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Uranium: Demand and Supply

The civilian nuclear industry is poised for world-wide expansion. Rapidly growing demand for electricity, the uncertainty of natural gas supply and price, soaring prices for oil, concern for air pollution and the immense challenge of lowering greenhouse emissions, are all driving a fresh look at nuclear power. At the same time, fading memories of Three Mile Island and Chernobyl is increasing confidence in the safety of new reactor designs. So the prospect, after a long hiatus, of new nuclear power construction is real, with new interest stirring in countries throughout the world.[1]

Australia is already a significant supplier of uranium – yet the growing demand is providing an unparalleled opportunity for Australia to be the dominant supplier of a crucial global commodity.[2]

1 Mr Lance Joseph (Australian Governor on the Board of the International Atomic Energy Agency 1997–2000), *Submission no. 71*, p. 1.

2 Nova Energy Ltd, *Submission no. 50*, p. 8.

Key messages —

- **Demand for uranium is a function of nuclear generating capacity in operation worldwide, combined with the operational characteristics of reactors and fuel management policies of utilities.**
- **There are currently 441 commercial nuclear power reactors operating in 31 countries. In 2005, nuclear reactors generated 2 626 billion kilowatt-hours of electricity, representing approximately 16 per cent of world electricity production. Some 27 nuclear reactors are currently under construction and a further 38 are planned or on order worldwide.**
- **Expectations of increased world nuclear generating capacity and demand for uranium are underpinned by:**
  - ⇒ **forecasts for growth in world electricity demand, particularly in China and India;**
  - ⇒ **improved performance of existing nuclear power plants and operating life extensions;**
  - ⇒ **plans for significant new nuclear build in several countries and renewed interest in nuclear energy among some industrialised nations; and**
  - ⇒ **the desire for security of fuel supplies and heightened concerns about greenhouse gas emissions from the electricity sector.**
- **New reactor construction combined with capacity upgrades and life extensions of existing reactors are projected to outweigh reactor shutdowns over the next two decades, so that world nuclear capacity will continue to increase and thereby increase projected uranium requirements.**
- **Several forecasts for world nuclear generating capacity and uranium requirements have been published. A conservative forecast by the IAEA and OECD-NEA predicts that nuclear generating capacity will grow to 448 gigawatts electrical by 2025, representing a 22 per cent increase on current capacity. This would see annual uranium requirements rise to 82 275 tonnes by 2025, also representing a 22 per cent increase on the 2004 requirements of 67 430 tonnes.**
- **Uranium mine production meets only 65 per cent of world reactor requirements. The balance of requirements are met by secondary sources of supply, notably inventories held by utilities and ex-military material. Secondary supplies are expected to decline over**

coming years and the anticipated tightness in supply has been reflected in a six-fold increase in the uranium spot market price since December 2000.

- **A significant source of secondary supply has been provided through the down-blending of highly enriched uranium (HEU) removed from weapons and military stockpiles in both the Russian Federation and the USA. To date, more than 10 460 nuclear warheads have been converted into fuel to generate electricity through a Russia-USA HEU Purchase Agreement. This agreement will run to 2013 and is unlikely to be renewed.**
- **Uranium mine production must expand to meet a larger share of reactor requirements as secondary supplies are exhausted.**
- **Australia possesses 36 per cent the world's low cost uranium resources, twice the resources of Canada. However, Australia accounts for only 23 per cent of world production and lags substantially behind Canada. Provided that impediments to the industry's growth are eliminated, there is great potential for Australia to expand production and become the world's premier supplier of uranium.**
- **Sufficient uranium resources exist and are likely to be discovered to support significant growth in nuclear capacity in the longer-term.**
- **Total Conventional Resources of uranium, amounting to some 14.8 million tonnes of uranium, are sufficient to fuel 270 years of nuclear electricity generation at current rates of consumption. There is considerable potential for the discovery of additional economic resources, particularly as higher uranium prices are now stimulating increased exploration. Utilisation of Unconventional Resources, such as the uranium in phosphates, would extend supply to over 670 years at current rates of consumption.**
- **Wider deployment of advanced reactor technologies, particularly Fast Neutron Reactors, and alternate fuel cycles have the potential to extend the supply of uranium resources for thousands of years.**

Introduction

2.1 The Committee commences the report of its inquiry into the strategic importance of Australia's uranium resources by considering the global demand and supply of uranium in the context of world electricity consumption trends and nuclear power's share in the electricity generation mix.

2.2 The Committee provides a summary of forecasts for world nuclear generating capacity and associated uranium requirements. Competing views on the outlook for new nuclear power plant construction are then considered, followed by an assessment of the role of existing plant performance in influencing the demand for uranium.

2.3 Uranium supply is provided by a combination of primary (mine) production and secondary sources. The contribution of each part is discussed. The Committee then considers the argument that world uranium resources are insufficient to support an expansion of nuclear power and, hence, represent only a temporary response to the problem of climate change.

2.4 The Committee concludes the chapter with an assessment of the implications of the supply/demand balance for further mine production and the potential for Australia's uranium production to expand to meet requirements.

2.5 The chapter commences with an overview of the nuclear fuel cycle, which establishes a context for the discussion in subsequent chapters of matters including greenhouse gas emissions, waste, safety and proliferation risks associated with nuclear power generation.

What is uranium?

2.6 Uranium is a radioactive metallic element, naturally occurring in most rocks, soil and in the ocean. In its pure form, uranium is a silvery white metal of very high density—1.7 times more dense than lead. Uranium is found as an oxide or complex salt in minerals such as pitchblende, uraninite and brannerite. Concentrations of uranium also occur in substances such as phosphate rock deposits and minerals such as lignite.[3]

2.7 Uranium is 500 times more abundant in the Earth's crust than gold and as common as tin.[4] While uranium can be found almost everywhere, including in seawater, concentrated uranium ores are found in relatively few places, usually in hard rock or sandstone. Concentrations of uranium that are economic to mine for use as nuclear fuel are considered orebodies.[5] Economically extractable concentrations of uranium occur in

3 e-CBD Pty Ltd, *Australian Uranium*, 'About Uranium', viewed 16 December 2005, <http://www.australianuranium.com.au/about-uranium.html>.

4 Uranium's average abundance in the Earth's crust is 2.7 parts per million (ppm) while the concentration in sea water is 0.003 ppm.

5 According to the Uranium Information Centre (UIC), the typical concentration of uranium in high-grade ore is 20 000 ppm, or 2 per cent uranium. Low grade ores are

more than a dozen different deposit types in a wide range of geological settings.[6]

2.8 Uranium has two major peaceful purposes: as the fuel in nuclear power reactors to generate electricity, and for the manufacture of radioisotopes for medical and other applications.

2.9 Naturally occurring uranium exists as a mix of three isotopes in the following proportions: U-234 (0.01%), U-235 (0.71%) and U-238 (99.28%).[7] Uranium-235 has a unique property in that it is the only naturally-occurring fissionable isotope. That is, the nucleus of the U-235 atom is capable of splitting into two parts when hit by a neutron. As the atom splits, a large amount of energy is released as heat and several new neutrons are emitted. This process is called fission. The neutrons emitted from the split nucleus may then cause other U-235 atoms to split, thus giving rise to a chain reaction if the mass of fissionable material exceeds a certain minimum amount known as the critical mass. The process of fission is harnessed in nuclear power generation, which is described in the following section, and in nuclear weapons.[8]

2.10 Following mining and milling, uranium metal (U) is sold as uranium oxide concentrate (UOC) which is comprised of uranium oxide (U_3O_8) and small quantities of impurities. Until 1970 uranium mine product was sold in the form of 'yellowcake' (ammonium diuranate), which is the penultimate uranium compound in U_3O_8 production. Following mining and milling, uranium enters the remaining stages of the nuclear fuel cycle, which are described below.

2.11 Uranium demand and supply are generally expressed in terms of tonnes U, while uranium mine production, ore reserves, ore grades and prices are commonly described in terms of U_3O_8. Uranium prices are generally

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1 000 ppm, or 0.1 per cent uranium. See: UIC, *Supply of Uranium*, Nuclear Issues Briefing Paper No. 75, viewed 7 June 2006, <http://www.uic.com.au/nip75.htm>.

6 World Nuclear Association (WNA), *Can Uranium Supplies Sustain the Global Nuclear Renaissance?*, WNA, London, 2005, p. 3.

7 An atom, which is the smallest particle into which an element can be divided chemically, consists of a nucleus of protons and neutrons, surrounded by a cloud of electrons. The number of protons in the nucleus determines what element the atom represents (92 in the case of uranium). Isotopes occur where atoms of the same element have different numbers of neutrons. That is, isotopes are nuclides (or 'nuclear species' of the same element) with the same number of protons, but different numbers of neutrons. For example, U-235 has 92 protons and 143 neutrons, while U-238 has 92 protons and 146 neutrons.

8 UIC, *Submission no. 12*, pp. 18–22; Minerals Council of Australia (MCA), *Commodity Information Sheets: Uranium*, Australian Atlas of Mineral Resources, Mines and Processing Centres, Geoscience Australia (GA), MCA and the Australian Government Department of Industry, Tourism and Resources, Canberra, 2003, viewed 30 May 2005, <www.australianminesatlas.gov.au/info/factsheets/uranium.jsp>.

expressed in terms of US dollars per pound U_3O_8. The glossary of this report contains definitions of uranium production and other mining terminology.[9]

2.12 Uranium was first recognised as a potential energy source by Ernest Rutherford in 1904 and first used as nuclear fuel in 1942. The first nuclear reactor to produce electricity was in Idaho, USA in December 1951. In 1954 the world's first nuclear powered electricity generator commenced operation at Obninsk in Russia, with other early generators at Calder Hall, England (1956) and Pennsylvania, USA (1957).[10]

The nuclear fuel cycle

2.13 The civil nuclear fuel cycle refers to the sequence of processes, from uranium mining through to final disposal of waste materials, associated with the production of electricity from nuclear reactions. The main stages in the fuel cycle are:

- mining and milling of the uranium ore;
- conversion and enrichment of the uranium;
- fuel fabrication to suit the requirements of reactors;
- fission in a reactor for the generation of power, or production of radioisotopes (for medical, industrial or research purposes);
- reprocessing of the used fuel elements; and
- disposal and storage of wastes.

2.14 In Australia, the fuel cycle is undertaken to the stage of uranium milling. A description of each of the stages, submitted by the Uranium Information Centre (UIC), follows.[11]

2.15 There are two common types of nuclear fuel cycle. The 'closed' nuclear fuel cycle, which is illustrated in figure 2.1, includes the reprocessing of used fuel whereby uranium and plutonium are separated and recycled into new fuel elements. The 'open' (or once-through) fuel cycle excludes reprocessing and all the used fuel is treated as waste for disposal.[12]

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9 Dr Donald Perkin, *Exhibit no. 3, The significance of uranium deposits through time*.

10 WNA, *Outline History of Nuclear Energy*, WNA, London, 2005, viewed 31 March 2006, <http://world-nuclear.org/info/inf54.htm>.

11 UIC, *loc. cit*.

12 International Atomic Energy Agency (IAEA), *Country Nuclear Fuel Cycle Profiles*, IAEA, Vienna, 2001, p. 1.

Uranium mining

2.16 Both excavation and in situ techniques are used to recover uranium. Excavation may involve underground and open pit methods.

2.17 In general, open pit mining is used where deposits are close to the surface and underground mining is used for deep deposits, typically greater than 120 metres deep. Open pit mines require large surface excavations, larger than the size of the ore deposit, since the walls of the pit must be sloped to prevent collapse. As a result, the quantity of material that must be removed to secure access to the ore may be large. Underground mines have relatively small surface disturbance and the quantity of material that must be removed to gain access to the ore is considerably less than in the case of an open pit mine.

2.18 An increasing proportion of the world's uranium now comes from in situ leaching (ISL), where groundwater with added peroxide is circulated through a very porous orebody to dissolve the uranium and pump it to the surface. Depending on the nature of the host and enclosing rocks, ISL may use slightly acid or alkaline solutions to keep the uranium in solution. The uranium is then recovered from the solution in a conventional mill.

2.19 The decision as to which mining method to use for a particular deposit is governed by the nature of the orebody, safety, environmental and economic considerations. In the case of underground uranium mines, special precautions, consisting primarily of increased ventilation, are required to protect against airborne radiation exposure.

Uranium milling

2.20 Milling, which is generally carried out close to a uranium mine, extracts the uranium from the ore. Most mining facilities include a mill, although where mines are close together, one mill may process the ore from several mines.

2.21 In a mill, uranium is extracted from the crushed and ground-up ore by leaching, in which either a strong acid (usually sulphuric acid) or a strong alkaline solution is used to dissolve the uranium. The uranium is then removed from this solution and precipitated. The bright yellow powder produced by this process is referred to as 'yellowcake'. The yellowcake is then dried and usually heated to produce a fine black powder containing over 98 per cent U_3O_8, which is then packed in 205-litre drums and shipped as UOC. Typically, 70 to 90 per cent of the uranium metal in the original ore is recovered in the milling process. The original ore itself may contain as little as 0.1 per cent uranium. The UOC usually contains small quantities of impurities such as sulphur, silicon and zircon.

2.22 The remainder of the ore, containing most of the radioactivity and nearly all the rock material, becomes tailings, which are placed in engineered facilities near the mine. These facilities are referred to as tailings dams. Tailings contain long-lived radioactive materials in low concentrations and toxic materials such as heavy metals. However, the total quantity of radioactive elements is less than in the original ore, and their collective radioactivity will be much shorter-lived. These materials are isolated from the environment for the period necessary to allow their radioactivity to reduce to background levels.

2.23 When mining and milling has been completed the tailings are covered with clay and topsoil to allow vegetation to be established and to keep radiation levels to the normal background value experienced near a uranium orebody. Alternatively, tailings may be filtered to a dry state and the solids disposed of in subsurface storage areas.

Conversion

2.24 The product of a uranium mill is not directly usable as a fuel for a nuclear reactor. Additional processing, generally referred to as enrichment, is required for most types of reactors. This process requires uranium to be in gaseous form and this is achieved by converting the UOC into uranium hexafluoride (UF_6), which is a gas at relatively low temperatures.

2.25 At a conversion facility, uranium is first refined to uranium dioxide (UO_2), which can be used as the fuel for those types of reactors that do not require enriched uranium. Most uranium is then converted into UF_6, ready for the enrichment plant.

Enrichment

2.26 As noted above, natural uranium consists, primarily, of a mixture of two isotopes of uranium. Only 0.71 per cent of natural uranium is fissile, or capable of undergoing fission. The fissile isotope of uranium is uranium-235 (U-235), while most of the remainder is uranium-238 (U-238).

2.27 In the most common types of nuclear reactors, a higher than natural concentration of U-235 is required. The enrichment process produces this higher concentration, typically between 3.5 per cent and five per cent U-235, by removing over 85 per cent of the U-238. This is done by separating UF_6 into two streams, one being enriched to the required level and known as low-enriched uranium. The other is depleted in U-235 and is called 'tails.'

2.28 There are two enrichment processes in large scale commercial use, each of which uses UF_6 as a feedstock—gaseous diffusion and gas centrifuge. Both processes use the physical properties of molecules, specifically the one per cent mass difference, to separate the isotopes. The product of this stage of the nuclear fuel cycle is enriched uranium hexafluoride, which is reconverted to produce enriched UO_2.

Fuel fabrication

2.29 Reactor fuel is generally in the form of ceramic pellets. These are formed from pressed UO_2 which is sintered (baked) at a high temperature (over 1 400 degrees celsius). The pellets are then encased in metal tubes to form fuel rods, which are arranged into a fuel assembly ready for introduction into a reactor. The dimensions of the fuel pellets and other components of the fuel assembly are precisely controlled to ensure consistency in the characteristics of fuel bundles.

Power generation

2.30 Inside a nuclear reactor the nuclei of U-235 atoms split (fission) and, in the process, release energy. This energy is used to heat water and turn it into steam. The steam is used to drive a turbine connected to a generator which produces electricity. Some of the U-238 in the fuel is turned into plutonium in the reactor core (plutonium-239, Pu-239, is formed when the U-238 isotope absorbs a neutron), and this yields about one third of the energy in a typical nuclear reactor. The fissioning of uranium is used as a source of heat in a nuclear power station in the same way that the burning of coal, gas or oil is used as a source of heat in a fossil fuel power plant.

2.31 With time, the concentration of fission fragments (such as bromine, caesium and iodine among others, which are produced from the splitting of the U-235 atoms) and heavy elements, formed in the same way as plutonium in a fuel bundle, will increase to the point where it is no longer practical to continue to use the fuel.[13] After 18–24 months the 'spent fuel' is removed from the reactor. The amount of energy that is produced from a fuel bundle varies with the type of reactor and the policy of the reactor operator.

2.32 In a typical light water reactor (LWR), which is the most common type of reactor, fuel elements are used over 3–4 operating cycles, each of 12–18 months (i.e. the reactor might be unloaded every 12 months, with a third of the core being replaced each time).[14]

13 Fission fragments (or 'products') are daughter nuclei resulting either from the fission of heavy elements such as uranium, or the radioactive decay of those primary daughters. 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.

14 Australian Safeguards and Non-Proliferation Office (ASNO), *Annual Report 2003–2004*, Commonwealth of Australia, Canberra, 2004, p. 105.

Used fuel storage

2.33 When removed from a reactor, a fuel bundle will be emitting both radiation, principally from the fission fragments, and heat.[15] Used fuel is unloaded into a storage pond immediately adjacent to the reactor to allow the radiation levels to decrease. In the ponds the water shields the radiation and absorbs the heat. Used fuel is held in such pools for several months to several years. Issues associated with waste management are addressed in chapter five and issues associated with radiation and health are addressed further in chapter six.

