management Database (NEWMDB), Vienna, Austria.

Figure 3. A truck transporting three casks of transuranic waste to the Waste Isolation Pilot Plant (WIPP) in New Mexico, USA

Some 30 countries currently operate licensed repositories for low level radioactive waste. They are located in a range of environments; generally speaking, there is a relationship between the aridity of the environment and the degree of engineering required. Examples of radioactive waste facilities with their web address are provided below. The Spanish near surface disposal facility for LLW at El Cabril is reviewed in detail.

- Morvilliers, France (Very Low Level Waste including decommissioning waste), land fill disposal.
    - http://www.andra.fr/radioactive-waste/low-level-radioactivity-waste.htm
- Centre de l'Aube, France (Low Level Waste) near surface disposal.
    - http://www.laradioactivite.com/fr/site/pages/StockageFMAVC.htm
- El Cabril, Spain, (Low Level Waste), near surface disposal
    - http://www.enresa.es/activities_and_projects/low_and_intermediate_wastes#bloque133
- US Ecology Richland, USA (Low Level Waste)
    - http://www.americanecology.com/richland.htm
- Olkiluoto (VLJ Repository), Finland (Low Level Waste) Subsurface disposal
    - http://www.tvo.fi/www/page/1647/

6.1 Case Study: El Cabril Radioactive Waste Disposal Facility, Spain

The El Cabril radioactive waste disposal facility in Spain provides an example of a modern purpose-built facility. It is designed to offer secure and safe disposal of low level waste produced in Spain. It is a vault-type surface disposal facility. ENRESA (Empresa Nacional de Residuos Radiactivos SA) has operated the facility since 1992; site preparation commenced in 1986. It is located approximately 100 km north-east of Seville (population of 1.5 million people).

The capacity of 100,000m^3 is much larger than the proposed National Radioactive Waste Management Facility in Australia, because Spain generates approximately 20% of its electricity from eight nuclear reactors. In 2006, it was 38% full. Australia has accumulated less than 5000 m^3 of LLW and ILW, i.e. approximately 5% of the capacity of El Cabril.

Figure 4. El Cabril Radioactive Waste Facility: The storage vaults are in the foreground, adjacent to two movable white roofs to cover each vault while being filled and sealed.

The low level wastes are transported by road to the El Cabril disposal facility, and is usually received at the facility in 200 litre drums. The waste is characterised and undergoes a series of tests to ensure compliance with the waste acceptance criteria. Representatives from ENRESA inspect the waste prior to transport and liaise with the relevant authorities, who are fully informed of the shipment. The transport vehicles (Figure 6) are specifically designed and are equipped with shielding, locking devices etc. ENRESA have transported radioactive waste over a total of nearly 3 million kilometres, without any noteworthy incident.

The disposal concept is to create multiple barriers between the waste and the environment. These drums are conditioned by placing them in large 11 m^3 concrete containers (Figure 5a). The containers are filled and sealed with cement to immobilise the waste packages, after which they weigh approximately 24 tonnes. The containers are then placed into one of the storage vaults shown in Figure 5b, each of which has capacity for 320 containers. The vault is then backfilled with gravel and a closing concrete slab is constructed. The base slab of the platforms, on which the disposal vaults sit, forms an important part of the storage system. It provides the mechanical support for the vaults, and collects any water that may enter the system by channelling it to a network of pipes installed in accessible galleries below the platforms.

Figure 5. a) Loading radioactive waste packages of LLW and ILW into disposal containers.

b) Loading disposal containers into the storage vaults.

Figure 6. A truck used to transport LLW and ILW waste packages from different sites in Spain to El Cabril.

6.2 The Australian situation

As noted above, Australia does not have an operating low level waste disposal facility (except for the Mt Walton Intractable Waste Disposal Facility, in Western Australia, used for the disposal of low level waste produced in that state). As a result Australia's low level and intermediate level waste is held at a host of widely dispersed locations across the country.

