5

Radioactive waste

> *Uranium mining and nuclear energy produce operational and decommissioning radioactive wastes which are contained and managed. Although experience with radioactive waste storage and transport over half a century has clearly demonstrated that civil nuclear wastes can be managed without adverse environmental impact, the question has become political with a focus on final disposal. In fact, nuclear power is the only energy-producing industry which takes full responsibility for all its wastes and costs this into the product – a key factor in sustainability.*[1]

> *If you take a look at all the nuclear waste ever generated in Canada's history – that is 40 or 45 years of electricity generation – all of that waste today is stored at the plant site[s] in … very small containers. If you put it all together … it would be about the size of a basketball arena and maybe 10 feet deep. So you are talking about a very, very small amount of material that has produced … 40 years of electricity. It is just an astonishing fact.*[2]

> *Global warming would strike me as an extreme risk for humanity whereas a small amount of decaying uranium waste in the middle of a granite craton in the middle of Australia far from any life is of absolutely minimal risk.*[3]

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1 Uranium Information Centre, *Submission no. 12*, p. 37.
2 Mr Jerry Grandey (Cameco Corporation), *Transcript of Evidence*, 11 August 2005, p. 9.
3 Dr Timothy Sugden (Nova Energy Ltd), *Transcript of Evidence*, 23 September 2005, p. 75.

Key messages —

- **At each stage of the nuclear fuel cycle there are proven technologies to manage and dispose of the radioactive wastes safely.**
- **While some radioactive waste is produced at each stage of the nuclear fuel cycle, the volumes of high level waste (HLW) are extremely small, contained and have hitherto been safely managed. There is an international scientific consensus that disposal in geologic repositories can safely and securely store HLW for the periods of time required for the long-lived waste to decay to background levels.**
- **The generation of electricity from a typical 1 000 megawatt (MWe) nuclear power station, which would supply the needs of a city the size of Amsterdam, produces approximately 25–30 tonnes of spent fuel each year. This equates to only three cubic metres of vitrified waste if the spent fuel is reprocessed. By way of comparison, a 1 000 MWe coal-fired power station produces some 300 000 tonnes of ash alone per year.**
- **HLW is accumulating at 12 000 tonnes per year worldwide. The International Atomic Energy Agency states that this volume of spent fuel, produced by all of the world's nuclear reactors in a year, would fit into a structure the size of a soccer field and 1.5 metres high—even without any being reprocessed for re-use. This contrasts with the 25 billion tonnes of carbon waste released directly into the atmosphere each year from the use of fossil fuels.**
- **To date, there has been no practical need and no urgency for the construction of HLW repositories. This has been due to the small volumes of waste involved and the benefit of allowing interim storage for up to several decades to allow radioactivity to diminish so as to make handling the spent fuel easier.**
- **While plans for geologic repositories are now well advanced in several countries, finding sites for repositories has been problematic. This has been due in large part to a lack of public acceptance. 'Not in my backyard' arguments about the siting of repositories have been fuelled by misperceptions of the level of risk involved in radioactive waste management and the operation of repositories. However, some countries, notably Finland and Sweden, have managed this process successfully and with a high degree of public involvement and support. In Australia, industry and Government must do more to inform and reassure the public in relation to these matters.**

- **Transport of radioactive waste is undertaken safely and securely—in sharp contrast to other energy industries. Since 1971, there have been more than 20 000 shipments of spent fuel and HLW over more than 30 million kilometres. There has never been any accident in which a container with highly radioactive material has been breached or leaked. In contrast, in OECD countries over the past 30 years more than 2 000 people have been killed in accidents involving the transport of LPG.**
- **Advanced nuclear reactors and spent fuel reprocessing technologies are now being developed which will significantly reduce the quantity and toxicity of nuclear waste, potentially reducing the required isolation period to just a few hundred years and further reducing the disposal/storage space required. These technological advances could potentially obviate the need for geologic repositories altogether.**
- **Nuclear power utilities are charged levies to provide funds for the management of the industry's waste and for the eventual decommissioning of plants. In the US, the Nuclear Waste Fund now amounts to over US$28 billion, while more than US$23 billion has been set aside for decommissioning. These costs are factored into the cost of the electricity generated and the prices paid by consumers.**
- **In contrast, wastes from fossil fuel power are not contained or managed, involve enormous volumes and a range of toxic pollutants that do not decay. Moreover, the cost of the environmental externalities these energy sources create are generally not factored into the price of the electricity produced.**

Introduction

5.1 This chapter addresses the management of radioactive waste generated across the nuclear fuel cycle, from uranium mining to the decommissioning of nuclear power plants. This is the first of three key issues which critics of uranium mining and nuclear power claim are fatal for the civil nuclear power industry. The other two issues relate to safety and proliferation. The chapter commences with a discussion of the different perceptions of risk associated with these three key issues.

5.2 The Committee provides an overview of the types of radioactive waste and describes how this waste is currently being managed. In turn, the Committee considers the:

- categories of radioactive waste;
- wastes produced in each of the nuclear fuel cycle stages;

- radioactive wastes in Australia;
- regulation of radioactive waste management;
- management and disposal of high level and long-lived waste; and
- cost of radioactive waste management and plant decommissioning.

5.3 The Committee also describes the Australian radioactive waste form known as 'synroc' (synthetic rock), which is a sophisticated means for immobilising high level waste.

5.4 The Committee then considers arguments critical of nuclear power and uranium mining on the basis of the waste generated, namely that:

- the disposal of nuclear waste remains an unresolved issue;
- the storage and transport of radioactive waste poses unacceptable environmental and health risks;
- radioactive waste must be secured for long periods of time and therefore imposes undue burdens on future generations; and
- reprocessing of used fuel generates larger quantities of transuranic waste and involves greater proliferation risks.

The three 'unresolved' issues for nuclear power

5.5 It was alleged in evidence that there remain three unresolved issues associated with the nuclear fuel cycle and its industries that, in the view of some submitters, are such as to justify a winding back of uranium mining and an eventual end to the use of nuclear power worldwide. These issues relate to the:

- generation and management of *radioactive waste* across the nuclear fuel cycle, principally waste from the operation of nuclear reactors, but also waste from uranium mines;
- *safety* of the fuel cycle, particularly the operation of nuclear reactors and the risks to health from fuel cycle industries, including uranium mining; and
- risk of *proliferation* of nuclear materials and technologies, and their diversion for use in weapons programs.

5.6 Examples of the concerns expressed by some submitters about these three key issues follows:

- The Australian Conservation Foundation (ACF) argued that:

> Risk of reactor accidents and threat of nuclear terrorism, unresolved nuclear waste management and increasing concern

over weapons proliferation are all strong reasons for Australia to end rather than expand uranium mining and exports.[4]

- The Medical Association for the Prevention of War (MAPW) (Victorian Branch) argued that:

  The proliferation, accident, terrorist attack, and inherent nuclear fuel cycle health and environmental dangers of nuclear reactors, have never been more apparent. They are unacceptable and unsustainable …

  Uranium mining in Australia, rather than being expanded, should be rapidly phased out as another dangerous relic of a century in which the demise of human societies and unimaginable harm to the ecosphere, of which they are a part and which supports them, was seriously courted.[5]

- The Arid Lands Environment Centre (ALEC) submitted that:

  … there is no guarantee that Australian uranium stays out of a nuclear weapon. Nuclear power is not safe to operate, nor do we have any solutions to an already growing waste crisis.[6]

5.7 For the opponents of uranium mining and nuclear power, the risks from the use of uranium and nuclear power clearly outweigh any benefits:

> We believe that this industry poses such significant risk, if used inappropriately or poorly in either civil or military, that the risks overcome any social benefit from it.[7]

5.8 Similarly, the MAPW (Victorian Branch) expressed opposition to the export of uranium and the use of nuclear power on the basis that the risks associated with use of nuclear technology are too high:

> We see nuclear technology as inherently different from any other technology that we are called upon to make decisions about and to manage, both in terms of its quantitative potential for harm—either as weapons or otherwise—and in terms of its qualitative effects, in particular the hereditary mutagenic, carcinogenic and very persistent nature of the materials involved. Some of these risks are inherent, some are manageable clearly, but it is the considered position of my association … that these risks are really inherently too high to be acceptable.

4 ACF, *Submission no. 48*, p. 4.
5 MAPW (Victorian Branch), *Submission no. 30*, p. 16.
6 ALEC, *Submission no. 75*, p. 1.
7 Mr Dave Sweeney (ACF), *Transcript of Evidence*, 19 August 2005, p. 80.

> Any activities that increase the number of and the dissemination of facilities at which nuclear materials are handled and increase the volume and dissemination of nuclear materials do increase, we believe, the risks of accident, terrorism, proliferation and waste that are the inherent problems associated with the nuclear cycle.[8]

5.9 Convinced that the risks associated with nuclear power are 'so high', the MAPW argued that 'the threshold for decision making should err very substantially on the side of safety, and precaution should be applied to a very high degree.'[9]

5.10 In contrast, Heathgate Resources, who operate the Beverley uranium mine in South Australia (SA), argued that:

> The risks associated with the nuclear fuel cycle and uranium mining, under any rational assessment, are probably lower than the risks associated with the alternatives. One of the primary determinations of the Fox inquiry back in the seventies was that the risks associated with the nuclear fuel cycle and with uranium mining were not such that they should prohibit Australia from being involved in it. That is probably still true today.
>
> Myself and all of those working in the uranium industry—I personally have been involved in it for 30 years— are proud of what we do … We often feel misunderstood but we would like a rational assessment of all the issues relating to it because we believe that, on balance, the nuclear industry would come out ahead.[10]

5.11 On the different perceptions of risk, Heathgate also observed that:

> The bottom line decision I have come to is that their [the opponents of nuclear power] understanding, their perception of risk, is different to mine. They seem to want a world where there is no risk and unfortunately that is not life. I think a rational assessment of it all indicates that you have to accept that there are risks involved in every human activity and it is a matter of determining what is an acceptable level of those risks.[11]

5.12 The AMP Capital Investors Sustainable Funds Team (AMP CISFT), who oppose the use of nuclear power, also observed that 'the acceptable risk

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8 Associate Professor Tilman Ruff (MAPW Victorian Branch), *Transcript of Evidence*, 19 August 2005, p. 24.

9 *ibid*., p. 25.

10 Mr David Brunt (Heathgate Resources Pty Ltd), *Transcript of Evidence*, 19 August 2005, p. 103.

11 *ibid*., p. 103–04.

question is a difficult one, because everyone will have their own particular view' of what is acceptable.[12]

5.13 Representatives of BHP Billiton observed that debates about uranium need to encompass these key issues that drive public perceptions about nuclear power; namely, proliferation, waste disposal and safety:

> The public perception of the words 'uranium', 'nuclear' and words like that … is driven by issues about safety … concerns about weapons proliferation; and concerns about long-term waste disposal. I do not believe it is essentially driven by the mining of uranium per se or the generation of energy by nuclear means per se. The issues in the public mind, in my view, are around those three things, and those three things probably need to be encompassed in any debate about nuclear fuel. They are not necessarily directly related to nuclear fuel because of the differences in the forms of uranium you need to move from the power cycle into the weapons cycle, for example. They are not connected, but that is what is in people's minds.[13]

5.14 Silex Systems, an Australian company developing and commercialising a uranium enrichment technology, also noted that the 'three big issues' for nuclear power are proliferation, reactor safety and waste remediation.[14]

5.15 The following four chapters examine the evidence presented to the Committee in relation to each of these three key issues. In this chapter the Committee discusses the waste generated at each stage of the nuclear fuel cycle and its management. Chapter six addresses the safety of the nuclear power industry. Chapters seven and eight examine the proliferation of technologies and materials for weapons purposes and the effectiveness of safeguards regimes.

5.16 Before discussing the management of radioactive waste, the chapter commences with an explanation of the concepts of radiation and radioactivity. These concepts are employed in the discussion of nuclear waste in the remainder of this chapter and the discussion of the safety of the nuclear fuel cycle in the next.

12 Dr Ian Woods (AMP CISFT), *Transcript of Evidence*, 16 September 2005, p. 30.

13 Dr Roger Higgins (BHP Billiton Ltd), *Transcript of Evidence*, 2 November 2005, p. 23.

14 Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 4.

Radiation and radioactivity

5.17 Radioactivity refers to the spontaneous decay of an unstable atomic nucleus (referred to either as a radionuclide or a particular radioisotope), giving rise to the emission of radiation. Radiation may be understood as energy travelling through space, which can be transmitted in the form of electromagnetic waves, or it can be carried by energetic sub-atomic particles. Whereas radiation refers to the energy released during radioactive decay, radioactivity refers to the rate at which the material emits radiation. All radioactivity reduces naturally over time.[15]

5.18 The process of radioactive decay is characterised by a 'half-life'. The half-life of a radioisotope is the time taken for half of its atoms to decay, leaving the residue only half as radioactive. After 10 such half-lives, about one-thousandth of the activity remains. Each radioactive element has its own fixed half-life which can vary from seconds to many millions of years. Radioisotopes with long half-lives (e.g. uranium-238, which has a half-life of 4.5 billion years) give out very low levels of radiation, albeit over a geological time scale, whereas radioisotopes with short half-lives (e.g. radon-220, which has a half-life of 56 seconds) emits very much more radiation but over a shorter period. The rate of decay of an isotope is inversely proportional to its half life—the higher the intensity of radioactivity in a given amount of material, the shorter the half lives involved.[16]

5.19 Effects on matter of radiation fall into two classes: ionising and non-ionising radiation. Ionising radiation has energy capable of causing chemical changes damaging to living tissue and includes x-rays and the radiation from the decay of both natural and artificial radioactive substances. Non-ionising radiation includes light, heat, microwaves and radio waves.[17]

5.20 There are four types of ionising radiation, each having different penetrating powers:

- Alpha particles (atomic nuclei consisting of 2 protons and 2 neutrons) are intensely ionising but can be readily stopped by a few centimetres of air, a sheet of paper, or human skin. Alpha-radioactive substances

15 Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 'Radioactivity', *Radiation Basics*, viewed 18 August 2006, <http://www.arpansa.gov.au/basics/radioactivity.htm>.

16 World Nuclear Association (WNA), *Radioactive Wastes*, Information and Issues Brief, March 2001, viewed 20 June 2005, <http://www.world-nuclear.org/info/inf60.htm>.

17 ARPANSA, 'Ionizing and Non-ionizing Radiation', *Radiation Basics*, viewed 18 August 2006, <http://www.arpansa.gov.au/basics/ion_nonion.htm>.

are safe if kept in any containers sealed to air. Radon gas, given out by uranium ore, has decay products that are alpha-emitters.

- Beta particles are fast-moving electrons emitted by many radioactive elements. They are more penetrating than alpha particles and can penetrate into the body, but can be shielded by a thin piece of wood or plastic. Exposure produces an effect like sunburn, but which is slower to heal. Beta-radioactive substances are also safe if kept in appropriate sealed containers.
- Gamma rays are high-energy electromagnetic waves almost identical with x-rays and of shorter wavelength than ultraviolet radiation. They are very penetrating and need substantial thicknesses of heavy materials such as lead, steel or concrete to shield them. They are the main hazard to people in dealing with sealed radioactive materials. Doses can be detected by badges worn by workers in exposed situations.
- Neutrons are mostly released by nuclear fission, and apart from a little cosmic radiation, they are seldom encountered outside the core of a nuclear reactor. Fast neutrons are very penetrating as well as being strongly ionising and hence very destructive to human tissue. They can be slowed down (or 'moderated') by wood, plastic, or (more commonly) by graphite or water.[18]

5.21 All living organisms are exposed to ionising radiation on a continuous and daily basis. This type of exposure is referred to as 'background radiation', the sources of which include radioactive materials and their decay products in the natural environment such as radioactivity in rocks and soil of the Earth's crust (referred to as terrestrial), in building materials and from outer space (referred to as cosmic radiation).[19]

5.22 There are two basic measures of radiation in the International System (SI) of units—the 'activity' of the radiation and the level of 'exposure' or dose. Activity refers to how much radiation is coming out of a radioactive material and the unit of activity is the 'becquerel' (Bq), which is the number of nuclear disintegrations per second, with one Bq equal to one nucleus decaying per second. Exposure measures the effect of radiation on substances that absorb it and is expressed in several ways, to account for the different levels of harm caused by different forms of radiation and the different sensitivity of body tissues:

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18 Uranium Information Centre (UIC), *Nuclear Electricity*, UIC, Melbourne 2003, viewed 18 August 2006, <http://www.uic.com.au/neAp1.htm>.