2.34 Depending on policies in particular countries, some used fuel may be transferred to central storage facilities. Ultimately, used fuel must either be reprocessed or prepared for permanent disposal.

Reprocessing

2.35 In a reprocessing facility the used fuel is separated into its three components: uranium, plutonium and waste (which contains fission products). Reprocessing enables recycling of the uranium and plutonium into fresh fuel, and produces a significantly reduced amount of waste (compared with treating all spent fuel as waste).

2.36 Used fuel is about 95 per cent U-238 but it also contains about one per cent U-235 that has not fissioned, about one per cent plutonium and three per cent fission products, which are highly radioactive, with other transuranic elements formed in the reactor.[16]

Uranium and plutonium recycling

2.37 The uranium from reprocessing, which typically contains a slightly higher concentration of U-235 than occurs in nature, can be reused as fuel after conversion and enrichment, if necessary. The plutonium can be directly made into mixed oxide (MOX) fuel, in which uranium and plutonium oxides are combined. In reactors that use MOX fuel, Pu-239 substitutes for the U-235 in normal uranium oxide fuel.

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15 Radiation may be defined 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. Light and heat from the sun are examples of natural forms of radiation. Radioactivity refers to the spontaneous decay of an unstable atomic nucleus, giving rise to the emission of radiation. See: UIC, *Radiation and the Nuclear Fuel Cycle*, UIC, Melbourne, 2004, viewed 20 June 2005, <www.uic.com.au/nip17.htm>.

16 Transuranics are very heavy elements formed artificially by neutron capture and possibly subsequent beta decay(s). Transuranics have a higher atomic number than uranium (92) and all are radioactive. The best known are neptunium, plutonium, americium and curium.

Used fuel disposal

2.38 The longer that used fuel is stored, the easier it is to manage final disposal, due to the progressive diminution of radioactivity. After 40 to 50 years of storage, the radioactivity level of the fuel falls to 0.1 per cent of its original level. This, and the fact that the volumes of waste involved are not, relatively, large, have meant that final disposal facilities (as opposed to storage facilities) have not been operated since civil nuclear power programs were introduced. There is also a reluctance to dispose of used fuel because it represents a significant energy resource which could be reprocessed at a later date to allow recycling of the uranium and plutonium.

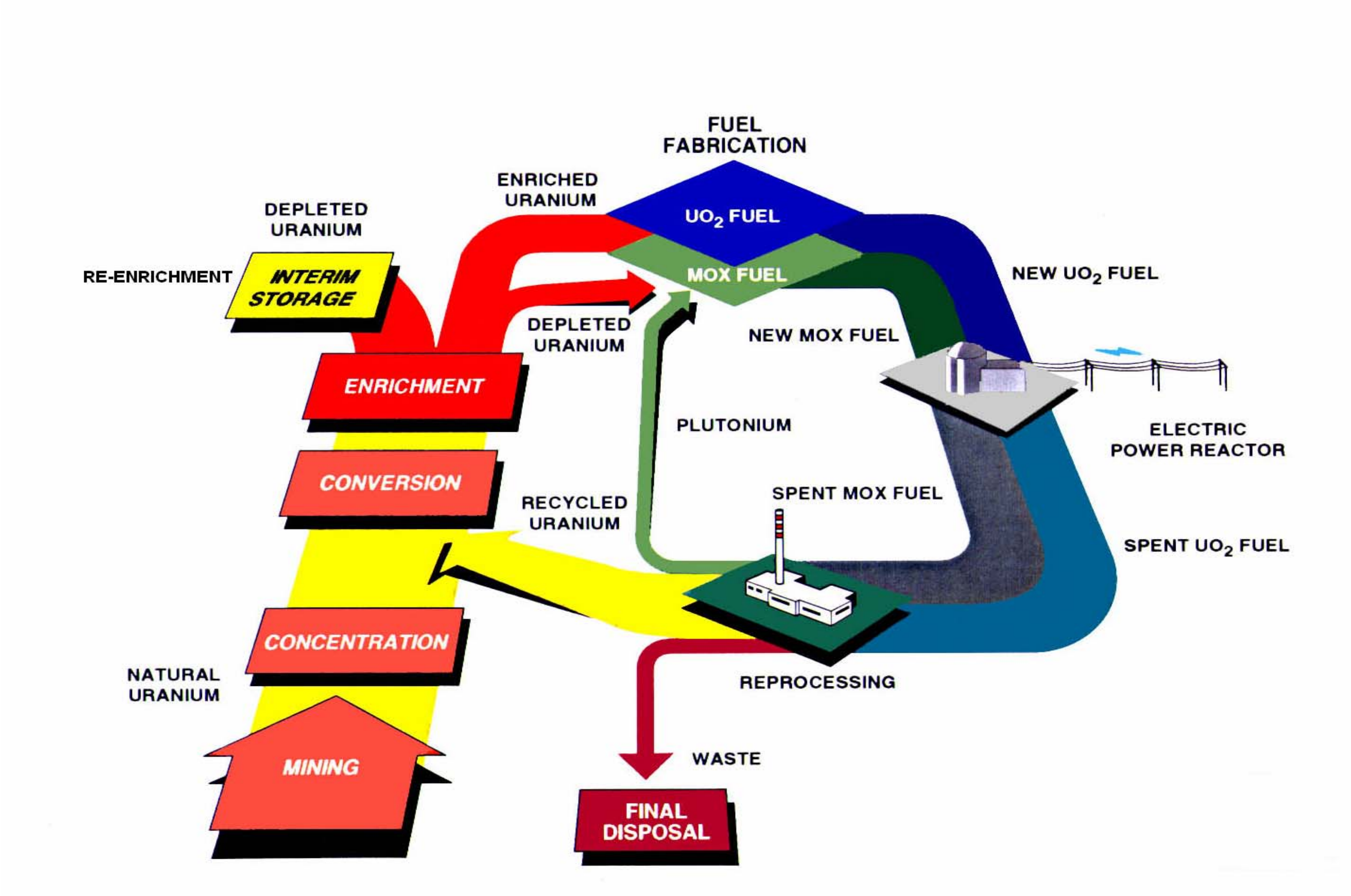
2.39 Technical issues related to disposal have been addressed and a number of countries have determined their own optimum approach to the disposal of used fuel and waste from reprocessing. The most commonly favoured method for disposal is placement into deep geological repositories. The USA is now building a national repository under Yucca Mountain in Nevada, which is scheduled to be operational by 2017. Sweden is proposing to have a deep geological repository in operation by about 2017 and Finland by 2020. Issues associated with the management of the waste produced across the nuclear fuel cycle are addressed in chapter five.

The military fuel cycle

2.40 According to the Australian Safeguards and Non-Proliferation Office (ASNO), the military fuel cycle involves the production of special grades of nuclear material, substantially different to the material used in civil programs, principally plutonium and weapons-grade uranium. While nuclear reactors require uranium enrichment to no more than five per cent, nuclear weapons must have U-235 enriched to about 90 per cent. Weapons-grade plutonium is generally produced in dedicated plutonium production reactors, usually natural uranium fuelled, where irradiated fuel can be removed after short irradiation times. Issues associated with the proliferation of technologies and materials that have military uses, notably uranium enrichment and used fuel reprocessing or plutonium-separation, are addressed in chapter seven.[17]

17 ASNO, *Annual Report 2003–2004, op. cit.*, p. 107.

Figure 2.1 The nuclear fuel cycle



Source Areva

World electricity production

2.41 As the main civil use for uranium is in generating power, the demand for uranium needs to be assessed in the context of world electricity consumption trends and nuclear power's share of electricity production.

2.42 Global primary energy demand is forecast by the International Energy Agency (IEA) to expand by more than half between 2003 and 2030, reaching 16.5 billion tonnes of oil equivalent by 2030. Energy demand is projected to grow at a rate of 1.6 per cent per year over the period.[18]

2.43 According to the IEA, in 2003 world electricity production was 16 742 terawatt-hours (TWh).[19] As listed in table 2.1, fuel for world electricity production was provided 39.9 per cent by coal, 19.2 per cent by natural gas, 6.9 per cent by oil (for a total of 66 percent from fossil fuels), 16.3 per cent by hydro, 1.2 per cent by combustible renewables (such as biomass), and 0.7 per cent from geothermal, solar and wind combined. Nuclear was the fourth largest fuel source for electricity generation at 15.7 per cent.[20]

Table 2.1 Shares of world electricity production by fuel type in 2003

Fuel type	**World production** (TWh)	**Percentage of world total**
Nuclear	2 635.35	15.7
Coal	6 676.24	39.9
Oil	1 151.73	6.9
Natural gas	3 224.70	19.2
Hydro	2 725.82	16.3
Geothermal	53.74	0.3
Solar and wind	68.51	0.4
Combustible renewables	200.70	1.2
Total	**16 741.88**	100

Source IEA, *Electricity Information 2005*, p. I.39.

2.44 Among the fuel types for electricity generation in OECD countries, the strongest growth in the 30 years to 2004 was from solar and wind generation at 17.6 per cent. Aside from renewables, nuclear power experienced the strongest growth, with an average annual growth of

18 IEA, *World Energy Outlook 2005*, OECD/IEA, Paris, 2005, p. 80.
19 One terawatt-hour equals one billion kilowatt-hours of electricity.
20 IEA, *Electricity Information 2005*, OECD/IEA, Paris, 2005, pp. I.39.

electricity generation of 7.8 per cent—larger than the inputs from natural gas (4.2 per cent), coal (2.9 per cent) and hydro (0.8 per cent).[21]

2.45 Electricity generation, which uses some 40 per cent of the world's primary energy supply, is forecast by the IEA to grow at an annual rate of 2.5 per cent between 2002–30, faster than overall energy demand, and rise to 31 657 TWh by 2030. World consumption of electricity is expected to double by 2030.[22]

2.46 Some 1.6 billion people worldwide currently have no access to electricity and demand from developing countries is forecast to more than triple by 2030. In particular, the growth in world demand for electricity is likely to be driven by the industrial modernisation of India and China, with a quarter of the world's projected increase in electricity production to 2030 expected to occur in China. In contrast, growth in electricity demand in the OECD nations will be slower at 1.4 per cent per year.[23]

2.47 According to the IEA, new power plants with a combined capacity of 4 800 gigawatts (GW) are expected to be built worldwide over the period to 2030, with half of these new plants to be built in developing countries. China is expected to require the largest increase, with 860 GW of capacity expected to be added over the period. The IEA estimates that the capacity additions will require investment of over US$4 trillion in new plant construction. Total investment in the electricity sector over the three decades to 2030, including generation, transmission and distribution, is expected to be some $10 trillion.[24]

Nuclear power in the world's electricity generation mix

2.48 Nuclear power programs, which were launched in the USA in the 1960s and in Europe at the beginning of the 1970s, expanded rapidly in the following two decades. Nuclear power generation rose from 100 TWh in 1970 to 2 000 TWh in 1990, with a total of 399 reactors constructed over the period.[25] The rate of growth slowed in the years following, largely as a reaction to public concern about the safety of nuclear reactors after

21 *ibid.*, p. I.22. See also: Cameco Corporation, *Submission no. 43*, p. 7.

22 IEA, *World Energy Outlook 2004*, OECD/IEA, Paris, 2004, pp. 192–193; Nova Energy Ltd, *Submission no. 50*, p. 3; Heathgate Resources Pty Ltd, *Exhibit no. 57, Energy for the World – Why uranium?*, p. 2.

23 IEA, *World Energy Outlook 2004*, *op. cit.*, pp. 193, 196–197. See also: Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 2; Mr James Brough (Australian Nuclear Forum), *Transcript of Evidence*, 16 September 2005, p. 42.

24 IEA, *World Energy Outlook 2004*, *op. cit.*, p. 208.

25 Australian Bureau of Agricultural and Resource Economics (ABARE), *Submission no. 14*, p. 4; Areva, *Submission no. 39*, p. 4.

accidents at Three Mile Island in 1979, Chernobyl in 1986, and Tokaimura in 1999.[26]

2.49 Information published by the World Nuclear Association (WNA) indicates that there are currently 441 commercial nuclear power reactors operating in 31 countries, with an aggregate installed generating capacity of over 369 gigawatts electrical (GWe).[27] In 2005, nuclear reactors produced 2 626 TWh of electricity which, as noted above, represents approximately 16 per cent of world electricity production.[28] Of the 441 nuclear reactors worldwide, 360 are operated by countries eligible to use Australian uranium under bilateral agreements with Australia, described in chapter eight.[29]

2.50 Uranium requirements to fuel the world's reactors are currently 65 478 tonnes of uranium (tU), or 77 218 t U_3O_8, per year.[30] In 2004, world uranium requirements were accounted for principally by the following regions: North America, which used 20 025 tU (38.6 per cent of the world total); Western Europe, which used 17 775 tU (26.4 per cent); East Asia, which used 12 430 tU (18.4 per cent); and Central and Eastern Europe, which used 9 935 tU (14.7 per cent).[31]

2.51 The share of nuclear power in total electricity generation varies significantly across countries, with some 85 per cent of nuclear electricity produced in 17 OECD countries. Nuclear plants account for more than 22 per cent of electricity production in OECD countries (with 61 per cent from fossil fuel plants), while in non-OECD countries only 6.1 per cent of electricity is generated by nuclear plants (with 72.4 per cent from fossil fuels).[32] Western Europe (33.8 per cent), North America (30.6 per cent) and East Asian countries (19.5 per cent) had the largest shares of world installed nuclear capacity in 2004.[33]

2.52 In many countries nuclear power supplies a substantial proportion of national electricity requirements. Some 15 countries generate more than 25 per cent of their total electricity requirements from nuclear power plants (NPPs). Among these, France generates 79 per cent, Lithuania 70 per cent, Belgium 56 per cent, Sweden 47 per cent, South Korea 45 per cent, and

26 *ibid*.

27 Installed capacity is the measure of a power station's electric generating capacity at full production, usually measured in megawatts (MW) or gigawatts (GW).

28 2 626 TWh is 2 626 billion kilowatt-hours.

29 The Hon Alexander Downer MP, *Submission no. 33*, p. 4.

30 WNA, *World Nuclear Power Reactors 2004-06 and Uranium Requirements*, WNA, London, 2006, viewed 10 May 2006, <http://www.world-nuclear.org/info/reactors.htm>.

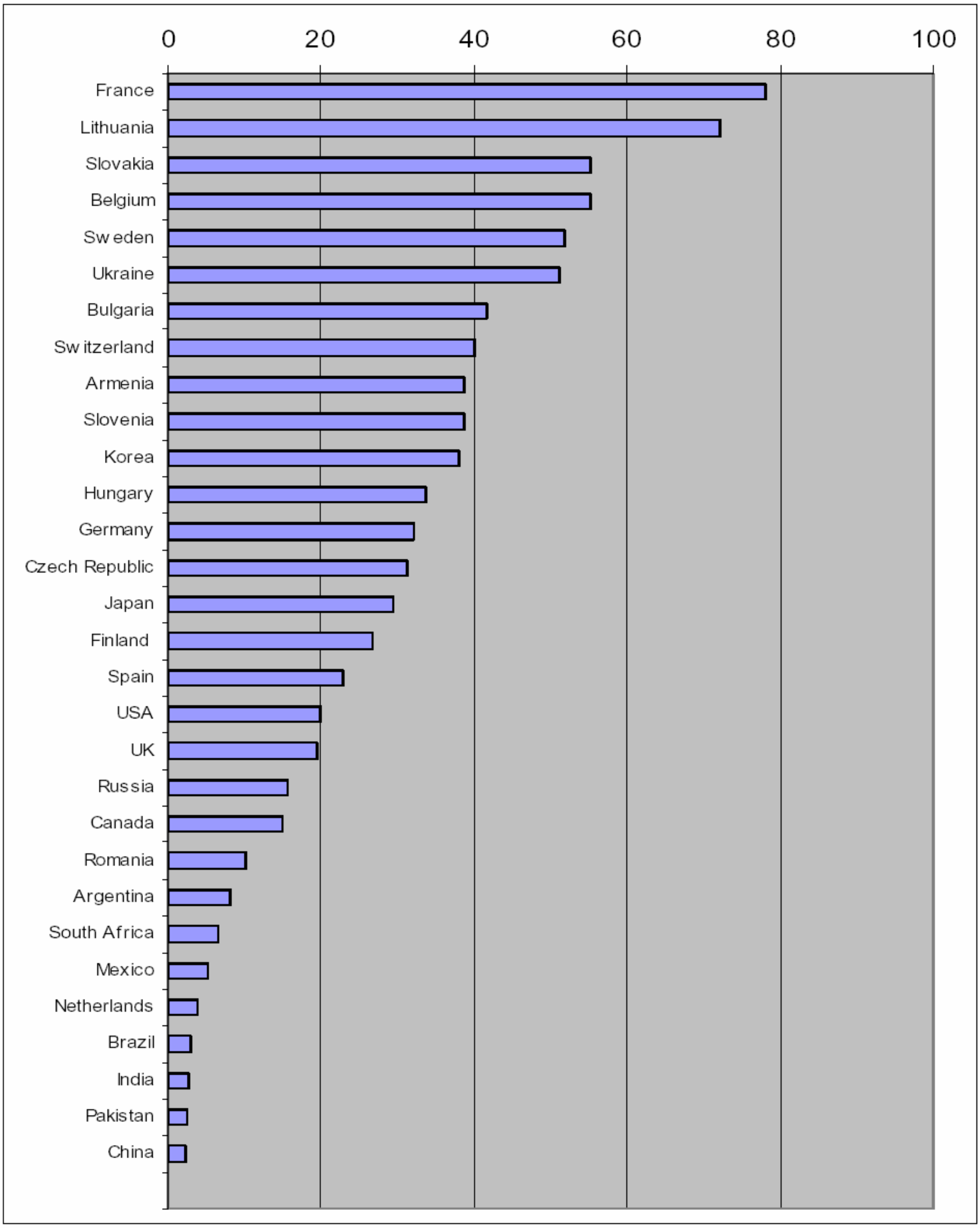
31 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, OECD, Paris, 2005, p. 43.