7. Management and Disposal of Used Nuclear Fuel and HLW

Radioactive waste, as explained previously, is radioactive material for which no further use is envisaged. Some countries define used nuclear fuel as waste, whereas others do not. This issue is explored in the following section. Under international law, used nuclear fuel is not defined as waste unless so designated by the responsible country[24].

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[24] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, particularly Article 10.

7.1 Reprocessing

Some countries regard used nuclear fuel as a valuable resource because of the uranium and plutonium that remains in the fuel. This includes France, the UK, Japan and Russia. The uranium and plutonium is recovered by reprocessing and can then be used to fabricate new fuel assemblies[25].

Reprocessing is the chemical process where plutonium and uranium are separated from the fission products in the used fuel and are then able to be recycled. While reprocessing was originally developed to extract plutonium for use in nuclear weapons, today it is used primarily to treat used fuel from civilian nuclear power reactors. It offers benefits in increased uranium and plutonium utilisation, and a reduction in the volume of high level waste. The liquid waste from the reprocessing of spent fuel must be solidified to be suitable for transportation and disposal. The most frequently used solidification process is vitrification, i.e. the waste products are melted together with glass material at high temperatures such that they are incorporated into the glass structure. The melted mixture is poured into stainless steel containers, and, after controlled cooling, these are sealed by welding and then decontaminated to remove possible surface contamination.

The primary risk associated with reprocessing relates to the theft and diversion of plutonium, for use in a nuclear weapon[26], or fission products that could be used in a radiological dispersal device or an improvised explosive device. The former risk led to the 1977 decision of the US government ‘to defer indefinitely commercial reprocessing of used nuclear fuel’, a policy which is still in effect today. However, this position is being reconsidered by the current US administration (see section 8 below).

7.2 Storage of Used Nuclear Fuel

After discharge from the reactor, used nuclear fuel must be stored to manage the high levels of heat and radiation which are emitted. Used fuel is most commonly transferred to used-fuel pools at the reactor site for at least one year, but generally for several years. The pools are 7-15 metres deep and equipped with storage racks and the necessary controls to maintain temperature, water quality and safety (see Figure 7). Some operators store used fuel in the pools for decades prior to reprocessing, while others, most notably in the USA, transfer the fuel to dry cask storage.

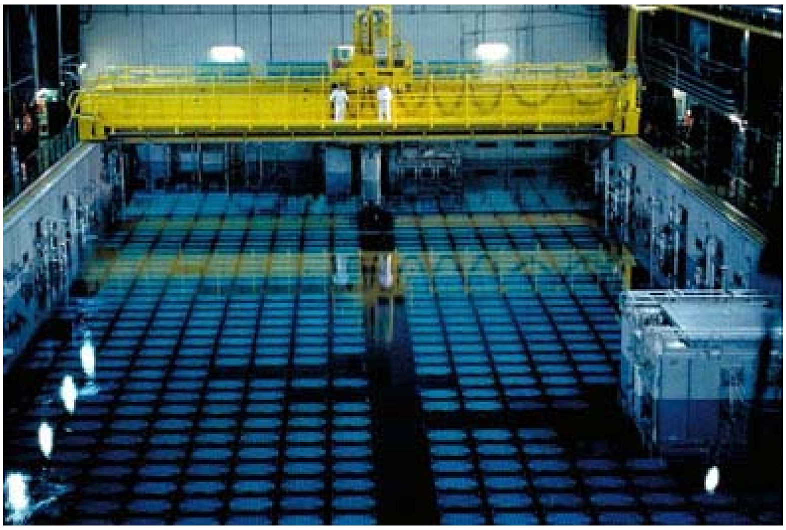

Figure 7. A used fuel storage pool located at La Hague, France

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[25] Plutonium separated during the reprocessing process is used in so-called “mixed-oxide (MOX)” fuel.
[26] The isotopics of plutonium from commercial nuclear power reactors differs from plutonium produced for weapons purposes, in ways that make it much less suitable for weapons purposes.