19 ARPANSA, 'Cosmic Radiation Exposure', *Radiation and Health Information*, 25 March 2005, viewed 18 August 2006, <http://www.arpansa.gov.au/pubs/factsheets/cosmic.pdf>;

- 'Absorbed dose' refers to the energy deposited in a kilogram of tissue by the radiation and is measured in a unit called the 'gray' (Gy), where one Gy represents the deposition of one joule of energy per kilogram of tissue.
- 'Equivalent dose' refers to the effect of radiation exposure on human tissue and is measured by the 'Sievert' (Sv) (or millisievert – mSv – which is one thousandth of a sievert, or micosievert - μSv – which is one millionth of a sievert). The equivalent dose takes into account the biological effects of the different types of radiation listed above, because some types are more dangerous to tissue than others (alpha particles and neutrons cause more damage per gray than beta or gamma radiation). Consequently, a 'radiation weighting factor' is taken into account in determining the equivalent dose.
- 'Effective dose' takes into account what part of the body was exposed to radiation, because some organs are more sensitive to radiation than others. Consequently, the effective dose incorporates a 'tissue weighting factor', and is also measured by the Sievert.[20]

5.23 Total natural background radiation exposure worldwide averages 2.4 mSv per year, with actual exposures varying depending on geology and altitude. The sievert is also used in setting radiological protection standards, with the maximum annual dose allowed for a uranium miner currently set at 20 mSv.[21] The health effects of radiation exposure are discussed in the following chapter.

5.24 Up to 85 per cent of the annual human radiation dose is from natural sources (e.g. buildings/soil, cosmic radiation, radon gas from the Earth and present in the air, and food), with the remainder arising from human activities, of which x-rays and other medical procedures account for the largest part.[22]

Radioactive waste

5.25 The International Atomic Energy Agency (IAEA) defines radioactive waste as:

> … material that contains, or is contaminated with, radionuclides at concentrations or activities greater than clearance levels as

20 UIC, *Radiation and Nuclear Energy*, Briefing Paper No. 17, viewed 18 August 2006, <http://www.uic.com.au/nip17.htm>; ARPANSA, 'Units for Measuring Radiation', *Radiation Basics*, viewed 18 August 2006, <http://www.arpansa.gov.au/basics/units.htm>.

21 UIC, *Submission no. 12*, p. 46; ARPANSA, 'Cosmic Radiation Exposure', *loc. cit*.

22 UIC, *Radiation and Nuclear Energy, loc. cit.*

established by the regulatory body, and for which no use is foreseen.[23]

5.26 'Clearance levels' are those established by the relevant regulatory body in each country, expressed in terms of activity concentrations and/or total activities, at or below which sources of radiation can be released from nuclear regulatory control.

5.27 Radioactive wastes (or 'radwaste') comprise a variety of materials, which can be in solid, liquid or gaseous form, requiring different types of management to protect people and the environment from the effects of ionising radiation and heat. While radwaste is generated from the use of radioactive materials in industrial applications, research and medicine, the following discussion focuses on the wastes produced from the activities associated with the generation of nuclear power; that is, the civil nuclear fuel cycle, outlined in chapter two.

Types of radioactive wastes

5.28 Some radioactive waste is produced at all stages of the nuclear fuel cycle. The persistence of the radioactivity (the decay period) determines how long the waste requires management, while the concentration (radioactivity level) and heat generation determine how the waste will be handled. These considerations also inform suitable disposal methods.[24]

5.29 Three general principles are employed in the management of radioactive waste: concentrate-and-contain; dilute-and-disperse; and delay-and-decay. While the first two are also used in the management of non-radioactive waste, delay-and-decay is unique to the management of radioactive waste. This approach involves storing the waste while its radioactivity is allowed to decrease naturally through decay of the radioisotopes in it, as described in a discussion of the management of high level waste below.[25]

5.30 The general considerations for classifying radioactive wastes are: how long the waste will remain at a hazardous level; what the concentration of the radioactive material is; and whether the waste is heat generating.[26]

5.31 The IAEA categorises radioactive waste into the classes of exempt, low, intermediate (short-lived and long-lived), and high level waste, which are summarised as follows:

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23 IAEA, *The Principles of Radioactive Waste Management*, IAEA, Vienna, 1995, viewed 18 August 2006, <http://www-pub.iaea.org/MTCD/publications/PDF/Pub989e_scr.pdf>, p. 20.

24 WNA, *Radioactive Wastes, loc. cit.*

25 UIC, *Nuclear Electricity, op. cit.*, viewed 23 August 2006, <http://www.uic.com.au/ne5.htm#5.4>.

26 WNA, *Radioactive Wastes, loc. cit.*

- Exempt waste refers to waste for which activity levels are at or below clearance levels.

  The UIC explains that this waste contains radioactive materials at a level which is not considered harmful to people or the environment. It consists mainly of demolished material, such as concrete, plaster, piping and so on, produced during rehabilitation or dismantling operations on nuclear industrial sites. The waste is disposed of with domestic refuse.[27]

- Low level waste (LLW) refers to waste in which the concentration of or quantity of radionuclides is above clearance levels. LLW contains enough radioactive material to require action for the protection of people, but not so much that it requires shielding in handling, storage or transportation.

  LLW is comprised of items such as paper, rags, tools, clothing and filters which contain small amounts of mostly short-lived radioactivity. These wastes may be disposed of in shallow land burial sites. To reduce their volume, LLW are often compacted or incinerated before disposal. LLW comprises some 90 per cent of the volume but only one per cent of the radioactivity of all radioactive wastes.

- Short-lived intermediate level waste (ILW) refers to waste that requires shielding, but needs little or no provision for heat dissipation, and contains low concentrations of long-lived radionuclides. Radionuclides in short-lived waste will generally have half-lives shorter than 30 years. Short-lived waste also refers to waste which will decay to a level considered to be insignificant in a time period during which institutional control can be expected to last.

  LLW and short-lived ILW are of three kinds: process wastes from the treatment, purification and filtration systems of fluids in direct contact with the parts of the reactor that may be contaminated with radioactivity; technological wastes arising from the necessary maintenance carried out on a nuclear power plant, such as rags, tools and protective clothing; and decommissioning wastes which occur at the end of a reactor's life.[28]

  Disposal methods for treated and conditioned LLW and short-lived ILW are typically in shallow concrete-lined trenches or engineered surface facilities, with the wastes isolated for up to 300 years, thus facilitating institutional and administrative control of the disposal site.

27 UIC, *Waste Management in the Nuclear Fuel Cycle*, Briefing Paper No. 9, viewed 17 August 2006, <http://www.uic.com.au/nip09.htm>.

28 WNA, *Radioactive Wastes*, *loc. cit.*

The IAEA reports that, worldwide, some 40 near-surface disposal facilities have been operating safely during the past 35 years, and an additional 30 facilities are expected to be in operation over the coming 15 years.[29]

- Long-lived intermediate level waste refers to waste that requires shielding, but needs little provision for heat dissipation. Concentrations of long-lived radionuclides, which have a half-life of greater than 30 years, exceed limitations for short-lived waste.

  ILW typically contains resins, chemical sludges and metal fuel cladding as well as contaminated materials from reactor decommissioning, such as the dismantled internal structures of the reactor core. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal. ILW makes up some seven per cent of the volume and has four per cent of the radioactivity of all radwaste.

  Long-lived ILW (e.g. from fuel reprocessing) require a high degree of isolation from the biosphere and will eventually be disposed of in geologic repositories. This waste is being kept in interim storage pending final disposal.

  Long-lived ILW will first be treated and conditioned by incorporating it into cement and then placing it in concrete containers. In some cases, the conditioned waste will be subsequently placed into additional containers made of steel. Special packages, or casks, are used for transporting long-lived ILW.

- High level waste (HLW) contains large concentrations of both short and long-lived radionuclides, and is sufficiently radioactive to require both shielding and cooling. HLW generates more than two kilowatts per cubic metre of heat.

  HLW is generated from the use of uranium fuel in a nuclear reactor. Spent (or 'used') reactor fuel contains the fission products and transuranic elements generated during reactor operations.[30] HLW can be considered as the 'ash' from 'burning' uranium. HLW accounts for over 95 per cent of the total radioactivity produced in the process of

29 ANSTO, *Submission no. 29*, p. 10.

30 When a nucleus undergoes fission, it splits into two fragments, releases neutrons and energy. The fragments are often called *fission products*, which may be stable or unstable, i.e. radioactive. Important fission product isotopes (in terms of their relative abundance and high radioactivity) are bromine, caesium, iodine, krypton, rubidium, strontium and xenon. They and their decay products form a significant component of nuclear waste.
Transuranics are very heavy elements formed artificially by neutron capture and possibly subsequent beta decay(s). These elements have a higher atomic number than uranium (92) and all are radioactive. Neptunium, plutonium, americium and curium are the best-known.

electricity generation, but only three per cent of the volume of all radwaste.[31]

Dr Helen Caldicott argued that in the process of fissioning, the fuel becomes 'one million times more radioactive than the original uranium' and:

> … two hundred new elements are made, all of which are much more dangerous and radioactive than the original uranium. That is nuclear waste. Some last for seconds and decay. Some last for millions of years.[32]

In particular, Dr Caldicott drew the Committee's attention to iodine, strontium-90, caesium-137 and plutonium.

HLW contains materials which require a high degree of isolation from the biosphere for long periods of time. There are two distinct kinds of HLW, which are described in a section on the management of HLW, below.

Wastes produced in each of the fuel cycle stages

5.32 Mining wastes are generated by traditional uranium mining as fine sandy tailings which contain virtually all the naturally occurring radioactive elements found in uranium ore. These are collected in engineered tailings dams and finally covered with a layer of clay and rock to inhibit the leakage of radon gas and ensure long-term stability. In the short term, the tailings material is often covered with water. After a few months, the tailings material contains about 75 per cent of the radioactivity of the original ore. These are not classified as radioactive wastes.[33]

5.33 ARPANSA notes that the Olympic Dam and Ranger uranium mines produce some 10 million tonnes of uranium mill tailings per year. At the Olympic Dam mine, the coarse fraction of tailings is used underground as backfill, and the fine tailings material still containing potentially valuable minerals (rare earths, etc.) is emplaced in tailings dams. At the Ranger mine, tailings were emplaced in an engineered dam on the lease until

31 UIC, *Submission no. 12*, pp. 37–38; IAEA, *Classification of Radioactive Waste: A Safety Guide*, IAEA, Vienna, 1994, viewed 18 August 2006, <http://www-pub.iaea.org/MTCD/publications/PDF/Pub950e_web.pdf>. World Nuclear Association (WNA), *Radioactive Wastes, loc. cit.*; Australian Nuclear Science and Technology Organisation (ANSTO), *Submission no. 29*, p. 10.

32 Dr Helen Caldicott, *Transcript of Evidence*, 16 September 2005, p. 3.

33 UIC, *Submission no. 12*, p. 37; UIC, *Waste Management in the Nuclear Fuel Cycle*, *loc. cit*. See also: UIC, *Environmental Aspects of Uranium Mining*, Briefing Paper No. 10, viewed 21 August 2006, <http://www.uic.com.au/nip10.htm>.

1996, but are now all deposited into a worked-out pit.[34] At the Beverley mine, solid wastes are disposed of in a near-surface repository, and liquid waste is concentrated in evaporation ponds and injected into the mined aquifer.[35] The Committee considers the waste and environmental impacts of uranium mining in Australia in chapter ten.

5.34 Uranium oxide concentrate (UOC) from mining is not significantly radioactive, barely more so than the granite used in buildings. It is refined then converted to uranium hexafluoride gas (UF_6). As a gas, it undergoes enrichment to increase the U-235 isotope content from 0.7 per cent to about 3.5 to 5 per cent. It is then turned into a hard ceramic oxide (UO_2) for assembly as reactor fuel elements.

5.35 The main by-product of enrichment is depleted uranium (DU), principally the U-238 isotope, which is stored either as UF_6 or uranium oxide (U_3O_8). Some 1.2 million tonnes of DU is now stored worldwide. Some DU is used in applications where its extremely high density makes it valuable, such as radiation shielding, the keels of yachts and for military projectiles. It is also used, with recycled plutonium (Pu), for making mixed oxide fuel and to dilute highly-enriched uranium (HEU) from dismantled weapons in its conversion to reactor fuel.[36]

5.36 In terms of the waste generated during reactor operations, a typical large (1 000 MWe) light water reactor (LWR) will generate 200–350 cubic metres (m^3) of LLW and ILW per year. This waste is produced as a result of operations such as the cleaning of reactor cooling systems and fuel storage ponds, the decontamination of equipment, filters and metal components that have become radioactive as a result of their use in or near the reactor. The maintenance of a typical reactor produces less than 0.5 m^3 of long-lived ILW each year.[37] In the case of spent fuel, where this is considered waste, 20 m^3 (30 tonnes) is produced per year, which corresponds to a 75 m^3 disposal volume following encapsulation. When the same volume of used fuel is reprocessed, 3 m^3 of vitrified waste (glass) is produced, which is equivalent to a 28 m^3 volume placement in a disposal canister.[38]

34 ARPANSA, *Radioactive Waste Management in Australia*, viewed 21 August 2006, <http://www.arpansa.gov.au/is_waste.htm>.

35 G Taylor et. al., *Review of Environmental Impacts of the Acid In-situ Leach Uranium Mining Process*, CSIRO, Melbourne, 2004, pp. 35–37, viewed 12 July 2005, <http://www.environment.sa.gov.au/epa/pdfs/isl_review.pdf>.

36 UIC, *Submission no. 12*, p. 38.

37 WNA, *Radioactive Wastes*, *loc. cit*.

38 UIC, *Waste Management in the Nuclear Fuel Cycle*, *loc. cit*.

5.37 ANSTO explained that the volume of waste produced by all power reactors amounts to some 200 000 m^3 of LLW and ILW, and 10 000 m^3 of HLW (including spent fuel designated as waste) each year worldwide.[39]

5.38 Some waste is also produced during the decommissioning of nuclear reactors. Most of this material, as noted above, is LLW and short-lived ILW. About 99 per cent of the radioactivity in a reactor is associated with the fuel which is removed before invoking decommissioning options. Apart from any surface contamination of plant, the remaining radioactivity comes from 'activation products' in steel components which have been exposed to neutron irradiation for long periods. Their atoms are changed into different isotopes such as iron-55, cobalt-60, nickel-63 and carbon-14. The first two are highly radioactive, emitting gamma rays, but correspondingly with short half-lives so that after 50 years from closedown their hazard is much diminished. Some caesium-137 may also be in decommissioning wastes. Some scrap material from decommissioning may be recycled, but for uses outside the industry very low clearance levels are applied, so most is buried.[40]

5.39 The IAEA has defined three options for decommissioning, after the removal of the spent fuel:

- Immediate dismantling, also referred to as 'Decon' (decontamination) in the US, allows for the facility to be removed from regulatory control relatively soon after shutdown. In this option, all components and structures that are radioactive are cleaned or dismantled, packaged and shipped to a waste disposal site, or are temporarily stored on site.
- Safe enclosure, or 'Safstor' (safe storage), postpones the final removal of controls for a longer period, usually for up to 60 years, which allows time to act as a decontaminating agent. Once the radioactivity has decayed to lower levels, the plant is then dismantled.
- Entombment entails encasing radioactive structures, systems and components in a long-lived substance, such as concrete. The encased plant would be appropriately maintained, and surveillance would continue until the radioactivity decays to a level that permits termination of the plant's license.[41]

39 ANSTO, *Submission no. 29.1*, p. 1.

40 UIC, *Submission no. 12*, p. 43.

41 US Nuclear Energy Institute (NEI), *Decommissioning of Nuclear Power Plants*, Fact sheet, May 2002, viewed 24 August 2006, <http://www.nei.org/index.asp?catnum=3&catid=278>.