32 IEA, *World Energy Outlook 2004*, *op. cit.*, p. 200; IEA, *Electricity Information 2005*, *op. cit.*, p. I.3.

33 IAEA and OECD-NEA, *loc. cit.*

Japan 29 per cent from NPPs. The USA generates 19 per cent and the UK generates 20 percent from nuclear.[34] The nuclear share of electricity in each country operating NPPs is illustrated in figure 2.2.

Figure 2.2 Nuclear share of electricity by country in 2004, per cent of each country's total



Source WNA, *The Global Nuclear Fuel Market—Supply and Demand 2005–2030*, p. 26.

34 WNA, *World Nuclear Power Reactors 2004-06 and Uranium Requirements*, *loc. cit*; Dr Ron Cameron (ANSTO), *Transcript of Evidence*, 13 October 2005, p. 2.

2.53 The world's nuclear reactors, which are commonly classified according to the type of coolant they use, fall into one of three main categories:

- light water reactors (LWR), which represent over 80 per cent of the nuclear capacity installed in the world. There are 362 LWRs currently in operation and these are divided into two groups: pressurised water reactors (PWR), with 268 in operation in 2005, and boiling water reactors (BWR), with 94 in operation;
- pressurised heavy water reactors (PHWR) designed in Canada, known as 'CANDU' technology, with 40 in operation; and
- gas-cooled Magnox and advanced gas-cooled reactors (AGR), with 23 units operating in the UK.[35]

Other reactor types include fast neutron reactors (four in operation) and Russian-designed graphite-moderated light water reactors, of which there are currently 12 in operation.[36]

2.54 In addition to the world's nuclear reactors used to generate electricity, 56 countries operate a total of 280 research rectors and over 220 small reactors are used for naval propulsion.[37]

The outlook for nuclear power and the demand for uranium

2.55 World demand for uranium, as indicated by the uranium requirements to fuel nuclear reactors, is a function of nuclear electricity generating capacity in operation worldwide, combined with the operating characteristics of individual reactors and the fuel management policies of utilities. Generating capacity is in turn influenced by the outlook for the continued operation of existing NPPs and the prospects for new NPP construction.[38]

2.56 The Committee commences its discussion of these matters by providing an overview of the forecasts for nuclear generating capacity and uranium

35 Areva, *op. cit.*, p. 5. Coolant is a liquid or gas circulating through the reactor core so as to transfer the heat from it. A moderator is material which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite. See: UIC, *Nuclear Power Reactors*, Briefing Paper No. 64, viewed 7 June 2006, <http://www.uic.com.au/nip64.htm>.

36 UIC, *Nuclear Power Reactors*, *loc. cit.*

37 UIC, *Research reactors*, Nuclear Issues Briefing Paper No. 66, UIC, Melbourne, 2004, viewed 10 may 2006, <http://www.uic.com.au/nip66.htm>; UIC, *Nuclear powered ships*, Briefing Paper No. 32, UIC, Melbourne, 2005, viewed 10 may 2006 <http://www.uic.com.au/nip32.htm>.

38 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, WNA, London, 2005, pp. 28, 69, 78; UIC, *Submission no. 12*, p. 29.

demand published by the IEA, WNA, International Atomic Energy Agency (IAEA) and the OECD Nuclear Energy Agency (OECD-NEA).

International Energy Agency

2.57 In terms of forecasts for the world electricity generation mix, the IEA predicts that coal and gas-fired generation will provide over 75 per cent of the world's incremental demand for electricity to 2030. Some 40 per cent of new generating capacity is expected to be gas-fired, while coal-fired capacity is expected to account for some 30 per cent of new construction.[39]

2.58 Coal is forecast to remain the predominant fuel for electricity generation, falling slightly to 38 per cent by 2030. However, while coal's market share in the OECD is expected to decline substantially over the projection period (to 33 per cent in 2030), developing countries are expected to increase their use of coal for electricity generation:

> Over the projection period, most new coal-fired power plants will be built in developing countries, especially in developing Asia. Coal will remain the dominant fuel in power generation in those countries because of their large coal reserves and coal's low production costs. Developing countries are projected to account for almost 60% of world coal-based electricity in 2030. China and India together will account for 44% of worldwide coal-based electricity generation.[40]

2.59 The share of oil in world electricity generation is expected to fall to 4 per cent while natural gas and non-hydro renewables (biomass, wind, geothermal, solar, tidal and wave energy) are predicted to increase their market share. Largely driven by government action in the OECD countries to reduce carbon dioxide emissions, non-hydro renewable sources are forecast to increase from 2 per cent in 2002 to 6 per cent in 2030. Of these, wind power's market share is projected to increase the most, with a tenfold increase from 0.3 per cent of global electricity in 2002. Hydropower's share is forecast to fall to 13 per cent in 2030.[41]

2.60 In both the 2004 and 2005 editions of *World Energy Outlook*, the IEA presents a subdued forecast for nuclear power. The IEA predicts that while nuclear generating capacity will increase in absolute terms, its share of world electricity generation will nearly halve—from 17 per cent in 2004 to 9 per cent in 2030. In its reference scenario, the IEA predicts that world nuclear capacity will increase only slightly to 376 GWe in 2030. While new

39 IEA, *World Energy Outlook 2004, op. cit.*, pp. 196, 208.

40 *ibid.*, p. 197.

41 *ibid.*, pp. 196–203.

nuclear plants with a combined capacity of 150 GWe are expected to be added by 2030, these will simply replace older reactors being retired in France. The IEA predicts that three quarters of existing nuclear capacity in OECD Europe will be retired by 2030 and over one third of existing plants will be shut down across the entire OECD.[42]

2.61 The IEA notes that three European countries have policies in place to phase out nuclear power (Germany, Belgium and Sweden). The Slovak Republic and the Spanish Government have also canvassed phasing out nuclear power. However, the IEA notes that four OECD countries (France, Finland, Japan and Korea) plan to increase their use of nuclear power.[43]

2.62 While the IEA expects large declines in nuclear production in Europe and an increase in nuclear output in only a few Asian countries, it nonetheless qualifies these predictions by noting that:

> These projections remain very uncertain. Shifts in government policies and public attitudes towards nuclear power could mean that this energy source plays a much more important role than projected here.[44]

2.63 In its *World Energy Outlook* for 2006, the IEA presents a more optimistic forecast for world nuclear generating capacity, concluding that, if public confidence is regained, nuclear power could make a "major contribution" to curbing carbon dioxide emissions, reducing dependence on imported gas and providing baseload electricity supply.[45] In its latest Reference Scenario, the IEA predicts nuclear generating capacity will increase from 368 GW in 2005 to 416 GW in 2030. In its Alternative Policy Scenario, more favourable nuclear policies raise nuclear generating capacity to 519 GW by 2030, so nuclear's share in the world energy mix rises. The IEA also notes that interest in building nuclear reactors has increased as a result of rising fossil fuel prices, which have made nuclear power relatively more competitive. It is concluded that new nuclear plants could produce electricity at less than five US cents per kWh.

2.64 In line with forecasts of increased nuclear generation of electricity, the IEA predicts annual demand for uranium will increase from 68 000 tonnes in 2005 to between 80 000 and 100 000 tonnes by 2030. This demand is expected to be met mainly by new mine production.[46]

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42 *ibid.*, pp. 200, 207.

43 *ibid.*, p. 201.

44 IEA, *World Energy Outlook 2005*, *op. cit.*, p. 85.

45 IEA, *World Energy Outlook 2006*, OECD/IEA, Paris, 2006, p. 43.

46 *ibid.*, p. 376.

World Nuclear Association

2.65 In its 2005 analysis of *The Global Nuclear Fuel Market*, the WNA develops three scenarios for nuclear power to 2030 (lower, reference and upper scenarios), ranging from a slow decline in nuclear generating capacity to a substantial revival over the period.[47]

2.66 In the reference scenario, the WNA assumes continued improvements in the relative economics of nuclear power generation against coal and gas alternatives, public acceptance problems for nuclear begin to diminish, but the concerns about global warming fail to translate into a major shift in the electricity generation mix. In the reference scenario, the WNA predicts that nuclear generating capacity will rise to 378 GWe by 2010 and then grow to 446 GWe by 2020 and to 524 GWe by 2030. This represents an annual average growth rate in nuclear generating capacity of 1.4 per cent over the period. Given that world electricity demand growth is forecast, as noted above, to be substantially greater than this at 2.5 per cent, the WNA accepts that the nuclear share of total generation is likely to decrease substantially to around 13 per cent of the world total in 2030.[48]

2.67 In contrast to the IEA's virtually static outlook for nuclear generating capacity, the WNA's reference case predicts nuclear capacity will rise by 157 GWe in the period to 2030. The WNA argues that:

> The IEA assessment of nuclear shutdown capacity of 150 GW by 2030 looks very high, given recent experience. Although smaller and older reactors will shut down in many countries and politically-inspired closures may take place in others, the current stock of reactors is generally performing very well in economic terms and operating lives are being extended … Other features to note include the extent of actual and planned capacity increases and the widespread development of life extension programs for existing reactors as they are refurbished (Belgium, France, Netherlands, Spain, Sweden, USA).[49]

2.68 The IEA's reactor retirement schedule is also said to assume that nuclear's economic position and public acceptance deteriorates, so existing reactors are retired earlier.[50]

2.69 In the WNA's upper scenario, world nuclear capacity is forecast to be 740 GWe in 2030, which would maintain nuclear's share of world electricity at the current levels of 16–17 per cent. In the lower scenario, nuclear

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47 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030, op. cit.*, pp. 38–40.

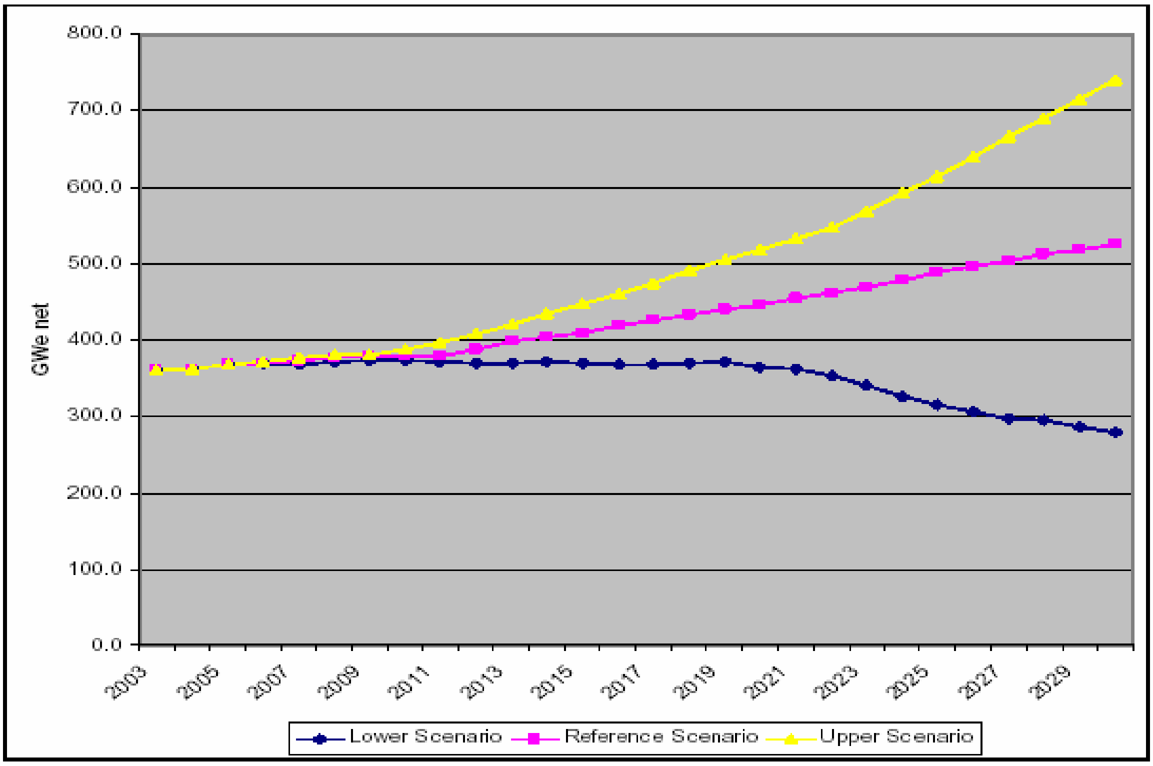
48 *ibid.*, p. 2.

49 WNA, *The New Economics of Nuclear Power*, WNA, London, 2005, p. 14.

50 *ibid.*

generating capacity still rises slightly to 372 GWe by 2010, but then falls away to 279 GWe in 2030.[51] Figure 2.3 illustrates world nuclear generating capacity to 2030 in the three WNA scenarios.

Figure 2.3 World nuclear generating capacity to 2030



Source WNA, *The Global Nuclear Fuel Market—Supply and Demand 2005–2030*, p. 64

2.70 Based on its scenarios for nuclear generating capacity, the WNA has developed demand forecasts for uranium, which take into account a range of factors including the life of existing reactors and prospects for construction of new NPPs. In the reference scenario, reactor uranium requirements are expected to rise from 66 000 tU in 2004 to 71 500 tU in 2010, 84 700 tU in 2020 and to 110 800 tU in 2030, with an annual growth rate of 2 per cent over the period.[52] The prospects for new plant construction are discussed further in the section commencing on page 36.

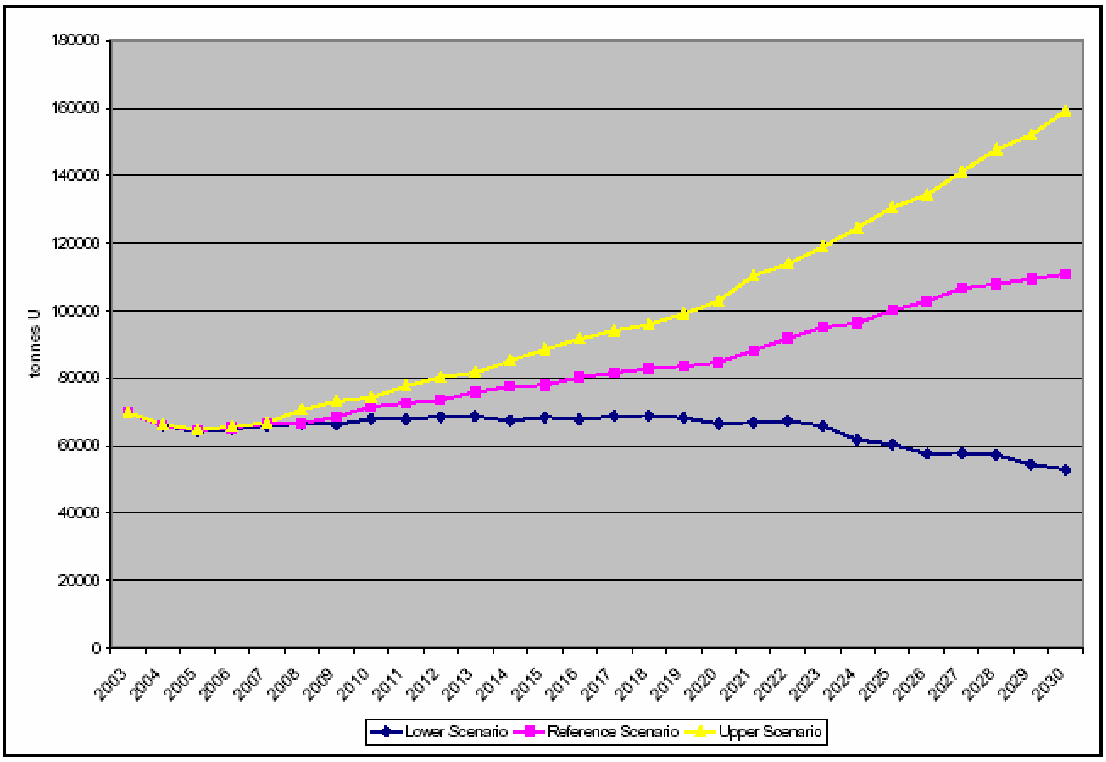
2.71 In the upper scenario, uranium requirements are forecast to be 159 200 tU in 2030, while in the lower scenario they are 52 800 tU in 2030.[53] Figure 2.4 depicts the WNA's forecasts for uranium requirements in the three scenarios to 2030.

51 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, p. 2.

52 *ibid*.

53 *ibid*.

Figure 2.4 Uranium requirements to fuel nuclear reactors to 2030



Source WNA, *The Global Nuclear Fuel Market—Supply and Demand 2005–2030*, p.82.

International Atomic Energy Agency and OECD Nuclear Energy Agency

2.72 In the joint IAEA and OECD-NEA publication *Uranium 2005: Resources, Production and Demand,* which is widely cited as an authoritative study and commonly referred to as the 'Red Book', the agencies provide 'low' and 'high' estimates for future nuclear power deployment to 2025.

