Chapter 2
Radiation, Radioactive Waste and Waste Management

This chapter provides background to radiation and types of radioactive waste, and presents a summary of waste management practices from around the world.

2.1 Radiation and Radioactivity

2.1.1 Radiation

Radiation is the emission and propagation of waves or sub-atomic particles. There are two types of radiation — ionising radiation, so called because it has sufficient energy to 'ionise' matter that it hits, and non-ionising radiation. Ionising radiation includes X-rays and the radiation that comes from radioactive elements, and it has the ability to break the bonds that bind electrons to atoms, thus causing ionisation of the matter through which it passes and damage to living tissue. Non-ionising radiation includes light, heat and radar. The type of radiation associated with radioactive waste is ionising radiation.

2.1.2 Radioactivity

All matter is made up of atoms, some of which are unstable because they have excess energy. Unstable atoms break down spontaneously and release their excess energy, thus forming stable atoms. Radioactivity is the term used to describe the breakdown of unstable atoms and the associated release of energy, which is in the form of sub-atomic particles or electromagnetic waves.

Over time, radioactive material is completely broken down, stable atoms are formed and therefore there is no further release of energy or radiation. The time taken for this decay process is measured in terms of an atom's half-life. One half-life is the time for half of the radioactive atoms to decay to stable atoms. After two half-lives, one quarter of the original radioactive atoms will remain. Some radioactive substances have half-lives of less than a second; others have half-lives of thousands and even billions of years.

Radioactivity is a natural part of our Earth and the universe. Naturally occurring radioactive materials are present in:

- soil and rocks
- floors and walls of our homes, schools and offices
- our food and drink.

There are also radioactive gases in the air we breathe and naturally occurring radioactive elements in our muscles, bones and tissues.

The radiation from these natural radioactive sources is called background radiation and it varies from place to place. The amount of background radiation we receive depends on where we live and the types of activities in which we are involved. The higher we are above sea level, the more we are exposed to radioactivity by way of cosmic radiation. Some soils and rocks, for example, granites, are naturally more radioactive than others, and if we live in areas where these occur, our exposure to background radiation is increased. Some activities, for example air travel and certain medical treatments, increase our exposure to radiation.

During the past 100 years, radioactive materials have come to be used in a wide range of beneficial medical, industrial and environmental applications, including:

- diagnosis and treatment of diseases
- sterilisation of medical supplies and of personal care products
- tracking pollution
- industrial process monitoring and control, and agricultural monitoring and pest control
- in life-saving devices such as smoke detectors.

Further information on the beneficial uses of radiation in Australia is provided in Section 2.2.

The energy emitted from unstable atoms can be released in four forms: alpha (α) particles, beta (β) particles, gamma (γ) radiation and neutrons.

Alpha particles are atomic nuclei. They can travel only a few centimetres in air. A sheet of paper or a layer of skin can stop them. They are intensely ionising, but are only dangerous if they are released inside our bodies. Substances that emit alpha particles are safe if kept in containers sealed to air.

Beta particles, which are electrons or positrons, can travel metres in the air and several millimetres into the human body. They can be stopped by a small thickness of light material such as aluminium or plastic sheeting. Exposure produces an effect like sunburn, but which is slower to heal. Substances that emit beta particles are safe if kept in appropriate sealed containers.

Gamma rays are very energetic electromagnetic radiation, and are the main hazard to people in dealing with sealed radioactive materials. They are much more penetrating than alpha particles or beta particles, and are much more energetic than such non-ionising electromagnetic radiation as ultraviolet, visible and infrared radiation, radar and radio waves. A thick barrier of lead, concrete or water will stop gamma rays.

Neutrons are sub-atomic particles that have no electrical charge. They are released by nuclear fission and are also a very small component of cosmic radiation. On Earth, they are rarely encountered outside the core of a nuclear reactor. Neutrons can be very penetrating as well as being (indirectly) strongly ionising and hence very destructive to human tissue. A thick barrier of lead, concrete or water can stop them.

Figure 2.1 indicates the relative penetration of each type of radioactivity.

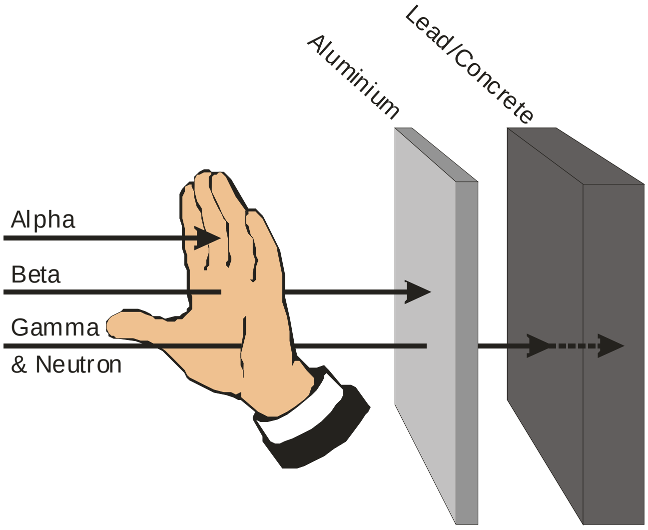

FIGURE 2.1
Penetrating powers of forms of radioactivity

2.1.3 Radioactivity and Radiation Protection

A radiation dose is the measure of how much energy is absorbed when radiation hits body tissue. The different types of radiation (alpha, beta and gamma) have different penetrating power and carry different levels of energy, resulting in different effects on humans. Alpha radiation cannot penetrate skin; beta radiation will penetrate skin but will not penetrate far into human tissue, and therefore is often referred to as a ‘skin dose’.

Thus the effects of alpha and beta radiation are of most significance if radioactive material is taken into the body by inhalation of contaminated dust, or by ingestion of contaminated food or drink. Gamma radiation penetrates most matter and so may be of health significance for both internal and external radiation sources.

In biological tissues, the process of changing atoms through ionisation also changes the molecules containing those atoms and it may thus cause damage to the cells containing those molecules. If cellular damage does occur and it is not adequately repaired, it may either prevent the cell from surviving and reproducing, or it may result in a viable or modified cell.

Most organs and tissues of the body are unaffected by the loss of even substantial numbers of cells, but if the number lost is large enough, there will be observable harm reflecting a loss of tissue function. The probability of causing such harm will be zero at small doses but, above some level of dose (the threshold), it will increase steeply to unity (100%). Above the threshold, the severity of the harm will also increase with the dose. This type of effect is called ‘deterministic’, meaning ‘results from prior conditions’.

The outcome is very different if the irradiated cell is modified rather than killed. Despite the existence of highly effective defence mechanisms, the clone of cells resulting from the reproduction of a modified but viable cell may result, after a prolonged and variable delay called the latency period, in the development of a cancer.

The probability of a cancer resulting from radiation usually increases with increments of dose, probably with no threshold, in a way that is roughly proportional to dose, at least for doses well below the thresholds for deterministic effects. The severity of the cancer is not affected by the dose. This kind of effect is called ‘stochastic’, meaning it is of a random or statistical nature. If the damage occurs in a cell whose function is to transmit genetic information to later generations, any resulting effects are expressed in the progeny of the exposed person. This type of stochastic effect is called ‘hereditary’.

These considerations are taken into account in international recommendations and national standards for radiation protection, and are discussed further in Sections 3.1 and 3.2 respectively.

2.2 Uses of Radioactivity in Australia

Radioactive materials play a number of important roles in our everyday lives, being used in medicine, industry and even in our homes. Both naturally occurring and artificial radioactive materials can be used.

2.2.1 Medical Uses

For most people, perhaps the most important use of radioactive materials is by medical practitioners and hospitals. Radiation from these materials is important in the treatment of a number of diseases, particularly cancers such as thyroid cancer. Radiopharmaceuticals (drugs that contain a radioactive material) are also important in diagnoses of many diseases or conditions, in therapeutic uses, and for the palliation of pain. They can be injected into the body, inhaled or taken orally to enable imaging (or picturing) of body organs such as the heart, kidneys, liver and lungs.

Millions of hospital patients have benefited from the therapeutic and diagnostic uses of radioactive materials. As noted in Section 1.6.1, the Australian Nuclear Science and Technology Organisation (ANSTO) estimates that in 2000–2001 about 525,000 people in Australia underwent a nuclear medicine procedure for the treatment or diagnosis of medical conditions such as cancer (pers. comm. to DEST 2002).

2.2.2 Industry

Australian industry uses radioactive materials in a variety of ways to improve productivity and safety, and to obtain information that could not be obtained in other ways.

Radioactive materials are used in industrial radiography, measuring devices, process control in factories, civil engineering, checking gas and oil pipelines for leaks and weaknesses, material analysis, and in oil and mineral exploration. These uses directly and indirectly influence our everyday lives. For example, nuclear measuring devices are used in tasks ranging from testing the moisture content of soils, to measuring the thickness of paper and plastics during manufacturing, to checking the fluid height in bottles. Radioactive materials are even used in devices designed to detect explosives.

2.2.3 Agriculture

In agriculture, radiation and radioisotopes are used to improve food crops, preserve food, and control insect pests (by sterilising pupae). They are also used to measure soil moisture content in vineyards, erosion rates, salinity and the efficiency of fertiliser uptake in the soil and to quantify the sustainable yield of aquifers.

2.2.4 Sterilisation

One of the most beneficial uses of radiation is for sterilisation. Syringes, dressings, surgical gloves, heart valves and surgical instruments can be sterilised after packaging by using radiation. This type of sterilisation can be used where more traditional methods such as heat treatments or toxic chemicals cannot be used, such as in the sterilisation of powders and ointments, as well as in biological preparations like tissue grafts. Like other applications of radioactive materials, the radiation sources used to sterilise these materials must then be disposed of at the end of their useful lives.

2.2.5 Environment

Radioactive materials are used as tracers to measure environmental processes, including the monitoring of silt, water and pollutants. They are also used to measure and map effluent and pollution discharges from factories and sewerage plants, and sand movement around harbours, rivers and bays. As well, they are used to measure and monitor physiological processes to assist conservation of fauna. Radioactive materials of this nature have short half-lives and quickly decay to background levels (in several days).

2.2.6 In Our Homes

One of the most common uses of radioactive isotopes in the home is in smoke detectors. These life saving devices contain tiny amounts of radioactive material that make the detector sensitive to smoke. The radiation dose to the occupants of the house is very much less than that from natural background radiation. Nevertheless, it is important that this material is disposed of in a responsible way.

2.3 Radioactive Waste Classification

According to the International Atomic Energy Agency (IAEA) 'radioactive waste may be defined as material that contains, or is contaminated with, radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body, and for which no use is foreseen' (International Atomic Energy Agency 1994a). This is essentially a legal or regulatory definition in that material with radionuclide concentrations or activities below the established exempt levels (i.e. below levels of radionuclide activity that would warrant safety concerns) is still radioactive from a physical point of view but represents a negligible radiological hazard, and so would not need to be subject to regulatory controls.