Dry cask storage is widely used for storing used fuel in the USA. The casks are usually steel cylinders that are sealed by welding or bolting, providing leak-tight containment. Additional layers of concrete or steel provide multiple barriers and the necessary shielding protection. Numerous designs are available, including vertical or horizontal storage in a concrete vault, or freestanding on a concrete pad as shown in Figure 8. Some containers serve a dual purpose, being suitable for transportation and storage. They are known as CASTOR containers (**CA**sk for **S**torage and **T**ransport of **R**adioactive material)

In the USA, licenses for 60 year dry cask storage have been issued at some nuclear plants. Despite the view that managed storage is sound for 100 years[27], dry cask storage is still an interim solution. Unless reprocessed, used nuclear fuel ultimately needs to be disposed in a deep geologic disposal facility. Even if reprocessing is employed, the solidified wastes will still need to be disposed of in such a geologic facility.

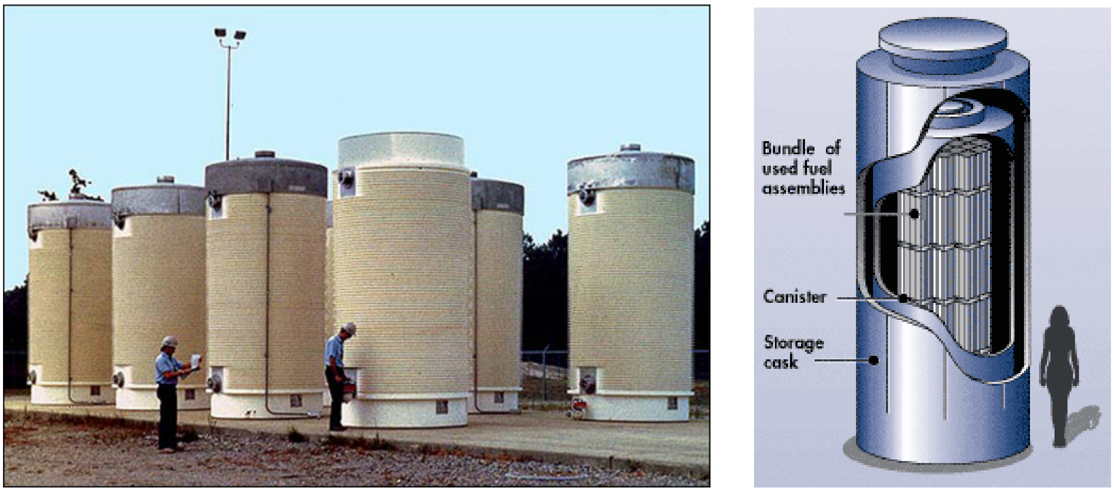

Figure 8. Dry cask storage on a concrete pad with cutaway schematic of a cask

7.3 Disposal of High Level Waste and Used Nuclear Fuel

The main characteristics governing the disposal of used fuel and high level waste are the long-lived radioactivity content, and the significant quantities of heat from radioactive decay which normally continues for several centuries. The necessary degree of containment and isolation from the accessible environment is best provided by the integrity and stability of deep geological disposal with engineered barriers[28]. Adequate long-term safety must also be provided without reliance on active controls or ongoing maintenance. Geological repositories are therefore designed to be passively safe, using multi-barrier systems.

Those engineered barriers include the physical form of the waste, the waste container(s) and the geology of the disposal facility. Reprocessed waste is usually immobilised in a matrix such as borosilicate glass or ceramic which has excellent resistance to radiation and leaching. The wasteform or the used fuel is sealed inside a corrosion-resistant container such as stainless steel or copper. The container will be placed inside a suitable rock structure hundreds of metres underground. The space surrounding the containers will then be backfilled with an impervious material that is compatible with the geology of the location.

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[27] Massachusetts Institute of Technology, The Future of the Nuclear Fuel Cycle, An Interdisciplinary MIT Study, 2010.

[28] The Long Term Storage of Radioactive Waste: Safety and Sustainability: A Position Paper of International Experts, International Atomic Energy Agency, Vienna, 2003 - http://www-pub.iaea.org/MTCD/publications/PDF/LTS-RW_web.pdf.