2.73 The low projection assumes that the present barriers to nuclear deployment continue to prevail in most countries, including low electricity demand growth, continued public opposition to nuclear power and inadequate mechanisms for nuclear technology transfer and project funding in developing countries. The low projection assumes no new nuclear power plants are built beyond what is currently under construction or firmly planned, and old NPPs are retired on schedule.[54] Similar to the IEA reference scenario described above, the agencies' low

54 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, pp. 53–55; and see also IAEA, *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030*, IAEA, Vienna, July 2005, pp. 6–7, viewed 5 June 2006, <http://www-pub.iaea.org/MTCD/publications/PDF/RDS1-25_web.pdf>.

projection assumes expansion for nuclear power in East and South Asia, contraction in Western Europe and stability in North America.[55]

2.74 In contrast, the high projection assumes a moderate revival of nuclear deployment taking into account global concerns over climate change and implementation of some policy measure to facilitate deployment such as enhancing technology transfer to developing countries.[56]

2.75 The agencies forecast that by 2025 world nuclear capacity will grow to 449 GWe in the low demand case and 533 GWe in the high demand case. The low case represents growth of 22 per cent and the high case represents an increase of 44 per cent from current capacity. Accordingly, uranium requirements are projected to rise to between 82 275 tU and 100 760 tU by 2025, representing 22 per cent and 50 per cent increases respectively, compared to the 2004 total.[57]

2.76 The Red Book qualifies its projections for nuclear capacity and uranium demand, noting that there are 'great uncertainties in these projections as there is an ongoing debate on the role that nuclear energy will play in meeting future energy requirements.'[58]

2.77 In general, the IAEA notes 'a sense of rising expectations for nuclear power' and states that its current projections are markedly different from even four years ago.[59] The IAEA explains that its revised forecasts have been driven by:

> … nuclear power's performance record, by growing energy needs around the world coupled with rising oil and natural gas prices, by new environmental constraints including entry-into-force of the Kyoto Protocol, by concerns about energy supply security in a number of countries, and by ambitious expansion plans in several key countries.[60]

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55 IAEA, *Nuclear Technology Review – Update 2005*, IAEA, Vienna, July 2005, p. 8, viewed, 5 June 2006, <http://www.iaea.org/About/Policy/GC/GC49/Documents/gc49inf-3.pdf>.

56 IAEA, *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030, loc. cit.*

57 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, pp. 10, 53.

58 *ibid.*, p. 11.

59 Dr Mohamed ElBaradei, *Nuclear Power: Preparing for the future*, Statements of the Director General of the IAEA, 21 March 2005, viewed 5 June 2006, <http://www.iaea.org/NewsCenter/Statements/2005/ebsp2005n004.html>.

60 IAEA, *Nuclear Technology Review – Update 2005*, *op. cit.*, p. 1.

The prospects for nuclear power and new plant construction

2.78 Evidence to the Committee was sharply divided on the prospects for future nuclear capacity and particularly on the outlook for new NPP construction.

2.79 The IAEA and OECD-NEA state that the key factors that will influence future nuclear electricity capacity and construction include:

- projected growth of base load electricity demand;
- the cost-competitiveness of new NPPs and fuel compared to other energy sources, particularly with deregulation of electricity markets;
- concerns about security of fuel supplies;
- public attitudes and acceptance towards the safety of nuclear energy and proposed waste management strategies;
- concerns about the connection between the civil nuclear fuel cycle and military uses; and
- environmental considerations, in particular consideration of the role nuclear energy can play in reducing air pollution and greenhouse gas emissions.[61]

2.80 For the IAEA and OECD-NEA, 'evidence suggests that many nations have decided that the balance of these factors supports construction of new nuclear power plants', with significant building programs now underway in China, India, Japan and the Russian Federation.[62]

2.81 The installation of new nuclear capacity will increase uranium requirements where new construction outweighs reactors retirements. According to information published by the WNA, at the end of May 2006 there were 27 nuclear reactors under construction in 11 countries (which will have a generating capacity of 21 GWe), with a further 38 planned or on order (40.7 GWe) and another 115 reactors are proposed (65.4 GWe).[63] During 2003 and 2004 seven new reactors commenced to produce electricity, while 11 reactors were permanently shut down (eight in the UK).[64] The world's nuclear power reactors, reactors being constructed, planned and proposed, and their uranium requirements are listed by country in appendix D.

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61 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, p. 52.

62 *ibid*.

63 WNA, *World Nuclear Power Reactors 2004-06 and Uranium Requirements*, *loc. cit*.

64 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, p. 42.

2.82 While existing NPPs are clustered in Europe, the US and Japan, submitters observed that new construction is currently centred in the Asian region, notably China, India and South Korea, with 18 plants (or 66 per cent of the total) currently under construction.[65]

2.83 The IAEA notes that 'current expansion, as well as near-term and long-term growth prospects, is centred in Asia', and that 20 of the last 30 reactors to have been connected to the grid were in Asian countries.[66] The WNA also predicts that over the next few years nuclear construction will be concentrated in Asia (China, South Korea and India), and to some extent in Russia and other Eastern European countries.[67]

2.84 China currently has four reactors under construction and is planning a fivefold increase in nuclear capacity from 6.6 GWe to 40 GWe by 2020.[68] The expansion will require the construction of two reactors every year over the period.[69] India is currently constructing eight reactors and intends to triple nuclear generating capacity to 20 GWe by 2020. India also plans that by 2050 nuclear power will contribute 25 per cent of the country's electricity generation—a hundredfold increase on 2002 nuclear generating capacity.[70] Japan currently has one plant under construction and plans to build another 12 reactors. Japan also plans to expand nuclear's contribution to 41 per cent of total electricity generation by 2014, up from 29 per cent currently.[71] Indonesia will commence construction of its first NPP in 2010, to be completed by 2016, with plans for a further three NPPs to be constructed by 2025.[72] Plants are also being considered in Vietnam, Malaysia, Poland, Belarus, Turkey, Serbia and Egypt.[73]

2.85 Elsewhere, the Russian Federation plans to raise nuclear capacity from 22 GWe to 40–45 GWe by 2020, and has four reactors currently under

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65 UIC, *Submission no. 12*, p. 7; Areva, *loc. cit.* This figure also includes two NPPs currently under construction in Taiwan. See also: Minerals Council of Australia, *Submission no. 36*, p. 6; ANSTO, *Submission no. 29*, p. 3.

66 IAEA, *Nuclear Technology Review – Update 2005*, *op. cit.*, p. 4. See also: Dr Ron Cameron, *op. cit.*, pp. 1–2.

67 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, p. 33.

68 UIC, *Nuclear Power in China*, Nuclear Issues Briefing Paper No. 68, viewed 6 June 2006, <http://www.uic.com.au/nip68.htm>.

69 Mr Alan Eggers (Summit Resources Ltd), *Transcript of Evidence*, 3 November 2005, p. 1.

70 UIC, *Nuclear Power in India and Pakistan*, Nuclear Issues Briefing Paper No. 45, viewed 1 June 2006, <http://www.uic.com.au/nip45.htm>.

71 WNA, *World Nuclear Power Reactors 2004-06 and Uranium Requirements*, *loc. cit.* UIC, *Nuclear Power in Japan*, Briefing Paper No. 79, viewed 6 June 2006, <http://www.uic.com.au/nip79.htm>.

72 The Hon Alexander Downer MP, *Submission no. 33.2*, pp. 9–10.

73 Dr Ron Cameron, *op. cit.*, p. 2; Cameco Corporation, *Submission no. 43*, pp. 3–4.

construction.[74] Finland has commenced construction on a new plant—the first new nuclear construction in Western Europe since 1991, and France plans to commence construction of a new reactor (the European Pressurised Water Reactor) in 2007.[75]

2.86 Several submitters expressed 'optimism and enthusiasm about the opportunities for nuclear energy', pointing variously to the:

- growing world demand for electricity;
- life extensions and refurbishments of existing reactors;
- increasing concern about greenhouse gas emissions and security of fuel supply; and
- plans for significant new NPP construction in several countries and renewed interest in some industrialised nations.[76]

For Cameco, these favourable trends are expected to result in 470 nuclear reactors being in operation by 2015.[77]

2.87 Compass Resources argued that:

> … driven partly by high fossil fuel costs and the greenhouse gas reduction imperative … it seems likely that nuclear energy will play an increasing role in meeting the growth in world energy demand.[78]

2.88 The MCA cited a number of recent developments it claims indicates that nuclear electricity generation will continue to grow:

- during 2004 seven new reactors were connected to electricity grids overseas and another was restarted after major refurbishment;
- Japan's newest and largest Advanced Boiling Water Reactor has commenced commercial operation bringing the country's number of reactors in commercial operation to 54. In addition, grid connection of the first unit of a further nuclear power plant is expected with

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74 Dr Mohamed ElBaradei, *Nuclear Power: Preparing for the future*, *loc. cit.*

75 *ibid*. See also: IAEA, *Nuclear Technology Review – Update 2005*, *op. cit.*, p. 6; UIC, *Nuclear Power in Russia*, Briefing Paper No. 62, viewed 6 June 2006, <http://www.uic.com.au/nip62.htm>; UIC, *Nuclear Energy in Finland*, Briefing Paper No. 76, viewed 6 June 2006, <http://www.uic.com.au/nip76.htm>; UIC, *French Nuclear Power Program*, Briefing Paper No. 28, viewed 6 June 2006, <http://www.uic.com.au/nip28.htm>.

76 See for example: Cameco Corporation, *op. cit.*, p. 2; Energy Resources of Australia Ltd, *Submission no. 46*, p. 3; ANSTO, *Exhibit no. 74, Presentation by Dr Ian Smith and Dr Ron Cameron*, p. 8; Jindalee Resources Ltd, *Submission no. 31*, p. 2; Summit Resources Ltd, *Submission no. 15*, p. 20.

77 Cameco Corporation, *loc. cit.*

78 Dr Malcolm Humphreys (Compass Resources NL), *Transcript of Evidence*, 16 September 2005, p. 62.

commercial operation in October 2005. At least three more units are expected to be built or are planned to be built at this site;

- the 20th nuclear power reactor in the Republic of Korea (and sixth Korean Standard Nuclear Power Plant) was connected to the grid in December 2004 and a further four plants are due to come on line over the period 2010–2013;
- the Republic of Korea is also establishing a joint venture in Kazakhstan to mine uranium;
- in a speech given by the President of the United States to the April 2005 National Small Business Conference, President Bush said:

  > … the first essential step toward greater energy independence is to apply technology to increase domestic production from existing energy resources. And one of the most promising sources of energy [for the USA] is nuclear power;

- public sentiment in Sweden and to an extent in the UK, among others, appears to be changing in favour of nuclear power according to various polls. In Sweden, which has faced the prospect of phasing out nuclear power, public opinion is now 80 per cent favourable. The change reflects public concern and media coverage related to energy security and environmental concerns, particularly regarding climate change;
- various nuclear generators in Europe and the USA are implementing capacity upgrades and extending operating licenses—one third of the current 103 US plants have had 20 year licence extensions; and
- the chief executives of 20 European Union energy companies recently called upon governments to make nuclear power a central part of their energy policies on the basis of energy security and environmental protection.[79]

2.89 Mr Lance Joseph, Australian Governor on the Board of the IAEA from 1997 to 2000, asserted that:

> The civilian nuclear industry is poised for world-wide expansion. Rapidly growing demand for electricity, the uncertainty of natural gas supply and price, soaring prices for oil, concern for air pollution and the immense challenge of lowering greenhouse emissions, are all driving a fresh look at nuclear power. At the same time, fading memories of Three Mile Island and Chernobyl is increasing confidence in the safety of new reactor designs. So the

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79 MCA, *Submission no. 36*, p. 8. The Medical Association for the Prevention of War (MAPW) (WA Branch) note similar favourable demand side trends in *Submission no. 8*, p. 4.

> prospect, after a long hiatus, of new nuclear power construction is real, with new interest stirring in countries throughout the world.[80]

2.90 Similarly, the Australian Nuclear Forum (ANF) proposed that use of nuclear power will expand and demand for reactor fuel will increase as:

> … the fear of more 'Chernobyl's' recedes and it becomes clearer that fossil fuel plants cannot be made sufficiently environmentally friendly and that the 'alternative' methods of generating electricity prove to be incapable of meeting demand.[81]

2.91 ANSTO argued that given the expansion plans announced by several countries and nuclear's improved economic competitiveness due to fuel cost increases and emission constraints impacting upon fossil fuels:

> It seems clear … that the proportion of the world's electricity that is derived from nuclear power will increase from present levels during the next two or three decades, and the demand for uranium will increase correspondingly.[82]

2.92 The UIC cited forecasts prepared by International Nuclear Inc (iNi), an independent consulting organisation which specialises in uranium supply-demand-price trends, which broadly supports the WNA's conclusions summarised above. iNi forecasts that uranium oxide requirements will rise to nearly 84 000 tonnes per year by 2010 and to almost 91 900 tonnes by 2020. These forecasts are said to be conservative in that they make no allowance for a potential increase in nuclear generation arising from concerns over greenhouse gas emissions from other forms of electricity generation.[83]

2.93 ANSTO also noted that, to date, plans for new nuclear build have been driven primarily by energy demand and not by greenhouse gas mitigation concerns.[84] The Department of the Environment and Heritage (DEH) also noted that, in addition to the 'massive growth in energy demand' in India and China, countries expanding the use of nuclear power are doing so for reasons of energy security.[85]

2.94 Energy Resources of Australia Ltd (ERA) also emphasised the role of energy security, arguing that 'market behaviour has fundamentally changed, with security and stability of fuel supply becoming the most

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80 Mr Lance Joseph, *Submission no. 71*, p. 1.
81 ANF, *Submission no. 11*, p. 2.
82 ANSTO, *op. cit.*, pp. 3–4.
83 UIC, *Submission no. 12*, p. 8.
84 Dr Ron Cameron, *loc. cit*.
85 Mr Barry Sterland (DEH), *Transcript of Evidence*, 10 October 2005, p. 14.

important issues for nuclear utilities.'[86] ERA noted that utilities are increasing plant output and operating efficiencies, which are in turn increasing uranium demand. Power plant construction is also being seen as an important option in responding to greenhouse gas emissions.[87]

2.95 ERA also pointed to new NPP construction around the world. It was argued that while no new orders have yet been placed in North America, significant pre-order work is being undertaken by utilities, including applications for early site permits and the streamlining of regulatory processes. In addition, countries such as Chile, which were previously opposed to nuclear power, are now considering the nuclear option.[88]

2.96 In 2002 the US Government launched Nuclear Power 2010 (NP 2010), a public-private partnership to identify new sites for plants, develop advanced reactor technologies and test new regulatory processes. NP 2010 assumes that the first new power plant order will be placed in 2009 and construction will be completed by 2014. Ten energy companies or consortia in the US have indicated that they will apply to build 16 new NPPs.[89]

2.97 In contrast to these assessments, groups critical of nuclear power argued that construction of new reactors is unlikely to keep pace with retirements. The Australian Conservation Foundation (ACF) argued that there is likely to be no significant expansion of global nuclear power or total uranium demand. ACF predicted that the number of nuclear power plants across the western world will decline over the next 25 years:

> The number of reactors across the USA and western Europe peaked some 15 years ago and is highly likely to continue to decline with the scheduled closure of some 50 nuclear power plants in western Europe across a range of countries, given government legislation, government policy and government schedules of closure based on ageing and unsuitability for extension of life for existing reactors.[90]

2.98 Specifically, the ACF argued that:

- across the EU-15 countries in the last 25 years only two NPPs have been ordered and started construction (France in 1991 and Finland in 2004);

86 ERA, *Submission no. 46*, p. 2.

87 *ibid.*, p. 3.

88 *ibid.*, pp. 2-3. See also: MAPW (WA Branch), *op. cit.*, p. 3.

89 ABARE, *loc. cit*; Dr Ron Cameron, *op. cit.*, p. 10.

90 Mr David Noonan (ACF), *Transcript of Evidence*, 19 August 2005, p. 75.

- in the expanded EU-25 group of countries, Finland has the only new plant under construction and there is one other at a planning stage, in France;
- the number of reactors in the EU-25 will continue to decline with legislative nuclear power phase outs in Germany and Belgium, to see 25 NPPs close by 2025;
- nuclear phase out policies exist in Spain, the Netherlands and Sweden, which will see a further 21 NPPs close by 2030;
- in the UK, nine NPPs are set to close from 2007 to 2020 due to the ageing of plants that are unsuited to life extensions; and
- in the USA, despite Presidential support for nuclear power, there has not yet been an order for a new reactor.[91]

2.99 It was argued that the only prospects for significant expansion of nuclear power are in India and China. ACF noted that in China the nuclear share of electricity generation will 'only increase from the present 2% toward some 6–10% by 2025'.[92] While it was conceded that this represents a significant increase in nuclear generating capacity, it was argued that this 'shows that nuclear is not a major answer to electricity supply in China in the foreseeable future'.[93]

2.100 Friends of the Earth (FOE) also stated that the future of nuclear power is uncertain. It was argued that, assuming a reactor life of 40 years, a total of 280 reactors will need to be built over the next 20 years to offset reactor shutdowns. FOE claimed that 'even if lifetime extensions significantly increase the average reactor lifespan, it is doubtful whether new reactors will keep pace with shut downs.'[94]

2.101 Consistent with the IEA view, ABARE also argued that despite a substantial amount of capacity expected to be added in Japan, China, India, the Russian Federation and South Korea, 'total growth in nuclear capacity will be largely offset by reactor retirements, particularly in Europe.'[95] ABARE predicted that world demand for uranium will rise by one per cent over 2005 and 2006.

2.102 More broadly, the Uniting Church (Synod of Victoria and Tasmania) claimed that demand for uranium will fall over time due to: legislative phase outs of nuclear power in some countries; investment in nuclear power being overly risky; 'unresolved' waste storage issues; safety and

91 ACF, *Submission no. 48*, p. 4–5.

92 *ibid.*, p. 5.