Radioactive waste is often broadly categorised as low, intermediate or high level (International Atomic Energy Agency 1994a), depending upon the specific activities of radionuclides present, the type of radiation emitted, the level of shielding required and the amount of heat, if any, generated during the radioactive decay process. It can also be classified as short-lived or long-lived, depending on the half-lives of the radionuclides present.

The IAEA has proposed various classifications for radioactive waste, notably in 1981 and 1994. The latter document recommends that classification distinction between intermediate and low level wastes should be based on criteria including site/disposal specific criteria. 'Activity limitations for a given disposal facility will in particular depend on the radiological, chemical, physical and biological properties of individual radionuclides ... Classification should be related in individual radionuclides, taking the various exposures and exposure pathways into account' (International Atomic Energy Agency 1994a). In practice, most nations use their own classification schemes, particularly for low level and intermediate level waste, based on the clearance levels for radioactive materials in their particular jurisdiction, on the types of waste that they produce and broadly on international classification schemes.

The disposal method adopted for any particular category of radioactive waste must ensure that the environment is adequately protected and that present and future members of the general public, and disposal site personnel, are not subjected to an unacceptable radiological dose or risk.

The 1992 National Health and Medical Research Council (NHMRC) 1992 *Code of practice for near-surface disposal of radioactive waste in Australia* (NHMRC 1992 Code) proposed four categories for Australian radioactive waste, in which the activity concentrations of radionuclides exceed the limits permitted under the 1985 *Code of practice for disposal of radioactive waste by the user* (NHMRC 1985). The classifications were based on international recommendations for radioactive waste management adapted for the types of radioactive waste generated in Australia. Those categories of waste suitable for near-surface disposal are:

- Category A
- Category B
- Category C.

Radioactive waste that does not meet quantitative and qualitative criteria for near-surface disposal is designated as Category S in the NHMRC 1992 Code. The waste categories are described in Table 2.1.

The classifications in Table 2.1 are only used by Australian regulatory authorities for classifying waste destined for disposal, not as a general classification system.

Category A, B and C waste has been referred to collectively as 'low level and short-lived intermediate level waste' (e.g. Department of Industry, Science and Resources 1999), or 'low level waste' (e.g. Department of Industry Science and Resources 2001) in publications relating to the national radioactive waste repository or national store. In this environmental impact statement (EIS), we refer to Category A, B and C waste as low level and short-lived intermediate level waste.

TABLE 2.1 Categories of radioactive waste from the NHMRC 1992 Code

Category	Definition
Category A	Solid waste with radioactive constituents, mainly beta or gamma emitting radionuclides, whose half-lives are considerably shorter than the institutional control period. The radioactivity will decay substantially during this period. Long-lived alpha-emitting radionuclides should only be present at very low concentrations. This category of waste comprises, predominantly, lightly contaminated or activated items such as paper, cardboard, plastics, rags, protective clothing, glassware, laboratory trash or equipment, certain consumer products and industrial tools or equipment. It may also include lightly contaminated bulk waste from mineral processing or lightly contaminated soils.
Category B	Solid waste and shielded sources with considerably higher levels of beta or gamma radiation than Category A wastes. Long-lived alpha-emitting radionuclides should be at relatively low levels. This category typically includes gauges and sealed sources used in industry and medical diagnosis and therapy, and small items of contaminated equipment.
Category C	Solid waste containing alpha-, beta- or gamma-emitting radionuclides with activity concentrations similar to those for Category B. However, this waste comprises bulk materials, such as those arising from the processing of radioactive minerals, significantly contaminated soils, or large items of contaminated equipment.
Category S	Waste that does not meet the specifications of Categories A, B, C. Typically, this category comprises sealed sources, gauges or bulk waste which contain radionuclides at higher concentrations than are allowable under Categories A, B, or C.

2.3.1 Low Level Waste

Low level waste contains low levels of short-lived beta and gamma emitting radionuclides and normally very low levels of alpha emitting radionuclides. Special shielding is normally not required for transport and handling of this material. It includes items such as wrapping materials and discarded protective clothing, and laboratory plant and equipment.

Low level waste corresponds to Category A, B or C waste under the NHMRC 1992 Code, and broadly corresponds to short-lived low and intermediate level waste as defined in the IAEA Safety Guide, number 111-G-1.1 (International Atomic Energy Agency 1994a).

Disposal in near-surface structures is commonly practised for this category of waste as it does not need to be isolated from the human environment for periods of longer than a few centuries. It is considered that institutional control of disposal sites can be maintained for such periods of time and should not be an unacceptable burden on future generations.

2.3.2 Intermediate Level Waste

Intermediate level waste contains significant levels of beta and gamma emitting radionuclides and could also contain significant levels of alpha emitters. The waste sometimes requires shielding during handling and transport. According to IAEA classification, short-lived radioactive materials have a half-life of about 30 years or less, and typically include gauges and sealed sources used in industry and medical diagnosis and therapy, and small items of contaminated equipment.

Short-lived intermediate level waste corresponds to Category A, B, and C waste in the NHMRC 1992 Code, and broadly corresponds to short-lived low and intermediate level waste as defined in the IAEA Safety Guide (International Atomic Energy Agency 1994a). Disposal options for short-lived intermediate level waste are similar to those for low level waste as the waste decays to very low levels within the institutional control period.

'Long-lived intermediate level waste', or 'intermediate level waste' (e.g. Department of Industry, Science and Resources, 2001), is not suitable for near-surface disposal. It is classified as Category S waste in the NHMRC 1992 Code, and broadly corresponds to the long-lived low and intermediate level waste as defined in the IAEA Safety Guide (International Atomic Energy Agency 1994a). The levels of radionuclides in long-lived intermediate level waste exceed the amounts allowed in Category B and C waste.

Australian long-lived intermediate level waste consists of historical waste concentrates from mineral sands processing, some types of disused sealed sources and industrial gauges, reactor components, irradiated fuel components, and ion-exchange resins and filters (e.g. as a result of reactor operation). In the future it will also include waste arising from the processing of research reactor fuel, which will be returned to Australia in glass or cement in around 2015.

2.3.3 High Level Waste

High level waste contains high levels of beta and gamma radiation emitters and significant levels of alpha emitters, and generates significant amounts of heat (greater than 2 kW/m^3, or about the same as an electric kettle). This category of waste corresponds to the high level waste as defined in the IAEA Safety Guide (International Atomic Energy Agency 1994a).

Such waste requires careful handling, substantial shielding, provision for dissipation of heat and long-term immobilisation and isolation from the biosphere. Outside of Australia, nuclear power reactors and some military activity generate high level waste. Australia does not generate high level radioactive waste and thus has no need or responsibility to store or dispose of any such material.

2.4 Waste Management in Australia

Two states have purpose-built facilities for the management of radioactive waste: Western Australia and Queensland.

2.4.1 Mount Walton East, Western Australia

Western Australia has an intractable waste disposal facility, operated in the form of a near-surface repository, which accepts low level and short-lived intermediate level radioactive waste, as well as toxic and chemical wastes. The facility is located at Mount Walton East, 100 km northwest of Kalgoorlie, and about 480 km northeast of Perth. It is owned by the WA Government and was established in 1992.

The Radiation Health Section of the Health Department of WA, located at the Queen Elizabeth Medical Centre in Perth, had been a collection point and store for unwanted radioactive sources for over 20 years. The store was nearing capacity and the WA Government decided that it needed to establish a disposal facility to accommodate this waste, as well as chemical wastes for which WA was responsible.

The site was chosen after extensive site investigations and community consultation. The repository site occupies 25 km^2 and at present less than 2% of the site has been used for waste disposal.

All of the low level radioactive waste disposed of at the site has been buried as Category B waste, which requires a minimum of 5 m backfill/overburden. Chemical wastes disposed at the site include hydrocarbons, pesticides, herbicides, fungicides, arsenic wastes and heavy metal wastes.

The radioactive waste accumulated at the Queen Elizabeth II Medical Centre store originated from hospitals, various government departments, private companies and members of the public. Waste types disposed of at the facility include:

- used radiation gauges
- wastes from medical use of radioisotopes
- disused exit signs containing tritium
- process equipment from the mineral sands industry containing radium-contaminated scale or build-up on the interior surfaces of production pipes.

Up to 1996, 125 m^3 of low level and short-lived intermediate level waste had been conditioned and disposed of at the site. It is projected that by 2014 a further 40 m^3 of conditioned waste will be disposed at Mount Walton (International Atomic Energy Agency 2000).

All of the waste disposed of at the facility is the responsibility of the state of Western Australia. The corporate entity that operates the site is Waste Management (WA), which was required to obtain the approval of the responsible authorities, the Western Australian Environmental Protection Authority and the Radiological Council of Western Australia, to build and operate the facility.

The disposal of radioactive waste is controlled by the *Radiation Safety Act 1975* of Western Australia, and *Radiation Safety (General) Regulations 1983*. As part of its approval, the disposal operation is required to comply with the requirements of various management plans associated with the site and with the NHMRC 1992 Code. The facility has been operated under the Western Australian *Environmental Protection Act 1986* since 1992.

All low level radioactive wastes received at the Mount Walton East facility must be packaged in compliance with the *Code of practice for the safe transport of radioactive substances 1990*. Generally, the low level radioactive waste is conditioned by placing it into a 60 L steel drum, which is then filled with a fluid cement mixture and returned to the Radiation Health Section store in Perth. Once the waste has set within the drums, the 60 L drums are placed into the centre of a 205 L steel drum. A specific and dense concrete mix is then poured into each 205 L drum to encase the waste, after which the lids of the drums are fitted.

The contents of each drum are recorded and a number for identification purposes is painted on its surface. Each drum is inspected after concreting and radiation levels at a distance of 1 m from the drum are measured and recorded and the correct signage is then applied for transport. The conditioning process provides both a primary and secondary level of protection against spillage of the waste in the event that primary containers are breached, and keeps the risk of emission to the environment of waste spilt or emitted from the primary package, in the event of a traffic accident, as low as reasonably achievable.

The transport of all radioactive wastes to the facility is undertaken by Waste Management (WA) and transport operations such as methodology, controls, routes, emergency response and timing are described in specific transport procedure documents. Transport to the facility is by trucks, usually in convoys of two or more vehicles (at least one of which is fitted with a satellite telephone for an emergency) during daylight hours. Emergency response teams are on-call during loading, transport and the unloading operations.

Performance and Safety

Before the initial disposal of radioactive waste at the facility, a comprehensive pre-disposal radiation monitoring program was initiated. In November 1992, baseline measurements of gamma radiation levels, radionuclides in air and radionuclides in soil were taken. Radon concentrations in air were also measured before any radon generating waste was disposed of at the site.

Since 1992 a continual environmental radiation monitoring program has investigated the gamma radiation levels over the disposal structures and perimeters of the security compounds and the radon concentrations in the air, both in the vicinity of the disposal sites and at a remote site.