Guiding principles can be found in the multilateral legal instruments adopted under the auspices of the IAEA, in particular the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The IAEA also publishes a safety series specifically on the disposal of used fuel and high level waste, including the 'Geologic Disposal of Radioactive Waste Safety Requirements'[29].

7.4 The Australian situation

Australia does not generate any used fuel that would be classified as HLW. Power reactor fuel generates significantly greater quantities of heat from radioactive decay compared to research reactor fuel. The *Commonwealth Radioactive Waste Management Act 2005* defines "high level radioactive material", as "material which has a thermal energy output of at least 2 kilowatts per cubic metre (as explained in Section 3.1). The radioactive waste generated from the reprocessing of HIFAR and MOATA fuel does not meet this criterion.

Used fuel from ANSTO's former reactors has been safely shipped overseas for reprocessing or storage since 1963. Since then, ANSTO has planned and managed nine shipments, two to the UK, four to France and three to the USA. ANSTO no longer retains any used fuel from its former HIFAR and Moata reactors. The residual waste material from the reprocessing of the fuel sent to France and one of the shipments to the UK will, under international agreements, return to Australia. No material will be returned to Australia from the other shipments.

The intermediate level waste resulting from reprocessing ANSTO's used fuel overseas will eventually require geological disposal in Australia. However, the small volumes involved means that Australia can afford to wait and learn from overseas experience in the establishment of such facilities, storing the material in the interim period. The first shipment of reprocessed fuel waste to Australia is due in 2015.

A multi-barrier approach is taken to the transport and storage of ANSTO's reprocessed fuel waste. The first barrier is vitrification (see section 7.1 above). The vitrified waste form is contained in stainless steel sealed casks (the second layer) each weighing ~ 500kg. The third layer is the TN-81 stainless steel transport cask, which is 6.5 metres long and 3m in diameter. The walls are 25cm thick, and it weighs ~100 tonnes empty (Figure 9).

Figure 9. 500kg stainless steel canisters, used to store vitrified intermediate level waste from the reprocessing of ANSTO fuel (left) and the 100 tonne AREVA TN-81 transport and storage cask, capable of storing 28 canisters of ILW (right)

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[29] http://www-ns.iaea.org/standards/

8. International Experience in the Management and Disposal of HLW

It is generally accepted amongst technical experts in the field that properly established deep geological disposal is an appropriate management approach for HLW and used nuclear fuel[30]. However, there is no deep geological disposal facility for used fuel or HLW yet in operation. The only operating geological repository to date is the Waste Isolation Pilot Plant (WIPP) in the USA (see section 6 above).

The first permanent disposal facility for high level waste to be built in the world is likely to be located in Northern Europe. Sites at Forsmark in Sweden and Eurajoki in Finland have been selected. In Finland, site works have commenced in preparation to apply for a construction licence in 2012 and start operation in 2020[31]. In Sweden, site works on the underground facility could commence in 2013, with full construction beginning in 2015, and operation by 2023[32]. Finnish and Swedish HLW will be disposed of in crystalline bedrock at a depth of almost 500 metres.

Countries which reprocess their used fuel must still dispose of the high level waste arising from the reprocessing operation[33]. Many of those countries have also concluded that deep geological repositories are the best solution to the problem of high level waste disposal. Switzerland and France are currently assessing the deep geological disposal option for their high level waste, and are in the process of authorising the selection of sites. A French law passed in 2006 on radioactive waste management requires that a deep geological repository for HLW be available by 2025[34].

The situation in the United States is often cited as an example of the difficulties of arriving at a national consensus about the disposal of used fuel and radioactive waste. The United States operates 104 nuclear power reactors, the most of any country, and consequently generates the most used nuclear fuel. Despite substantial policy debate, the issue of waste disposal is not yet resolved. In 1982, the US Congress passed the *Nuclear Waste Policy Act*, which directed the US Department of Energy to site, build and operate an underground geologic disposal facility to dispose of used fuel. In 1987, the Act was amended and Yucca Mountain in Nevada was selected as the sole location for all used fuel generated in the US. Originally scheduled to open in 1998, major delays to the Yucca Mountain Project have been encountered, in large part due to problems with funding, legal challenges and political opposition to the selected site.