93 *ibid.* See also: Mr David Noonan, *op. cit.*, p. 76.

94 FOE, *Submission no. 52*, p. 4. See also: Wind Prospect Pty Ltd, *Submission no. 4*, p. 2.

95 ABARE, *loc. cit.*.

health problems; and security concerns associated with use of nuclear power.[96]

2.103 ACF also noted that the IAEA has predicted that nuclear's share of world electricity supply will drop to 12 per cent in its low forecast by 2030. Cameco agreed that there may be a decline in the proportion of the world's energy supplied by nuclear, given the predicted overall growth in energy demand. However, it was argued that total nuclear capacity will still increase, as was concluded in the forecasts summarised above.[97]

2.104 Mr Ian Hore-Lacy, General Manager of the UIC, observed that there is a renewal of interest in nuclear power in Europe, beyond the new plants announced for Finland and France:

> I do not see any reduction in nuclear capacity or interest in Europe. I note the policies of the German government, I note the policies of the Swedish government and I note that those policies are timed, as it were, to possibly take effect way into the future, several changes of government away. In other words, for Germany it will be about 2010 before their current policies matter, if they last that long. In fact, they might not last till Christmas.[98]

2.105 The UIC argued that it is now well understood that German policies to phase out nuclear power, while simultaneously increasing renewables to 20 per cent of total electricity, will be impossible without also adding significant new capacity from fossil fuel plants. However, this will make the country's carbon dioxide reduction target under the Kyoto Protocol simply unattainable.[99] More generally, Nova Energy argued that in both Germany and the UK there is opposition to nuclear phase outs as renewables cannot provide baseload power requirements. The Committee addresses these matters further in chapter four.

2.106 ABARE noted that, rather than shutting down reactors, some European countries are now reconsidering nuclear energy and others are looking to extend the life of existing reactors by up to 20 years.[100] Claims of renewed public support for nuclear power in Europe were also supported by a range of opinion polls conducted in countries including Sweden, Germany and the Netherlands.[101]

2.107 In general, BHP Billiton expressed confidence that:

96 The Uniting Church in Australia (Synod of Victoria and Tasmania), *Submission no. 40*, pp. 9–13.

97 Mr Jerry Grandey (Cameco), *Transcript of Evidence*, 11 August 2005, p. 15.

98 Mr Ian Hore-Lacy (UIC), *Transcript of Evidence*, 19 August 2005, p. 90.

99 UIC, Exhibit no. 49, Nuclear Industry in Europe, p. 3; Nova Energy Ltd, *op. cit.*, p. 4.

100 Mr Will Mollard (ABARE), *Transcript of Evidence*, 5 September, p. 14.

101 Mr John Reynolds, *Submission no. 5*, p. 8.

> … all credible projections of world energy demand and supply options indicate that uranium does have an important role to play in meeting the world's energy needs. We believe … that the meeting of these needs will require a mix of fuels, fossil fuels, uranium and renewable energy sources.[102]

2.108 Specifically, BHP Billiton estimated that, as a proportion of all energy sources, nuclear power will increase. As a consequence, the company predicts a 60 per cent increase in demand for uranium over the next decade.[103]

Existing plant performance and uranium demand

2.109 As mentioned above, in addition to installed nuclear capacity and the outlook for new plant construction, the demand for uranium is also influenced by the performance and operating characteristics of reactors, and fuel management policies of utilities. Among these is the capacity factor (or 'load factor') of reactors, which is the actual power generated during a period of time expressed as a percentage of the power which would have been generated if the plant had operated at full power continuously throughout the period. The WNA explains that a rise in load factor is a main influence on demand for uranium (and enrichment), with a nearly linear relationship between load factor and fuel requirements.[104]

2.110 In addition to the prospects for new nuclear build, the UIC, ANSTO, Paladin Resources and Areva emphasised the substantial increases in nuclear generating capacity that have been achieved in recent years due to gains in existing NPP availability and productivity. Areva stated that while installed nuclear capacity increased by only 1.2 per cent over the period 1989 to 2004, following the Chernobyl accident, nuclear power generation continued to grow at an average annual rate of 2.1 per cent over the period due to efficiency improvements at existing reactors. Thus, the average reactor capacity factor rose from 67 per cent in 1989 to over 80 per cent by the end of 2004.[105]

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

103 *ibid.*, p. 20.

104 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, pp. 70–72. Among the other factors are: reactor operation cycle lengths, selection of tails assay (e.g. increased enrichment effort lowers the tails assay, which means less natural uranium is required), the ratio between natural uranium and enrichment prices, fuel design and management, fuel burn up, and reactor power levels. These factors are discussed in: WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, op. cit., pp. 69–79; IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, p. 51–52.

105 Areva, *loc. cit.*

2.111 Similarly, Dr Mohamed ElBaradei, Director General of the IAEA, has observed that in 1990 nuclear plants on average were generating electricity 71 per cent of the time, but by 2003 availability had increased to 81 per cent. This represented 'an improvement in productivity equal to adding more than 25 new 1 000 megawatt nuclear plants—all at relatively minimal cost.'[106] Furthermore, Professor Leslie Kemeny noted that by 2005 reactor capacity reached a record average of 91.5 per cent in the USA.[107]

2.112 The UIC noted that the increase in output from existing plants over the past five years has amounted to 235 TWh, which is equal to the output from 33 large new nuclear plants.[108] The increased productivity and availability of NPPs lead to the gains in output mentioned, which in turn leads to an increased demand for uranium.

2.113 A significant increase in output has also been attained through 'up-rating' the capacity (i.e. increasing the power levels) of some plants, by up to 15–20 per cent. According to the WNA this has been a particular focus in the USA, Sweden and Eastern European countries.[109]

2.114 The UIC also noted that a considerable number of reactors are being granted life extensions. For example, in the USA, the Nuclear Regulatory Commission has now approved license extensions for 30 NPPs, adding 20 years to the originally licensed plant life of 40 years. Some 85 NPPs in the USA are eventually expected to be granted licence renewals.[110] The IAEA has reported that approximately three quarters of the USA's 104 NPPs have either received, applied for, or stated their intention to apply for a license extension.[111] Furthermore, ANSTO noted that 60 years is now seen as the minimum operating lifetime for reactors in Japan.[112]

2.115 While reactors are being operated more productively, with higher capacity factors and power levels mentioned above, efficiencies are dampening demand for uranium. For example, increased burn up of nuclear fuel has reduced uranium requirements and increased enrichment requirements. Many utilities are increasing the initial enrichment of their fuel (e.g. from 3.3 per cent to more than 4 per cent U-235) and then burning the fuel longer or harder to leave only 0.5 percent U-235. Over the 20 years from

106 Dr Mohamed ElBaradei, *Nuclear Power: Preparing for the future*, *loc. cit*.

107 Professor Leslie Kemeny, *Exhibit no. 9, Power to the people*, p. 2.

108 UIC, *Submission no. 12*, p. 7. See also: ANSTO, *op. cit*., p. 4; Dr Mohamed ElBaradei, *Nuclear Power: Preparing for the future*, *loc. cit*.

109 WNA, *The New Economics of Nuclear Power*, *op. cit*., p. 12. See also; Paladin Resources Ltd, *Submission no. 47*, p. 4.

110 UIC, *Submission no. 12*, p. 7.

111 IAEA, *Nuclear Technology Review – Update 2005*, *op. cit*., p. 6.

112 ANSTO, *loc. cit*.

1970, there was a 25 per cent reduction in uranium demand per kWh output in Europe.[113]

Supply of uranium

2.116 At the end of 2004 commercial nuclear reactors in operation worldwide required 67 320 tU (or 79 390 t U_3O_8), of which world uranium mine production supplied 40 263 tU, or approximately 60 per cent of requirements.[114] This was an improvement on the previous year, in which world mine production (35 772 tU) provided only 52 per cent of world demand (68 435 tU).[115]

2.117 Coverage of annual uranium requirements by mine production rose to an estimated 64.9 per cent in 2005 due to an increase in production levels to 41 869 tU, coupled with a slight decline in global uranium requirements to 64 600 tU.[116]

2.118 World uranium mine production (also referred to as primary production) is insufficient to meet uranium requirements, meeting an average of only 57 per cent of annual requirements over the past 14 years. The shortfall has been met by secondary sources of supply since the late 1980s. Secondary supplies are essentially inventories, stockpiles and recycled materials of various types. These supplies can be regarded as previous uranium production held off the commercial nuclear fuel market for an extended period.[117]

2.119 Figure 2.5 shows the relationship between world mine production and uranium requirements for electricity generation (including the former Soviet Union and Eastern bloc countries). The continuous line shows world demand for uranium and the dashed line shows mine production. The shaded region between demand and primary production illustrates the balance of supply provided by secondary sources.

113 UIC, *Submission no. 12,* p. 29. See also: WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, pp. 77–78.

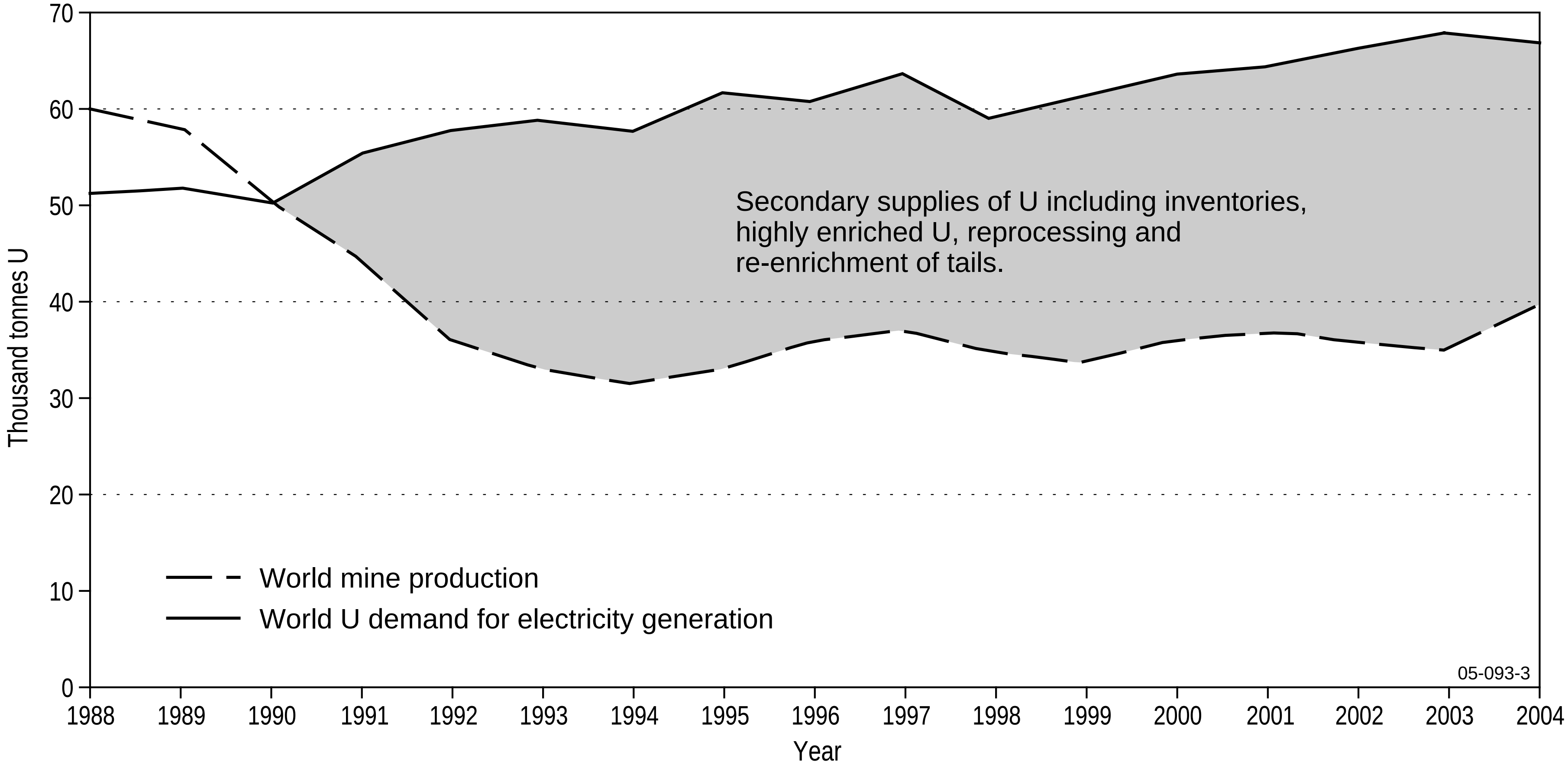
114 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, p. 10. One tonne of uranium oxide is equivalent to 0.848 tonnes of uranium.

115 Geoscience Australia, *Submission no. 42*, p. 12.

116 RWE NUKEM, *NUKEM Market Report*, May 2006 edition, RWE NUKEM Inc, Danbury, Connecticut, May 2006, p. 22.

117 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, pp. 127–128.

Figure 2.5 Comparison of world uranium mine production and world uranium demand for electricity generation, 1988–2004



Source Geoscience Australia, *Submission no. 42*, p. 12.

Secondary sources of supply

2.120 While secondary supply sources are a common feature in commodity markets, Geoscience Australia (GA) noted that 'uranium is unique among energy fuel resources in that a significant portion of demand is supplied from secondary sources rather than mine production.'[118] Fuel requirements in excess of world mine production are currently met from the following secondary sources, in decreasing order of importance:

- stockpiles of natural and low-enriched uranium (LEU), held by electricity utilities and conversion plants—up to 30 per cent of total world demand;
- down-blending of highly enriched uranium (HEU) removed from decommissioned weapons and military stockpiles in both the Russian Federation and the USA—10 to 13 per cent of world demand. Current arrangements run up to 2013, covering the period of Moscow Treaty reductions, described below;
- re-enrichment of depleted uranium tails, which involves recovering the residual fissile material from depleted uranium tails at enrichment plants—3 to 4 per cent of world demand. This is only commercially viable if there are enrichment plants with low operating costs and available excess capacity; and
- uranium from reprocessing used reactor fuel (known as reprocessed uranium or 'RepU')—approximately 1 per cent of world demand.[119]

In addition, some 2–3 per cent of the demand for reactor fuel is met by the use of recycled plutonium in the form of MOX.[120]

2.121 In February 1993 the Russian Federation and US Governments entered into an HEU Purchase Agreement for the disposition of HEU extracted from nuclear weapons (the so-called 'Megatons to Megawatts' program).[121] The Agreement committed Russia to convert (down-blend) 500 tonnes of HEU from its dismantled nuclear warheads into LEU for civilian use. Under the Agreement, the US Enrichment Corporation receives deliveries of LEU from the Russian Federation for sale to

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118 GA, *Exhibit no. 61, op. cit.*, p. 10.

119 The Hon Alexander Downer MP, *Submission no. 33*, p. 4; GA, *Submission no. 42*, p. 5.

120 In January 2005 there were 35 reactors (8 per cent of the world's operating fleet) licensed to use MOX fuel.

121 See: *Report on the Effect of the Low-Enriched Uranium Delivered Under the HEU Agreement* published by the US DOE, 2004, viewed 16 June 2005, <http://www.ne.doe.gov/reports/RptEffectLow-Enriched%20UraniumDec312004.pdf>. A paper on *The US-Russia HEU Agreement* has been published by the WNA, viewed 9 June 2006, <http://www.world-nuclear.org/trade_issues/tbriefings/heu/index.htm>.

commercial NPPs. ABARE noted that this quantity of HEU is equivalent to approximately 150 000 tonnes of natural uranium, or twice annual world demand.[122] The HEU Purchase Agreement will run for 20 years until 2013 and is supplying the equivalent of some 9 000 tonnes of natural uranium per year on average.[123]

2.122 Silex observed that the Russian HEU material sold to the US has meant that: 'More than 10 000 Russian nuclear warheads have been converted to electricity through this path.'[124] The MAPW (WA Branch) cited research by the Nuclear Energy Institute which found that former Russian warheads were powering one in ten US homes in 2004.[125] A smaller amount of ex-military uranium from US sources is also beginning to become available.

2.123 While it is anticipated that secondary supplies will continue to play a major role in supplying commercial markets, GA and other submitters observed that there is now considerable uncertainty about the quantities of secondary supplies likely to be available for the market in the future. One source of uncertainty is that many countries are unable to provide detailed information on government (i.e. ex-military) and utility stockpiles due to confidentiality concerns.[126]

2.124 ASNO observed that of the secondary sources of supply listed above, only re-enrichment of depleted uranium tails can be increased to maintain supply in the event of a major drawdown of utility inventories. It is expected that the stockpiles accumulated by utilities in the 1970s and 1980s will be exhausted over the next decade and the supply of HEU retired from weapons will also fall away, unless more is released from weapons stockpiles.[127]

2.125 Submitters commented that the supply of Russian HEU is gradually coming to an end. The Russian Federation is now choosing to retain HEU to meet its own demand for electricity generation, which cannot be met by its own mine production, and hence no follow-on HEU purchase

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122 Mr Will Mollard (ABARE), *Transcript of Evidence*, 5 September 2005, p. 14.

123 Areva, *op. cit.*, p. 9.

124 Dr Michael Goldsworthy (Silex Systems Ltd), *Transcript of Evidence*, 9 February 2006, p. 8. The IAEA reports that as of 3 January 2006, 262 tonnes of HEU had been down-blended and 7 670 tonnes of LEU had been delivered to the US. These deliveries represent 10 467 nuclear warheads. It is expected that 20 000 warheads will be dismantled over the life of the Agreement. See: IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, p. 65.