Radioactive waste in Australia

5.40 In Australia, radioactive waste is generated by research, industry, medical applications, research reactor operations and radiopharmaceutical production. Currently, Australia has accumulated about 3 800 m^3 of LLW and short-lived ILW considered suitable for disposal in a near-surface repository. This waste, which is currently stored at over 100 locations around the country, is being generated at about 40 m^3 per year (less than the volume of one shipping container). In addition, Australia has accumulated 500 m^3 of long-lived ILW and the estimated future annual arisings of long-lived ILW is some 5.5 m^3. Some long-lived ILW will be generated during the decommissioning of the research reactor at Lucas Heights and the eventual decommissioning of the replacement research reactor. Australia does not currently generate any HLW.[42]

5.41 In July 2004, the Prime Minister announced that the Australian Government will construct co-located facilities on Commonwealth land for the management of LLW and ILW produced by Australian Government agencies (which are currently stored at 30 locations around Australia). This followed the collapse in 2001 of state and Federal negotiations over the site of a proposed national waste management repository.[43]

5.42 In July 2005, the Minister for Education, Science and Training announced three potential sites for the Commonwealth Radioactive Waste Management Facility. The three sites, all located in the NT, are on Commonwealth land administered by the Department of Defence. Studies are now being undertaken to assess the suitability of these sites.[44]

5.43 ANSTO informed the Committee of the benefits of a central repository to take all of Australia's LLW and ILW. The benefits were said to include ensuring that: Australia's waste management is consistent with international best practice; all waste is stored in a purpose-built facility

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42 Australian Government Department of Education, Science and Training (DEST), *Amounts of Radioactive Waste in Australia*, viewed 21 August 2006, <http://www.radioactivewaste.gov.au/Radiation_radioactive_waste/Amounts_radioactive_waste_Australia.htm>.

43 Senate Employment, Workplace Relations and Education Legislation Committee, *Report into the Commonwealth Radioactive Waste Management Bill 2005 and Commonwealth Radioactive Waste Management (Related Amendment) Bill 2005*, Commonwealth of Australia, Canberra, 2005, p. 7, viewed 31 August 2006, <http://www.aph.gov.au/Senate/committee/eet_ctte/radioactive05/report/report.pdf>.

44 DEST, *Radioactive waste management*, viewed 21 August 2006, <http://www.radioactivewaste.gov.au/radioactive_waste_management/>.

that can be properly monitored; and that all waste is properly packaged and secured.[45]

5.44 ANSTO argued that at present some waste held by the states is not packaged properly and nor is it secure.[46] The waste storage in some jurisdictions could not guarantee long-term stability. However, ANSTO sought to assure the Committee that the LLW and ILW involved is not suitable for so-called 'dirty bombs', which is examined in chapter eight.

5.45 In contrast to the position of the NT Government, the Northern Land Council (NLC) argued emphatically that 'a radioactive waste facility may be safely built in some parts of the Northern Territory'.[47] The NLC argued that if the repository is to be built in the NT, Aboriginal people should be involved in selecting its location. The NLC also remarked that there is potential for Australia to develop world's best practice in the field of waste repositories:

> So, if the Territory is to have this thing plonked on it, especially if it is to occur on Aboriginal land, we at least want to sit down at the table with the Commonwealth government and the Territory government to make sure that Aboriginal people have a say in where it goes and share in the benefits in terms of employment and in terms of an agreement. In terms of world's best practice, we believe that the Northern Territory Department of Minerals and Energy could actually deal itself into a sphere of excellence in mining and in nuclear waste repositories that would set Australia apart.[48]

5.46 The Northern Territory Minerals Council (NTMC) also expressed support for the construction of a LLW and ILW repository in the NT, or elsewhere in Australia, subject to a scientific, environmental and economic appraisal.[49]

Regulation of radioactive waste management

5.47 Standards, guidelines and recommendations for the management of radioactive waste have been developed by international and regional organisations, including the IAEA (notably its Radioactive Waste Safety Standards Program—RADWASS), OECD Nuclear Energy Agency and the International Commission on Radiological Protection (ICRP). These agencies assist countries in establishing and maintaining national

45 Dr Ron Cameron (ANSTO), *Transcript of Evidence*, 23 October 2005, pp. 16–17.

46 *ibid*., p. 17.

47 Mr Norman Fry (NLC), *Transcript of Evidence*, 24 October 2005, p. 19.

48 *ibid*., p. 22.

49 Ms Kezia Purick (NTMC), *Transcript of Evidence*, 24 October 2005, pp. 34–35.

standards. National policies, legislation and regulations are all developed from these internationally agreed standards, guidelines and recommendations.[50]

5.48 The IAEA states that the objective of radioactive waste management is to:

> … deal with radioactive waste in a manner that protect human health and the environment now and in the future without imposing undue burdens on future generations.[51]

5.49 To achieve this objective, the IAEA has established nine fundamental principles of radioactive waste management, which were published in 1995 as part of its RADWASS program, as follows:

- Protection of human health

  Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.

- Protection of the environment

  Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.

- Protection beyond national borders

  Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.

- Protection of future generations

  Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

- Burdens on future generations

  Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

- National legal framework

  Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.

- Control of radioactive waste generation

  Generation of radioactive waste shall be kept to the minimum practicable.

- Radioactive waste generation and management interdependencies

50 UIC, *Waste Management in the Nuclear Fuel Cycle, loc. cit.*

51 IAEA, *The Principles of Radioactive Waste Management, op. cit.*, p. 3.

Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

- Safety of facilities

  The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.[52]

5.50 Radioactive waste management itself is defined as all activities, administrative and operational, that are involved in the handling, pre-treatment, treatment, conditioning, storage and disposal of waste from a nuclear facility, including transportation.[53]

5.51 The principal international legal agreement intended to achieve a high level of safety worldwide in spent fuel and radioactive waste management is the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* (the Joint Convention), which entered into force in 2001.[54]

5.52 The Joint Convention applies to spent fuel and radioactive waste resulting from civilian nuclear reactors and applications, and to spent fuel and radioactive waste from military or defence programs if and when such materials are transferred permanently to and managed within exclusively civilian programs. The Convention also applies to planned and controlled releases into the environment of liquid or gaseous radioactive materials from regulated nuclear facilities. Wastes from the mining and milling of uranium ores are also subject to the Joint Convention.[55]

5.53 The IAEA explains that the obligations of the parties with respect to the safety of spent fuel and radioactive waste management are based to a large extent on the nine fundamental principles listed above. They include, in particular, the obligation to establish and maintain a legislative and regulatory framework to govern the safety of spent fuel and radioactive waste management and the obligation to ensure that individuals, society and the environment are adequately protected against radiological and other hazards, inter alia, by appropriate siting, design and construction of facilities and by making provisions for ensuring the safety of facilities both during their operation and after their closure. The Convention also imposes obligations on parties in relation to the transboundary movement of spent fuel and radioactive waste based on the concepts contained in the

52 *ibid.*, pp. 4–9.

53 *ibid.*, p. 20.

54 See: IAEA, *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, IAEA Information Circular 546, 24 December 1997, viewed 21 August 2006, <http://www.iaea.org/Publications/Documents/Infcircs/1997/infcirc546.pdf>.

55 IAEA, *Documents Related to the Joint Convention – Background*, viewed 21 August 2006, <http://www-ns.iaea.org/conventions/waste-jointconvention.htm>.

IAEA Code of Practice on the International Transboundary Movement of Radioactive Waste.[56]

5.54 Various other international agreements seek to provide for, inter alia, the physical protection of nuclear material, the safe transportation of radioactive material, protection of the environment from radioactive waste and the control of imports and exports of radioactive waste.[57]

5.55 The regulation of radioactive waste management and disposal in Australia is the responsibility of each jurisdiction. At the state and territory level, the use of radiation and radioactivity is regulated by environmental protection authorities and state health departments. State and territory provisions are principally based on several national codes of practice and standards, described below, which in turn draw upon the international guidance mentioned above.[58]

5.56 At the Federal level, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is responsible for regulating the management and storage of radioactive waste at the Australian Nuclear Science and Technology Organisation (ANSTO), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Department of Defence.

5.57 Among its other functions, ARPANSA has the responsibility of promoting uniformity of radiation protection and nuclear safety policy across jurisdictions. In this way, ARPANSA plays a major part in establishing a framework for radioactive waste management across all jurisdictions.[59]

5.58 There are currently three national codes for regulating waste management:

- The *Code of Practice for the Disposal of Radioactive Wastes by the User* (1985) provides for small amounts of low level solid waste below defined limits to be disposed of by the user to an urban land-fill waste tip. The Code is currently under revision.[60]
- The *Code of practice for the near surface disposal of radioactive waste in Australia* (1992) provides the basis for the near-surface disposal of solid radioactive waste that has been classified as LLW and short-lived ILW. The code is intended to apply to disposal of contaminated plant and equipment resulting from handling or processing of naturally-occurring materials which contain radioactive contaminants in low but non-trivial amounts, and to waste arising from processing of minerals remote from

56 *ibid.*

57 UIC, *Waste Management in the Nuclear Fuel Cycle, loc. cit.*

58 ARPANSA, *Submission no. 32*, p. 4.

59 *ibid.*, p. 3.

60 See: ARPANSA, *Code of Practice for the Disposal of Radioactive Wastes by the User,* 1985, viewed 21 August 2006, <http://www.arpansa.gov.au/pubs/rhs/rhs13.pdf>.

any mine site and where disposal at the mine site is inappropriate. The code also applies to disposal of waste arising from the rehabilitation, decontamination or decommissioning of sites or facilities where radioactive materials have been produced, stored, used or dispersed. The code establishes the requirements for site selection, design criteria and operational requirements for either a national near-surface disposal facility or for a purpose-built land-fill disposal trench.[61]

- The *Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing* (2005) provides a uniform framework for radiation protection in the mining and mineral processing industries, and for the safe management of radioactive waste arising from mining and mineral processing.[62]

5.59 A new national code is currently being developed to cover the treatment, conditioning, packaging, storage, and transport or radioactive waste in Australia.[63]

Management of high level waste

5.60 As mentioned above, a typical large nuclear reactor generates about 25–30 tonnes of spent fuel per year. Spent reactor fuel gives rise to HLW which may be of two distinct kinds:

- in countries where used fuel is not reprocessed (that is, where countries have adopted an 'open' fuel cycle), the used fuel itself in fuel rods is considered a waste and therefore classified as HLW; or
- in countries where spent fuel is reprocessed to recycle material (that is, where countries have adopted a 'closed' fuel cycle), the fission products and transuranic elements are separated from uranium and plutonium and treated as HLW (the uranium and plutonium is then re-used as fuel in reactors, as described below).

5.61 Spent fuel assemblies discharged from a reactor core are highly radioactive and produce heat. They are therefore initially placed into large water filled pools (storage ponds) which act to cool the spent fuel and shield the radiation. The spent fuel assemblies will remain in storage ponds for a number of years while the heat and radioactivity decreases considerably. The spent fuel will then be either sent for long-term storage

61 See: ARPANSA, *Code of practice for the near surface disposal of radioactive waste in Australia*, 1992, viewed 21 August 2006, <http://www.arpansa.gov.au/pubs/rhs/rhs35.pdf>.

62 See: ARPANSA, *Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing,* 2005, viewed 21 August 2006, <http://www.arpansa.gov.au/pubs/rps/rps9.pdf>.

63 ARPANSA, *Radioactive Waste Management in Australia, loc. cit.*

or reprocessed, which typically occurs some five years after reactor discharge.[64]

5.62 If the used fuel is reprocessed, as occurs with fuel from British, French, Swiss, Japanese and German reactors, HLW comprise highly-radioactive fission products and some transuranic elements with long-lived radioactivity. These are separated from the used fuel, enabling the uranium and plutonium to be recycled. The waste generates a considerable amount of heat and requires cooling. The waste, which consists mostly of concentrated liquid nitric acid, is then incorporated into borosilicate (Pyrex) glass (vitrified), encapsulated into heavy stainless steel cylinders about 1.3 metres high and stored for eventual disposal.[65]

5.63 If the used reactor fuel is not reprocessed, all the highly radioactive isotopes remain in the fuel assembly. The entire fuel assembly is accordingly treated as HLW for direct disposal. This type of HLW also generates a lot of heat and requires cooling. However, since the used fuel largely consists of uranium (with a little plutonium) it represents a potentially valuable resource, hence there is an increasing reluctance to dispose of it irretrievably.[66]

5.64 For both types of HLW there is a cooling period of 20 to 50 years between removal from the rector and disposal, with the conditioned spent fuel or conditioned HLW from reprocessing retained in interim storage. During this period the level of radioactivity and heat from the spent fuel falls rapidly, down to one thousandth of the level at discharge after 40 years. This provides a technical incentive to delay further action with HLW until the radioactivity has reduced to a small fraction of its original level.

5.65 Interim storage facilities may be at one central location, as in Sweden (at the Central Interim Storage Facility for Spent Nuclear Fuel, or CLAB, located in Oskarshamn in southern Sweden), or at reactor sites, as in the US (where spent fuel is stored at 126 sites in 39 states).[67]

5.66 After storage for about 40 years the spent fuel assemblies are ready for encapsulation or loading into casks ready for indefinite storage or permanent disposal underground.

5.67 Direct disposal has been chosen by Finland, Sweden and, until recently, the US. However, evolving concepts lean towards making the used fuel recoverable in the event future generations see it as a resource. This requires allowing for a period of management and oversight before a

64 UIC, *Nuclear Electricity, loc. cit.*

65 UIC, *Submission no. 12*, p. 39.

66 *ibid.*

67 WNA, *Radioactive Wastes, loc. cit.*

repository is closed. Increasingly, reactors are using fuel enriched to over four per cent U-235 and burning it longer, to end up with less than 0.5 per cent U-235 in the used fuel. This provides less incentive to reprocess.[68]

Reprocessing spent fuel

5.68 Fresh uranium oxide fuel contains up to five per cent U-235. When the fuel reaches the end of its useful life and is discharged from the reactor, it contains some 95 per cent U-238, three per cent fission products (the residues of the fission reactions) and transuranic isotopes, one per cent plutonium and one per cent U-235. The plutonium is formed by the neutron irradiation of U-238. In total, some 96 per cent of the spent fuel is comprised of the original uranium and contains over half of the original energy content (excluding the U-238).[69]

5.69 Spent fuel thus contains about a quarter of the original fissile U-235 and much of the plutonium that has been formed in the reactor. Reprocessing undertaken in Europe and Russia (and planned for Japan) separates the uranium and plutonium from the wastes so they can be recycled for re-use in a nuclear reactor as mixed-oxide (MOX) fuel. There are some 34 reactors currently licensed to use MOX fuel across Europe, with 75 others in the licensing process. Japan proposes to introduce MOX fuel into 20 of its reactors by 2010.[70]

5.70 The benefits of recycling are said to be conservation of uranium (it saves 30 per cent of the natural uranium otherwise required), minimising the amount of HLW, reducing reliance on new uranium supply, reducing the inventory of separated plutonium and reduction of spent fuel storage requirements.

5.71 After reprocessing, the recovered uranium is re-enriched and then handled in a normal fuel fabrication plant. The plutonium needs to be recycled through a dedicated MOX fuel fabrication plant where it is mixed with depleted uranium oxide to make fresh MOX fuel. MOX fabrication plants are typically integrated with reprocessing plants. European reactors currently use over five tonnes of plutonium a year in fresh MOX fuel, although all reactors routinely burn much of the plutonium which is continually formed in the core by neutron capture.