In 2009, the US Secretary of Energy announced that Yucca Mountain was no longer considered an option. Although political factors were clearly important in the decision, he indicated that deep geological disposal might not be the best solution for US used fuel and the issue needed to be reassessed. Citing increased knowledge in the area of waste management and storage, he suggested alternative options such as reducing waste inventories by burning up long-lived actinide wastes in fast reactors. In February 2010 and at the direction of President Obama, he formed a “Blue Ribbon Commission” to evaluate all options for storage, processing and disposal of nuclear fuel and waste[35].

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[30] Nuclear Energy Agency-OECD, ‘Radioactive Waste in Perspective’, No 6350, 2010.

[31] http://www.posiva.fi/en/

[32] http://www.skb.se/default____24417.aspx

[33] As compared to direct disposal of used fuel, reprocessing significantly reduces the volumes of high level waste which must be disposed of, but does not eliminate the need for a long-term disposal solution.

[34] http://www.andra.fr/international/pages/en/menu21/waste-management/waste-management-issues-at-national-level/high-level-waste-and-long-lived-intermediate-level-waste-1618.html.

[35] In particular, the commission is to evaluate advanced fuel cycle technologies that would optimize energy recovery, resource utilization, and the minimization of materials derived from nuclear activities

There are a number of reasons why there has been a delay in the creation of geological disposal facilities. Public acceptance is probably the most important factor. Additionally, in many countries the need is not urgent, as the volumes of waste are small and there is a technical advantage in waiting while technical processes are refined elsewhere. There has also been uncertainty in many countries as to their used fuel management policy, for example, whether used fuel is to be recycled and how, and decisions on reprocessing facilities. As most of the energy content of uranium is left unutilised by a once-through fuel cycle, used fuel is considered a resource rather than a waste in many countries. Uncertainty of future nuclear policy has also played a part in delaying the creation of geological disposal facilities.

9. Radioactive Sources

The problem of disused radioactive sources is of significant international concern. Millions of radioactive sources have been and continue to be used around the world for a wide range of beneficial applications in medicine, agriculture, industry and research. The vast majority, such as smoke detectors, are of relatively low radioactivity and do not pose a safety or security threat. However, some applications – particularly medical applications such as radiotherapy - require sources of high activity. In some cases where high activity sources have been lost, stolen or abandoned (referred to as ‘orphan sources’), they have led to radiation accidents. Another concern is that such sources could be used in a radiological dispersal device – a dirty bomb. While such a device would not cause widespread death or injury, the resulting panic and clean up could be costly and cause significant disruption and concern in the community.

Due to the risks of sources becoming orphaned, and thus of greater safety and security risk, most countries require licensees to either send disused sources back to the supplier or to send them to a licensed recycling or waste management facility. In these countries, licensees are prohibited from retaining disused sources beyond the period required to arrange shipment to the supplier, recycler or waste management facility. Most countries also ensure that central storage or disposal facilities for disused or orphaned sources, which cannot be returned to the supplier, are available - and this is considered international best practice[36].

As noted above, most Australian jurisdictions do not have licensed central facilities for the storage of disused high-activity sources. In fact, holders of such sources are usually required to hold onto such sources indefinitely if return to the supplier is not possible. Again, a centralised national facility that could take such sources for secure storage and/or eventual disposal would be the ideal situation.

There have been a number of serious accidents overseas as a result of improper care, storage or disposal of radioactive sources. Perhaps the most well known was in Goiania, Brazil where a radioactive source used for radiotherapy was abandoned when a facility was closed down. Two locals scavenging for scrap took the head of the radiotherapy unit, which contained the radioactive source and in their effort to dismantle it ruptured the capsule. A number of people were exposed to large doses of radiation and four people died[37].

