II. URANIUM DEMAND

This chapter summarises the current status and projected growth in world nuclear electricity generating capacity and commercial ***reactor-related uranium requirements***. Relationships between uranium supply and demand are analysed and important developments related to the world uranium market are described. The data for 2007 and beyond are estimates and actual figures could differ.

A. CURRENT COMMERCIAL NUCLEAR GENERATING CAPACITY AND REACTOR-RELATED URANIUM REQUIREMENTS

World (370.23 GWe net as of 1 January 2007)

On 1 January 2007, a total of 435 commercial nuclear reactors were operating in 30 countries and 27 reactors were under construction (about 21.4 GWe net).[4] During 2005 and 2006, seven reactors were connected to the grid (about 5.3 GWe net) and ten reactors were permanently shut down (about 3.2 GWe net). Seven of these shutdowns occurred on 31 December 2006. Table 25 and Figures 7 and 8 summarise the status of the world's nuclear power plants as of 1 January 2007. The global nuclear power plant fleet generated about 2 630 TWh of electricity in 2005 and about 2 675 TWh in 2006 (Table 26).

World annual uranium requirements amounted to 66 500 tU in 2006 and are estimated to increase to about 69 110 tU in 2007.

OECD (308.60 GWe net as of 1 January 2007)

As of 1 January 2007, the 343 reactors in operation in 17 OECD countries constituted about 83% of the world's nuclear electricity generating capacity. A total of three reactors were under construction with a net capacity of about 4.5 GWe. During 2005 and 2006, four reactors were connected to the grid (about 3.3 GWe net) and eight reactors were shut down (about 2.4 GWe net).

Within the OECD there are significant differences in nuclear energy policy. Japan and South Korea remain committed to continued growth in nuclear energy, whereas several member countries in Western Europe have made commitments to phase out nuclear energy, notably Belgium, Germany, Spain and Sweden, although some are reconsidering such commitments. At the same time, other countries in Western Europe, such as Finland and France, remain committed to the use of nuclear energy. In North America there are indications that construction of new capacity in Canada and the United States will take place, in the case of the United States stimulated by incentives provided in the 2005 *Energy Policy Act*.

The OECD reactor-related uranium requirements were 56 625 tU for 2006 and are expected to increase to 57 690 tU in 2007.

4. Figures include the reactors operating and under construction in Chinese Taipei.

Table 25. **Nuclear data summary**
(as of 1 January 2007)

COUNTRY	Operating reactors	Generating capacity (GWe net)	2006 Uranium requirements (tU)	Reactors under construction	Reactors started up during 2005 and 2006	Reactors shut down during 2005 and 2006	Reactors using MOX
Argentina	2	0.94	120	1	0	0	0
Armenia	1	0.38	90	0	0	0	0
Belgium	7	5.83	880	0	0	0	1
Brazil	2	1.80	450	0	0	0	0
Bulgaria	2	1.91	505	2	0	2	0
Canada	18	12.50	1 800	0	0 (a)	0	0
China (b)	10	7.57	1 200	3	1	0	0
Czech Republic	6	3.49	665	0	0	0	0
Finland	4	2.68	465	1 (c)	0	0	0
France	59	63.26	7 185 +(d)	0	0	0	20
Germany	17	20.34	3 710 (d)	0	0	1	7
Hungary	4	1.78	380	0	0	0	0
India	16	3.78	445	6	2	0	1
Iran, Islamic Rep. of	0	0.00	0	1	0	0	0
Japan	55	47.10 +	7 940 (d)	1	3	0	1
Korea, Republic of	20	17.45	3 200 +	1	1	0	0
Lithuania	1	1.19	60	0	0	0	0
Mexico	2	1.37	200 +	0	0	0	0
Netherlands	1	0.48	65	0	0	0	0
Pakistan	2	0.43	65 *	1	0	0	0
Romania	1	0.65	100 *	1	0	0	0
Russian Federation	31	21.74	4 000	5	0	0	NA
Slovak Republic	5	2.03	490	0	0	1	0
Slovenia	1	0.70	250	0	0	0	0
South Africa	2	1.84	280	0	0	0	0
Spain	8	7.45	1 725	0	0	1	0
Sweden	10	9.03	1 600	0	0	1	0
Switzerland	5	3.22	265	0	0	0	3
Ukraine	15	13.80	2 480	2	0	0	0
United Kingdom	19	10.50	2 165	0	0	4	0
United States	103	100.10	22 890	0	0	0	0
OECD	343	308.60	56 625	3	4	8	32
TOTAL	**435**	**370.23**	**66 500**	**27**	**7**	**10**	**33**