5.72 Major commercial reprocessing plants operate in France (La Hague), Britain (Sellafield) and Russia (Chelyabinsk), with a capacity of some 5 000 tonnes per year and cumulative civilian experience of 80 000 tonnes over 50 years. France and Britain also undertake reprocessing for utilities

68 UIC, *Submission no. 12*, p. 39.

69 WNA, *Radioactive Wastes, loc. cit.*

70 *ibid.*

in other countries, notably Japan, which has made over 140 shipments of used fuel to Europe since 1979. At present, most Japanese used fuel is reprocessed in Europe with the vitrified waste and the recovered uranium and plutonium (as MOX) being returned to Japan to be used in fresh fuel. Russia also reprocesses some used fuel from Soviet-designed reactors in other countries.[71]

5.73 The HLW from reprocessing comprises the non-reusable part of the spent fuel; that is, both the fission products and transuranic elements other than plutonium. The fission products are then vitrified. Currently, France has two commercial plants to vitrify HLW left over from reprocessing and plants also exist in Britain and Belgium. The capacity of the western European plants is 2 500 canisters (1 000 tonnes) per year. The hulls and end fittings of the fuel assemblies are compacted to reduce the total volume of the waste and are frequently incorporated into cement before being placed into containers for disposal as ILW.[72]

5.74 The small quantities of used fuel from the Australian research reactor and the replacement reactor at Lucas Heights in Sydney are likely to be reprocessed. Some used fuel from Lucas Heights has already been shipped to Europe for reprocessing, and the small amount of separated waste will be returned to Australia for disposal as ILW.[73]

Disposal of high level waste

5.75 Whether the HLW is vitrified material from reprocessing or entire spent fuel assemblies, it eventually requires final disposal. HLW are highly radioactive for long periods of time and must therefore be isolated from the biosphere while the radioactivity decreases.[74]

5.76 In contrast to storage, which the Joint Convention defines as the holding of spent fuel or waste with the intention of retrieval, disposal means the emplacement of spent fuel or waste in an appropriate facility without the intention of retrieval, although subsequent reprocessing might be possible. This indicates that disposal is the final expected step in a waste management plan. Another distinction is that storage implies continued supervision, so that safety is provided by a combination of engineered features and active controls, whereas disposal implies a move towards reliance on the immobilisation of the waste and the passive safety functions of the disposal's system of engineered and natural barriers, making active controls unnecessary. Despite this, ANSTO noted that some

71 UIC, *Submission no. 12*, p. 40.
72 UIC, *Nuclear Electricity, loc. cit.*
73 UIC, *Submission no. 12*, p. 39.
74 ANSTO, *Submission no. 29*, p. 10.

countries are now investigating the possibility of longer-term storage, up to several hundred years.[75]

5.77 The cumulative inventory of stored spent fuel worldwide amounts to about 270 000 tonnes, much of which is located at reactor sites.[76] Annual arisings of spent fuel are about 12 000 tonnes, and one quarter of this is reprocessed.[77]

5.78 All countries that have so far made a policy decision on a final step for the management of long-lived radioactive waste have selected geological disposal—the emplacement of sealed waste-bearing canisters in mined structures (geologic repositories), typically several hundred metres below the Earth's surface in rock, clay or salt.[78]

5.79 ANSTO observed that there is now broad international scientific agreement that deep geological disposal, using a system of engineered and natural barriers to isolate the radioactive waste, is the best method of disposal for HLW.[79] This consensus is outlined in a position paper, *The Long Term Storage of Radioactive Waste: Safety and Sustainability*, which was prepared by international experts and published by the IAEA in 2003.[80]

5.80 To ensure that no significant environmental releases occur over tens of thousands of years, 'multiple barrier' concepts are proposed to isolate the wastes from the biosphere. The barriers are:

- immobilisation of waste in an insoluble matrix such as borosilicate glass or ceramic;
- sealing inside a corrosion-resistant container, such as stainless steel or copper;
- location deep underground in a stable rock structure; and
- surrounding the containers with an impermeable backfill such as bentonite clay if the repository is in a wet environment.[81]

5.81 ANSTO explained that the desired geological criteria for a repository site includes that it is distant from a watertable. Also, it is useful if the geology is such that even if the waste did migrate it would move so slowly that it would take thousands of years to reach any water table or population:

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75 *ibid.*, pp. 11, 12.

76 *ibid.*, p. 10.

77 UIC, *Submission no. 12*, p. 40.

78 Some 14 countries propose to dispose of HLW in a geologic repository, including: Belgium, Finland, France, Germany, the Netherlands, Spain, Sweden, Switzerland, the UK and the US.

79 ANSTO, *Submission no. 29*, p. 11.

80 See: IAEA, *The Long Term Storage of Radioactive Waste: Safety and Sustainability—A Position Paper of International Experts*, IAEA, Vienna, 2003, viewed 5 September 2006, <http://www-pub.iaea.org/MTCD/publications/PDF/LTS-RW_web.pdf>.

81 UIC, *Submission no. 12*, pp. 38–39.

> So the concept is that the package provides containment, that the way you seal it in the repository provides containment and that the geology provides containment as well. All of those mean there is essentially no risk …[82]

5.82 ANSTO observed that 'Australia has some of the best geology in the world' for a repository and that 'there are hundreds of sites in Australia which would be suitable for that purpose.'[83] For example, it was noted that the site originally selected for a repository in South Australia was excellent: 'it would be tens of thousands of years before radioactivity would reach any water table' and 'by that time there is almost no radioactivity left.'[84]

5.83 The US Office of Civilian Radioactive Waste Management (OCRWM) notes that Belgium, Canada, Finland, France, Germany, Sweden, Switzerland, the UK, and the US have all performed detailed studies in underground research laboratories.[85]

5.84 The IAEA notes that it has established a Network of Centres of Excellence in Training and Demonstrations of Waste Disposal Technologies to help build confidence and capacity throughout the world in geological disposal of radioactive wastes. The network links eight underground laboratories located in Canada, Belgium, Switzerland, Sweden, UK and the US.[86]

5.85 The safety of final disposal in geologic repositories has also been examined through studies of natural analogues; notably, the sites of nuclear chain reactions which occurred in nature and produced HLW. In particular, some 17 natural nuclear reactors, which existed some 2 billion years ago in (Oklo) Gabon, West Africa, and which continued for about 500 000 years before dying away, produced nuclear waste which has remained at the site where it was generated and then naturally decayed into non-radioactive elements. These natural analogues are said to provide confirmation that long-lived waste can be safely and securely geologically isolated.[87]

5.86 The UIC stated that after being buried for about one thousand years, most of the radioactivity from HLW will have decayed. The amount of

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82 Dr Ron Cameron, *op. cit.*, p. 16.

83 *ibid.*, p. 15.

84 *ibid.*, p. 16.

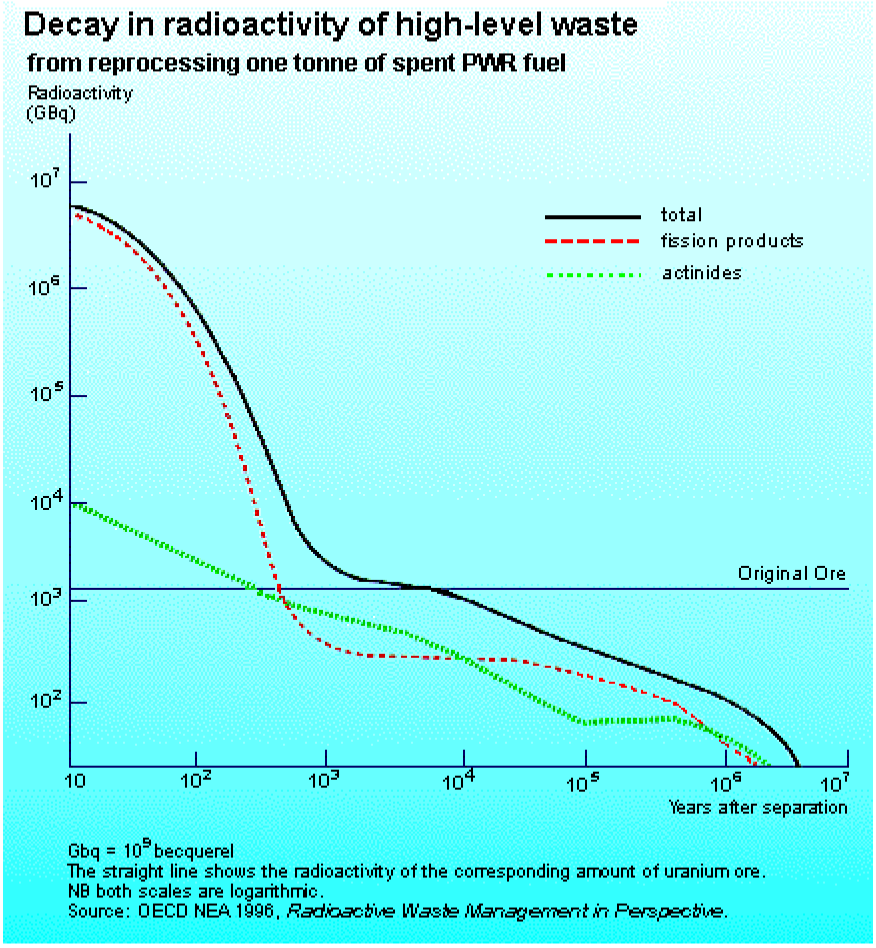
85 US Department of Energy (DOE), OCRWM, *Radioactive Waste: an international concern*, Factsheet, 2001, viewed 24 August 2006, <http://www.ocrwm.doe.gov/factsheets/doeymp0405.shtml>.

86 IAEA, *Features: Underground Repositories*, 23 January 2004, viewed 9 September 2005, <http://www.iaea.org/NewsCenter/Features/UndergroundLabs/index.html>.

87 UIC, *Submission no. 12*, p. 43.

radioactivity then remaining would be similar to that of the equivalent naturally-occurring uranium ore from which it originated, though it would be more concentrated.[88] This is illustrated in figure 5.1 which shows the decay in radioactivity of HLW from reprocessing one tonne of spent fuel.

Figure 5.1 Decay in radioactivity of high level waste



5.87 The process of selecting appropriate sites for geologic repositories for HLW is now underway in several countries with the first expected to be commissioned in the next decade. Finland and Sweden are also well advanced with plans and site selection for direct disposal of used fuel.[89]

5.88 The US has opted for a final repository at Yucca Mountain in Nevada. In July 2006 the US Department of Energy (DOE) announced that it will submit a license application to the US Nuclear Regulatory Commission (NRC) to construct the Yucca Mountain repository by mid 2008. The DOE also announced that if requested legislative changes are enacted, the

88 *ibid.*, p. 41.

89 Information on the Olkiluoto site in Finland available online, viewed 24 August 2006, <http://www.posiva.fi/englanti/>.

repository will be able to begin accepting spent fuel and HLW in 2017.[90] A geological repository, the Waste Isolation Pilot Plant (WIPP), for US military transuranic wastes has been in operation in New Mexico since 1999.

5.89 Appendix G indicates the measures that various countries have in place or planned to store, reprocess and dispose of used fuel and other radioactive wastes.

5.90 While each country is responsible for disposing of its own wastes, the possibility of international nuclear waste repositories is now being considered and Russia has enacted legislation to enable this to occur.[91] Mr Jerry Grandey also predicted that, over time, the world will shift towards a system of assurances of fuel supply combined with a few repositories from which spent fuel could be retrieved and reused.[92]

Synroc — an Australian technology for immobilising high level waste

5.91 Other than borosilicate glass, another means of immobilising HLW is an Australian-designed waste form known as 'synroc' (synthetic rock), which is a ceramic containment material for HLW. Synroc was said to represent a more sophisticated way to immobilise such waste and may eventually come into commercial use for civil wastes.[93]

5.92 ANSTO explained that waste forms to immobilise HLW must be able to prevent groundwater causing any significant movement of radionuclides back to the biosphere and that nuclear material contained within the waste form should not be able to be removed. That is, the aqueous durability and chemical resistance of the waste form is of extreme importance. It was argued that synroc, which was first developed by Professor Ted Ringwood of the ANU in 1978, has been especially designed for the immobilisation of HLW and to meet these overriding requirements.[94]

5.93 The synthetic rock waste form is an advanced ceramic composed of titanate minerals that are formed in nature, and as such are both highly stable and groundwater resistant. Synroc incorporates the waste fission products and actinides in the crystalline lattices of the synthetic materials,

90 See: DOE, Office of Public Affairs, *DOE Announces Yucca Mountain License Application Schedule*, News Releases, 19 July 2006, viewed 24 August 2006, <http://www.ocrwm.doe.gov/info_library/newsroom/documents/ym-schedule-2006.pdf>. Information on the Yucca Mountain project available online from the US Office of Civilian Radioactive Waste Management, viewed 24 August 2006, <http://www.ocrwm.doe.gov/ym_repository/index.shtml>.

91 UIC, *Nuclear Electricity*, *loc. cit.*

92 Mr Jerry Grandey, *op. cit.*, p. 11.

93 UIC, *Submission no. 12*, p. 40.

94 ANSTO, *op. cit.*, p. 15.

keeping them 'locked up' for millions of years.[95] It was argued that synroc has been:

> … demonstrated in nature to contain uranium, thorium, plutonium et cetera for millions of years … It is a ceramic, resistant to leaching by water and capable of being stored safely in deep underground repositories.[96]

5.94 ANSTO has continued to develop synroc for the past 25 years, with the waste form exposed to various durability and leachability tests. Various compositions of synroc have now been developed, with Professor Ringwood's original composition now referred to as synroc-A. Synroc-C is now seen as the 'standard' synroc waste form. ANSTO has also developed other forms of ceramic and glass-ceramic compositions in response to different types of waste.

5.95 In terms of its commercial applications, ANSTO submitted that, internationally, synroc is the 'the disposal route of choice for plutonium-contaminated material.'[97] ANSTO has been designing, fabricating and testing waste forms for specific applications worldwide:

- The 'synroc-D' variation has been found to be suitable for various waste streams in Russia and discussions concerning a potential 20 tonnes/year synroc plant in Russia have been held.
- A synroc waste form for immobilisation of surplus weapons plutonium was selected by a competitive process over 70 other candidate waste forms by the US government in 1997. The DOE then called for bids to build a plutonium immobilisation plant. ANSTO set up an American company (ANSTO Inc.) and a joint venture with Cogema of France through their US subsidiaries to bid for the contract to build the plant. The venture also included US companies Burns & Roe, and Battelle. After bids were submitted, the DOE announced that it was deferring immobilisation plans. This was due to a number of factors, chiefly a change in the US Administration, and the associated change in policy with regard to weapons plutonium.
- It was announced on 15 April 2005 that British Nuclear Fuels has formally approved funding for the design and construction of a demonstration facility at Sellafield in the UK to immobilise five tonnes of plutonium-containing residues in a glass-ceramic matrix developed by ANSTO. ANSTO will also provide input into the design of the plant.

95 *ibid*. *Actinides* are those elements with an atomic number of 89 (actinium) or above. Minor actinides are americium and curium, while the major actinides are plutonium and uranium.

96 Dr Ian Smith (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 12.

97 *ibid*., p. 17.

- ANSTO has recently commenced constructing the first stage of a 'mini-synroc' plant for the long-term immobilisation of the wastes from molybdenum-99 (Mo-99) production at ANSTO's own Lucas Heights facilities. Mo-99 is extracted during a process to produce technetium-99, a widely used medical diagnostic agent.[98]

5.96 In other evidence, representatives of the Australian Nuclear Forum (ANF) remarked that while synroc is without doubt the best waste form available, it may in fact offer more than is required by industry. The synroc process was also said to be more expensive than the borosilicate glass alternative. It was also submitted that countries such as France and Britain have already made very large investments in their present waste management approaches and Australia cannot realistically expect these countries to simply abandon these plans and embrace synroc. However, it was suggested that synroc will find a place for special applications and may be more widely adopted once current vitrification plants become obsolete.[99]

Disposal of other radioactive wastes

5.97 Generally, short-lived ILW (mainly from decommissioning reactors) are disposed of through near surface burial while long-lived ILW (from fuel reprocessing) will be disposed of deeper underground. Low level wastes are also disposed of in near surface burial sites.

5.98 A small proportion of low level liquid wastes from reprocessing plants are discharged to the sea. These include radionuclides which are distinctive, notably technetium-99 (sometimes used as a tracer in environmental studies), which can be discerned many hundreds of kilometres away. However, UIC stated that such discharges are regulated and controlled, and the maximum dose any person would receive from them is a small fraction of natural background.