125 MAPW (WA Branch), *op. cit.*, p. 4.

126 GA, *Exhibit no. 61, op. cit.*, p. 11. The IAEA and OECD-NEA and the WNA reports contain forecasts for secondary sources of supply.

127 The Hon Alexander Downer MP, *op. cit.*, pp. 4–5.

agreement is expected.[128] Summit Resources argued that while secondary sources, particularly the downblending of weapons grade material 'will continue for some time … it is diminishing in its contribution and the industry is expanding. So a large shortfall of uranium is coming.'[129]

2.126 Evidence suggested however that there may be additional secondary supplies released on to the market. For instance, ABARE noted that the US and Russian Federation are each committed to holding stockpiles of some 26 000 tonnes of U_3O_8 until 2009, which could then be released to the market. The availability or unavailability of these secondary supplies could significantly influence the uranium spot market, although ABARE commented that should the US decide to release its stockpiles it is expected that it would do so in a manner that would minimise market impact.[130]

Primary production

2.127 The WNA describes four key periods in the history of uranium mine production:

- a military era, from 1945 to the late 1960s, in which production rose rapidly to satisfy military requirements for HEU and plutonium. Demand from this source fell away sharply from 1960 onwards and production halved by the mid 1960s;
- a period of rapidly expanding civil nuclear power, lasting from the late 1960s to the mid 1980s, in which uranium production rose again as reactors were ordered. Production peaked in 1980 and stayed above annual reactor requirements until 1985;
- a period dominated by inventory over-hang, extended by supply from the Newly Independent States, lasting from the mid 1980s up to 2002; and
- the current period, which commenced in 2003, in which the market has reacted strongly to the perception that secondary supplies are beginning to run out and that primary production needs to rise sharply to fill more of the gap still evident with reactor requirements.[131]

128 Mr John Carlson (ASNO), *Transcript of Evidence*, 10 October 2005, p. 20; UIC, *Submission no. 12*, p. 30; GA, *Submission no. 42,* p. 5; WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, p. 167.

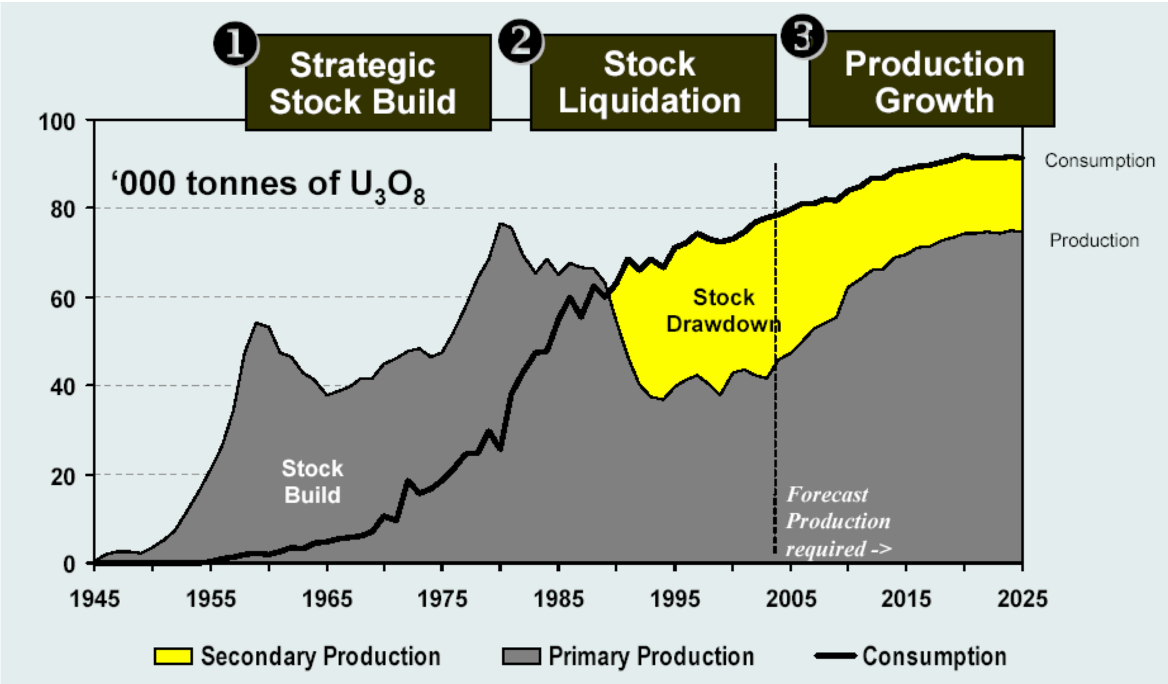
129 Mr Alan Eggers (Summit Resources Ltd), *Transcript of Evidence*, 3 November 2005, p. 2.

130 Mr Will Mollard, *op. cit.*, p. 13. See also: ABARE, *Australian Commodities: Forecasts and Issues*, vol. 13, no. 3, September Quarter 2005, ABARE, Canberra, September 2005, p. 504.

131 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, p. 99; Mr Donald Perkin, *op. cit.*, pp. 14, 42.

2.128 Figure 2.6 depicts uranium oxide consumption and production from 1945 to the present and includes a forecast developed by WMC Resources (acquired by BHP Billiton in July 2005) to 2025. The periods of production history listed above are evident in the diagram.

Figure 2.6 Uranium oxide consumption and production from 1945 and forecast to 2025



Source WMC Resources Ltd, *Olympic Dam's Position in the World Uranium Industry*, Presentation by Mr Andrew Michelmore, December 2004, p. 12.

2.129 The WNA's assessment was corroborated in evidence which argued that the industry anticipates that secondary supplies are beginning to run out and that primary production must now rise to meet demand. Specifically, the UIC stated that the proportion of uranium demand met by secondary supplies is expected to fall from 41 per cent in 2004 to about 17 per cent in 2025, and hence 'additional primary production will be needed to meet uranium demand.'[132]

2.130 Similarly, GA argued that:

> … there is an emerging consensus that, by about 2020, there will be a considerably greater requirement for primary uranium from mine production. Given the long lead times for environmental clearances and permitting of new uranium mines, new discoveries will be needed in the short to medium term.[133]

132 UIC, *Submission no. 12*, p. 8. See also: Cameco Corporation, *op. cit.*, p. 3.

133 Mr Aden McKay (GA), *Transcript of Evidence*, 5 September 2005, p. 4.

2.131 Areva also argued that the decline in secondary supplies will require the discovery of more uranium resources and additional production:

> There is no doubt that the weapons grade material coming on stream to be used as fuel was equivalent to several new world-class uranium deposits … When that stops— and the world's energy needs will continue to increase—that part of the supply will basically diminish and it will gradually disappear over a few years. Therefore, we will have to find significantly more resources and reserves to mine in order to fill that gap. Every year, the uranium usage in power plants is increasing reasonably significantly. The number of power plants being [constructed] or on order at this point in time is certainly quite high compared with what it has been over the previous 10 years. The requirement for uranium will become very significant over time and suddenly this supply will not be there any more.[134]

2.132 Paladin Resources argued that:

> World demand for uranium to provide fuel for existing and new plants now under construction exceeds world uranium production twofold … There is ample evidence that the inventory disposals are coming to an end and the industry must now elicit new uranium supplies to meet present demand and to underwrite future nuclear power expansion.[135]

2.133 Heathgate Resources, owners of the Beverley uranium mine in South Australia, submitted that:

> For the first time in 30 years, the uranium business is moving towards primary production. The need to resume uranium exploration is required in order to find and develop more low cost uranium reserves and resources.[136]

2.134 ASNO argued that because of diminishing secondary supplies:

> Clearly expansion of the international uranium mining industry will be required to meet future demand even if there is no significant expansion of the nuclear power industry.[137]

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134 Mr Stephen Mann (Areva), *Transcript of Evidence*, 23 September 2005, p. 8; Areva, *loc. cit.*

135 Paladin Resources Ltd, *loc. cit.*

136 Heathgate Resources Pty Ltd, *Submission no. 49*, p. 1.

137 The Hon Alexander Downer MP, *loc. cit.* See also: Dr Clarence Hardy (ANA), *Transcript of Evidence*, 16 September 2005, p. 52; Summit Resources Ltd, *op. cit.*, p. 20; Dr Rod Hill (CSIRO), *Transcript of Evidence*, 19 August 2005, p. 1.

2.135 Drawing on analysis by iNi, the UIC argued that because of the decline in secondary supply, between 2004 and 2020, annual primary production of uranium oxide will have to rise by nearly 28 000 tonnes, or 60 percent, to 74 500 tonnes in order to meet demand.[138]

2.136 The view that primary production must rise to meet future requirements was supported by the WNA, which concludes that:

> The ending of the HEU deal between Russia and the United States in 2013 may prove to be a major watershed, and it is clear that primary production must rise substantially to make up the loss of this source of supply.[139]

2.137 Moreover, in its forecasts of world uranium requirements and supply to 2030, the WNA argues:

> It is clear … that, in addition to current uranium reserves, there is a requirement for the discovery of new uranium deposits to meet demand in the longer term future.[140]

2.138 Similarly, the IAEA and OECD-NEA state that projected primary production capability to 2025 indicates that secondary sources will continue to be needed to meet projected requirements. The 2005 Red Book states that after 2015 secondary sources are expected to decline in availability and that reactor requirements will have to be increasingly met by expanding production from existing mines, developing new mines or introducing alternate fuel cycles:

> A sustained near-term strong demand for uranium will be needed to stimulate the timely development of needed Identified Resources. Because of the long lead-times required to identify new resources and to bring them into production (typically in the order of 10 years or more), there exists the potential for the development of uranium supply shortfalls and continued upward pressure on uranium prices as secondary sources are exhausted. The long lead times required to bring resources into production continues to underscore the importance of making timely decisions to increase production capability well in advance of any supply shortfall.[141]

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138 UIC, *Submission no. 12*, pp. 3, 8.

139 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030*, *op. cit.*, p. 4.

140 *ibid.*, p. 182.

141 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, p. 11; ERA, *op. cit.*, p. 3. Canada's Uranium Production & Nuclear Power

Uranium price

2.139 Nova Energy stated that the relative availability of primary and secondary sources of supply of uranium, combined with the level of demand from military and civilian users have determined the market price for mined uranium since the 1940s. Nova Energy cited research which identifies three distinct periods of uranium price history:

- a weapons procurement era (1940–1969);
- an inventory accumulation era (1970–1984); and
- an inventory liquidation period (1985–2004).[142]

2.140 During the weapons procurement and inventory accumulation periods uranium was supplied almost entirely from mine production and the average spot market price was US$54.18/lb U_3O_8 (in 2005 dollars), with a peak of $110/lb U_3O_8 in 1976. During the inventory liquidation era, spot prices fell to an average US$14.57/lb U_3O_8 as secondary sources became available for sale on the market. Nova Energy argued that the effect of the inventory liquidation was to artificially depress the price of uranium in a period when mine supply was declining and demand increasing.[143]

2.141 Market perceptions of diminishing secondary supplies are now a significant influence on the uranium price. Areva stated that the gradual depletion of secondary supplies is now placing considerable upward pressure on spot prices for uranium, which doubled from year-end 2002 to year-end 2004. In the period since, the uranium spot price has more than doubled again.[144]

2.142 GA noted that, in addition to a decrease in the availability of HEU from the Russian Federation, the price increase has been due to very high world oil prices, temporary reductions in mine supply due to the flooding of the McArthur River mine in Canada, and damage to the metallurgical plant at Olympic Dam caused by fires in 2003.[145]

2.143 ASNO observed that because the demand for uranium is relatively inelastic with respect to the price of natural uranium supply, there is expected to be a major increase in price as the inventory drawdown process comes to an end. Reprocessing capacity limitations would also prevent recycled uranium or plutonium from substantially affecting such price rises.[146]

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142 Nova Energy Ltd, *loc. cit.*

143 *ibid.*, pp. 4–5.

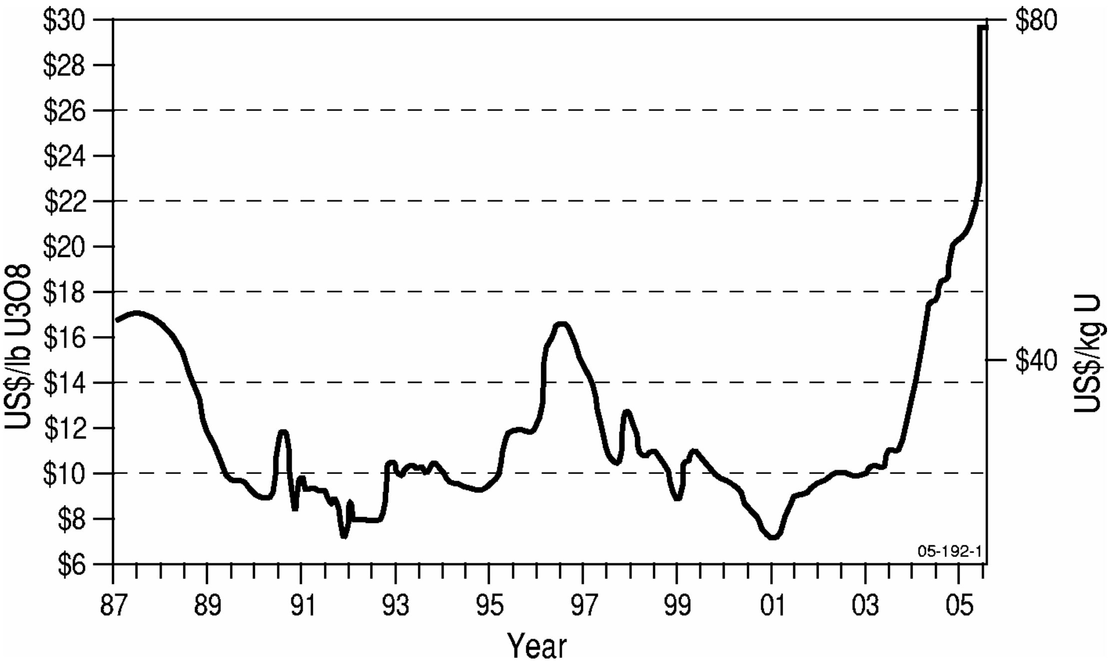
144 Areva, *loc. cit.*

145 GA, *Submission no. 42*, p. 5.

146 The Hon Alexander Downer MP, *op. cit.*, p. 5.

2.144 During the course of the Committee's inquiry, the spot price for uranium oxide doubled from approximately US$22 per pound U_3O_8 to US$44/lb U_3O_8.[147] The spot market prices for uranium since 1988, in both US$/kg U and US$/lb U_3O_8, are shown in figure 2.7.

Figure 2.7 Spot market prices for uranium



Source Geoscience Australia, *Exhibit no. 61*, *Australia's uranium resources and exploration*, p. 8 (Ux Consulting Company, LLC).

2.145 The IAEA and OECD-NEA explain that the over-production of uranium to 1990, combined with availability of secondary sources, resulted in prices trending downwards from the early 1980s until 1994 when they reached their lowest point in 20 years. Between 1990 and 1994 the decrease in supply, including exploration and production, saw prices rise modestly. This trend reversed as better knowledge of the state of inventories maintained downward pressure on uranium prices. Beginning in 2001, the price of uranium has rebounded from historic lows to levels not seen since the 1980s.

2.146 Although most uranium is sold under long-term contract rather than on to the spot market, the spot market prices give an indication of the state of the world uranium market in which future contracts will be written. ERA noted that market prices for long-term contracts increased at a faster rate than spot prices during 2003 and 2004 and by December 2004 the long-

147 From March 2005 to June 2006. Uranium spot prices available from the Ux Consulting Company, LLC, viewed 8 June 2006, <http://www.uxc.com/review/uxc_prices_mth-end.html>.

term indicators had risen to US$25/lb U_3O_8. In the first half of 2005 prices rose even higher, with long-term prices reaching US$30 per pound.[148]

2.147 Nova Energy argued that the tightness in secondary supplies, combined with the long lead times required to discover, gain regulatory approvals and develop new mines or to expand existing facilities means that 'the stage is set for a significant increase in spot and contract prices, perhaps matching or exceeding the highs of 1976.'[149]

2.148 The price of natural uranium is unlikely to significantly affect the cost of nuclear fuel or the overall cost of the electricity generated because the mined cost represents only a quarter of the cost of the fuel loaded into a reactor.[150] The economics of nuclear power are discussed further in chapter four.

2.149 The substantial increase in the uranium price can be expected to stimulate expansion of existing mines as well as exploration for uranium. The rise in price will also mean that the economics of known, but economically less attractive, orebodies will improve, leading to development of new mines.[151]

2.150 Dr Donald Perkin explained the relationship between the uranium price, exploration activity and production as follows:

> … a real increase in commodity price results in an increase in exploration activity; increases in exploration expenditure begin almost immediately the price starts to rise and exploration activity tends to reach its maximum about two years after the commodity price peaks. Increases in prices and in levels of exploration expenditure over time leads to a significant increase in the level of known economic resources because of the higher rate of discovery of new ore deposits … as well as through the addition of some previously known sub-economic resources reclassified into the economically viable category … Production of U_3O_8 increases about a year after commodity prices start to rise and the increases in production lasts well after prices peak, an apparent 'momentum' effect which continues several years into the downturn section of the cycle, due largely to contractual sales arrangements containing fixed … spot prices written into agreements.[152]

148 ERA, *op. cit.*, p. 2.
149 Nova Energy Ltd, *op. cit.*, p. 7.
150 UIC, *Submission no. 12*, p. 30.
151 ANSTO, *Submission no. 29*, p. 4.
152 Dr Donald Perkin, *Exhibit no. 3, The significance of uranium deposits through time*, Abstract, p. 2.