The environmental impacts of the operations are restricted to the site and include:

- the clearing of vegetation
- dust generation
- use of septic tanks/leach drains.

An independent compliance audit of the management of the facility, commissioned by the Waste Management Division of the Western Australian Department of Environmental Protection, commented that the encapsulation of the waste in concrete and the waste disposal techniques used at the facility exceeded the requirements of a good radioactive waste management practice (Radiation Dosimetry Systems 1996).

The report recommended that all sampling and monitoring techniques should be detailed and properly documented, a detailed facility closure plan be developed, and post-rehabilitation monitoring and surveillance programs be outlined.

The general conclusions drawn were that the facility and the waste management program met the crucial requirements set out in the NHMRC 1992 Code, and that the program and facility were in general compliance with the IAEA's recommendations for a good low level radioactive waste disposal facility.

2.4.2 Esk, Queensland

The Queensland Government has a purpose-built store at Esk, which holds much of that State's low level and short and long-lived intermediate level radioactive waste. The facility is not a repository in that it is not a disposal structure. The waste held in the store, which is suitable for near-surface disposal, will be disposed of in the national repository.

The Esk storage facility is located in an elevated flood free area of state-owned pine forest, approximately 10 km west of Esk in southeast Queensland. The process of site selection involved extensive public consultation and a detailed environmental impact assessment.

The Esk facility began operation in December 1994 and consists of three storage areas, two general storage areas and a special radium storage area, providing approximately 120 m^2 of floor space. There is also an external preparation area that is to be used for conditioning of waste, when the material is prepared for final relocation to the national repository.

The storage facility is designed and constructed to withstand an earthquake one point higher on the Richter scale than the maximum recorded for the area. The outer walls of the three key storage areas are constructed of 400 mm thick reinforced concrete. All other walls and ceilings are 200 mm concrete (Wallace et al. 1995).

The comprehensive security and environmental monitoring system developed and implemented on site ensures the safety of both the public and the environment. The system includes a 30 m buffer zone surrounded by a 3 m barbed wire topped fence; soil, groundwater and air monitoring stations, external and internal sensors that activate a remote alarm and cameras to monitor and record intrusion; and daily site inspections by a local security firm (Wallace et al. 1995).

The Esk store only accepts radioactive materials produced from industrial, medical and research activities that are appropriately conditioned and packaged. The facility does not accept unsealed liquid radioactive material, radioactive material from other states, or medical wastes that may be contaminated with pathogens.

All aspects of the store and its operations are well regulated and subject to the requirements of Queensland radiation safety and control legislation, and the Esk Operation Management Plan. Under the facility management plan monthly, quarterly and six monthly internal audits have been undertaken (Wallace et al. 1995).

2.5 Accepted International Practice

In developing the proposal for a near-surface repository in Australia, a range of waste management practices from around the world has been considered. The term ‘accepted practice’ is considered less subjective than the term ‘best practice’ and is therefore used in this report. What is ‘best’ for one environment and set of circumstances is not necessarily ‘best’ in another example.

This section highlights what is required for the national near-surface radioactive waste repository to achieve internationally accepted practice and describes in general terms the different types of waste repositories.

This section also provides examples of existing international repositories elsewhere. Included are examples of repositories located in parts of countries where population densities and climatic conditions are similar to those of central–north South Australia such as the USA, China and South Africa. Also described are some examples of repositories designed for wet and densely populated environments.

Most facilities overseas are designed to take large volumes of radioactive waste generated by the nuclear power industry or by military use of radioactive materials.

2.5.1 Overseas Strategies and Accepted Practice

A near-surface repository should fulfil two important and related functions: one is to limit dispersion of the radionuclides contained in the waste so that acceptable levels in the human environment are not exceeded; the other is to protect the waste from surface and near-surface deteriorating processes such as erosion, encroachment by deep-rooted vegetation, burrowing by animals and intrusion by humans.

International experience shows that near-surface disposal can be safely applied when sites are carefully selected and repositories are designed and operated to take into account the characteristics of the site and the waste (International Atomic Energy Agency 1985).

Accepted international practice, as outlined in IAEA Guidelines (e.g. International Atomic Energy Agency 1981, 1984) is that solid low level and short-lived intermediate level radioactive waste is suitable for disposal in near-surface repositories. This type of facility provides the required isolation for this type of waste to decay to acceptable levels within a period of time for which institutional control of the repository can reasonably be expected to continue (International Atomic Energy Agency 1981, 1984). The content of long-lived radionuclides in near-surface disposal facilities should be less than the limits established by the relevant regulatory authority.

The IAEA Radioactive Waste Safety Standards are aimed at establishing a comprehensive and coherent set of principles, requirements and recommendations for the safe management of radioactive waste and formulating the guidelines necessary for their application (International Atomic Energy Agency 1999a). The operation of near-surface disposal facilities should be consistent with the following IAEA Safety Standards:

- The principles of radioactive waste management (1995)

- Siting of near-surface disposal facilities (1994b)
- Safety assessment for near-surface disposal of radioactive waste (1999b)
- Near-surface disposal of radioactive waste: safety requirements (1999a).

IAEA's Safety Standard Series *Near surface disposal of radioactive waste: Safety requirements* (1999a), sets out the basic requirements that international experience has shown to be necessary for ensuring the safety of near-surface radioactive waste repositories. It covers the requirements relating to protection of human health, the assessment procedures needed to ensure that safety is achieved, and the technical requirements for waste acceptance and for siting, design, construction, operation and closure of the repository, and the post closure phase.

This IAEA standard also provides guidelines for establishing a comprehensive quality assurance program which should be applied to all safety related activities, structures, systems and components of the disposal system, including all related activities from planning through to siting, design, construction, operation, the various steps in the safety assessment process, closure, long-term record keeping and institutional control activities associated with the repository. The quality assurance program ensures that the relevant safety requirements and criteria are met.

In relation to national legislation and regulations, acceptable practice for the national radioactive waste repository would be achieved by complying with the *Australian Radiation Protection and Nuclear Safety Act 1998* (ARPANS Act), and the relevant licence conditions once licences to site, construct and operate the facility had been issued. The ARPANS Act makes reference to the NHMRC 1992 Code, which is intended to encourage uniform practice in Australia for the near-surface disposal of radioactive waste. It also requires compliance with internationally accepted practice, including relevant IAEA safety series and other international documents.

The following system of radiation protection is recommended by the International Commission on Radiological Protection (1991, 1997) and has been adopted by NHMRC. The NHMRC 1992 Code recommends that the characteristics of the site chosen for the disposal facility and the design of facilities for waste treatment, packaging or conditioning for disposal shall ensure that the following system of radiation protection is adhered to:

- No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiological detriment it causes (justification).
- The magnitude of individual radiation exposures, the number of people exposed and the likelihood of incurring the exposures where these are not certain to be received shall be kept as low as reasonably achievable, economic and social factors being taken into account (optimisation).
- The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits or to some control of risk in the case of potential exposures (individual dose and risk limits).

Accepted practice could be interpreted as meaning 'a facility designed in such a way that there is no unacceptable risk or detriment to humans, other biota or the environment, at present, and that future risks or detriment will not exceed those currently accepted' (NHMRC 1992).

Siting the repository in accordance with the selection criteria discussed in Sections 1.5 and 5.2 of this report and taking the characteristics of the selected site into account would address accepted practice for siting the facility.

The hydrogeological characteristics of a site are usually the main factors controlling radionuclide migration, as water is the most likely medium for off-site transport of radioactive materials. If the site with its hydrogeological characteristics does not provide adequate confinement, various artificial barriers are commonly used to improve site performance. This may be by the conditioning of waste (e.g. with concrete) or special engineering of the repository (International Atomic Energy Agency 1985).

2.5.2 Type and Number of Repositories

Near-surface disposal structures may be:

- below ground trenches or pits (e.g. repositories in the western USA; Mt Walton East, Western Australia; Rokkasho-Mura, Japan)
- disposal structures above the ground's surface (e.g. Centre d'Aube, France; El Cabril, Spain); facilities built above ground are intended to be mounded-over during closure, to create an artificial hill (International Atomic Energy Agency 1999a).

Some nations also dispose of low level and short-lived intermediate level waste in subsurface facilities located in rock caverns tens of metres or more below the ground's surface (International Atomic Energy Agency 1999), for example, Sweden, Finland and Germany.

Near-surface disposal has been practiced since the 1940s and there are more than 100 near-surface repositories for low level and short-lived intermediate level radioactive waste either operating or being established in over 30 countries around the world (Table 2.2; International Atomic Energy Agency 1999b).

TABLE 2.2 Near-surface repositories around the world

Country	Repository (date opened/closed)	Repository concept
In the process of site selection		
Australia		ENSF
Belgium		ENSF
Brazil		ENSF
Bulgaria		ENSF
Canada (historic low level waste)		–
China (East)		–
(Southwest)		–
Croatia		–
Cuba		MC
Ecuador		ENSF
Hungary		–
Indonesia		ENSF
Korea, Republic of		
Pakistan		
Slovenia		
Turkey		ENSF
United Kingdom		GR
United States (Connecticut)		–
(Illinois)		ENSF
(Massachusetts)		–
(Ohio)		ENSF
(Michigan)		ENSF
(New Jersey)		–
(New York State)		ENSF
(Pennsylvania)		ENSF

Country	Repository (date opened/closed)	Repository concept
Site selected		
China	Guangdong Daya Bay	ENSF
Cyprus	Ari Farm	SNSF
Egypt	Inshas	ENSF
Mexico	Laguna Verde	ENSF
Peru	RASCO	ENSF
Romania	Cernavoda	ENSF
Switzerland	Wellenberg	MC
Under licensing		
Canada	Chalk River	ENSF
Germany	Konrad	GR
Norway	Himdalen	MC
Slovak Republic	Mohovce	ENSF
United States	Ward Valley, California	ENSF
	Boyd County, Nebraska	ENSF
	Wake County, North Carolina	ENSF
	Fackin Ranch, Texas	ENSF
Under construction		
China	Gobi, Gansa	ENSF
Finland	Loviisa	MC
In operation		
Argentina	Ezeiza (1970–)	ENSF
Azerbaijan	Baku (1960s–)	ENSF
Australia	Mt. Walton East (1992–)	ENSF
Belarus(1)	Ekores, Minsk reg. (1964–)	ENSF
Brazil	Abadia de Goias (1996–)	ENSF
Czech Republic	Richard II (1964–)	MC
	Bratrstvi (1974–)	MC
	Dukovany(I994–)	ENSF
Finland	Olkiluoto (1992–)	MC
France	Centre de I'Aube (1992–)	ENSF
Germany	Morsleben (1981–)	GR
Georgia	Tabilisi (1960s–)	ENSF
Hungary	RHFT Puspokszilagy (1976)	ENSF
	Solymar (1960–1976)[3]	ENSF
India	Trombay (1954–)	S/ENSF
	Tarapur (1968–)	ENSF
	Rajasthan (1972–)	ENSF
	Kalpakkam (1974–)	ENSF
	Narora (1991–)	ENSF
	Kakrapar (1993–)	ENSF
Iran	Kavir Ghom–desert (1984–)	SNSF
Israel	Negev Desert	SNSF
Japan	Rokkasho (1992–)	ENSF
	JAERI, Tokai (1995–1996)	SNSF
Kazakhstan	Almaty	ENSF
	Kurchatov (1996–)	ENSF
	Ulba (1996–)	ENSF
Kyrgyzstan	Tschuj (1965–)	ENSF
Latvia	Baldone (1961–)	ENSF