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in a manner consistent with U.S. nonproliferation goals: http://www.whitehouse.gov/the-press-office/presidential-memorandum-blue-ribbon-commission-americas-nuclear-future

[36] http://www-ns.iaea.org/downloads/rw/code-conduct/info-exchange/chair-report-tm-june-july2009.pdf

[37] See “The Radiological Accident in Goiania, Brazil”, http://www-pub.iaea.org/MTCD/publications/PDF/Pub815_web.pdf.

9.1 The Australian situation

As Australia does not have a central store for disused sources, such sources are stored in a range of locations around Australia. Both Queensland and Western Australia have facilities in place for the management of some classes of radioactive waste; other states have no such facilities, apart from ad hoc arrangements for the management of some "orphaned" radioactive sources.

10. Transportation of Radioactive Waste

Tens of millions of shipments of radioactive material are conducted worldwide every year on public roads, railways and ships. In addition to shipments of radioactive waste, there are shipments of radioactive materials for use in medicine, industry, agriculture, research, non-destructive testing and minerals exploration. Only about 5% of shipments are related to the nuclear fuel cycle, i.e. the activities associated with nuclear power generation. This includes uranium mining, uranium enrichment, fuel fabrication, power generation, fuel storage, reprocessing and disposal. Transport packages are robust and secure and are designed to meet international regulations published by the IAEA[38] which have been integrated into the regulations of mode-specific international organisations such as the International Maritime Organisation and the International Civil Aviation Organisation.

The safety of radioactive material shipments primarily depends on the design of the packaging which, in addition to providing adequate shielding during normal transport conditions, must be able to withstand accident conditions. There are many different types of packaging that can be used, depending on the hazard posed by the material to be shipped. Containers can vary from small containers with little or no shielding up to heavily shielded packages for the transportation of used fuel or high level waste. These containers are often fabricated from stainless steel with integral shielding and can weigh more than 100 tonnes. An extremely conservative approach to cask design is adopted, which means the casks are able to withstand conditions in excess of what is expected. Casks are tested and certified to withstand fire, impact, pressure, liquid ingress, heat and cold. To reassure the public of the negligible risks in transport, extreme tests have been conducted. In one example, a locomotive was crashed into a transport cask to demonstrate the resistance to impact, as shown in Figure 10. Highly radioactive materials are often packaged in 'dual-use containers', (containers suitable for transportation and long-term storage) to reduce the amount of handling.

Figure 10. Impact testing of a transport cask conducted at US-DOE Sandia National Laboratory.

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[38]. International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, IAEA Safety Series, No TS-R-1, 2009.

In several decades of transporting radioactive materials around the world, there has never been an in-transit accident with serious human health, economic or environmental consequences arising from radioactivity[39]. Since 1971, more than 50,000 tonnes of used fuel and high-level waste have safely been transported a combined distance of more than 30 million kilometres. The transport of hazardous materials such as petrol and toxic chemicals, which are routinely carried by road, poses a much greater potential threat to public health.

10.1 The Australian situation

In Australia, individuals and organisations including ANSTO transport radioactive materials every day. Those radioactive materials are used for a large variety of applications, including to diagnose and treat disease, sterilise bandages and other medical goods, and check the integrity of aircraft, roads, bridges and pipelines. On average, ANSTO sends about 1,750 packages of radioisotopes for medical uses per month to hospitals and radiopharmacies around Australia and overseas.

There is also a large number of non-ANSTO movements of radioactive material used for medical and industrial purposes across Australia. Many of these movements involve high activity industrial sources, each of which contains much more activity than an entire truckload of low-level waste.

The transport of both ANSTO and non-ANSTO radioactive material is undertaken in accordance with the Australian *Code of Practice for the Safe Transport of Radioactive Material*[40], produced by ARPANSA and based on the regulations published by the International Atomic Energy Agency.

There has been no transport incident in the movement of ANSTO's materials with significant radiological consequences.