Sources: IAEA Power Reactor Information System (www.iaea.org/programmes/a2/) except for *Generating capacity* and *2006 Uranium requirements*, which use Government-supplied responses to a questionnaire, unless otherwise noted and rounded to the nearest five tonnes. MOX not included in U requirement figures.

NA Data not available.

* Secretariat estimate.

\+ Data from NEA *Nuclear Energy Data*, OECD, Paris, 2007.

(a) During 2005, one reactor at the Pickering site, shut down in 1997 for safety concerns, was restarted.

(b) The following data for Chinese Taipei are included in the world total but not in the total for China: six nuclear power plants in operation, 4.9 GWe net; 830 tU; two reactors under construction; none started up or shut down during 2005 and 2006.

(c) Construction of Okiluoto-3 (1.6 GWe net EPR) officially began in December 2005.

(d) Excluding MOX fuel.

Figure 7. **World installed nuclear capacity: 370.23 GWe net**
(as of 1 January 2007)

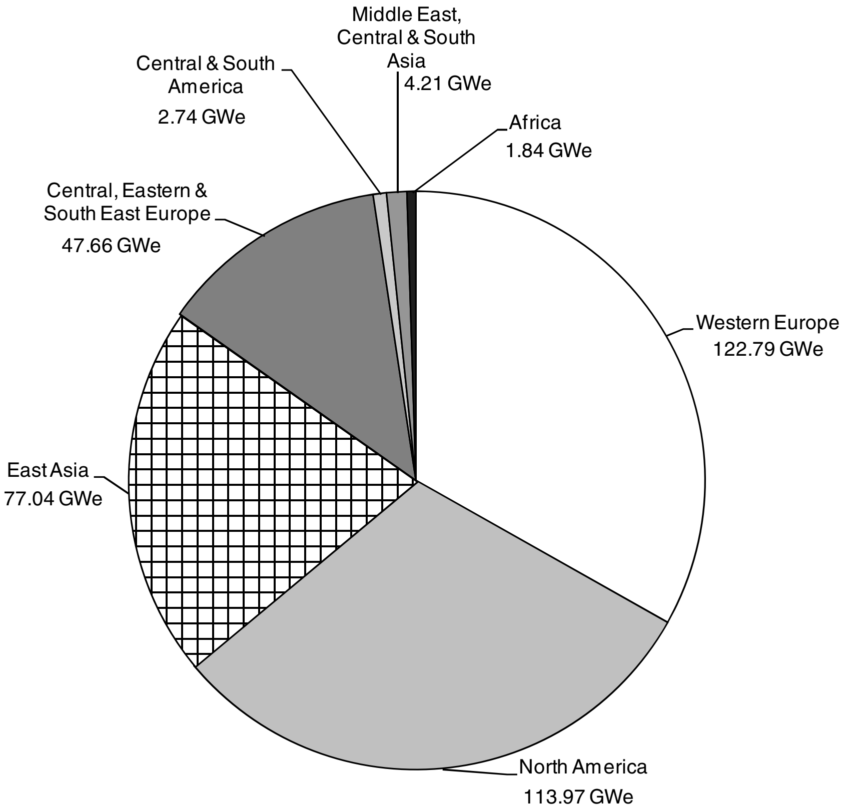

Figure 8. **2006 world uranium requirements: 66 500 tU**