Country	Repository (date opened/closed)	Repository concept
Lithuania	Maishiogala (1970s–1989)	ENSF
Mexico	Maquixco (1972–)	SNSF
	La Piedrera (1983–1984)	ENSF
Moldova	Kishinev (1960–)	ENSF
Norway	Kjeller (1970–1970)(4)	ENSF
Pakistan	Kanupp (1971–)	SNSF
	PINSTECH (1969–)	SNSF
Poland	Rozan (1961–)	ENSF
Romania	Baita–Bihor (1985–)	GR
Russia(2)	Sergiev Posad, Moscow reg. (1961–)	ENSF
	Sosnovyi Bor, Leningrad reg.	ENSF
	Kazan, Tatarstan	ENSF
	Volgograd	ENSF
	Nijnyi Novgorod	ENSF
	Irkutsk	ENSF
	Samara	ENSF
	Novosibirsk	ENSF
	Rostov	ENSF
	Saratov	ENSF
	Ekaterinburg	ENS
	Ufa, Bashkortostan	ENSF
	Cheliabinsk	ENSF
	Habarovsk	ENSF
South Africa	Pelindaba (1969–)	SNSF
	Vaalputs (1986–)	SNSF
Spain	El Cabril (1992–)	ENSF
Sweden	SFR (1988–)	MC
	Oskarshamn NPP (1986–)	SNSF
	Studsvik (1988–)	SNSF
	Forsmark NPP(1988–)	SNSF
	Ringhals NPP (1993–)	SNSF
United Kingdom	Dounreay (1957–)	SNSF
	Drigg (1959–)	S/ENSF
Ukraine	Dnepropetrovsk center	ENSF
	L'vov center	ENSF
	Odessa center	ENSF
	Kharkov center	ENSF
	Donetsk center	ENSF
United States	RWMC, INEEL (1952–)	S/ENSF
	SWSA 6, ORNL (1973–)	S/ENSF
	Disposal Area G,LANL (1957–)	SNSF
	Barnwell, South Carolina (1971–)	SNSF
	200 East Area Burial Ground, Hanford (I940s–)	SNSF
	200 West Area Burial Ground, Hanford (1996–)	SNSF
	Richland. Washington (1965–)	SNSF
	Savannah River Plant site (1953–)	SNSF
	Beatty, Nevada (1962–1992)	ENSF
	Maxey flats. Kentucky (1963–1978)	SNSF
	ORNL SWSA I (1944–1944)(3)	SNSF

Country	Repository (date opened/closed)	Repository concept
	ORNL SWSA 2 (1944– 1946)	SNSF
	Shefield, Illinois (1967–1978)	SNSF
	West Valley New York (1963–1975)	SNSF
Uzbekistan	Tashkent (1960s–)	ENSF
Viet Nam	Dalat (1986–)	ENSF
Operation stopped or under closure		
Armenia	Ereven	ENSF
Bulgaria	Novi Han (1964–1994)	ENSF
Estonia	Tammiku (f. Saku) (1964–1996)	ENSF
France	Centre de la Manche (1969–1994)	ENSF
Germany	Asse (1967–1978)	GR
Russian Federation(2)	Mormansk	ENSF
	Groznyi Chechnya	ENSF
Tajikistan	Beshkek	ENSF
Ukraine	Kiev center (–1992)	ENSF
Closed		
Czech Republic	Hostim (1953–1965)	MC
Hungary	Solymar (1960–1976)(3)	ENSF
Japan	JAERI, Tokai (1995–1996)	SNSF
Mexico	La Piedrera (1983–1984)	ENSF
Norway	Kjeller (1970–1970)(4)	ENSF
Lithuania	Maishiogala (1970s–1989)	ENSF
United States	Beatty, Nevada (1962–1992)	ENSF
	Maxey Falts, Kentucky (1963–1978)	SNSF
	ORNL SWSA 1 (1944–1944)(3)	SNSF
	ORNL SWSA 2 (1944–1946)	SNSF
	Shefield, Illinois (1967–1978)	SNSF
	West Valley, New York (1963–1975)	SNSF

(1) There are 77 repositories built to accommodate waste from Chernobyl accident.
(2) Repositories in Russian Federation started operation from 1961 to 1967
(3) Waste was moved to another repository (from Solymar to RHFT Puspokszilagy; from ORNL SWSA-1 to ORNL SWSA-2).
(4) Waste will be moved to a new repository (Himdalen) when constructed.

SNSF = simple near-surface facility
MC = mined cavity
ENSF = engineered near-surface facility
GR = geological repository
S/ENSF = SNSF and ENSF

Generally, near-surface repositories established in wet environments have greater levels of engineering than those established in arid environments, as commonly the watertable in wet environments is close to the ground surface and local groundwater is of good quality and in use as a resource.

Summaries of near-surface/subsurface disposal facilities are provided in: International Atomic Energy Agency 1995; Nuclear Energy Agency Nuclear Waste Bulletins (e.g. 1998); and Nuclear Energy Agency 1999.

The following section provides a brief outline of some representative examples of various types of operating facilities from around the world. Near-surface facilities are divided into those that operate in arid environments (e.g. Areas 5 and 3, Nevada Test Site (NTS), USA; Envirocare, Utah, USA; US Ecology, Richland, Washington, USA; Vaalputs, South Africa; Northwest Repository, China; Mount Walton East, WA, Australia); and those which are sited in wet environments (e.g. Centre de la Manche and Centre de l’Aube, France; Drigg, UK;

Rokkasho-Mura, Japan), as there are design differences between facilities sited in the arid and wet situations. An example of a subsurface facility (in Sweden) is also given.

Issues discussed include the size, age, characteristics, performance, safety and regulatory arrangements of these examples.

2.5.3 Near-Surface Repositories in Arid Environments

Area 5 and Area 3, Nevada Test Site, USA

Two disposal sites for US Department of Energy (US DOE) low level and short-lived intermediate level waste are located on the NTS in the USA.

The NTS is used by the USA to test military devices and, similarly to the Woomera Prohibited Area, is now being considered for additional uses such as launching of commercial satellites and various industrial uses. The NTS occupies an area of over 3500 km^2 of federally owned land with controlled access. The closest populated area is about 40 km to the southeast and the major population centre of Las Vegas is about 105 km southeast. The NTS is now the main disposal site for US DOE low level and short-lived intermediate level waste. Figure 2.2 shows the NTS repository.

FIGURE 2.2
Nevada Test Site repository

Once accepted for disposal at the NTS, low level waste is disposed either in the engineered pits and trenches at the Area 5 Radioactive Waste Management Site, at Area 3, or in subsidence craters created by the underground testing of nuclear devices. The environment is arid with an annual rainfall of 150 mm. Evaporation rates are high, surface water flows only rarely and the top of the watertable is deep (235 m below Area 5 and 488 m below Area 3) (US Department of Energy 2000).

From 1961, Area 5 was used to dispose of low level waste generated by NTS operations. In 1978, NTS began accepting low level waste generated by offsite US DOE facilities. The total site area at Area 5 is 37 ha, and it contains 17 landfill cells (pits and trenches). Four pits are currently in operation; one for mixed radioactive and toxic waste, two for disposal of low level waste, and one for disposal of low level waste containing asbestos.

Trenches are 25.3–345 m long, 9–102 m wide, and 3.7–14.6 m deep. Low level waste is disposed of in wooden or metal boxes (1.2 m or 60 cm high), which are placed in a specially arranged grid system in shallow excavated trenches without lining. Small gaps are left between boxes to allow soil backfill to infill voids. Steel drums (200 L) are placed on their sides in spaces between rectangular boxes.

The top of the emplaced wastes is 1.2 m below ground surface. A 2.4 m temporary cover of alluvium is placed on the wastes bringing the top to 1.2 m above the surrounding land. Any subsidence is filled to maintain a sloping top surface that will shed water. Work is underway on the final cover design, and the preliminary view is that a thicker alluvium cover might be all that is required. The total disposed volume is more than 254,880 m^3 and available capacity would allow for disposal of a further 141,600 m^3.

The disposal trenches are fitted with open-ended pipes that will allow the soil beneath the waste to be sampled. The mixed waste cells are fitted with vadose zone monitoring stations, consisting of pipes that extend 1.5 m below the bottom of the trench. The pipes are used for moisture meter monitoring and gas sampling.

Area 3 occupies 20 ha of the NTS, and uses the subsidence craters for the disposal of bulk low level and short-lived intermediate level debris, including soils, from US DOE and US DOE-approved on- and off-site generators.

The craters are 13.7–27.4 m deep. Packages for disposal include cargo containers, supersacks, burrito wraps (made of plastic) and uncontainerised waste such as large equipment. The container is the only barrier between the radioactive waste and the host rock. Each waste layer is covered by compacted soil of 30–90 cm in depth.

At the time of formation, the seven craters within Area 3 were 122–178 m in diameter and 14–32 m in depth. Five craters have been filled with more than 283,200 m^3 of disposed waste and the available capacity in two remaining craters is 226,560 m^3 (US Department of Energy 2001; US DOE pers. Comm. 2000).

The general policy for management of US DOE wastes is established in the *Atomic Energy Act 1954*, as amended. The US DOE is generally responsible for regulating its own waste, and regulates the low level waste facilities on the NTS. The US Environmental Protection Agency (US EPA), has responsibility for setting national environmental protection standards that serve as a basis for the regulations promulgated by US DOE (International Atomic Energy Agency 2000).

US DOE has the regulatory authority to implement its own regulations and to issue orders that implement health, safety and environmental protection policies on the radioactive waste generated at departmental facilities. The department is subject to regulatory oversight by the US EPA for the management of the non-radioactive hazardous constituents of radioactive wastes that are generated at US DOE facilities (International Atomic Energy Agency 2000).

The US DOE performance requirements for its facilities are comparable to requirements established by the Nuclear Regulatory Commission (NRC) (US Regulatory Commission 1990), which is responsible for regulating commercial facilities. The performance requirements include the following:

- Protection of the general population from releases of radioactivity — Concentrations of radioactive material that may be released to the general environment in groundwater, surface water, air, soil, plants or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.
- Protection of individuals from inadvertent intrusion — The design, operation and closure of the land facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.
- Protection of individuals during operations — Operations at the land disposal facility must be conducted in compliance with relevant standards for radiation protection.

Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable.

- Stability of the disposal site after closure — The facility must be sited, designed, used, operated and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site to that only surveillance, monitoring or minor custodial care are required.

Performance of Area 5, NTS

US DOE undertakes regular environmental monitoring around the NTS. Air monitoring and ecosystem monitoring have been undertaken at and around the NTS for about 20 years. Groundwater has been monitored for about eight years and the unsaturated zone has been monitored for contaminants for about 12 years. As of 2000 the monitoring results have shown no detection of contaminant transport exceeding health, safety and environmental standards (US Department of Energy 2000).

Owing to the comparable design and location of Area 5 with the repository proposed for central–north South Australia, only the performance of Area 5 is covered in this report. Details of the 2000 monitoring program for Area 3 can be found in Bechtel Nevada (2001a). The 2000 environmental monitoring results taken at and around Area 5 of the NTS are given below (Bechtel Nevada 2001a,b):

- Direct radiation was not above background levels.
- Air tritium concentrations were slightly above background levels but still well below any concentration of concern.
- Gross alpha radiation, gross beta radiation, gamma radiation, americium concentrations, and plutonium concentrations in air particulate monitoring data indicate that radionuclide concentrations in the air at Area 5 were not above surrounding background levels.
- Groundwater monitoring data indicate that the groundwater in the uppermost aquifer below Area 5 has not been contaminated by the facility (tritium groundwater concentrations from February 1993 to December 2000 were all below the investigation level, the minimum detection level and the drinking water standard).
- Vadose zone monitoring data indicate that in 2000 rainfall infiltrated less than one metre before being evaporated.
- Tritium concentrations in the surrounding area's biota were reduced as compared to previous years.

Envirocare, Utah, USA

In the mid-1970s the US DOE and the State of Utah investigated 29 sites with potential to permanently receive uranium mill tailings from an abandoned uranium mill site. After an eight year siting process to determine the best location, a location in Utah's West Desert was chosen in an area approximately 128 km west of Salt Lake City. The site, called Clive, was preferred because of its remote location (64 km from the nearest community), low annual rainfall (approximately 200 mm), annual evaporation rate of more than 1500 mm and poor quality groundwater (about twice the salinity of seawater) at 12 m below the surface. Non-saline water exists at depths of 400 m.

The facility is a commercial operation that began operating in 1984 when mill tailings were received. These tailings will be contained for 1000 years. The wastes disposed of at this site are naturally occurring radioactive materials including uranium mill tailings, and mixed low level and short-lived intermediate level waste (Envirocare of Utah 2001).

Separate trenches are used for different types of waste. The mixed wastes are placed on cell liners which comprise part of the cover. Drummed wastes are emptied, with the drums being crushed and buried with the waste. The cell embankment top slopes are covered with a compacted 2.1 m thick clay cover, a rock filter layer, and a 60 cm thick rock erosion barrier to ensure long-term protection of the environment (Envirocare of Utah 2001). Over 12 million m^3 of waste have been disposed of at the site.

The NRC is responsible for regulating and licensing commercial waste management facilities. The US EPA is responsible for setting national environmental protection standards that serve as a basis for the regulations promulgated by NRC.

Performance and Safety

The Envirocare facility is inspected on a quarterly basis and examined for overall site radiation safety, environmental monitoring procedures, quality assurance and the construction and integrity of the waste disposal cells (Envirocare of Utah 2000). The NRC reported that it found, during an audit in September 2000, that the facility was in compliance with all licence requirements, and was meeting or exceeding the reviewed regulations.

US Ecology, Richland, Washington, USA

The Richland Low Level Radioactive Waste Disposal Facility is a commercial operation that began in 1965 and is operated by US Ecology. The facility is located approximately 32 km northwest of the city of Richland, Washington and occupies approximately 40 ha of the 1450 km^2 US DOE Hanford Site, which leases the land to the State of Washington (Washington State Department of Health and Washington State Department of Ecology 2000).

Like the national near-surface radioactive waste repository proposed for central–north of South Australia, the Richland facility is located in a dry arid climate. The average annual rainfall at the site is approximately 159 mm, mostly falling during the months of November to February. The depth to groundwater under the facility is approximately 91 m. The geology of the site is characterised by thick basaltic lava flows, which are overlain by unconsolidated sediments. The two main formations under the site are the Hanford Formation to a depth of approximately 76 m consisting of alternating layers of silt, fine sand and medium to coarse sand over poorly sorted sands, silts and gravels; and the middle member of the Ringold Formation, consisting of silty, sandy gravel with well-rounded pebbles and small amounts of cementation (Washington State Department of Health and Washington State Department of Ecology 2000).

From 1965 to December 2000 more than 393,000 m^3 of low level waste had been received at the site. The waste consisted of solid or solidified materials, contaminated materials, cleaning wastes, protective clothing, gloves, laboratory wastes and naturally occurring or accelerator produced radioactive material (US Ecology 2001a).

Presently wastes are contained in 20 separate trenches that are excavated into the surficial sediments. Standard disposal trenches are up to 46 m wide, 396 m long and 14 m deep. Waste is contained in rectangular metal boxes, which are disposed of in the trenches within 2.4 m of the ground surface, and then backfilled with site soil. Drums (200 L) are randomly disposed of in the trenches. When the capacity of each trench is reached, it is covered with at least 2.4 m of soil and capped with a layer of gravel (US Ecology 2001a). The facility has about 1.27 million m^3 of unused capacity (US Ecology 2001b).

Performance and Safety

Operations and closure of the commercial facility are regulated by the Washington Department of Health under the authority of the *Washington Nuclear Energy and Radiation Control Act* (Chapter 70.98 RCW) and through agreement with the US NRC. The primary instrument for regulating the commercial low level radioactive waste disposal site is the Washington State Radioactive Materials License (WN-I019-2), issued by the Washington Department of Health NRC, to US Ecology (Washington State Department of Health and Washington State Department of Ecology 2000). The performance requirements established by the NRC, which is responsible for regulating commercial facilities, are similar to the DOE performance requirements for the NTS above.

Environmental monitoring is undertaken to ensure compliance with appropriate regulations and the facility standards manual. The environmental monitoring program at the site includes air, soil, vegetation and groundwater. Vadose zone monitoring for tritium and radon is an experimental program also currently operating at the site. The environmental monitoring assessment process is complicated by the facility's proximity to the Hanford 200 Areas, which contain irradiated uranium fuel processing facilities, plutonium separation facilities and major radioactive waste storage and disposal facilities (US Ecology 2001a).

The environmental monitoring program for 2000 did not detect any increase in environmental radioactivity. Results are summarised below (US Ecology 2001a):

- All site airborne emissions including gross alpha, gross beta, airborne iodine-125, gamma emitters, tritium and radon were below levels that would be detectable at offsite locations, and offsite doses from site operations were indistinguishable from background. Air monitoring results for 2000 either fell below the investigation level and the site reporting level, or were not significantly different to background levels or trend comparisons with historical data.
- Soil monitoring consists of gross beta, isotopic uranium and plutonium, and gamma emitters. The 2000 soil monitoring report indicated that all monitoring results were below their required investigation level, consistent with results from previous years and within normal background levels. Plutonium was not detected in the site soil samples.
- Vegetation samples in 2000 were analysed for gross beta, total uranium, isotopic plutonium, gamma emitters and tritium. The 2000 monitoring results indicated that analysed vegetation samples either fell below the investigation and the site reporting level or were not significantly different to background levels or trend comparisons to historical data.
- Groundwater samples were analysed for gross alpha, gross beta, tritium, ^{14}C, ^{99}Tc, gamma emitters, isotopic plutonium, isotopic uranium and other non-radiological parameters. The results indicated that there was no facility impact on groundwater in 2000.

Vaalputs, South Africa

The Vaalputs repository in South Africa takes low level waste from the Koeberg nuclear power reactors, and the South African Nuclear Energy Corporation Ltd, a public company owned by the state, previously called the Atomic Energy Corporation of South Africa, operates the facility. The facility has been operational since 1986, following a siting process that began in 1979.

The facility is situated on the Bushmanland Plateau, in an arid area of northwestern Cape Province, about 600 km north of Cape Town. The site covers an area of 10,000 ha, with the disposal area of some 35 ha, of dimensions 700 x 500 m. Rainfall is bimodal, with an annual average of about 74 mm and usually comes in the form of heavy storms. Groundwater at the site is generally about 50 m below the surface, and has an age of 6000–10,000 years (US Department of Energy 1998).

Operational wastes from the Koeberg nuclear power reactors, comprising clothing and other laboratory equipment, are compacted in steel drums; filter resins and short-lived intermediate level wastes are cemented into 5 tonne concrete canisters. Approximately 1500 drums and 500 concrete containers are produced per annum at Koeberg.

The wastes are transported by road from the Koeberg to the Vaalputs repository where they are disposed of in two pre-constructed trenches, 100 m long x 20 m wide x 7.5 m deep, one for concrete containers with intermediate level waste, and one for drummed low level waste. The trenches are excavated in a weathered residual clay formed above granite and metamorphic rocks. The clay is up to 30 m thick at the site, and is overlain by wind-blown sand and calcrete. As of December 1995, some 2345 concrete containers and 4609 other packages, mainly steel drums, had been disposed of. Up to this time material was placed in the repository and left uncovered until that section of the repository was full.

Deliveries of waste from Koeberg were halted in September 1996, when some of the concrete canisters and steel drums were observed to be cracked, thought by the Atomic Energy Corporation to be due to prolonged exposure to frost and rain. Sampling around the site did not find evidence of any contamination and the Council for Nuclear Safety lifted the delivery ban after an inspection in September 1997. The Atomic Energy Corporation invited an inspection by an IAEA review group, which confirmed the integrity and radiological safety of the site (Atomic Energy Corporation 1999). Waste shipments to the site recommenced in 1999.

Waste is now transported to the site once per year, and trenches are now compartmentalised to allow for more rapid filling and capping with 1.5–2 m of clay. A series of cut-off walls are constructed after emplacement of each shipment, so that they can be covered immediately and protected from the elements.

The Council for Nuclear Safety is the South African regulatory authority. It is the licensing agency for the construction and operation of nuclear installations, and was established in *Nuclear Energy Amendment Act 1988*.

Performance and Safety

Routine environmental monitoring on and around the Vaalputs repository site has been undertaken since 1984. Owing to the arid climate of the region environmental monitoring is limited to borehole water, soil and vegetation monitoring.