5.99 Dr Helen Caldicott and others expressed concern about so-called 'routine releases' from nuclear reactors of noble gases—xenon, krypton and argon—and tritium, which the nuclear industry has also allegedly 'not coped with'.[100] Dr Caldicott argued that the claim by industry that it dilutes such emissions to safe levels prior to release is fallacious.[101]

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98 ANSTO, *op. cit.*, p. 16.

99 Mr James Bough and Dr Philip Moore, *Transcript of Evidence*, 16 September 2005, pp. 47–48.

100 Dr Helen Caldicott, *Transcript of Evidence*, 16 September 2005, p. 14.

101 Dr Helen Caldicott, *Exhibit no. 25, Nuclear Madness*, pp. 76–77; Mr Justin Tutty, *Submission no. 41*, p. 5; Uniting Church in Australia (Synod of Victoria and Tasmania), *Submission no. 40*, p. 12.

5.100 The UIC stated that nuclear power stations and reprocessing plants do indeed release small quantities of radioactive gases (e.g. krypton-85 and xenon-133) and trace amounts of iodine-131 to the atmosphere. However, it was argued that these have short half-lives, and the radioactivity in the emissions is diminished by delaying their release. Also, the first two are chemically inert. It was argued that the net effect is too small to warrant consideration in any life-cycle analysis.[102]

5.101 Dr Caldicott made a specific allegation that the research reactor at Lucas Heights in Sydney discharges more radioactive waste into the air and water than bigger, more powerful plants overseas. It was specifically alleged that emissions of iodine-131 exceed that of the reprocessing plant at Sellafield in the UK.[103]

5.102 ARPANSA responded that airborne discharges of iodine-131 from Lucas Heights exceed those of Sellafield because of the nature of the activities undertaken at the two facilities—radiopharmaceuticals are produced at Lucas Heights, whereas Sellafield is a reprocessing facility. Consequently, the iodine-131 present in any material sent to Sellafield for reprocessing would have decayed away before it was received by the plant.[104]

5.103 In 2003–04, airborne discharges of iodine-131 from Lucas Heights amounted to 26.5 gigabecquerel (GBq). By way of context, ARPANSA explained that a common treatment for thyroid disease is the ablation of the thyroid using iodine-131 capsules. Each iodine-131 capsule can contain as much as 6 GBq of iodine-131. Hence, the total annual release of 26.5 GBq of iodine-131 from Lucas Heights is equivalent to approximately only four iodine-131 therapy capsules used for treatment of thyroid disease.[105]

5.104 ARPANSA stated that from the public health point of view, when looking at discharge levels it is important to consider the total effective doses received by the public as a result, rather than a breakdown by nuclide. The dose for all nuclides discharged from the Lucas Heights site calculated for the nearest resident to the site was 2.6 microSieverts in 2003–04:

> This is a trivial dose comparable to what might be received on a Sydney-Melbourne flight [two microsieverts] and far below doses received from discharges from the Sellafield plant. The emission of

102 UIC, *Submission no. 12*, p. 42.

103 Dr Helen Caldicott, *Exhibit no. 25, op. cit.*, p. 53.

104 ARPANSA, *Submission no. 32.1*, p. 1.

105 *ibid.*

individual nuclides are monitored to follow trends in release related to the various activities carried out by ANSTO.[106]

Costs of radioactive waste management and decommissioning

5.105 The cost of managing and disposing of nuclear power wastes was said to represent about five per cent of the total cost of the electricity generated. Most nuclear utilities are required by governments to set aside a levy (e.g. 0.1 cents per kilowatt hour in the US and 0.3 cents/kWh in Sweden) to provide for the management and disposal of wastes. More than US$28.3 billion has been committed to the US Nuclear Waste Fund to date, and the fund is growing at some $800 million per year.[107] However, the AMP CISFT claimed that it will take US utilities 50 years to collect enough to pay for Yucca Mountain, which it argued will cost $58 billion.[108]

5.106 Total costs of decommissioning vary depending on the sequence and timing of the various stages in the decommissioning program, location of the facility, current radioactive waste burial costs, and plans for spent fuel storage. However, decommissioning also typically contributes less than five per cent to total electricity generating costs. In the US, the NRC estimates that the cost of decommissioning currently ranges between US$280 and $612 million per power plant, with the US Nuclear Energy Institute suggesting that the average cost figure is about $320 million per reactor.[109]

5.107 In the US, utilities may demonstrate financial assurance for decommissioning by one or more of the following: prepayment, where utilities deposit funds in a separate account as a trust fund before the plant begins operating; nuclear power levy, which is the main US system, where utilities place funds in a trust fund outside the utility's control, based on a percentage of the electricity rates charged to consumers; and a surety fund purchased by the utility to guarantee that decommissioning costs will be paid by another party if the utility defaults.[110]

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106 *ibid*. See also: Mr James Brough, *Transcript of Evidence*, 16 September 2005, p. 47; and ANSTO, *Managing Radioactive Wastes and Spent Reactor Fuel*, Brochures, June 2003, viewed 29 August 2006, <http://www.ansto.gov.au/info/reports/manradw/wastem1g.html>.

107 UIC, *Nuclear Power in the USA*, Briefing Paper No. 58, viewed 24 August 2006, <http://www.uic.com.au/nip58.htm>; NEI, *Costs: Operating / Building / Waste Disposal*, Nuclear Statistics, viewed 24 August 2006, <http://www.nei.org/index.asp?catnum=2&catid=351>.

108 AMP CISFT, *Exhibit no. 65, The Nuclear Fuel Cycle Position Paper*, p. 18.

109 NRC, *Financial Assurance for Decommissioning*, viewed 24 August 2006, <http://www.nrc.gov/what-we-do/regulatory/decommissioning/finan-assur.html>.

110 *ibid*.

5.108 Utilities must report to the NRC at least once every two years on the status of decommissioning funds, annually once the reactor is within five years of permanently shutting down, and annually after shut down. Utilities typically collect 0.1 to 0.2 cents/kWh to fund decommissioning and, as of 2001, US$23.7 billion had been collected.[111]

Concerns about radioactive waste and its management

5.109 Those submitters that were opposed to the use of nuclear power advanced the following arguments in relation to radioactive waste:

- the disposal of nuclear waste remains an unresolved issue;
- the storage and transport of radioactive waste poses unacceptable environmental and health risks;
- radioactive waste must be secured for long periods of time and therefore imposes undue burdens on future generations; and
- reprocessing of used fuel generates larger quantities of transuranic waste and involves greater proliferation risks.

These claims are considered in turn, along with responses from industry and other submitters.

Disposal of nuclear waste is 'unresolved'

5.110 The AMP CISFT argued that nuclear waste remains an unresolved issue for three principal reasons: no country has successfully implemented a long-term plan for waste disposal and is unlikely to do so for some years; if the use of nuclear power continues to grow, a large number of repositories will need to be built and it is a significant challenge to identify where and how these will be constructed; and, third, the growth markets for nuclear power, China and India, have no plans to develop waste management sites.[112] In summary, the AMP CISFT argued that:

> … it is a bit hard to come to the conclusion that [the nuclear power industry] are responsibly managing [waste] and can demonstrate that they will be able to responsibly manage it in the near future.[113]

5.111 Specifically, AMP CISFT argued that, although the industry has had 50 years to develop a plan for the long-term storage of its HLW, it is unlikely that a repository will commence operating before 2020 at the earliest:

111 NEI, *Decommissioning of Nuclear Power Plants, loc. cit.*

112 AMP CISFT, *Submission no. 60*, pp. 3–5.

113 Dr Ian Woods (AMP CISFT), *Transcript of Evidence*, 16 September 2005, p. 28.

> This will mean that for over 70 years, at the very least, the nuclear power industry has and will not have addressed its major life cycle waste issues.[114]

5.112 Most submitters who expressed concerns about nuclear waste also made this argument, with the MAPW (WA Branch) asserting that: 'The waste problem, unresolved despite almost 60 years of research, is on its own enough to spurn nuclear power', and the Public Health Association of Australia asserting that: 'There is no safe method of long term storage of radioactive waste, including mining tailings, spent fuel rods or plutonium.'[115] Similarly, Ms Jo Vallentine argued that:

> It has been sixty years now, that attempts have been made to find a solution to the nuclear waste problem. One has not been found. Would it not then be prudent, with the huge masses of waste already accumulated, to desist from producing more?[116]

5.113 Other submitters also argued that because no repository has yet been built, there remains no proven solution for managing long-lived waste and, hence, nuclear waste remains an 'unsolved problem.'[117]

5.114 Some submitters also expressed 'moral outrage' because, again, there is allegedly 'no working solution to nuclear waste'.[118] Other submitters claimed that: 'Nuclear waste poisons everything it touches, mutates DNA and makes the earth unable to sustain life' and 'those who allow the development of a nuclear energy industry condemn our species to certain death.'[119]

5.115 Some submitters, including Mr Justin Tutty, Mrs Judy Forsyth and Ms Jeanie Wylie, also pointed out that some waste is radioactive for very long periods of time and asserted that waste cannot be safely disposed of in repositories:

> These wastes cannot be simply disposed of underground, out of sight and out of mind, without risking leaks back into the environment. This unsolved problem has simply been left as our deadly radioactive legacy for future generations.[120]

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114 AMP CISFT, *op. cit.*, p. 3.

115 Medical Association for the Prevention of War (MAPW) (WA Branch), *Submission no. 8*, p. 2; Public Health Association, *Submission no. 53*, p. 2.

116 Ms Jo Vallentine, *Submission no. 73*, p. 2. See also: Mr Colin Mitchell, *Submission no. 67*, p. 1.

117 See for example: Mr Justin Tutty, *Submission no. 41*, p. 6; Mr David Addison, *Submission no. 59*, p. 1; Mr W M Lewis, *Submission no. 65*, p. 1.

118 Ms Stephanie Riddel, *Submission no. 80*, p. 1.

119 Ms Kathleen Winter, *Submission no. 62*, p. 1; Ms Stephanie Riddell, *op. cit.*, p. 2.

120 Mr Justin Tutty, *loc. cit.*; Mrs Judy Forsyth, *Submission no. 74*, pp. 1, 3; Ms Jeanie Wylie, *Submission no. 63*, p. 1.

5.116 AMP CISFT argued that nuclear waste storage problems would be exacerbated if nuclear power were to expand. For example, it was argued that if there was a four-fold increase in nuclear generating capacity worldwide, the estimated quantity of HLW would be of the order of 29 000 tonnes per year, assuming conventional nuclear reactor technology is used. This would allegedly require a new disposal facility equivalent to the proposed Yucca Mountain every 2.5 years. The cumulative quantity of HLW requiring disposal by 2050 under this scenario would be 922 000 tonnes, or equivalent to 13.2 Yucca Mountain facilities.[121]

5.117 It was also argued that the future growth markets for nuclear power, notably India and China, have no plans for facilities to dispose of HLW: 'This raises significant questions about the responsible long-term management of nuclear waste that may be generated from uranium mined in Australia.'[122]

5.118 Finally, a number of submitters argued that because there are allegedly 'no adequate processes for the treatment, disposal, or containment of nuclear waste', the Australian Government should not permit uranium to be mined until there is a solution for the long-term storage of nuclear waste.[123] For example, AMP CISFT argued that:

> … as a responsible nation, it is difficult to see how Australia can encourage the further growth of an industry while the significant current waste liability remains unresolved and the expansion of the industry would create even greater challenges to be resolved.[124]

5.119 Similarly, the Arid Lands Environment Centre asserted that:

> As long as there is no acceptable method for disposing of uranium, no responsible government should permit its further development.[125]

5.120 Responses to these arguments from submitters who were supportive of nuclear power and uranium mining, included that:

- there is an international scientific consensus in support of geological disposal for long-lived waste and planning is now well advanced for HLW repositories in several countries;
- there has, in any case, been no pressing need for HLW repositories to date, because spent fuel requires interim storage for up to 50 years and

121 AMP CISFT, *op. cit.*, p. 4.
122 *ibid.*, p. 5.
123 Alice Action Committee and others, *Submission no. 79*, p. 1.
124 AMP CISFT, *loc. cit.*
125 Arid Lands Environment Centre, *Submission no. 75*, p. 3.

the accumulated inventory of HLW is very small, particularly in comparison to the wastes generated by other major energy industries;

- disposal of long-lived waste is not a technical problem but a political problem—one beset by misperceptions of risk leading to 'not in my backyard' arguments around the siting of repositories;
- moves to adopt a closed fuel cycle in the US and the development of advanced fuel cycles and reactor technologies will significantly reduce the isolation period and quantity of waste requiring final disposal; and
- LLW and short-lived ILW is already being successfully disposed of, including in repositories.

5.121 ANSTO, Areva and others argued that for long-lived ILW and HLW 'there is wide international agreement on engineered geologic disposal as an effective, feasible and promising waste management end-point.'[126] Areva noted that geological disposal has the support of scientists and experts under the aegis of the IAEA, OECD and European Commission, among other organisations.[127] The US OCRWM has also stated that an international scientific consensus has emerged:

> … that deep geologic disposal is technically feasible, provides a waste disposal solution that keeps the public safe, provides for security from intrusion, prevents the diversion of nuclear materials for harmful purposes, and protects the environment for both the short and long term.[128]

5.122 Most recently, in July 2006 the UK Committee on Radioactive Waste Management (CoRWM), which had been examining the long-term management of higher level radioactive waste in the UK since 2003, published its final report. CoRWM recommended, inter alia, geological disposal as the end point for the long-term management of radioactive wastes and robust storage for an interim period of up to 100 years. CoRWM also recommended that community involvement in proposals for the siting of a repository should be based on the principle of volunteerism.[129] As noted above, all countries that have so far made a policy decision on a final step for the management of long-lived radioactive waste have selected geological disposal as the best option.

5.123 Although numerous repositories for LLW and short-lived ILW exist, there is currently only one permanent disposal facility for long-lived ILW in

126 ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith*, slide 55.

127 Areva, *Submission no. 39*, p. 7.

128 OCRWM, *Radioactive Waste: an international concern*, *loc. cit*.

129 CoRWM, *Managing our Radioactive Waste Safely: CoRWM's Recommendations to Government*, CoRWM, London, July 2006, pp. 111–115, viewed 24 August 2006, <http://www.corwm.org.uk/pdf/FullReport.pdf>.

operation—the WIPP in New Mexico, for US military wastes. However, repository site selection, design and construction plans are well advanced in several countries, including Finland, Sweden and the US. For example, Finland's geological disposal site for spent fuel (Olkiluoto) was selected in 2000 and ratified by Parliament in 2001. Construction of an underground rock characterisation facility began in 2004, in anticipation of the issue of a construction license in 2010 and readiness for operation in 2020. As noted above, subject to approvals, Yucca Mountain will be able to receive waste in early 2017. BHP Billiton noted that:

> There has been a lot of work on long-term disposal of waste from power stations, particularly in the US and in Sweden in terms of disposal in geologically stable formations at depth. There has been a lot of work on that. Sweden has got a big laboratory and some of our people have visited it. It is something we are trying to learn about.[130]

Appendix G describes progress towards final repositories in various other countries.

5.124 BHP Billiton claimed that because the nuclear power industry generates small volumes of waste, there is, in any case, little need for an immediate method of long-term disposal:

> This is not an industry that generates large quantities of waste and therefore local storage is pretty easy to do. You can build storages and they are a small part of the cost of building a power station and so the pressure has not been there at this stage to go beyond that, because there is time to work out an appropriate solution for long-term disposal. Storages for the wastes being stored now do not take up a big space. They are not very difficult to construct and they are secure as they are.[131]

5.125 The UIC concurred with this view, arguing that, to date, there has been no practical need for HLW repositories as surface storage is required for up to 50 years, so that the heat and radioactivity of the waste can dissipate to levels which make handling and storage easier.[132] Similarly, the Association of Mining and Exploration Companies (AMEC) submitted that while safe methods for the final disposal of HLW are technically proven, they are not yet required.[133]

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130 Dr Roger Higgins (BHP Billiton Ltd), *Transcript of Evidence*, 2 November 2005, p. 24.

131 *ibid*.