World uranium production and resources

Uranium resources and production by country

2.151 In 2005, uranium was mined in 17 countries with the top 12 countries producing 99 per cent of the total output.[153] The quantity produced in each of these countries and the share of the world total for 2002–05 are listed in table 2.2.

2.152 Australia and Canada combined accounted for 50.5 per cent of world uranium production in 2005. Canada produced 11 628 tU, while Australian mines produced 9 522 tU.[154]

2.153 Production in 2005 represented a three per cent increase on the previous year's total. ABARE have forecast that world mine production will again rise modestly in 2006, as increases in Canada and China will be partly offset by the expected closure of a mine in the Czech Republic.[155]

2.154 GA and other submitters noted that the Athabasca Basin in northern Saskatchewan, Canada contains a number of extremely high-grade deposits, such as Macarthur River and Cigar Lake, with ore grades up to 20 per cent uranium. In contrast, the average ore grade at Olympic Dam in South Australia is 0.04 per cent uranium.[156]

2.155 Kazakhstan also contains significant uranium deposits and while the logistics are thought to be difficult, the deposits are now being developed through joint ventures with foreign companies. Several deposits in Kazakhstan are amenable to ISL mining. Mongolia also contains significant known mineralisation and exploration and mining activity is taking place in Niger and Namibia.[157]

153 RWE NUKEM, *op. cit.*, p. 12. For 2004 production figures see IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, pp. 28–29.

154 *ibid*.

155 ABARE, *op. cit.*, pp. 6–7.

156 Dr Ian Lambert (GA), *Transcript of Evidence*, 5 September 2005, p. 13; Mr Andrew Parker, *Submission no. 35*, p. 10.

157 Dr Ian Lambert, *op. cit.*, pp. 7–9; Mr Stephen Mann (Areva), Transcript of Evidence, 23 September 2005, p. 2; Paladin Resources Ltd, *Submission no. 47*, p. 2.

Table 2.2 World uranium production by country, 2002–2005

Country	**2002**		**2003**		**2004**		**2005**	
	tonnes U	Share of total (%)	tonnes U	Share of total (%)	tonnes U	Share of total (%)	tonnes U	Share of total (%)
Canada	11 607	32.0	10 446	29.4	11 596	28.5	11 628	27.8
Australia	6 854	18.9	7 595	21.4	9 406	23.1	9 522	22.7
Kazakhstan	2 834	7.8	3 150	8.9	3 719	9.1	4 357	10.4
Russia	3 000	8.3	3 158	8.9	3 200	7.9	3 431	8.9
Namibia	2 333	6.5	2 036	5.7	3 038	7.5	3 147	8.2
Niger	3 076	8.5	3 095	8.7	3 282	8.1	3 093	7.4
Uzbekistan	1 860	5.1	1 545	4.4	2 050	5.0	2 300	5.5
United States	883	2.4	779	2.2	877	2.2	1 039	2.5
Ukraine	1 100	3.0	1 000	2.8	800	2.0	800	1.9
China	500	1.4	750	2.1	750	1.8	750	1.8
South Africa	824	2.3	758	2.1	754	1.8	673	1.6
Czech Republic	465	1.3	346	1.0	412	1.0	108	1.0
Subtotal	*35 336*	*97.6*	*34 863*	*97.7*	*34 863*	*98.1*	*41 490*	*99.0*
Others*	859	2.4	835	2.3	773	1.9	380	1.0
TOTAL	**36 232**	**100.0**	**35 688**	**100.0**	**40 657**	**100.0**	**41 870**	**100.0**

Source RWE NUKEM, *NUKEM Market Report*, May 2006, p. 14.
* Other producing countries include: Brazil, Germany, India, Pakistan and Romania.

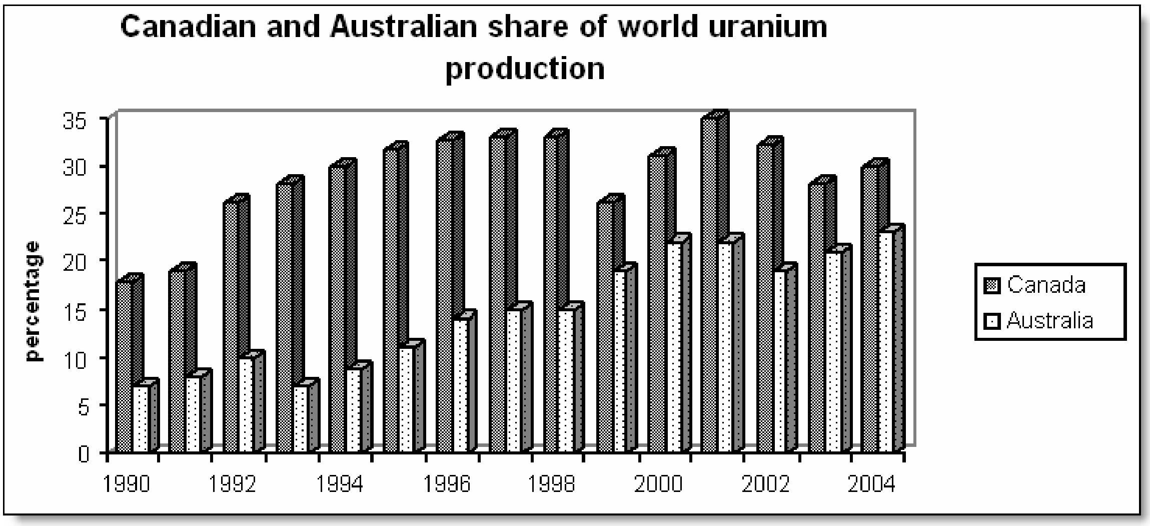
2.156 Australia produces less uranium than its proportional share based on its resources. Australia has the world's largest resources in what the IAEA and OECD-NEA classify as Reasonably Assured Resources (RAR) recoverable at less than US$40/kg U, or 'low cost'. In December 2005, Australia's resources were estimated to be 716 000 tU, which represents 36 per cent of world resources in this category. Other countries with large resources include Canada (15 per cent), Kazakhstan (14 per cent), Niger (9 per cent), Brazil (7 per cent), South Africa (5 per cent), Uzbekistan (4 per cent), Namibia (3 per cent) and Russian Federation (3 per cent).[158] Thus, while Australia possesses some 36 per cent of the world's uranium resources, it currently produces only 23 per cent of world mine output.[159]

158 IAEA and OECD-NEA, *Uranium 2005: Resources, Production and Demand*, *op. cit.*, p. 15; GA, *Submission no. 42*, pp. 15, 16. Updated resource figure to December 2005 provided by Mr Aden McKay (GA).

159 Nova Energy Ltd, *op. cit.*, p. 9.

2.157 Canada has less than half of the uranium resources of Australia but its annual production has been substantially higher, as depicted in figure 2.8.[160]

Figure 2.8 Canadian and Australian shares of world uranium production (1990–2004)



Source UIC, *Submission no. 12*, p. 9.

Uranium production by company

2.158 The world's three largest producers of uranium in 2005 were, in decreasing order of production, Cameco, Rio Tinto/ERA and Areva. WMC Resources, now owned by BHP Billiton, was the fifth largest producer in 2005, with 8.8 per cent of world production. Uranium production by company is listed in table 2.3.

2.159 The three largest producers each account for between 12–20 per cent of total uranium production worldwide. Combined, the ten largest producers represent approximately 75 per cent of world production.[161]

2.160 Cameco is the world's largest producer of uranium and accounts for almost 20 per cent of world production, with four operating mines in Canada and the US. Cameco owns the world's largest high-grade uranium deposit at McArthur River, Saskatchewan, along with mines at Key Lake and Rabbit Lake. In 2004, the McArthur River mine produced 7 200 tU, or almost 18 per cent of world production. Cameco has a 50 per cent interest

160 Further information on Canada's uranium production available from UIC, *Canada's Uranium Production and Nuclear Power*, Nuclear Issues Briefing Paper No. 3, viewed 12 June 2006, <http://www.uic.com.au/nip03.htm>.

161 Areva, *op. cit.*, p. 9. See also: UIC, *World Uranium Mining*, Nuclear Issues Briefing Paper No. 41, viewed 12 June 2006, <http://www.uic.com.au/nip41.htm>.

in the world's second largest high-grade uranium deposit at Cigar Lake in Saskatchewan, which is expected to commence production in late 2007.[162]

Table 2.3 World uranium production according to shareholder, 2004–2005

Company	2004		2005	
	tonnes U	Share of total (%)	tonnes U	Share of total (%)
Cameco	8 310	20.4	8 275	19.8
Rio Tinto	5 335	13.1	5 583	13.3
Areva	5 666	13.9	5 174	12.4
KazAtomProm	3 582	8.8	4 032	9.6
BHP Billiton (WMC Resources)	3 735	9.2	3 688	8.8
TVEL	3 200	7.9	3 431	8.2
Navoi	2 050	5.0	2 300	5.5
ONAREM (Niger)	1 089	2.0	1 032	2.5
General Atomics	919	2.3	875	2.1
NPV Vostok	800	2.0	800	1.9
CNNC	750	1.8	750	1.8
Anglo Gold	754	1.9	673	1.6
Denison	520	1.3	475	1.1
Subtotal	*36 710*	*90.3*	*37 089*	*88.6*
Others	3 947	9.7	4 781	11.4
TOTAL	**40 657**	**100.0**	**41 870**	**100.00**

Source RWE NUKEM, *NUKEM Market Report*, May 2006, p. 19.

2.161 ABARE informed the Committee that Cameco planned to increase production at its three Canadian mines by over three per cent in 2005 and that this increase could be larger if proposed capacity increases at McArthur River and Key Lake were approved. Cameco has applied for a licence to increase combined annual production at these mines by 18 per cent. However, the *RWE NUKEM Market Report* of May 2006 indicates that the review process was not progressing as rapidly as the company had hoped and consequently the proposed expansion may not be in place until 2007 or 2008.[163] The expected level of Cameco's total production capacity has also been boosted by an extension of the Rabbit Lake mine life to 2007 after additional reserves were identified.[164]

2.162 Rio Tinto, through its shareholdings in ERA (68 per cent) and Rössing Uranium in Namibia (69 per cent), was the second largest producer in

162 Cameco Corporation, *op. cit.*, p. 1; Cameco Corporation, *Profile*, viewed 12 June 2006, <http://www.cameco.com/investor_relations/profile/>.

163 RWE NUKEM, *op. cit.*, p. 14.

164 ABARE, *op. cit.*, p. 6.

2005, with an estimated 5 583 tU. ERA's Ranger mine in the Northern Territory produced 5 006 tU, which represented 12 per cent of world production in 2005. Ranger was the world's second largest mine by production in 2005 and the world largest uranium mines are listed in table 2.4.[165]

Table 2.4 The world's largest uranium mines 2004–2005, by production

Mine	Country	Main owner	2004		2005	
			tonnes U	Share of total (%)	tonnes U	Share of total (%)
McArthur River	Canada	Cameco	7 200	17.7	7 200	17.2
Ranger	Australia	ERA (Rio Tinto 68%)	4 753	11.7	5 006	12.0
Olympic Dam	Australia	BHP Billiton	3 735	9.2	3 688	8.8
Krasnokamensk	Russia	TVEL	3 000	7.4	3 300	7.9
Rössing	Namibia	Rössing Uranium (Rio Tinto 69%)	3 038	7.5	3 147	7.5
Rabbit Lake	Canada	Cameco	2 087	5.1	2 316	5.5
McClean Lake	Canada	Areva	2 310	7.9	2 112	5.0
Akouta	Niger	Areva/Onarem	2 005	4.9	1 778	4.2
Arlit	Niger	Areva/Onarem	1 277	3.1	1 315	3.1
Beverley	Australia	Heathgate Resources (General Atomics)	919	2.3	875	2.1
Vaal River	South Africa	Anglogold	754	1.9	673	1.6

Source RWE NUKEM, *NUKEM Market Report*, May 2006, pp. 17, 19; UIC, *World Uranium Mining*, Nuclear Issues Briefing Paper No. 41.

2.163 Areva is the only Group active in all stages of the nuclear fuel cycle and in 2004 was the world's second largest producer of uranium, with a market share of 12 470 tU sold and an output of 6 125 tU in 2004. Areva owns 142 000 tU in uranium reserves, which are equal to 20 times its 2004 production. The company's total underground mineral resources, including reserves, amount to approximately 490 000 tU. Areva also has access to the equivalent of 26 000 tU during the 2004 to 2013 timeframe of the HEU Purchase Agreement.[166]

2.164 Areva submitted that it owns uranium resources and conducts operations in Canada, Niger and Kazakhstan and the company expects to benefit from the renewed demand for primary production. From 2010 Areva intends to achieve combined annual production of some 4 000 tU per year from its deposits in Kazakhstan and Cigar Lake in Canada. The company

165 UIC, *World Uranium Mining, loc. cit*; RWE NUKEM, *op. cit.*, p. 20.

166 Areva, *op. cit.*, pp. 8, 10, 11.

explained that for each deposit it takes some 10–15 years from the first phases of exploration to the commencement of mining, with an average cost of €50 million per deposit. In 2004, Areva's exploration and mine development expenditure amounted to €16 million.[167]

2.165 The ten largest uranium mines in the world produced over 73 per cent of world output in 2005. These facts support the WNA's conclusion that:

> Firstly, uranium production is becoming increasingly concentrated in a small number of large mines in a limited number of countries, particularly Canada and Australia. Secondly, ownership of the major mines is becoming concentrated in a smaller number of companies…[168]

Adequacy of world uranium resources to meet long-term growth in nuclear capacity

2.166 Several submitters argued that world uranium resources are insufficient to support an expansion of nuclear capacity and, hence, that nuclear power represents at best a 'temporary response' to addressing climate change.[169] For example, FOE argued that:

> Relatively high-grade, low-cost uranium ores are limited and will be exhausted in about 50 years at the current rate of consumption. The estimated total of all conventional uranium reserves is estimated to be sufficient for about 200 years at the current rate of consumption. These resources will of course be depleted more rapidly in a scenario of nuclear expansion. It is far from certain that uranium contained in 'unconventional sources' such as granite, sedimentary rock or seawater can be recovered economically.[170]

2.167 Similarly, Mr Justin Tutty argued that:

> At the current rate of consumption, low cost uranium reserves will be exhausted in around 50 years. To maintain nuclear's share of the energy market, these reserves would be exhausted faster, as global energy demand is continuing to grow. If nuclear is actually meant to displace *future* fossil fuel use, then these reserves will be exhausted faster still. If nuclear is also intended to displace *current*

167 *ibid.*, p. 10.

168 WNA, *The Global Nuclear Fuel Market – Supply and Demand 2005–2030, op. cit.*, p. 3.

169 See for example: FOE et. al., *Exhibit no. 71, Nuclear Power: No Solution to Climate Change*, section 2.2; People for Nuclear Disarmament NSW Inc, *Submission no. 45*, p. 5; NT Greens, *Submission no. 9*, p. 1; APChem, *Submission no. 38*, p. 3.

170 FOE, *Submission no. 52*, p. 5.

> fossil fuel use, then these reserves clearly won't stretch far into the future.[171]

2.168 The ACF likewise argued that if all electricity currently generated by fossil fuels were replaced by nuclear power, 'there would be enough economically viable uranium to fuel reactors for between 3 and 4 years.'[172]

2.169 Other evidence rejected arguments of scarcity of world uranium supply in the longer-term. For example, Compass Resources argued that: 'Uranium is not, nor is likely to be, in short supply in the long term' and Mr Andrew Crooks asserted that: 'The reality is there is plenty of proven and probable uranium resources to last the world for several thousand years.'[173]

2.170 Mr Keith Alder, former General Manger and Commissioner of the Australian Atomic Energy Commission, argued that concerns about the future supply of uranium were first raised in the mid 1950s and have proved false. Concerns about an impending uranium shortage encouraged research into fast breeder reactors (FBRs) which can extend the energy extractable from a given quantity of uranium by up to a factor of 50. However, Mr Alder noted that:

> … it turned out that there was plenty of uranium … The antinuclear people often say, 'It's a stopgap exercise because we will run out of uranium.' That is absolute rubbish. There is an awful lot of uranium still to be discovered, particularly in Australia. I draw your attention to the Northern Territory … nobody has really had an extensive look very deep underground in the Northern Territory, and that is just one part of Australia.[174]

2.171 Mr Andrew Parker also argued that estimates of reserves lasting only a few decades are misleading because until recently there has been relatively little new exploration:

> It is not known how long the reserves will last because the funding of uranium exploration is many years and billions of dollars behind and no where near as comprehensive and complete as exploration for oil and gas. Indeed some of richest uranium deposits have only recently been discovered whereas all the really big oil fields were discovered over 40 years ago. It is likely that many more high-grade uranium deposits will be found and it has been estimated that the ultimate resource base is far larger.[175]

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171 Mr Justin Tutty, *Submission no. 41*, p. 3. Emphasis in original.