In contrast, accidents in the course of road transport of other hazardous materials such as petrol, flammable gases and toxic chemicals have caused loss of life as a direct result of the hazardous nature of the cargo. The risks associated with the transport of radioactive waste are much lower than the risks associated with the transport of many other hazardous materials, due to the specialised protection offered by the licensed transportation containers.

11. The Future of Radioactive Waste Management in Australia

11.1 The need for a national radioactive waste management facility

Wastes are currently held at more than 100 locations around Australia. These locations hold wastes generated by various medical, industrial and research applications, including disused radioactive sources, and are currently required to retain those wastes indefinitely. Waste is often stored indefinitely in facilities that were not designed for long term storage of such material. Such storage, while currently safe, is not ideal. In many cases, storage facilities were not designed for this use and are nearing capacity.

Indefinite storage of radioactive waste in small facilities is inconsistent with international best practice, which involves the provision of central storage or disposal facilities, with the imposition of regulatory requirements to ensure that risks are minimised. Australia is obliged to provide for safe and secure management of radioactive waste under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, and report on the implementation of its obligations every three years[41].

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[39] http://www-ns.iaea.org/downloads/rw/meetings/july2003_trans_saf_conf_summary_and_findings.pdf

[40] http://www.arpansa.gov.au/pubs/rps/rps2_2008.pdf

[41] http://www.arpansa.gov.au/Regulation/Collaborations/jointconv.cfm

The intermediate level waste generated from the reprocessing of ANSTO's used nuclear fuel from the HIFAR and Moata research reactors will also need to be stored appropriately. The waste is currently stored in the UK and France where the used fuel was reprocessed, and is scheduled to return to Australia around 2015.

Once a permanent central radioactive waste management facility is established, it will receive the waste now held in the UK and France, plus waste from the numerous Australian locations where it is currently held.

11.2 Location of a national facility

The location of a national facility has generated considerable discussion and debate. A number of factors must be considered in the location of such a facility. These are detailed in the *Code of Practice for the near-surface disposal of radioactive waste in Australia*, referenced in section 4.1 above.

The Code states, amongst other things, that a repository should be in an area of low population density, where the prospects for future development are very low and there is limited rainfall.

There have been suggestions that ANSTO's south-western Sydney campus in Lucas Heights should become the site of the national radioactive waste management facility. While the site is suitable for interim storage of limited quantities of radioactive waste, it does not meet the geographical and geological criteria for a disposal facility outlined in the *Code of Practice*.

In addition, changes to the *Australian Nuclear Science and Technology Organisation Act 1987,* which precludes non-Commonwealth waste being moved to the ANSTO campus, would be required. Furthermore, the waste storage capacity at ANSTO is insufficient to store all of Australia's radioactive waste.

11.3 Design of the Facility

The facility is likely to include a surface or near-surface disposal trench for low level waste and a store for the smaller volume of long-lived intermediate level waste. Some preliminary concept designs for such a facility were developed by ANSTO for the Department of Resources, Energy and Tourism, and can be found in a document issued in 2009[42].

12. Conclusion

Australia has generated relatively small volumes of low and intermediate level radioactive waste by comparison with other developed countries and with other types of hazardous waste. The absence of a central radioactive waste disposal or long-term storage facility in Australia means that many holders of radioactive waste, including disused industrial and medical sources, are currently forced to store them in conditions that may be unsafe or insecure.

The construction of a central radioactive waste management facility, designed and constructed specifically for the disposal or long term storage of such wastes, would alleviate these problems, bringing Australia's management of radioactive wastes into line with international best practice. Such facilities have operated safely overseas for many years.

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[42] http://www.ret.gov.au/resources/radioactive_waste/waste_mgt_in_aust/Pages/RadioactiveWasteManagementinAustralia.aspx

Like the rest of the nuclear industry, the management of radioactive waste is highly regulated. Any waste to be disposed of would have to meet general and site-specific acceptance criteria. The experience and well-established practices of the numerous waste management facilities overseas, including the exemplary safety record in waste transportation, can be employed in the design and operation of an Australian facility, under the guidance of national and international regulatory bodies.