132 UIC, *Submission no. 12*, p. 39.

133 AMEC, *Submission no. 20*, p. 5.

5.126 Moreover, the volumes of long-lived waste are said to be very small. Emphasising the very small proportion of spent fuel requiring isolation for long periods of time, ANSTO argued that:

> Ninety-five per cent of spent fuel is uranium, which is not a problem to store or worry about. You can actually reuse it. Four per cent is radioactive fission products—generally caesium and strontium are the major ones there—and they require treatment in isolation for about 200 years before they are back to background levels. One per cent of the components of the spent fuel are the materials that require hundreds of thousands of years of storage.[134]

5.127 On the long-lived wastes generated in Australia, ANSTO noted that the entire spent fuel from 40 years of reactor operations at Lucas Heights 'would come back in two large cylinders about three metres high … about 0.6 cubic metres per year.'[135]

5.128 The IAEA notes that the 12 000 tonnes of spent fuel produced from all the world's reactors each year would fit into a structure the size of a soccer field and 1.5 metres high—even without any being reprocessed for re-use.[136] Thus, the UIC argued that final disposal of HLW is not urgent in any logistical sense.

5.129 Mr Jerry Grandey argued that, rather than being the nuclear power industry's 'Achilles heel', nuclear waste is 'really the industry's strongest asset'.[137] The reasons given for this claim were that used nuclear fuel is:

> … easily contained, measured and controlled. If you take a look at all the nuclear waste ever generated in Canada's history—that is 40 or 45 years of electricity generation—all of that waste today is stored at the plant site[s] in … very small containers. If you put it all together … it would be about the size of a basketball arena and maybe 10 feet deep. So you are talking about a very, very small amount of material that has produced 35 to 40 years of electricity. It is just an astonishing fact …[138]

5.130 Areva also argued that a key feature of nuclear power is that the small quantities of waste permit sophisticated conditioning and management.[139] Likewise, Paladin Resources argued that while spent fuel is highly radioactive, the waste has several features which lends itself to ease of management: small volume; contained in the fuel assembly; decays at a

134 Dr Ian Smith, *op. cit.*, p. 12.
135 Dr Ron Cameron, *op. cit.*, p. 21.
136 Cited in ANSTO, *op. cit.*, p. 11.
137 Mr Jerry Grandey, *op. cit.*, p. 9.
138 *ibid.*
139 Areva, *Submission no. 39*, p. 7.

predictable rate; and is amenable to separation, encapsulation and isolation for the period necessary to render it harmless to the environment and people.[140]

5.131 ANSTO and industry consistently emphasised that management of radioactive waste is a political problem and *not* a technical problem. It was argued that LLW and short-lived ILW are safely stored in purpose built repositories which are in use worldwide. These wastes require compaction and, in some cases, storage in concrete. Long-lived ILW and HLW are encapsulated, usually in glass or synroc, and these are packed in highly secure casks. The encapsulation and casks are designed to last hundreds of thousands of years with low leachability.[141]

5.132 Mr John Reynolds also submitted that the problems of waste disposal are now less technical than political. The technologies are said to be well understood and a variety of safe means of disposal have been defined. Terminal storage facilities are already available in some places and in others, are being prepared.[142]

5.133 Silex explained that, as described above, there are essentially two nuclear waste forms that have been developed to date and that waste management is not a technical issue; rather, it is an issue of perception, which points to the need for improved education:

> There are two methods … borosilicate glass, which is the method that overseas countries are looking at, and a brilliant Australian invention called synroc … Currently, borosilicate glass is being used in several countries and is going to be used in the US in the future. These technologies involve the permanent immobilisation of the high-level waste inside a solid matrix. The borosilicate glass or the synroc is melted and becomes a slurry. The waste is powdered and mixed all the way through, like salt in a cake mix. This material is then cooled under high pressure. It becomes extremely hard and impervious to water. These bricks of waste matrix are then encased for safe measure. The plan is to place them in deep geological burial grounds.
>
> Successful demonstrations have already been concluded in Sweden. They have a fully operational pilot waste disposal system. There is a very large development in Yucca Mountain in the United States … I believe that the nuclear waste issue is … not a technical issue; it is [a] political and public issue—the 'not in my

140 Paladin Resources Ltd, *Submission no. 47*, p. 6.

141 ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith,* slide no. 54.

142 Mr John Reynolds, *Submission no. 5*, p. 6.

> backyard' syndrome. Again, the industry needs to educate the public and governments alike.[143]

5.134 ANSTO also argued that nuclear waste management is not a technical issue but remains a problem of public perceptions:

> The technology exists. It is safe. There are international guidelines. Everything is in place. The problem is political, and that is evidenced by there being a lot of social scientists in Europe now being employed by people in this business to try and provide the community with the assurance that it needs that the technology will work … The reason that I say that it is not a technological problem is that the Champagne district in France is the host of a low-level and short-lived intermediate waste dump and it has not affected its sales, tourism or any of those things.[144]

5.135 ANSTO also pointed to waste management approaches in Finland as:

> … an excellent example of how to manage it and to get a politically acceptable solution which is accepted by the people ... they have had interim storage of spent fuel. They have built their final repositories for low and short-lived intermediate waste and they have got a final geological repository which they are building simultaneously with the new reactor program.[145]

5.136 Similarly, Mr Keith Alder, previously the General Manager and then a Commissioner of the Australian Atomic Energy Commission, argued that:

> … a tremendous amount of rubbish is talked and published about the disposal of radioactive waste. The technical and economic problems of this were solved many years ago. The remaining problems are in public relations—the NIMBY syndrome, or 'not in my backyard'; that has been amply illustrated in Australia in the near past in looking for a national repository for radioactive waste—and, of course, politics.[146]

5.137 Mr Alder stated his conviction that the final disposal solution for radioactive waste is geologic repositories:

> I firmly believe the solution is to put it back where you got it from—which is deep in the ground. That has been done in France and Sweden, and they are well advanced towards doing it in the

143 Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 4.
144 Dr Ian Smith, *op. cit.*, p. 12.
145 *ibid.*, p. 13.
146 Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, p. 80.

United States. Australia [also] has very many suitable locations to do this.[147]

5.138 Nova Energy likewise argued that the disposal of nuclear waste is a political challenge rather than a technical issue and that the political process cannot respond to the 'not in my backyard' argument:

> … the technology to safely dispose of uranium waste is well developed. Countries like Sweden are certainly demonstrating that fact. When groups say that there is no solution and that it is an intractable problem, I think what they are really pointing at is that, whenever you suggest that there is a suitable site for disposing of uranium waste, someone will always be there saying, 'Not in my backyard.' That is the problem, not the technical issue. So I do not accept that there is no technical solution to uranium waste. I think it is just a human issue.[148]

5.139 In its position statement on the *Safe Management of Nuclear Waste and Used Nuclear Fuel*, the World Nuclear Association (WNA) argues that:

> In some countries with nuclear power, decisions on the disposal of conditioned [HLW] in deep geological repositories have been repeatedly postponed due to an absence of political will. Common misperceptions about nuclear waste have combined with political timidity to produce an impasse. Overcoming this impasse and achieving broader public support is today the central challenge for the safe long-term management of [HLW].[149]

5.140 The WNA contends that where public debate about disposal is still unresolved, the key challenges lie in two related areas: technical demonstration of the feasibility of repositories, for example, at research laboratories at underground sites; and in obtaining broader public support. The WNA argues that recent progress in Finland, Sweden, France and the US shows that these two issues are solvable:

> This experience shows that clear, transparent, step-by-step decision making—featuring public communication and involvement—can build local and national confidence to support site-selection and implementation of deep geological repositories.[150]

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147 *ibid*.

148 Dr Timothy Sugden (Nova Energy Ltd), *Transcript of Evidence*, 23 September 2005, p. 74.

149 WNA, *Safe Management of Nuclear Waste and Used Nuclear Fuel*, Position Statement, March 2005, p. 12, viewed 29 August 2006, <http://www.world-nuclear.org/position/waste.pdf>.

150 *ibid*.

5.141 However, Mr Jerry Grandey, Chief Executive Officer of Cameco Corporation, argued that opponents of nuclear power do *not* want to accept or admit that nuclear waste can be safely disposed of in repositories:

> Having participated in the debate in the US and in Canada, I can tell you that those people that are adamantly opposed to this industry … do not want a solution to the nuclear waste issue at all. If there is found to be a solution—technically it is not a problem; it [requires] a political solution—then in their mind there is no longer any argument against the use of nuclear energy. So you will find that segment of the population adamantly against any solution whatsoever …[151]

5.142 Nova Energy contended that the 'not in my backyard' arguments are the problem, not the technology to dispose of nuclear waste: 'There is a solution, but it means that the minority groups who protest need to be educated in some way to believe that the risk is minimal.'[152] Moreover, Nova argued that the risks associated with nuclear waste 'can be managed to a point where the risk level is trivial.'[153]

5.143 The risks associated with nuclear waste disposal was also compared with the costs that may be associated with global warming:

> Global warming would strike me as an extreme risk for humanity whereas a small amount of decaying uranium waste in the middle of a granite craton in the middle of Australia far from any life is of absolutely minimal risk.[154]

5.144 Similarly, the Australian Nuclear Association (ANA) argued that while perceptions of risk may well vary, 'the cost is that the greenhouse gas problem could be more dangerous in the future … than the risks of radioactive waste if we use nuclear power.'[155] Areva also submitted that the risk of any radioactive material passing the natural and engineered barriers of a repository and then reaching or affecting any population is so low that: 'There is no common measure with the global threat of climate change induced by the emission of greenhouse gases.'[156]

5.145 Submitters emphasised that the waste produced by nuclear power must also be compared to the waste generated by other energy systems. Mr Mark Chalmers, Managing Director of Heathgate Resources, argued that:

151 Mr Jerry Grandey, *op. cit.*, p. 10.
152 Dr Timothy Sugden, *loc. cit.*
153 *ibid.*
154 *ibid.*, p. 75.
155 Dr Clarence Hardy (ANA), *Transcript of Evidence*, 16 September 2005, p. 57.
156 Areva, *loc. cit.*

> I think that the whole waste concept is poorly understood generally by people in the public. The topic of nuclear waste, in my opinion, is solved … Again, it has to be looked at in the context of other waste with other energy sources also. When you look at the small quantities that are generated from nuclear power plants relative to the quantities of waste that come out of these other sources, like coal … it stacks up very well.[157]

5.146 Heathgate emphasised that some other wastes, such as arsenic, selenium, mercury and lead, are poisonous and exist forever—they never decay, unlike radioactive wastes.[158] Similarly, the UIC observed that:

> In the OECD some 300 million tonnes of toxic wastes are produced each year, but conditioned radioactive wastes amount to only 81,000 cubic metres per year. In countries with nuclear power, radioactive wastes comprise less than 1% of total industrial toxic wastes. Most toxic industrial wastes remain hazardous indefinitely.[159]

5.147 Dr Ian Smith, Executive Director of ANSTO, demonstrated to the Committee the actual volume of HLW which would be produced from generating nuclear electricity to power an average French household for twenty years (75 000 kWh). The volume of HLW fitted easily into the palm of one hand. However, if the same amount of electricity had been generated using coal, the waste produced would have been substantial:

> If they had made 75,000 kilowatt hours of electricity from coal they would have eight tonnes of solid waste which would contain uranium, thorium and heavy metals. According to the EPA in the United States, it would be quite a toxic substance with treatment times of about 10,000 years. This [the HLW] would have produced 1.5 kilograms of CO_2 and the coal would have produced 75 tonnes of CO_2.
>
> When you look at this, you can understand why France is a country whose CO_2 per dollar GDP is half the world average.[160]

5.148 The IAEA contrasts the 12 000 tonnes of HLW produced from all reactors worldwide each year with the 25 billion tonnes of carbon waste released directly into the atmosphere every year from the use of fossil fuels.[161] While a 1 000 MWe nuclear power plant generates some 30 tonnes of used

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157 Mr Mark Chalmers (Heathgate Resources Pty Ltd), *Transcript of Evidence*, 19 August 2005, p. 103.

158 Mr David Brunt (Heathgate Resources Pty Ltd), *Transcript of Evidence*, 19 August 2005, p. 104.

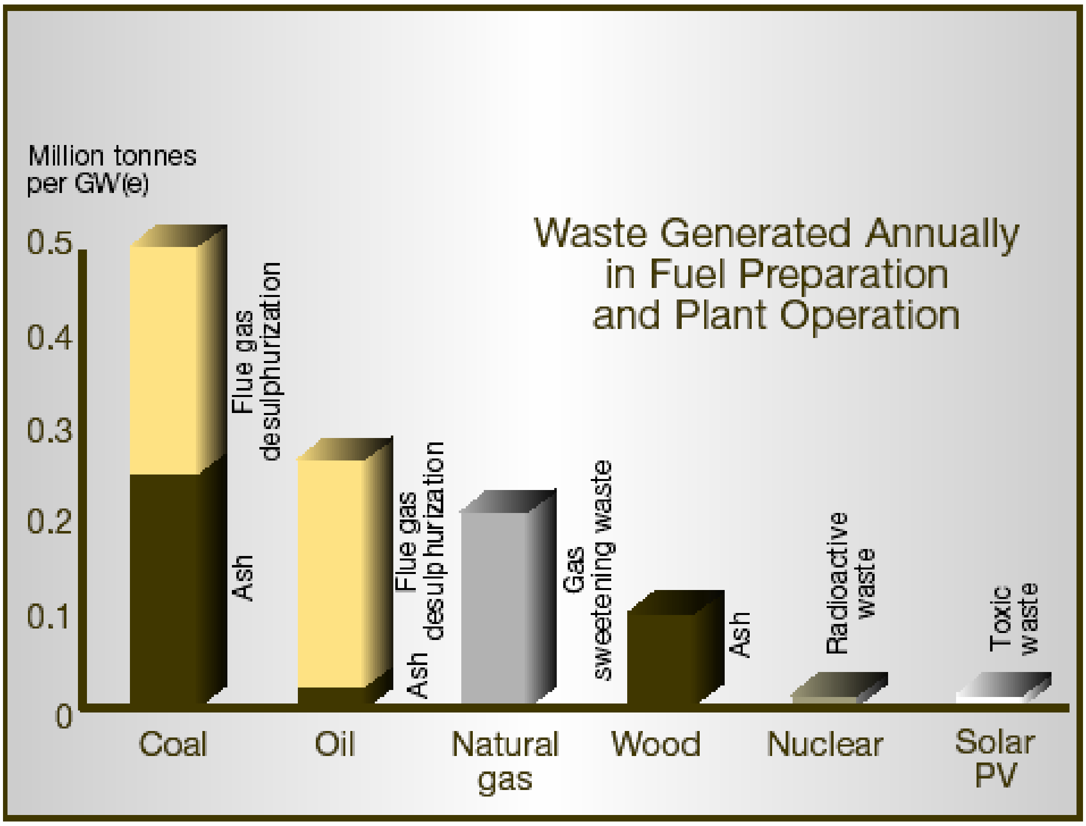
159 UIC, *Submission no. 12*, p. 37.

160 Dr Ian Smith, *op. cit.*, p. 13.

161 Cited in ANSTO, *op. cit.*, p. 11.

fuel per year, a similar sized coal plant produces some 300 000 tonnes of ash alone per year.[162] Figure 5.2 shows the volumes of waste generated annually in fuel preparation and plant operation for different energy sources. The Committee compared the environmental impacts of nuclear with coal and gas-fired power generation in the previous chapter.

Figure 5.2 Volumes of waste generated annually in fuel preparation and plant operation



Source IAEA, *Nuclear Power and Sustainable Development*, IAEA, Vienna, 2002, p. 3.