172 ACF, *op. cit.*, p. 13.

173 Compass Resources NL, *op. cit.*, p. 2; Mr Andrew Crooks, *Submission no. 84*, p. 4.

174 Mr Keith Alder, *Transcript of Evidence*, 16 September 2005, p. 81.

175 Mr Andrew Parker, *loc. cit.*

2.172 The ANF also observed that:

> Of course more reserves are certain to be discovered albeit at higher recovery costs, but fuel costs are not a large contributor to generating costs so the basic 50 year figure is probably conservative.[176]

2.173 BHP Billiton also noted that the price of nuclear generated electricity is not sensitive to uranium price, so the requirement to mine uranium recoverable at higher costs is not a major issue:

> … the cost of fuel in nuclear power generation is not a very high proportion of the total cost, and the generators are not particularly sensitive to the actual cost of uranium in their calculations. That means that a decade ago they were quite prepared to sign long-term contracts at significantly above the spot price, because they were more interested in security of supply than they were in the price. The price was not really driving the economics of nuclear power generation.
>
> In the meantime, demand has grown and mine output has not grown all that much, so the spot is now above the long-term contract price, and again the generators are not particularly worried about paying a high spot, because even now, at $30 a pound on the spot, it is not a very high proportion of the total cost of operating nuclear power stations.[177]

2.174 Similarly, Mr Alistair Stephens of Arafura Resources argued that the effect of a rise in uranium price is to make previously uneconomic resources viable for commercial use and to encourage greater exploration:

> The calculation that there are only 50 years of uranium resources left is made on the basis of the supply and demand relationship, so the grade of concentration of uranium in currently known resources that could be economically extracted would last 50 years. If the price of uranium were to increase, the amount of resources that are known would increase, so our supply of product would increase. That calculation also does not account for the fact that exploration will, in all probability, find new sources of uranium that could be used for injection into the supply relationship.[178]

2.175 The 2005 Red Book states that total Identified Resources (which includes RAR and Inferred Resources recoverable at costs of less than US$130/kg

176 ANF, *Exhibit no. 5, Uranium Mining in Australia*, p. 1; ANF, *Submission no. 11*, p. 2.

177 Dr Roger Higgins (BHP Billiton Ltd), *Transcript of Evidence*, 2 November 2005, p. 21.

178 Mr Alistair Stephens (Arafura Resources NL), *Transcript of Evidence*, 23 September 2005, p. 53.

U) amounts to 4.7 million tU. The IAEA and OECD-NEA state that these resources are sufficient to supply the current once-through fuel cycle for 85 years at 2004 rates of consumption. [179]

2.176 Total Conventional Resources (which includes all cost categories of Identified Resources plus Prognosticated and Speculative Resources) amounts to some 14.8 million tU. With the once-through fuel cycle, these resources are estimated to be sufficient for 270 years at current rates of consumption.[180]

2.177 Unconventional Resources, which includes uranium that can be recovered from phosphate deposits, seawater and black shale, would add another 22 million tU, bringing total uranium available for exploitation to over 35 million tU. Combining Conventional Resources with the uranium in phosphates would provide sufficient uranium to fuel 675 years of electricity generation at current rates of consumption. The IAEA and OECD-NEA thus conclude that 'sufficient nuclear fuel resources exist to meet energy demands at current and increased demand well into the future.'[181]

2.178 Mr Alder pointed out that the Japanese Government previously studied the extraction of uranium from seawater and while the cost was about eight to ten times the cost of mined uranium at the time of the study, 'they calculated that there is 4,000 million tonnes of uranium in the sea. I cannot see this world running out of uranium fuel.'[182] Moreover, as noted by BHP Billiton and Arafura Resources above, because the cost of uranium is a small proportion of the overall price of nuclear generated electricity, Mr Alder argued that:

> Even if it did cost five to 10 times the [current] price of uranium, if you look at the cost of the uranium that goes into the production of a kilowatt hour you see that it is negligible. If you multiplied the cost of uranium in the kilowatt hour by 10, the householder or the small industrial user would face a very small increase in power price.[183]

2.179 The IAEA and OECD-NEA reinforce the observations of submitters cited above, that exploration is highly likely to find new discoveries and expand the uranium resource base. Indeed, the 2005 Red Book reports that the rise in spot price has stimulated major new exploration activity, with worldwide exploration expenditure in 2004 totalling over US$130 million,

179 IAEA and OECD-NEA, *op. cit.*, pp. 361–365, 14.

180 *ibid.*, p. 21.

181 *ibid.*, p. 78.

182 Mr Keith Alder, *loc. cit.*

183 *ibid.*

a 40 per cent increase on the 2002 figure. Exploration expenditure in 2005 is expected to approach $200 million.[184]

2.180 The WNA, which has published a position statement on future uranium supplies, lists additional sources of nuclear fuel, including:

- reprocessing used nuclear fuel to recover unburned fissile material, which can increase the efficiency of uranium utilisation by up to 30 per cent (as noted above, reprocessing currently provides only 3 per cent of world nuclear fuel supply);
- increasing the enrichment level of fuel, which can save uranium use in reactors;
- using thorium, which is four times more abundant than uranium in the Earth's crust[185];
- greater fuel efficiency in advanced reactor designs, currently being developed in multinational research programs, which may be deployed beyond 2030; and
- using fast neutron reactors (FNRs) (of which FBRs are one sub-type), which utilise the U-238 component of natural uranium, as well as the existing stock of depleted uranium, by converting non-fissile U-238 to ('breed') fissile plutonium.[186]

2.181 ASNO explained that the development of the fast neutron fuel cycle will allow the most efficient use of uranium resources. Currently, the 'thermal' nuclear fuel cycle, typified by the LWR, is an extremely inefficient use of uranium resources, generating energy from the fissile isotope U-235 which comprises only 1/140th of natural uranium (i.e. 0.71 per cent of natural uranium is U-235). The once-through cycle will consume available supplies of uranium far more quickly because all used fuel is treated as waste for disposal. In contrast, the basis of the fast neutron cycle is the use of fast (unmoderated) neutrons to convert the predominant uranium isotope U-238 to plutonium as reactor fuel.[187] Theoretically, this could extend the energy value of uranium by up to a factor of 140, thereby making existing uranium reserves sufficient for several thousand years.

2.182 The 2005 Red Book reports that use of fast reactor technology, which is already proven, offers the prospects of multiplying uranium resources 50-fold. In this way, use of nuclear energy at current consumption levels may be extended by over 2 500 years based on Identified Resources, to over

184 IAEA and OECD-NEA, *op. cit.*, pp. 9, 25.

185 Australia's resources of thorium are described in the following chapter.

186 WNA, *Can uranium supplies sustain the global nuclear renaissance?*, WNA, London, 2005, pp. 6–7, viewed 13 June 2006, <http://www.world-nuclear.org/position/uranium.pdf>.

187 ASNO, *Exhibit no. 93, Notes to accompany an informal briefing on the GNEP initiative*, p. 6.

8 000 years with currently known Conventional Resources and to almost 20 000 years with total Conventional Resources and phosphates.[188]

2.183 Similarly, the ANF also argued that if FBRs became widely adopted the market demand for uranium may reduce because:

> Breeder reactors will extend uranium utilisation by about a factor of 60; in other words, rather than 50 years, the quantity of world reserves … will last for another 3 000 years. Also, if the 2.1 million tonnes of uranium already mined are taken into account (most of the U238 still remains) then the total rises to nearly 5 000 years.[189]

2.184 Despite the promise of breeder reactors in extending uranium utilisation, FOE argued that most FBR programs have been abandoned:

> Accepting that low-cost uranium resources are limited, nuclear advocates frequently argue that the use (and production) of plutonium in 'fast breeder' reactors will allow uranium resources to be extended almost indefinitely. However, most plutonium breeder programs have been abandoned because of technical, economic and safety problems.[190]

2.185 The ACF also argued that FBRs have been a 'technological and economic failure', but conceded that 'with use of fast breeder reactors a closed cycle could be reached that would end the dependency on limited uranium resources.'[191]

2.186 ASNO previously acknowledged that that despite the energy (and waste management) advantages of the fast neutron cycle, the development of FNRs has been slow for economic reasons, engineering complications and public concerns about the safety of conventional FBRs.[192]

2.187 However, evidence indicated that there is now renewed interest in plutonium recycling. ASNO informed that Committee that, having been committed to the once-through fuel cycle since the Carter Administration, the US is now embracing plutonium recycling because of its more efficient utilisation of uranium.

2.188 Through its recently announced Global Nuclear Energy Partnership (GNEP) initiative, the US intends that so-called 'fuel supplier' nations will use FNRs and advanced spent fuel separation, which will recycle plutonium and transmute longer-lived radioactive materials. These technologies will recycle plutonium *without* requiring plutonium

188 IAEA and OECD-NEA, *op. cit.*, p. 78.
189 ANF, *loc. cit.*
190 FOE, *Submission no. 52*, *loc. cit.*
191 ACF, *loc. cit.*
192 ASNO, *Exhibit no. 93, loc. cit.*

separation, which will meet the concern of some submitters that FBRs add to proliferation risks. Current plans by the US Government are to deploy commercial fast reactors in 2040.[193]

Potential for Australia's uranium production to expand

2.189 Evidence to the inquiry emphasised that if policies which are preventing the development of much of the nation's resource base are reversed, Australia will be well placed to expand production and meet the expected growth in uranium demand:

> Australia is well positioned in terms of its identified resources to take advantage of the expected growth in demand for uranium and expected increase in uranium prices. Australia has about one third of the world's low cost uranium. Seven of the top 20 known uranium deposits in the world are in Australia.[194]

2.190 Examples of observations by submitters making this argument include:

- 'Australia is already a significant supplier of uranium – yet the growing demand is providing an unparalleled opportunity for Australia to be the dominant supplier of a crucial global commodity.'[195]
- 'Australia is extremely well placed to take advantage of this situation, both in the immediate future and in the long term.'[196]
- 'With reserves twice those of Canada, despite little exploration over the last fifteen years, Australia is in the position of being capable of significantly increasing its uranium production and exports in direct competition with Canada … Additional low-cost mines in Australia would supply a substantial proportion of the needed increase in world output.'[197]
- 'Australia is, and should be, well positioned to capture a large part of this burgeoning market. We have the largest proportion of economic demonstrated resources of any country in the world. Moreover, our resources are the lowest cost uranium resources in the world, being almost entirely recoverable at less than $US29 a pound of U_3O_8.'[198]

193 Dr Ron Cameron, *op. cit.*, p. 11.
194 UIC, *Submission no. 12*, p. 8.
195 Nova Energy Ltd, *op. cit.*, p. 8.
196 Cameco Corporation, *op. cit.*, p. 3.
197 Association of Mining and Exploration Companies (AMEC), *Submission no. 20*, pp. 5–6.
198 Mr Mitch Hooke (MCA), *Transcript of Evidence*, 5 September 2005, p. 21.

2.191 CSIRO also commented that if Australia could source new deposits of uranium and obtain higher levels of recovery from known deposits, it could position itself as the global leader in the industry.[199]

2.192 Compass Resources suggested that Australia's considerable uranium resources potentially places the domestic industry in a similar position to iron ore or alumina:

> Australia is … in a fortunate position that, along with Canada and certain African countries it has substantial high grade resources of uranium that can be produced at relatively low cash costs. In this regard Australia's position for uranium places it with similar advantages to iron ore or alumina, that is it can become one of a limited number of countries that supply a significant proportion of annual world uranium consumption.[200]

2.193 It was also argued that production from other countries may not attract the safeguards and regulatory controls imposed on Australian exports. Nova Energy also argued that the two other countries with major resources, Canada and Kazakhstan, are either not as well regulated or not as well placed to meet the growing demands in the Asian region. Australia was said to be 'uniquely placed – it is geographically well located close to the major growth areas.'[201]

2.194 Similarly, the UIC argued that while Canada has achieved greater annual production than Australia to date and Kazakhstan (which has larger reserves than Canada in the category of RAR recoverable at less than US$80/kg U) is aiming for a fourfold increase in mine production, nonetheless:

> … Australia has good relations with the most rapidly growing markets for uranium, those in East Asia, and is a preferred supplier into those markets.[202]

2.195 AMEC also submitted that with forecast growth in nuclear capacity in East and South East Asia:

> Australia's abundance of uranium reserves will further ensure its future position as a leading world supplier to these markets, provided a politically and economically favourable environment in Australia is maintained.[203]

199 CSIRO, *Submission no. 37*, p. 7.
200 Compass Resources NL, *Submission no. 6*, p. 2.
201 Nova Energy Ltd, *op. cit.*, p. 9.
202 UIC, *Submission no. 12*, p. 9.
203 AMEC, *op. cit.*, p. 6.

2.196 While Australia has some 36 per cent of the world's resources of uranium, it was submitted that the key question remains:

> … whether Australian companies … can expand their production to meet this expected increasing demand and also whether they can export uranium to rapidly developing markets in China and India.[204]

2.197 Paladin Resources argued that sustained higher prices will be required to stimulate production because of the 'extreme tightness of supply extending for up to twenty years', but that:

> Australia will be the prime beneficiary of this new investment, if our uranium policies and regulations are brought into alignment with the realities of the world's civil nuclear power industry.[205]

2.198 Similarly, ANSTO submitted that:

> Prima facie, ANSTO believes that Australia is well placed to respond to increases in demand, given the size of our reserves. ANSTO notes, however, that current policy in some states precludes the development of new mines from known resources, and other states have legislation that prohibits the prospecting for, or the mining of, uranium. It is therefore possible that Australia will not be able to maximise the benefits that could be obtained from its uranium resources.[206]

2.199 Jindalee Resources argued that while 'Australia should be the world leader in the production of uranium', the:

> … current regulatory environment dissuades investment in uranium exploration, favours the entrenched position of three existing producers and leaves limited opportunity for the development of other mines by new entrants. This environment is clearly anti-competitive and has sterilised the majority of Australia's uranium deposits. It is in the National Interest that this environment is changed.[207]

2.200 The following chapter assesses Australia's uranium resources, production and exploration, while the impediments to the development of Australia's uranium resources are addressed in chapter eleven.

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204 Dr Clarence Hardy (ANA), *Transcript of Evidence*, 16 September 2005, p. 52.

205 Paladin Resources Ltd, *loc. cit.*

206 ANSTO, *Submission no. 29*, p. 5.

207 Jindalee Resources Ltd, *op. cit.*, p. 1.

Conclusions

2.201 Nuclear power generates some 16 per cent of the world's electricity. While nuclear's contribution varies, it provides a substantial proportion of national electricity requirements in many countries.

2.202 The Committee notes that forecasts for nuclear capacity and uranium requirements vary, but there are a number of positive demand side trends which indicate that growth in nuclear capacity is probable:

- forecasts for a doubling in world electricity demand in the period to 2030, with a tripling of demand forecast for developing countries;
- plans for significant new nuclear build in several countries and renewed interest in nuclear energy among some industrialised nations;
- improved performance of existing nuclear power plants and operating life extensions; and
- the desire for security of fuel supplies, electricity price stability and heightened concerns about greenhouse gas emissions from the electricity sector.

2.203 In a recent development, the Committee notes the announcement by the British Government in July 2006 that, in view of the potential benefits for its public policy goals of reducing carbon dioxide emissions while delivering secure energy at affordable prices, the British Government proposes to support new nuclear build and to address potential barriers to the construction of NPPs.[208]

2.204 The Committee notes that as of June 2006 there were 27 reactors under construction in 11 countries, with a further 38 planned or on order. New plant construction is centred in the Asian region, with China, Japan and India all having plans for a significant expansion of nuclear capacity.

2.205 While new reactor construction to date has been subdued, the Committee notes that dramatic improvements in plant availability and productivity over recent years have had the effect of significantly increasing nuclear capacity and, consequently, the demand for uranium. The Committee notes that the IAEA and OECD-NEA have concluded that new nuclear build combined with the improved performance of existing NPPs and operating life extensions will outweigh reactor retirements in the years to 2025, thereby increasing projected uranium requirements.

2.206 The IAEA and OECD-NEA 'low demand' scenario forecasts that world nuclear capacity will rise to 449 GWe by 2025, which would see annual

208 UK Department of Trade and Industry, *The Energy Challenge: Energy Review Report 2006*, HM Government, London, July 2006, viewed 12 July 2006, <http://www.dtistats.net/ereview/energy_review_report.pdf>.

uranium requirement rise to 82 275 tonnes U by 2025, representing a 22 per cent increase on the 2004 requirements of 67 430 tonnes.

2.207 Uranium is unique among fuel sources in that a significant portion of demand is met by so-called secondary sources, which are essentially inventories and stockpiles. Currently, primary production from mines only supplies some 65 per cent of uranium requirements. Evidence strongly indicates that secondary supplies are diminishing, particularly with the termination of an HEU Purchase Agreement between Russia and the US in 2013. The Committee concludes that primary production must increase to meet requirements.

2.208 The Committee rejects the argument that the world's uranium resources are insufficient to support an expansion of nuclear power in the decades ahead. Total Conventional Resources are sufficient for some 270 years of nuclear electricity generation at 2004 rates of consumption. The resource base is almost certain to expand as higher uranium prices stimulate new exploration. Furthermore, additional sources of supply can eventually be utilised, including reprocessing used nuclear fuel and wider deployment of advanced reactor technologies. Fast Neutron Reactors are capable of extracting far more energy from uranium and can extend the usable fuel from known uranium resources by a factor of 60. The Committee concurs with the IAEA that there are no resource constraints on the expansion of nuclear power.[209]

2.209 Australia possesses some 36 per cent of the world's low cost uranium resources and on this basis the Committee agrees with submitters that, subject to the elimination of impediments to the industry's growth, Australia is well placed to expand production and meet global demand. Moreover, the Committee concludes that Australia is uniquely placed to supply markets in the Asian region, where nuclear growth is currently centred.

2.210 The Committee believes that it is entirely unsatisfactory for the nation, which possesses more than double the low cost uranium resources of its nearest rival, to consistently lag behind in terms of production and exports. In the following chapter the Committee examines Australia's uranium resources more closely and discusses the nation's potential to occupy a key position in world uranium supply.

209 IAEA, *Nuclear Power's Changing Future*, Press Releases, 26 June 2004, viewed 15 June 2006, <http://www.iaea.org/NewsCenter/PressReleases/2004/prn200405.html>.