The 2000 environmental monitoring report (South African Nuclear Energy Corporation Ltd 2001) reached the following conclusion for the results on and around the Vaalputs site:

- The results for beta activity in water and soil indicated that the results were lower than 1999, while the alpha activities results showed a slight increase, which may be due to analytical or natural fluctuations.
- A single quarterly borehole result showed a caesium-137 (^{137}Cs) concentration higher than the analytical detection limit. Other boreholes closer to the trenches did not show any ^{137}Cs activity higher than the analytical detection limit. Four extra samples of that borehole were taken returning results that were below the detection limit for ^{137}Cs activity.
- The activities measured by the 2000 environmental monitoring program were well below the National Nuclear Regulator reporting levels.
- The monitoring results indicate that no measurable radiological impact could be detected from the activities at Vaalputs.

The Northwest Repository, China

China began operating a low level and short-lived intermediate level waste repository, known as the Northwest Repository, in the Gobi desert at the Lanzhou Nuclear Fuel Complex in 1998. The area is arid, with an average annual precipitation of 61.5 mm and a watertable at 30–35 m below the surface. A thick clay layer, which has good sorption properties for ^{137}Cs, exists at the site. The distance between the nearest river and site is over 2.5 km (De 1997; US Department of Energy 1998).

The total capacity of Northwest Repository is 200,000 m^3 of waste, with the initial phase having a capacity of 20,000 m^3. The waste is disposed of in underground vaults without a concrete base. The repository is divided into controlled and non-controlled areas. The controlled area includes disposing, buffer and operating zones, and the non-controlled area consists of administrative, auxiliary and utility buildings (De 1997; US Department of Energy 1998).

Several safety measures were adopted in designing the repository to protect the environment and the public from the potential contamination of radionuclides. This includes a multi-barrier approach for disposal units to isolate waste effectively, and to prevent human, animals or plants from inadvertent access to the waste. The monitoring of radiation dose, and sampling of air, water, soil, animals and plants are stipulated for the activities of waste disposal and the area adjacent to the repository (De 1997).

The China National Nuclear Corporation is responsible for the siting, construction and operation of repositories, but the approval of environmental impact assessment, issue of standards and inspection of disposal activities are undertaken by the National Environmental Protection Agency and its local administration.

In China the National Nuclear Safety Administration is responsible for standards and regulations, construction permits and operating licences, and the monitoring of plant operations.

2.5.4 Near-surface Repositories in Wet Environments

Centre de la Manche, France

Low level and short-lived intermediate level wastes in France are disposed of in engineered repositories. Nuclear power plants generate more than 70% of the waste and the remainder comes from medicine, industry and research.

The Centre de la Manche facility, located in Brittany about 400 km west of Paris, began operations in 1969 and closed in 1994. Average annual rainfall is 500–1000 mm. Initially, waste was buried in two shallow soil trenches with gravel bases. After 1978, the waste materials were placed in rectangular concrete trenches with drainage channels built at the trench bases. The waste is completely encapsulated by backfilling with concrete to form a monolith. A rainwater catchment system was also incorporated into the trench bottom structure. The whole monolith is capped with reinforced concrete.

In addition tumuli were built on top of the burial monolith consisting of stacked concrete containers of lower activity wastes, which were backfilled with gravel and stones, covered with compacted soil and clay, and topped with topsoil. The operational phase was completed in 1994, with 525,000 m^3 of waste successfully disposed of.

During 1991–97, the 15 ha repository site was capped with a multi-layered engineered cover, comprising layers of compacted coarse grained materials and a drainage layer of fine-grained sand on both sides of a bituminous geomembrane. The repository has now entered a 300-year institutional control period.

A complex water collection system was built into the facility to collect runoff water, water from the cover drainage, and water from drains along the base and walls of the facility.

A new environmental monitoring program was initiated in 1998 to monitor the integrity of the cover as well as potential releases from the waste into the water collection systems or into the general environment through surface water and groundwater. Supplementary monitoring of air, radon levels, and the ambient radiation dose rate and cover vegetation also takes place as part of the program.

Performance and Safety

A report to Greenpeace France in 1993 stated that there had been off-site contamination due to leachate migration away from the stored wastes. It was reported that activity levels of up to 500 times the natural background had been recorded in the general area of the site, and evidence of accumulation of long-lived alpha-emitting radionuclides had been found in the local St Helene stream. These claims have not been substantiated by the monitoring program (US Department of Energy 1998).

For the first 10 years of the 300-year institutional control period, a high level of surveillance is maintained. Surveillance of the centre involves monitoring of gamma radiation around the centre, grass, rainwater, subterranean water, air and surface water (ANDRA 2001a).

The maximum limit for gamma radiation around the centre is 570 nGy/h. Monitoring in 2000 and 2001 has recorded average values of 80–87 nGy/h of gamma radiation around the centre (ANDRA 2001b). Air monitoring around the centre also involves the measurement of alpha activity, beta activity and tritium levels.

Alpha activity has also remained well below the limit of 8 mBq/m^3, with all average quarterly values being too low to be detected by the measurement device. A similar situation occurred for beta activity and tritium levels during the same monitoring period with all average quarterly values being below the detection threshold of the measuring device as well as being below the limit of 6000 mBq/m^3 for beta activity and 80,000 mBq/m^3 for tritium (ANDRA 2001a).

Groundwater monitoring around the site consists of measuring alpha activity, beta activity and potassium-40 (^{40}K). The limit of alpha activity in groundwater is 18 Bq/L and the limit of beta activity is 91 Bq/L. As with the air monitoring results, all average quarterly values during the period from the second quarter 2000 up to and including the second quarter 2001 for both alpha and beta activity were too low to be detected by the measurement device. ^{40}K is a naturally occurring radioactive element and the average quarterly value during the measurement period was 0.06 Bq/L (ANDRA 2001a).

Centre de L'Aube, France

The Centre de L'Aube site, about 200 km east of Paris and about 60 km from Rheims in the Champagne district, was selected through a siting process that began in June 1984. Average annual rainfall is 500–1000 mm. The 95 ha site was selected based on its geology, which consists of an unsaturated layer of sand covering a thick layer of clay. Work on the site began in 1988 and the disposal facility started operations in 1992.

Waste sent to Centre de L'Aube is placed in 200 L and 400 L drums, metallic containers and reinforced concrete boxes. All waste packages are well characterised in terms of their radionuclide content, concentration and form. The wastes are solid. The centre is designed to accept 1,000,000 m^3 of waste over a 40-year period, and will be Europe's largest repository of this type. The disposal technology has evolved from the technology used at the Centre de la Manche.

The site uses near-surface concrete vaults and not the tumulus design used at the Centre de la Manche. All waste packages are placed in above-grade concrete vaults that are 24 x 21 x 8.5 m high. The vaults have 30 cm thick walls and each vault can accept 2500-3500 m^3 of waste depending on the waste package type. Waste emplacement takes place under a movable shelter equipped with an overhead crane and other waste handling equipment. The shelter prevents rainwater from contacting the waste, and eliminates the need for elaborate systems to collect and monitor surface runoff. Depending on waste type, the vaults are back-filled with either gravel or concrete, and are then topped with a concrete slab. All vaults are equipped with a system of drainage galleries to collect and monitor water.

As disposal vaults are completed, the spaces between the vaults will be filled with soil, which is mounded and graded to a smooth surface. Swales and surface drainage will be constructed to facilitate the rapid runoff of rainwater to minimise infiltration. Finally, a multi-layered engineered cover will be constructed over the entire repository. Once vegetated, the mound will look like a hill.

Performance and Safety

More than 1500 measurements have been taken at the Centre de L'Aube since it began receiving radioactive waste. Measurements are taken regularly and are compared with the baseline measurements at facility start-up. Monitoring for radiation sources at the centre involves measuring the air, plants, milk, surface water and groundwater (ANDRA 2001b). The monitoring program is similar to that described for Centre de la Manche, discussed above, and the limits are the same.

The following monitoring results are from the period from the second quarter 2000 up to and including the first quarter 2001. The average quarterly value for gamma radiation ranged from 92 to 98 mBq/m^3 (compared with the baseline level of 60–130 mBq/m^3). For alpha activity the results were too low to be detected, with all results for the period being less than the detection threshold of the measuring device (less than 0.04 mBq/m^3) and the baseline level was 0.15 mBq/m^3. Beta activity during the measuring period has ranged from an average quarterly value of 0.29 to 0.45 mBq/m^3 (compared with the baseline level of 0.02 mBq/m^3). Tritium monitoring results were also below the detection threshold of the measuring device (<0.7 Bq/m^3), compared with the baseline level of 2.2 Bq/m^3 (ANDRA 2001b).

Statutory limits for groundwater are 18 Bq/L for alpha activity, 91 Bq/L for beta activity and 270,000 Bq/L for tritium. The results at the Centre de L'Aube during the same monitoring period indicated above, showed that the average quarterly value for tritium and alpha and beta activity were below the detection threshold, while the average quarterly value for ^{40}K was 0.1 Bq/L (compared to the baseline level of 0.3 Bq/L (ANDRA 2001b).

Regulation

The Division for the Safety of Nuclear Installations shares overall nuclear regulations with the Radiation Protection Agency. The French National Agency for Radioactive Waste Management (ANDRA) is responsible for long-term radioactive waste management in France. The regulatory body for licensing nuclear facilities in France is the French Nuclear Safety Authority (DSIN). Repositories are required to comply with general rules for 'Nuclear Basic Facilities'. Fundamental Safety Rules (FSR) were also issued by DSIN and must be complied with (International Atomic Energy Agency 2000):

- FSR 1.2: Safety objectives and principles for design of surface long term disposal facilities for L/ILW-SL solid radioactive waste (19 June 1984)
- FSR 3.2e: Conditions for radioactive waste packages acceptance to be disposed in surface facilities (29 May 1995).

FSR 1.2 defines safety objectives and design bases for near-surface facilities in terms of:

- the short and long-term performance objectives for the facility in terms of dose limits for workers and members of the public
- safety-related design basis which provides for three distinct containment systems — the form and packaging of the waste, the engineering of the facility (including cover) and the natural materials of the site (soil or rock)
- site selection criteria
- limits on long-lived radionuclides in the waste
- an appropriate quality assurance program for the design construction and operation of the facility.

FSR 3.2e specifies acceptance criteria for solid radioactive waste packages that place conditions on the type of waste, conditioning requirements, characteristics of waste packages, the absence of non-radioactive hazardous materials, and quality control measures to confirm compliance of waste packages with specifications.

Drigg, Cumbria, United Kingdom

British Nuclear Fuels Ltd owns and operates the principal solid low level waste disposal site in the UK at Drigg, in West Cumbria. The annual average rainfall is about 1016 mm and the watertable is a few metres below the ground surface.

The 110 ha site has been operational since 1959 and has accepted more than 900,000 m^3 of waste. It is approximately 6 km south of the Sellafield nuclear fuel reprocessing site and waste comes from Sellafield and other British Nuclear Fuels Ltd sites, nuclear power plants, hospitals, research establishments and other industries. The waste typically consists of paper, packaging materials, plastic sheeting, protective clothing and scrap metal. All waste, including drums, is highly compacted before disposal.