5.149 Heathgate stressed that 'it is important that the world is as educated as it can be' about the waste issue and that the wider context of waste generated by all energy sources must be properly understood.[163] On this point, Paladin Resources stressed that:

> The argument put by some that nuclear waste is 'not worth the risk' misunderstands the real risk v benefit equation which applies to all sources of energy. Nuclear power deals with waste more explicitly and transparently than many other fuels.[164]

162 See for example: Mr Alan Eggers (Summit Resources Ltd), *Transcript of Evidence*, 3 November 2005, p. 2.

163 Mr Mark Chalmers, *op. cit.*, p. 104.

164 Paladin Resources Ltd, *loc. cit.*

5.150 Similarly, Ms Pepita Maiden, a former employee of British Nuclear Fuels, remarked that nuclear power has 'the best looked after waste in the world'.[165] In comparing the waste management of the nuclear power industry with fossil fuels, Professor Leslie Kemeny also argued that:

> The hydrocarbon technology has never accepted the handling of their waste products as being a legitimate cost to their fuel cycle. I believe the nuclear industry is the only one that has looked at its waste properly.[166]

5.151 However, as noted in the previous chapter, AMP CISFT argued that the UK nuclear industry's waste management has been subsidised by the British Government 'in the order of £184 million per year, which is equivalent to £2.50 (or about A$5) per megawatt hour.'[167] It was argued that this is inconsistent with British Nuclear Fuels' claim that waste management costs £0.80 per megawatt hour. Furthermore, AMP CISFT estimated that the cost of nuclear waste disposal in the UK of some £12–13 per megawatt hour is equivalent to the cost to produce electricity in Australia.[168]

5.152 In relation to the size and number of repositories that may be required in a scenario of global growth in nuclear power, ANSTO noted that the US Government is now looking to abandon the open (or once-through) fuel cycle and reprocess used fuel to extract and re-use the uranium and plutonium, as European countries already do, 'because if they kept going like that in expanded nuclear they would have to build a Yucca Mountain every eight or nine years.'[169] Moving to a closed fuel cycle will have the effect of significantly reducing US waste volumes in the future. The Committee describes two US initiatives which could result in a dramatic increase in the capacity of the Yucca Mountain repository in the final section of the chapter.

5.153 On a related point, AMP CISFT claimed that the growth markets for nuclear power, China and India, have no plans to develop waste management sites. While the Committee did not receive any evidence on waste management plans in these countries, the OCRWM and the UIC have published information which indicates that both countries do in fact have plans for nuclear waste management.

5.154 The UIC reports that when China started to develop nuclear power, a closed fuel cycle strategy was also formulated and declared at an IAEA

165 Ms Pepita Maiden, *Submission no. 56*, p. 2.

166 Professor Leslie Kemeny, *Transcript of Evidence*, 16 September 2005, p. 93.

167 Dr Ian Woods, *op. cit.,* p. 29.

168 *ibid*.

169 Dr Ron Cameron, *op. cit.*, p. 11.

conference in 1987. The spent fuel activities involve: at-reactor storage; away-from-reactor storage; and reprocessing. The China National Nuclear Corporation has drafted a state regulation on civil spent fuel treatment as the basis for a long-term government program. The OCRWM states that China is unique in that its repository plans are being developed concurrently with the early stages of nuclear power plant construction.

5.155 The OCRWM reports that four or five repositories for low-level radioactive waste will be constructed in China to dispose of accumulated wastes from the nuclear industry, the decommissioning of nuclear facilities, and from nuclear power plant operation. These wastes will be delivered to the facilities after a five-year interim storage period. Storage ponds at Chinese reactors will hold spent fuel for 15 years which will then be reprocessed. Industrial-scale disposal of LLW and ILW wastes already occurs at two sites, in the northwest and at Bailong in Guangxi autonomous region of south China.

5.156 The UIC reports that, based on expected installed capacity of 20 GWe by 2010 and 40 GWe by 2020, the annual spent fuel arisings in China will amount to about 600 tonnes in 2010 and 1 000 tonnes in 2020, the cumulative arisings increasing to about 3 800 tonnes and 12 300 tonnes, respectively.

5.157 Construction of a centralised spent fuel storage facility at Lanzhou Nuclear Fuel Complex began in 1994. The initial stage of that project has a storage capacity of 550 tonnes and could be doubled. A pilot reprocessing plant is under construction at Lanzhou. A large commercial reprocessing plant is planned to follow.

5.158 HLW will be vitrified, encapsulated and put into a geological repository some 500 metres deep. Site selection is focused on six candidate locations and will be completed by 2020. An underground research laboratory in the Gobi Desert will then operate for 20 years and actual disposal is anticipated from 2050.[170]

5.159 In relation to waste management in India, the UIC reports that radioactive wastes from nuclear reactors and reprocessing plants are treated and stored at each site. Waste immobilisation plants are in operation at Tarapur and Trombay and another is being constructed at Kalpakkam.

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170 See: OCRWM, *China's Radioactive Waste Management Program*, Fact Sheets, viewed 29 August 2006, <http://www.ocrwm.doe.gov/factsheets/doeymp0409.shtml>; UIC, *Nuclear Power in China*, Nuclear Issues Briefing Paper No. 68, viewed 29 August 2006, <http://www.uic.com.au/nip68.htm>.

Research on final disposal of HLW and long-lived wastes in a geological repository is in progress at the Bhaba Atomic Research Centre.[171]

5.160 In summary, the UIC submitted that:

> Uranium mining and nuclear energy produce operational and decommissioning radioactive wastes which are contained and managed. Although experience with radioactive waste storage and transport over half a century has clearly demonstrated that civil nuclear wastes can be managed without adverse environmental impact, the question has become political with a focus on final disposal. In fact, nuclear power is the only energy-producing industry which takes full responsibility for all its wastes and costs this into the product – a key factor in sustainability.[172]

The storage and transport of radioactive material

5.161 It was argued that there is potential for catastrophic human or technical error in the extraction, storage and transportation of radioactive material arising from the generation of nuclear power.[173] The NT Greens also argued that transport of nuclear materials poses risks of accidental environmental contamination.[174]

5.162 In contrast, the UIC submitted that HLW has been effectively and economically isolated, handled and stored safely virtually without incident in 31 countries since nuclear power began almost 50 years ago.[175] This view was endorsed by AMEC and Professor Leslie Kemeny, who also argued that HLW has been safely contained, stored and transported for over 50 years.[176]

5.163 Mr John Reynolds also submitted that:

> There is no record of adverse health effects or significant incidents or accidents in the handling, storage, transport and re-processing of used nuclear fuel … from electricity generation over the fifty year life of the industry.[177]

5.164 This evidence was corroborated by information published by the OCRWM in relation to the US experience of radioactive waste transport. Over the

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171 See: UIC, *Nuclear Power in India and Pakistan*, Nuclear Issues Briefing Paper No. 45, viewed 29 August 2006, <http://www.uic.com.au/nip45.htm>.

172 UIC, *Submission no. 12*, p. 37.

173 Alice Action Committee, *loc. cit*; Dr Helen Caldicott, *Exhibit no. 25*, *op. cit*., pp. 69–79.

174 NT Greens, *Submission no. 9*, p. 1.

175 UIC, *Submission no. 12*, p. 38.

176 AMEC, *op. cit*., p. 5; Professor Leslie Kemeny, *Submission no. 64*, p. 9.

177 Mr John Reynolds, *loc. cit*.

last 40 years approximately 3 000 shipments of spent fuel have been transported safely across some 1.7 million highway, rail and barge miles in the US. During this time, there have been no injuries, fatalities or environmental damage caused by the radioactive nature of the cargo.[178]

5.165 The OCRWM states that among several factors that have contributed to this success is the design of the casks in which the spent fuel assemblies and other HLW are transported. The casks are designed to keep the radioactive material from being released into the environment under both normal and accident situations. The casks must be able withstand a series of destructive tests: being dropped onto unyielding surfaces, punctured, exposed to intense heat, and being submerged under water. The NRC has also established regulations to minimise the possibility of theft, diversion, or attacks on waste shipments.[179]

5.166 The UIC states that since 1971 there have been more than 20 000 shipments of spent fuel and HLW (over 50 000 tonnes) over more than 30 million kilometres. It is claimed that there has never been any accident in which a container with highly radioactive material has been breached, or has leaked.[180]

5.167 Dr Ian Smith also argued that large quantities of radioactive material have been safely transported around the world for decades without incident—in sharp contrast to other fuels:

> In the OECD countries in the last 30 years more than 2,000 people have been killed in transportation accidents shifting LPG around … For the nuclear industry, 20 million packages have been sent 30 billion kilometres without an accident. This is not an area where the facts indicate that there is a problem, though I guess there is a perception of a problem.[181]

5.168 The transport of radioactive material in Australia is conducted according to the Australian *Code of Practice for the Safe Transport of Radioactive Material* (2001), which effectively adopts international transportation requirements established by the IAEA.[182] The Code has been adopted by all the states and territories with the exception of Victoria, which ARPANSA notes is

178 See: OCRWM, *Transportation of Spent Nuclear Fuel*, Fact Sheet, viewed 29 August 2006, <http://www.ocrwm.doe.gov/factsheets/doeymp0500.shtml>.

179 *ibid*. See also: OCRWM, *Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste t Yucca Mountain: Frequently Asked Questions*, January 2006, viewed 29 August 2006, <http://www.ocrwm.doe.gov/transport/pdf/snf_transfaqs.pdf>.

180 UIC, *Transport of Radioactive Materials*, Nuclear Issues Briefing Paper no. 51, viewed 5 September 2006, <http://www.uic.com.au/nip51.htm>.

181 Dr Ian Smith, *op. cit*., p. 12.

182 See: ARPANSA, *Code of Practice for the Safe Transport of Radioactive Material,* 2001m, viewed 29 August 2006, <http://www.arpansa.gov.au/pubs/rps/rps2.pdf>.

now moving to adopt the Code. Among other elements, the Code establishes: provisions about a radiation protection program; emergency response; quality assurance; compliance assurance; requirements for packages (e.g. transportation casks) and definitions of package types.[183]

5.169 ANSTO notes that it transports radioactive material in accordance with the national Code and international standards. ANSTO states that the LLW and short-lived ILW which will eventually be transported to the Commonwealth Radioactive Waste Management Facility will be shipped in containers designed to remain intact in the event of an accident. Because ANSTO will only be transporting solid wastes, there is no danger of any leakage. Furthermore, ANSTO states that even in the event of an accident, because of the low levels of radiation in the waste and because of its solid nature, there would be no significant or life-threatening radiological consequences.[184]

Intergenerational equity

5.170 The NT Greens and the Uniting Church in Australia (Synod of Victoria and Tasmania) emphasised the issue of intergenerational equity: that the use of nuclear power comes at a cost for future generations who, it is claimed, must manage and secure the nuclear waste.[185] For example, the Uniting Church argued that:

> … present-day generations have no right at all to impose on future ones the enormous cost of human resources to care for the wastes and obsolete installations they leave behind them, to say nothing of the continuous risks this involves;

and

> Future generations have a right 'not to be confronted with products and wastes of earlier generations that threaten their health or require excessive expense for protection and control'.[186]

5.171 In relation to the ethical aspects of radioactive waste management, the UIC points to statements by the IAEA and OECD which support the geological disposal of long-lived wastes. For example, in 1995 the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency (OECD-NEA) published a collective opinion on the ethics of radioactive waste management which considered, inter alia, that:

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183 ARPANSA, *op. cit.*, pp. 5–6.

184 See: ANSTO, *Managing radioactive waste*, Brochure, May 2006, viewed 29 August 2006, <http://www.ansto.gov.au/info/brochures/Managing%20Radioactive%20Waste.pdf>.

185 NT Greens, *loc. cit.*

186 The Uniting Church in Australia (Synod of Victoria and Tasmania), *Submission no. 40*, pp. 6, 11.

- … from an ethical standpoint, including long-term safety considerations, our responsibilities to future generations are better discharged by a strategy of final disposal than by reliance on stores which require surveillance, bequeath long-term responsibilities of care, and may in due course be neglected by future societies whose structural stability should not be presumed;
- … after consideration of the options for achieving the required degree of isolation of such wastes from the biosphere, geological disposal is currently the most favoured strategy;
- … the strategy of geological disposal of long-lived radioactive wastes:
  - ⇒ takes intergenerational equity issues into account, notably by applying the same standards of risk in the far future as it does to the present, and by limiting the liabilities bequeathed to future generations; and
  - ⇒ takes intragenerational equity issues into account, notably by proposing implementation through an incremental process over several decades, considering the results of scientific progress; this process will allow consultation with interested parties, including the public, at all stages.[187]

5.172 The Radioactive Waste Management Committee concluded that:

- … the geological disposal strategy can be designed and implemented in a manner that is sensitive and responsive to fundamental ethical and environmental considerations;
- … it is justified, both environmentally and ethically, to continue development of geological repositories for those long-lived radioactive wastes which should be isolated from the biosphere for more than a few hundred years; and
- … stepwise implementation of plans for geological disposal leaves open the possibility of adaptation, in the light of scientific progress and social acceptability, over several decades, and does not exclude the possibility that other options could be developed at a later stage.[188]

5.173 Following a survey of OECD member countries, the IAEA and European Commission, the OECD-NEA's Radioactive Waste Management Committee issued an updated statement in 1999. The statement found that the consensus for pursuing geologic disposal as the only feasible route for assuring permanent isolation of long-lived wastes from the human environment remained unaffected.[189]

187 Cited in UIC, *Waste Management in the Nuclear Fuel Cycle, loc. cit.*

188 *ibid.*

189 *ibid.*

5.174 Among other findings, the review of developments in the geological disposal of radioactive waste over the preceding decade noted that delays in developing repositories have mainly been due to insufficient public confidence. It was argued that:

> There is an acute awareness in the waste management community of this lack of public confidence; efforts are needed by both implementers and regulators to communicate effectively to decision makers and the public their consensus view that safe disposal can be achieved.[190]

5.175 ANSTO submitted that geologic repositories are being designed so that they will not require monitoring and institutional controls.[191] However, another development noted by the OECD-NEA Committee has been a shift to establish strategies and procedures that will allow long-term monitoring of repositories, with the possibility of reversibility and retrievability.

Reprocessing

5.176 AMP CISFT and Friends of the Earth–Australia (FOE) argued that reprocessing of spent nuclear fuel does not represent a solution to the disposal of HLW. The reasons given for this were the proliferation risks involved in separating plutonium during reprocessing, which could then potentially be diverted for weapons purposes, and because reprocessing generates a greater quantity of transuranic waste. However, FOE and AMP CISFT conceded that the volume of the HLW stream requiring permanent disposal is indeed reduced by reprocessing.[192] The Committee addresses the proliferation aspects of reprocessing in chapters seven and eight.

5.177 Other submitters emphasised the significant reduction in waste volumes requiring geological disposal following reprocessing and the gains in resource utilisation. The WNA argues that:

> While the burden of nuclear waste is in any case remarkably small, reprocessing used nuclear fuel offers a means to reduce still further—by over 75 per cent—the overall volume of material requiring disposal in a deep geological repository.[193]

5.178 While ANSTO conceded that reprocessing may offer an opportunity for proliferation, it 'nonetheless minimises waste and maximises the use of the

190 *ibid*.

191 ANSTO, *Submission no. 29*, p. 11.

192 FOE, *Submission no. 52*, p. 12; AMP CISFT, *op. cit.*, p. 4.

193 WNA, *Safe Management of Nuclear Waste and Used Nuclear Fuel, op. cit.*, p. 14.

uranium.'[194] Moreover, ANSTO stated that 'the … value of spent fuel is quite enormous. Twenty per cent of the fuel load of the new generation of rectors will be spent fuel from the current reactors.'[195] Similarly, Mr Jerry Grandey argued that used nuclear fuel remains a potential source of energy and should therefore be stored rather than disposed of permanently:

> Ninety per cent of the energy is left in the spent fuel after it comes out of the reactor … spent fuel will be a tremendous resource. Hence it ought to be kept in storage.[196]

5.179 As noted in the discussion of reprocessing earlier in the chapter, the benefits of recycling uranium and plutonium into fresh fuel are said to include conservation of uranium, minimising the amount of HLW, reducing the inventory of separated plutonium and reduction of spent fuel storage requirements. Reprocessing also avoids leaving the plutonium in the used fuel, where it could eventually be recovered for illicit use.

Technologies to reduce the volume and toxicity of radioactive waste

5.180 Evidence suggested that developments in fuel cycle technologies may lead to a simplification of strategies for waste disposal. In particular, advanced reactors and new fuel cycles are now being proposed that will reduce the toxicity of waste, implying that isolation periods will not need to be as long, and further reduce waste volumes thereby reducing demands on repositories. In particular, new reprocessing technologies are being developed to be deployed in combination with fast neutron reactors. These developments also offer significant non-proliferation advantages and the main programs in which these technologies are being developed are described more fully in chapter seven.

5.181 ANSTO, ASNO, UIC and the Australian Institute of Nuclear Science and Engineering (AINSE) noted that research is now being undertaken to make radioactive waste less aggressive through transmutation, which offers a means of rapidly reducing the radiotoxicity of some waste. The UIC and ASNO explained that in the last ten years interest has grown in separating ('partitioning') individual radionuclides both to reduce long-term radioactivity in residual waste and to be able to turn separated long-lived radionuclides into shorter-lived ones, mostly by fission:

194 Dr Ian Smith, *op. cit.*, p. 13.

195 *ibid*.

196 Mr Jerry Grandey, *op. cit.*, pp. 10–11.

> … transmutation refers to the process of gaining a substantial reduction in the period over which waste arising from nuclear energy remains highly radiotoxic, by using the neutron flux within a reactor or other intensive source of neutrons to turn (transmute) long-lived radiotoxic elements into short-lived or stable elements. This transmutation step can substantially decrease the time needed to render the partitioned material harmless.[197]

5.182 ANSTO explained that while spent fuel may normally take 300 000 years before its activity reduces to the level of natural radiation from uranium ore, transmutation could reduce this to 300 years, as depicted in figure 5.3.[198] The top line indicates the activity of used fuel without treatment and the bottom line indicates the activity of used fuel with transmutation in advanced fuel cycles.

5.183 However, FOE expressed reservations about transmutation on the grounds that: the technology is immature and its future uncertain; it is useful only for certain types and forms of waste; it does not do away with the need for long-term management of the resulting wastes; it may require the use of reactors; and it may require reprocessing to separate waste streams prior to selective treatment.[199]

5.184 In contrast, AINSE was highly supportive of accelerator or reactor-driven waste destruction research of this kind and urged that Australia increase its involvement in the field.[200]

5.185 ASNO explained that efficient transmutation requires fast neutrons (those not slowed down by a moderator). Research into partitioning and transmutation initially arose in the context of expectations of the early deployment of fast breeder or other fast neutron reactors (FNRs), which did not eventuate.[201]

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197 ASNO, *Exhibit no. 93, Informal briefing on the US Global Nuclear Energy Partnership*, p. 13; UIC, *Processing of used nuclear fuel*, Nuclear Issues Briefing Paper No. 72, viewed 30 August 2006, <http://www.uic.com.au/nip72.htm>.

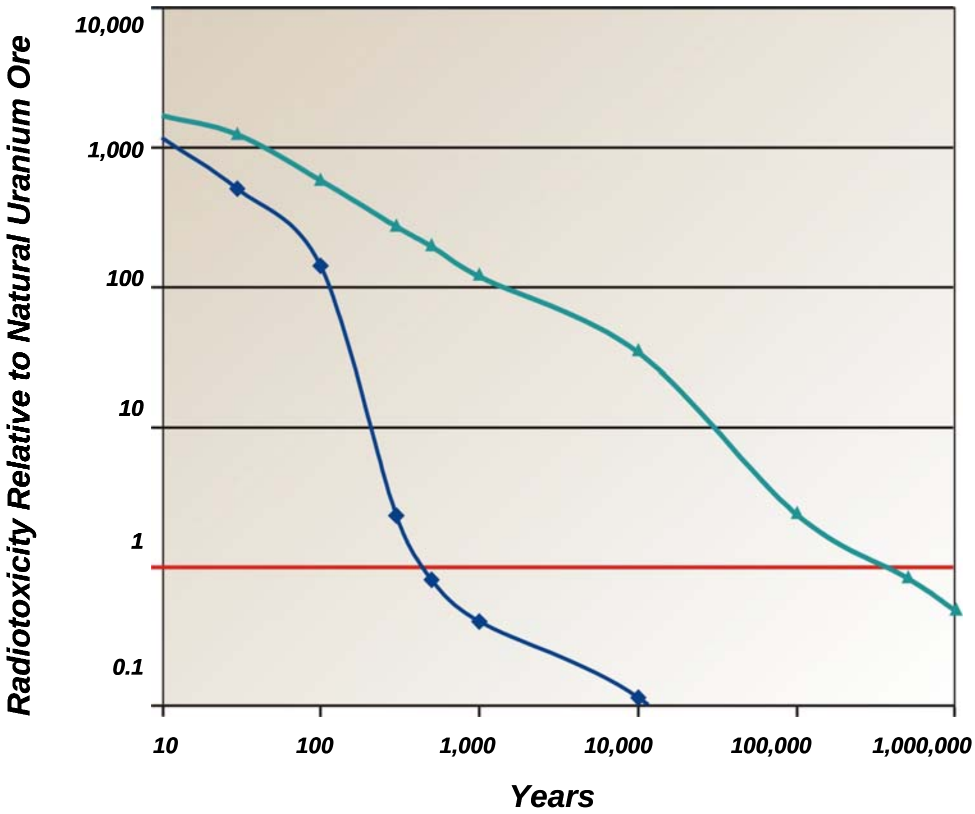
198 Dr Ian Smith, *op. cit.*, pp. 13–14.

199 FOE, *op. cit.*, p. 14.

200 AINSE, *Submission no. 77*, p. 2.

201 ASNO, *Exhibit no. 93, loc. cit.*

Figure 5.3 The effect of transmuting plutonium and higher actinides on the radiotoxicity of used nuclear fuel



Source ANSTO, *Exhibit no. 74, Presentation by Dr Ron Cameron and Dr Ian Smith,* slide 58.

5.186 However, as described more fully in chapter seven, in February 2006 the US Government announced a Global Nuclear Energy Partnership (GNEP) initiative which seeks to deploy FNRs for this purpose. Among its other objectives, GNEP intends that long-lived waste material will undergo treatment so that it can be transmuted into much shorter-lived materials. The GNEP proposal contains two significant elements:

- new reprocessing technology ('advanced spent fuel separation') in which plutonium is not fully separated, but remains mixed with uranium and highly radioactive materials (i.e. all transuranic elements are separated together, and not plutonium on its own); and
- deployment of Advanced Burner Reactors (ABRs), which are a type of FNR, to consume fuel which will be fabricated from the mix of uranium/plutonium plus most of the actinides and fission products.[202]

5.187 In ABRs, the fast neutrons are effective in fissioning the actinides and fission products so that they are transformed into shorter-lived materials. Hence, the eventual waste will have a shorter life.

202 *ibid.*, p. 2.

5.188 ASNO explained that as a result of these processes, GNEP promises to reduce the quantity of HLW and reduce the period HLW must be isolated from the environment—from around 10 000 years, which is the standard time period cited by industry, down to between 300 and 500 years. Furthermore, the resulting shorter-lived HLW may not necessarily need deep geologic disposal and could potentially be stored in specially designed above-ground buildings. This means that most countries with nuclear power would then be in a position to handle their own HLW (not just those with suitable geology for repositories).[203]

5.189 In other developments, ANSTO informed the Committee that two other initiatives, the Generation IV International Forum (GIF) and the US Advanced Fuel Cycle Initiative (AFCI) are also developing technologies which will have implications for waste management. Again, these initiatives are also intended to address proliferation hazards and are described at greater length in chapter seven.

5.190 A priority for both the GIF and AFCI is integrated waste management which:

> … implies the minimisation and management of radioactive waste, including reduction of the long-term stewardship burden, through for example the design and development of fuel that is directly disposable after use.[204]

5.191 AFCI aims to develop a fuel cycle which, in addition to assisting the transition from a once-through fuel cycle to the recycling of nuclear materials, will also reduce the toxicity and volume of waste. It is intended that these technologies will be deployed to support current nuclear power plants and, eventually, Generation IV reactor systems. The DOE explains that:

> In the longer term, AFCI's development of a system involving spent-fuel partitioning and recycling of actinides and other long-lived radioactive components in fast reactors for destruction through transmutation could result in a de facto fifty-fold increase in the technical capacity of the planned Yucca Mountain repository. This increase would come principally from the destruction of highly-radioactive materials contained in spent fuel (actinides) that generate the heat that limits repository capacity. Such a capacity increase would be more than enough to

203 *ibid*.

204 ANSTO, *op. cit.*, p.19.

> accommodate all the spent fuel generated in the US this century from any conceivable nuclear energy deployment scenario.[205]

5.192 GIF has identified six reactor technologies which the Forum members believe represent the future of nuclear energy. Some of these reactor types, such as the Modular Helium Reactor (MHR), now in advanced development by General Atomics (GA), allows for a so-called 'deep burn' (i.e. very extensive destruction) of transuranic waste. This means that the reactor is able to consume long-lived actinides from the spent fuel of conventional reactors and turn this into short-lived fission products. It is claimed that 95 per cent of the plutonium-239 and 60 per cent of the other actinides would be destroyed. The deep burn transmutation of transuranic waste promised by the MHR technology is expected to: significantly reduce the volume of residual waste requiring disposal in repositories; eliminate the attractiveness of the remaining waste for weapons purposes; and significantly reduce the amount of secondary waste production by minimising the reprocessing steps required.[206]

Conclusions

5.193 The Committee concludes that the radioactive wastes which are produced at each stage of the nuclear fuel cycle have, since the inception of the civil nuclear power industry 50 years ago, been responsibly managed. There are proven technologies for the management of all types of radioactive waste. For example, worldwide, some 40 near-surface disposal facilities for LLW and short-lived ILW have been operating safely for the past 35 years.

5.194 The Committee concurs with submitters that nuclear power deals with its waste more explicitly and transparently than many other sources of energy. Indeed, as one submitter observed, nuclear power has 'the best looked after waste in the world.'[207]

5.195 The Committee notes that HLW has several features which lends itself to ease of management: very small volumes; the radioactivity is contained in the spent fuel assemblies; it decays at a predictable rate; and is amenable

205 DOE, *Advanced Fuel Cycle Initiative*, January 2006, viewed 30 August 2006, <http://nuclear.gov/infosheets/afci.pdf>.

206 GA, *Exhibit no. 80*, *Sustainable Long Term Nuclear Power: Destruction of Nuclear Waste and Recycle of Resources for the long run using MHR Deep Burn Technology and Fusion*, slide 25. See also: Dr Ian Smith, *op. cit.*, p.13; UIC, *Nuclear Power in USA*, *loc. cit*; C Rodriguez et. al., 'Deep-Burn: making nuclear waste transmutation practical', *Nuclear Engineering and Design* 2805 (2003), p. 18.

207 Ms Pepita Maiden, *loc. cit*.

to separation, encapsulation and isolation. Moreover, the nuclear power industry significantly contributes to the cost of its waste management through levies imposed on utilities. That is, the cost of managing radioactive waste is internalised in the price of the electricity generated.

5.196 This is in sharp contrast to the wastes produced by fossil fuels, which are not contained or managed, involve enormous volumes and a range of toxic pollutants that do not decay. Moreover, the cost of the environmental externalities these energy sources create are generally not factored into the price of the electricity generated.

5.197 Much of the focus of submitters' concerns related to the management of long-lived waste. The Committee concludes that spent nuclear fuel has been routinely and safely removed from reactors, handled, stored, transported and reprocessed since the industry's inception.

5.198 To date, there has been little practical requirement for a means of final disposal of long-lived waste for two main reasons: the volumes of long-lived waste are very small; and spent fuel can be usefully placed in interim storage for up to several decades, to allow heat and radioactivity to dissipate, which assists handling.

5.199 The Committee wishes to emphasise the very small quantities of HLW that are generated worldwide each year—12 000 tonnes. The IAEA states that this volume of waste would fit into a structure the size of a soccer field and 1.5 metres high. The volume is significantly reduced—by over 75 per cent—if the spent fuel is reprocessed. The accumulated inventory of stored spent fuel amounts to only 270 000 tonnes.

5.200 The Committee believes that those opposed to the use of nuclear power are wrong in their assertion that there remains 'no solution' to dealing with spent fuel. There is an international consensus in support of geologic repositories for disposal of long-lived waste and plans for repositories are now well advanced in several countries.

5.201 However, the Committee notes that gaining public acceptance of radioactive waste management methods and, in particular, support for the siting of waste repositories has at times been difficult. This points to the importance of properly informing and reassuring the public about the real risks associated with radioactive waste, the management approaches used for the various types of waste, and the merits of geological disposal for long-lived waste.

5.202 The Committee notes the observation by the Director General of the IAEA that although most of the technical issues for spent fuel disposal or reprocessing have been solved and nuclear power produces only 12 000 tonnes of spent fuel per year, nevertheless:

> … public opinion will likely remain skeptical—and nuclear waste disposal will likely remain controversial—until the first geological repositories are operational and the disposal technologies fully demonstrated.[208]

5.203 The Committee hopes that, as the Director General of the IAEA remarks, community acceptance of HLW disposal will grow as repositories in Finland, the US, Sweden and elsewhere begin to operate. In Australia, it is to be hoped that the successful opening of the Commonwealth waste management facility will have a similar effect. The Committee returns to the issue of public acceptance and perceptions of risk in a discussion of the impediments to the industry's development in chapter 11.

5.204 The Committee suspects that it is in the interests of those adamantly opposed to nuclear power to continue to oppose construction of repositories and to exacerbate the 'not in my backyard' syndrome, precisely in order to perpetuate claims that 'no solution' exists for disposing of HLW and spent fuel. The Committee believes that this is not a constructive position to take.

5.205 The Director General of the IAEA has also advocated the possibility of multinational approaches to spent fuel management and disposal, noting that:

> Not all countries have the right geology to store waste underground and, for many countries with small nuclear programs, the costs of such a facility would be prohibitive.[209]

5.206 The Committee repeats the observation by ANSTO that 'Australia has some of the best geology in the world' for a repository and that 'there are hundreds of sites in Australia which would be suitable for that purpose.'[210] The Committee notes the constructive position taken by the NLC, which has supported the possible location of a radioactive waste facility in the NT, subject to the approval of the Traditional Owners. The Committee returns to this issue in chapter 12.

5.207 The Committee was also informed that there have been no adverse health effects or significant accidents associated with the transport of spent nuclear fuel. However, the same cannot be said for other energy industries, with evidence revealing that more than 2 000 people have been killed in LPG transportation accidents in OECD countries over the past 30 years.

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208 Dr Mohamed ElBaradei, *Nuclear Power: Preparing for the Future*, 21 March 2005, viewed 28 August 2006, <http://www.iaea.org/NewsCenter/Statements/2005/ebsp2005n004.html>.

209 *ibid*.

210 Dr Ron Cameron, *op. cit*., p. 16.

5.208 This leads to another issue raised by industry—that the waste generated by nuclear power must be compared to the waste generated by other energy sources. In this respect, the Committee notes the evidence that 300 million tonnes of toxic waste is produced annually in the OECD, but conditioned radioactive waste amounts to only 81 000 cubic metres. In countries with nuclear power, radioactive wastes comprise *less than one per cent* of total industrial toxic wastes, much of which never decays—unlike radioactive wastes—and remains hazardous forever. Furthermore, while the world's nuclear power plants generate 12 000 tonnes of HLW each year, some 25 billion tonnes of carbon waste is released directly into the atmosphere every year from the use of fossil fuels.

5.209 Moreover, industry argued that we should not fail to appreciate the risk versus benefit equation which applies to all energy systems. In this regard, the Committee concurs with those submitters who compared the trivial risks associated with geologic disposal of long-lived radioactive waste to the extreme risks for humanity from the uncontrolled emissions of carbon dioxide leading to global warming.

5.210 Claims that the generation of radioactive waste, its management and transportation pose unacceptable risks simply do not reflect the realities. Some submitters misperceive the risks involved and either misunderstand or ignore the historical record. The facts indicate that the radioactive wastes generated at the various stages of the nuclear fuel cycle continue to be safely and effectively managed. Indeed, the way in which the nuclear power industry manages its waste is an example for other energy industries to follow.

5.211 In the following chapter, the Committee considers the safety and public health implications of nuclear power and other fuel cycle activities.