In the past, disposal procedures at Drigg involved cutting a trench into the glacial clay deposit, and then tipping the waste into the trench. There are seven waste-filled trenches that occupy 17 ha of the Drigg site. Each trench is covered with an interim cap, which incorporates an impermeable membrane.

Since 1988 the waste has been containerised and stacked in a concrete engineered vault. The reason for changing the design was that past trenches had earthen bases and these were less effective in collecting rainwater for drainage and monitoring. The rain also softened the base and made it unstable under heavy loads (AEA Technology pers. comm. 2001). A concrete base also provides an adequate foundation for containers and forklifts. There is an underlying drainage system.

The current disposal trench is sited in an area of soft clay soil and high watertable. As the trench is some 5 m deep, lateral inflow of water is high and the trench sides are unstable. Consequently, concrete retaining walls have been constructed around the trench perimeter.

The concrete vault occupies 4 ha, and has the capacity to accept 180,000 m^3 of waste. The vault has three bays each about 60 m wide, 200 m long and 5 m deep. Waste is disposed of in solidified cubes in which the entire contents have been consolidated by grouting.

Before final closure of the site the seven waste filled trenches and concrete vaults will be capped with a thick, durable and low permeability engineered cover system, which will ensure that the waste is isolated from the local environment for the institutional control period.

Within the UK, the producers and owners of radioactive waste are responsible for managing wastes according to Government policy and the regulatory framework. Disposal of radioactive wastes is regulated by the Environment Agency (in England and in Wales), the Scottish Environment Protection Agency (in Scotland) and the Environment and Heritage Service (in Northern Ireland). The relevant information for radioactive substances and waste are:

- *Radioactive Substances Act 1993* (RSA93)
- *Health & Safety at Work Act 1974*
- *Nuclear Installations Act 1965*
- Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation 1997.

Performance and Safety

The British Nuclear Fuels Ltd *Discharge and monitoring of the environment in the United Kingdom: Annual Report 2000*, indicates that at no time during 2000 did the disposal of radioactive wastes at Drigg or discharges of radioactivity from the facility exceed the quantitative limits required by the Certificates of Authorisation. Furthermore, monitoring of the principal pathways that may affect members of the public due to the disposal at Drigg during 2000, confirmed that their impact was minimal.

The environmental monitoring program at and around the Drigg facility as required by the Radioactive Substances Act included monitoring of the marine pathway (as the facility is located on the coast, unlike that proposed for central–north South Australia), airborne and terrestrial pathways (including air, foodstuffs, surface water and sediments, boreholes and groundwater).

In 2000 the radioactivity in the air at Drigg indicated that the mean radioactivity concentrations of strontium-90 (0.0009 mBq/m^3), ruthenium-106 (<0.04 mBq/m^3), caesium-134 (<0.005 mBq/m^3), caesium-137 (<0.004 mBq/m^3) and plutonic alpha (<0.0001 mBq/m^3) were all below the detection limits. Detectable mean radioactivity concentrations were measured for the radionuclides americuim-241 (0.0003 mBq/m^3) and uranium alpha (0.0001 mBq/m^3).

The estimated maximum doses to members of the public from inhalation of airborne radioactive particulate material in the vicinity of the site, determined by combining the above results with the assumption of continuous occupancy, was 0.03 μSv, which may be due to aerial discharges from the nearby Sellafield facility (undertaking the reprocessing of fuel, waste management and decommissioning and other processes), with only a negligible contribution from Drigg.

The borehole and groundwater monitoring results for 2000 measured the mean radioactivity concentration for total alpha, total beta and tritium. With the exception of tritium they were generally below the limits of detection for the eight monitoring locations across site.

Rokkasho-Mura, Japan

The Rokkasho-Mura repository, operated by Japan Nuclear Fuel Limited (JNFL) is an engineered repository designed for the disposal of large volumes (up to 600,000 m^3) of low level and short-lived intermediate level waste produced by the Japanese nuclear power industry (Japan Nuclear Fuel Ltd website; Nuclear Engineering International 1999).

The facility is located in Aomori Prefecture, in northeast Honshu, about 60 km east of Aomori city, and is located adjacent to a saltwater marsh. The watertable is 1 m from the ground surface. The annual average rainfall is 500–1000 mm.

The facility began operation in 1992, and a second disposal facility on the same site began operations in 2000. The waste disposal centre occupies a 360 ha site. The low level waste produced by power stations is compressed or burned, mixed with concrete or cement, and placed in 200 L drums.

Waste is transported to Rokkasho-Mura by sea. Drums are inspected for physical integrity and radioactivity at the repository after arrival and repackaged if necessary. The drums are then placed in large concrete vaults in concrete containers. The vaults are 14–19 m below ground surface, in low permeability host rocks. The drums are placed in concrete disposal units below the watertable, and bentonite clay is placed around the concrete to act as a barrier to water flow.

The first disposal facility was designed to accept solidified waste (wastewater, filters and ion exchange resins) mixed with cement, bitumen or plastic. The disposal facility consists of 40 vaults and each vault can accept approximately 5000 waste drums. The reinforced concrete vaults have external dimensions of 24 x 24 m and are 6 m high. The walls and bottom slabs are 500 mm and 600 mm thick, respectively.

A cement grout backfill is placed between the drums after emplacement and the vaults are capped with a 500 mm thick reinforced concrete slab. The vault structures will eventually be covered by a low permeability sand–bentonite mixture at least 2 m thick. The entire repository site will be covered by 4 m of soil and then vegetated.

A 100 mm layer of porous concrete surrounds each compartment so that if any moisture leaks into the vault, it will flow through the porous layer and be taken by a drainage system to an inspection tunnel, instead of penetrating the drum disposal area (Nuclear Engineering International 1999).

The second disposal facility is designed to take dry, active waste. The facility was commissioned in 2000 and has received 1440 drums.

Performance and Safety

The performance of the repository (stage 1 and 2) is ensured by a multi-barrier approach:

- In the first stage, 30 years from waste disposal, the engineered barriers will remain intact and will contain radionuclides.
- In the second stage, 60 years from disposal, there is reliance on artificial and natural barriers for control of radioactive materials (as concrete starts to break down).
- In the third stage, reliance is on natural barriers for containment.

Soil and water near the repository is routinely monitored. In addition, sediment in the marsh, marsh and river water, and agricultural products such as crops, milk and fish are monitored.

The dose equivalent that the public could receive from radioactive materials in Disposal Facility 1 or 2 is well below the dose limit of I mSv per year specified by law (Japan Nuclear Fuel Ltd 1999).

For all scenarios investigated for the institutional control period, a maximum uptake of 0.029 mSv per year is calculated. After the institutional control period, a maximum value of 0.014 mSv per year is calculated.

There will be a 300-year institutional control period following closure of the repository.

The Nuclear Safety Commission is the regulatory authority in Japan.

2.5.5 Subsurface Engineered Facilities

Some countries (e.g. Sweden, Finland and Germany) dispose of low level and short-lived intermediate level waste in rock caverns commonly about 50–100 m below the ground's surface. This type of facility is used in countries with large quantities of short-lived intermediate level waste, and/or where possible sites for near-surface disposal are limited. In Sweden, the Swedish Final Repository is a sort of prototype for a geological disposal facility (SKB, pers. comm. 2001).

Swedish Final Repository, Sweden

The Swedish Final Repository is an example of a repository located in a mined cavity. It is used for operational waste from nuclear power plants (low level and short-lived intermediate level) as well as waste from other sources. The facility is located in eastern Sweden near the Forsmark nuclear power plant, and is situated 1 km offshore and 60 m below the bottom of the Baltic Sea. It is connected to the surface by two 1 km long tunnels.

The main features of the site that make it highly suitable for a radioactive waste repository are the nature of the bedrock, the depth below the water surface, and the very low groundwater flux. The bedrock in which the repository is built provides a good barrier to human intrusion and is very effective in retarding any movement in radionuclides. The water depth at the site is so great that exposure of the seabed is not expected to occur for more than a thousand years. In addition, there is effectively no flow in groundwater, and the natural environment therefore provides an effective barrier to the movement of radioactive materials, in a similar way to a sub-aerial environment with a deep watertable.

The repository has been in operation since 1988.

Its four rock caverns have a length of 160 m and a width of 14–18 m. The design of the cavern varies depending on the type of waste to be disposed — some are for low level waste, and some are for intermediate level waste. Further vaults are planned to accept decommissioning waste when it arises.

More active intermediate level waste is buried in a concrete silo, packaged in steel or concrete. The silo is 50 m high and has concrete walls approximately 1 m thick. Between the silo wall and the host rock is a thick layer of bentonite clay, which acts as a seal and prevents groundwater from flowing through the silo. The repository has a current capacity of 60,000 m^3 with a planned storage capacity of 90,000 m^3 and when it is full the entrance tunnels will be plugged and sealed with concrete to isolate and prevent further access. After sealing, no further monitoring of the repository is considered to be necessary, given its location.

2.5.6 Implications of International Disposal Practice for Australia

Near-surface repository designs vary depending on the environment, particularly with respect to rainfall and groundwater level, and the type and volume of waste. A repository design that is appropriate for a wet environment where there is a large amount of waste from the nuclear power industry would not be appropriate for Australia's needs or environment. Similarly, a rock cavern is not required for disposal of Australia's small quantity of low level and short-lived intermediate level waste when suitable sites are available for a near-surface facility.

Countries that have arid environments, for example USA, South Africa, China and Australia, tend to site near-surface disposal facilities in these areas. Facility designs are chosen to suit an environment with a deep watertable, where there is low average annual rainfall. There tends to be less engineering in these repositories compared to those sited in wet environments, as the natural environment provides a more effective barrier to the waste.

Given that about 70% of Australia is arid or semi-arid, and the successful operation of near-surface repositories in desert environments overseas, the design chosen for Australia's national repository is one of near-surface disposal in subsurface trenches or boreholes.

Apart from any other consideration, concrete structures above ground for the disposal of waste to be eventually covered by an artificial hill (similar to the design of Centre de l'Aube) would not be suitable for the landscape in central–north South Australia — the desert environment is flat, and in this setting such a structure would attract attention, and, potentially, human intrusion, and may be prone to accelerated erosion. The extra height is not required as the groundwater is between 38.8–68.7 m below surface at the three potential sites for the national repository (Table 8.4), whereas the base of the trenches will be only about 15–20 m below ground surface, well above the watertable.

Some engineering adopted in recent trenches designed for the Drigg facility aimed to keep rain out of trenches left open for successive disposal operations. In Vaalputs, leaving drums exposed in open trenches led to some failure of the containers and this practice is no longer used. Waste is now transported to the site once per year and the trenches are compartmentalised for rapid filling and capping.

The proposed Australian national repository would have trenches or boreholes (see Section 6.2.1) that are open only during short disposal campaigns and the structures will be covered between campaigns. Concrete disposal containers will be used for short-lived intermediate level waste.

The Mount Walton repository for toxic and radioactive waste, of broadly similar design to that proposed for the national repository, has operated safely in Western Australia since 1992.

2.6 Reviews Relevant to the Proposal

Over the last 20 years, a number of reviews in Australia by various bodies, including Parliamentary and expert committees, have examined matters relating to Australia's use of radioactive materials. Issues considered have ranged from the mining of uranium, to the need for a replacement research reactor and the management of radioactive waste.

Some recommendations and conclusions arising from the reviews, and the Government responses, are relevant to this proposal, and have been taken into consideration in progressing the national radioactive waste repository project.

Of particular relevance are the 1984 Australian Science and Technology Council (ASTEC) Report to the Prime Minister on Australia's role in the Nuclear Fuel Cycle, the 1996 Senate Select Committee on the Dangers of Radioactive Waste report, *No time to waste*, and the Government's response report (Commonwealth Government of Australia 1996).

Since 1999, issues associated with radioactive waste management arising from inquiries into the replacement research reactor have particularly focused on the management of long-lived intermediate level waste, rather than on the management of low level or short-lived intermediate level waste, the type of waste of interest in this EIS.

Relevant reviews and recommendations on radioactive waste management are summarised below.

Australia's Role in the Nuclear Fuel Cycle, ASTEC 1984

In 1983, in response to a request from the Prime Minister, ASTEC undertook an inquiry into Australia's role in the nuclear fuel cycle (Australian Science and Technology Council 1984). One of the aspects examined included 'the adequacy of existing technology for the handling and disposal of waste products by consuming countries and the ways in which Australia could further contribute to the development of safe disposal methods'.

ASTEC supported containing and isolating radioactive waste as far as practicable. The committee agreed on the placement of stable packaged waste in a multiple barrier repository (surface soils or in deeper rocks) as the most effective way of containment and isolation of radioactive waste. The committee indicated that, once the waste is isolated and contained, the main purpose of barriers should be to avoid or control water reaching the waste, as this would be the main mechanism for radionuclides to escape to the environment. It stated that, once such a disposal repository has been filled and closed, the waste and surrounding barriers should be passive and require minimal management.

ASTEC recommended that Australia should act as quickly as possible to complete a code of practice for the disposal of radioactive waste, to identify suitable sites for disposal of low level radioactive waste and to develop facilities for interim storage and disposal of low and intermediate level radioactive waste.

In response, in 1985, the Commonwealth/State Consultative Committee on Radioactive Waste Management recommended a national program to identify potentially suitable sites for a national near-surface repository.

In 1986, the NHMRC requested that its Radiation Health Standing Committee prepare a code of practice and guidelines on radioactive waste management to develop criteria for classifying radioactive waste for disposal and to provide guidance on the selection of sites for near-surface disposal of waste. The *Code of practice for the near-surface disposal of radioactive waste in Australia* was published in 1992.

Senate Select Committee, Research Reactor Review report: Future Reaction, August 1993 (McKinnon Report)

In 1992, the High Flux Australian Reactor (HIFAR) was identified by ASTEC as a facility likely to be in need of replacement.

In 1993, a review evaluated the costs and benefits of a new research reactor. The review stated that a 'crucial issue is final disposal of high-level wastes, which depends upon identification of a site and investigation of its characteristics. A solution to this problem is essential and necessary well prior to any future decision about a new reactor' (McKinnon 1993).

The review also recommended that HIFAR should be kept operational; that a probabilistic risk assessment be commissioned to ascertain HIFAR's remaining life and refurbishment possibilities; and that work should be started immediately to identify and establish a high level waste repository.

The former (Keating) Government broadly accepted the findings of the report.

It should be noted that Australia does not produce, and will not need to manage high level waste (see Section 2.3.3.)

Senate Select Committee Inquiry on the Dangers of Radioactive Waste Report: No Time to Waste, April 1996, and Government Response paper, November 1996

The Government's response to the Senate Select Committee's recommendations provided the framework for current radioactive waste management policy, with the establishment of a body to regulate the Commonwealth's use of radioactive materials, and projects to establish a national repository for low level and short-lived intermediate level waste, and a national store for long-lived intermediate level waste.

The Senate Select Committee recommendations and Government responses are summarised as follows:

- The Committee recommended that a regulatory body should be established to regulate the Commonwealth's use of radioactive materials. The Government responded that it was currently considering proposals for an independent body to regulate and licence radiation related activities of Commonwealth agencies. This resulted in the establishment of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).
- The Committee recommended that an up-to-date inventory be prepared of all existing and potential radioactive waste and that any changes to current accumulation rates be detected. The Government responded that it was in the process of compiling such an inventory.
- The Committee recommended that transport of radioactive materials should require assessment of the most appropriate transport mode, and the Government responded that the transport of all radioactive materials within Australia was controlled by the *Code of practice for the safe transport of radioactive substances 1990* (Department of the Arts, Sport, the Environment, Tourism and Territories 1990). This code was updated in 2001 by ARPANSA, as the *Code of practice for the safe transport of radioactive material (2001)* (Australian Radiation Protection and Nuclear Safety Authority 2001).
- The Committee recommended that feasibility studies be conducted into the suitability of disposing of low level contaminated soil from Fisherman's Bend in an active uranium mine, and the suitable portion of ANSTO's waste at a municipal tip. The Government accepted these recommendations. Disposal of low level waste in an operating uranium mine was subject to confirmation of cost, operational feasibility and safety.
- The Committee recommended the establishment of an above ground storage facility with the capacity to take low, intermediate and high level radioactive waste. The Government response stated that near-surface disposal, rather than storage, is more appropriate for low level and short-lived intermediate level radioactive waste and that the Government would proceed with a study to identify a suitable location for siting such a disposal facility. The study would also address the possibility of co-locating an above ground storage facility for long-lived intermediate level waste, at the same site (co-location of the two facilities has subsequently been ruled out).
- The Committee recommended that the national repository and store be adequately engineered to withstand all possible climatic conditions. The Government responded that a thorough safety assessment would be conducted of any radioactive waste management facility.
- The Committee recommended that the public should be consulted on the construction of a national storage facility and the transport arrangements. The Government responded that public participation had formed an important part of the site selection phases to date, and would be an integral part of further phases of the study.

Senate Select Committee on Uranium Mining and Milling, May 1998

This inquiry reported on issues associated with uranium mining and milling (Senate Select Committee on Uranium Mining and Milling in Australia, 1998). Wastes derived from these activities are disposed of at the relevant mine site, under a proposed new *Code of practice and safety guide radiation protection and radioactive waste management in mining and mineral processing* (to be released in 2002), which replaces the *Code of practice on radiation protection in the mining and milling of radioactive ores (1987)* (Department of the Arts, Sport, the Environment, Tourism and Territories, 1987) and the *Code of practice on the management of radioactive wastes from the mining and milling of radioactive ores (1982)* (Department of Home Affairs and Environment 1982).

The conclusions of the inquiry are not directly relevant to this proposal. However, the inquiry did note that a major issue was the disposal of radioactive waste, whether from the mining of uranium ore or at later stages of the 'nuclear fuel cycle'.

Senate Economics References Committee: A New Reactor at Lucas Heights, September 1999

In 1997, the Government announced its intention to build a new research reactor at Lucas Heights and to make available the funds to remove spent nuclear fuel for offshore reprocessing.

The Senate tasked the Senate Economics References Committee to review whether or not a new reactor should be built to replace the HIFAR reactor at Lucas Heights on the same site or at another site in Australia. In particular, the committee was to evaluate whether the issues raised by the 1993 Research Reactor Review (McKinnon 1993) had been satisfactorily addressed in the decision to proceed with a new reactor at Lucas Heights. The committee subsequently found, in September 1999, that the issues had not been satisfactorily addressed (Senate Economics References Committee 1999).

The committee noted that, while the government had nominated a site (region) for the location of a low level above-ground radioactive waste repository, the issue of where the Lucas Heights reactor waste would be stored had not been addressed. The spent fuel rods from the reactor at Lucas Heights cannot be stored at a low level repository, even if reprocessed overseas and returned as intermediate level waste.

The Government broadly accepted the findings of the report, and is progressing the establishment of a national store for the long-term storage of intermediate level radioactive waste.

Recommendations arising from the EIS into the Replacement Research Reactor, March 1999

In 1998 an EIS was prepared for the replacement research reactor. In March 1999 the Minister for the Environment and Heritage issued a number of recommendations, which subsequently became conditions when accepted by the former Minister for Industry, Science and Resources, in response to the EIS into the replacement research reactor.

The management of low level and short-lived intermediate level radioactive waste was not mentioned. However, the management of longer-lived intermediate level radioactive waste was referred to in the Environment Minister's Recommendation 27, which said:

> The Minister for Industry, Science and Resources, and the Minister for Health should give timely consideration to strategies for the long-term management and eventual permanent disposal of Australia's long-term intermediate level nuclear wastes, and associated issues.

Also, the Chief Executive Officer of ARPANSA (Dr John Loy) has recently stated that progress on the establishment of the national store will be a consideration in his assessment of the licence applications from ANSTO for the replacement research reactor. Dr Loy stated on 5 April 2002 in his decision on the construction licence for the replacement research reactor that he was expecting 'there will be significant progress by the time any licence to operate the replacement research reactor is sought'.

Parliamentary Standing Committee on Public Works: Replacement Nuclear Research Reactor, Lucas Heights, NSW, August 1999

In August 1999, the Parliamentary Standing Committee on Public Works gave approval for the replacement Research Reactor at Lucas Heights, following an inquiry which concluded that 'HIFAR is obsolete and will need to be permanently decommissioned in 2005' and that a need exists to replace HIFAR with a modern research reactor. The new reactor must be operational before 2005 (Parliamentary Standing Committee on Public Works 1999).

The committee concluded that the storage of radioactive waste at Lucas Heights is of major concern to the local community. It recommended that the removal of radioactive waste for disposal or storage at a national repository must be of high priority and is dependent on the timely provision of the repository and store.

The Government responded that it was progressing with the establishment of the national repository for low level and short-lived intermediate level waste, and the national store for long-lived intermediate level waste.

Senate Select Committee for an Inquiry into the Contract for the New Reactor: A New Research Reactor, May 2001

The majority of the *Report of the Senate Select Committee for an inquiry into the contract for a new reactor* (Senate Select Committee for an Inquiry into the Contract for a New Reactor 2001) dealt with issues directly relating to the need for a replacement research reactor and relevant contractual matters. The committee addressed the management of spent fuel and long-lived intermediate level radioactive waste in its recommendation that the Government should satisfactorily resolve the question of the safe disposal of new reactor spent fuel before approval to construct a new reactor is given.

The committee did not make any recommendations concerning the management of low level or short-lived intermediate level radioactive waste.

The Government responded to the committee's recommendations on radioactive waste management by noting the establishment of a process, separate from the project to establish a national radioactive waste repository, to site a store for long-lived intermediate level radioactive waste produced by Commonwealth agencies.