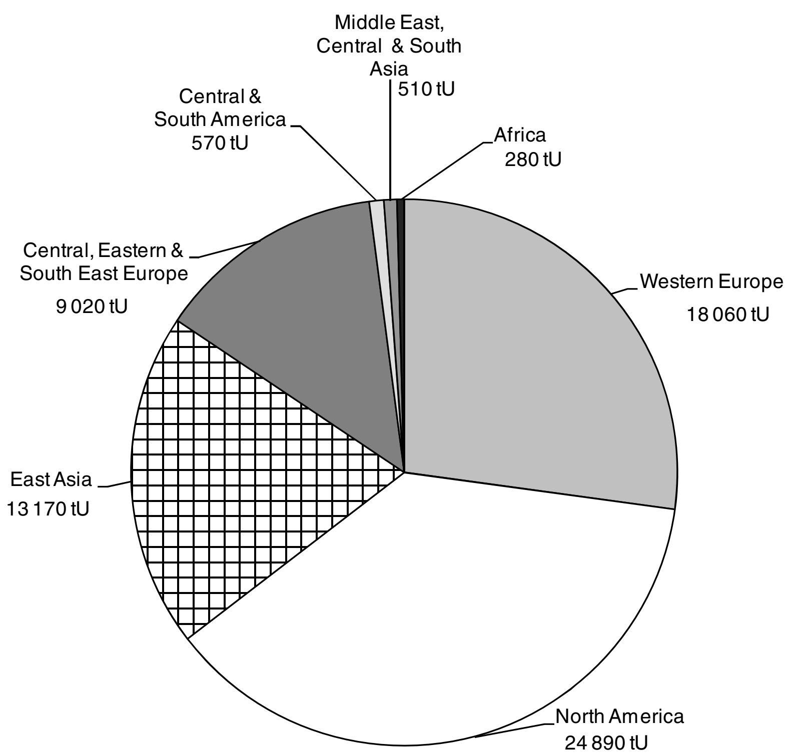

Table 26. **Electricity generated using nuclear power plants**
(TWh net)

COUNTRY	2003	2004	2005	2006
Argentina	8.40	8.50	6.40 *	7.15 *
Armenia	1.82	2.21	2.50 *	2.42 *
Belgium	44.90	44.90 (b)	45.30	44.31
Brazil	13.34	11.55	9.85	13.77
Bulgaria	16.09 *	15.60 *	17.30 (d)	18.13 (d)
Canada	70.70	84.20	86.70	94.00
China (c)	41.50	47.50	50.30	51.80
Czech Republic	24.40 (a)	24.80 (a)	23.30	24.50
Finland	21.70	21.70	22.40	22.30
France	419.80	426.80 (a)	430.00 (a)	428.70 (b)
Germany	156.20	155.70	154.60	158.70
Hungary	11.00 +	11.90 +	13.00	12.66
India	16.64	15.04	15.70 (d)	15.59 (d)
Japan	230.00	282.00	280.70 (d)	291.50 (d)
Korea (d)	123.50 (a)	123.97 (a)	139.50 (a) +	141.18 (a) +
Lithuania	15.50	15.10	9.50	8.70
Mexico	10.00 +	8.70 +	10.80 +	10.90 (a) +
Netherlands	3.60 +	3.60 +	3.30	3.60
Pakistan	1.81 *	1.93 *	2.40 *	2.55 *
Romania	5.10 *	5.10 *	5.10 *	5.18 *
Russian Federation	138.40	143.00	149.40	156.40
Slovak Republic	16.40	15.70	16.30	16.60
Slovenia	4.96	5.21	5.61	5.29
South Africa	12.67 *	14.28 *	12.20 *	10.07 *
Spain	59.20	60.90	55.40 +	57.80 +
Sweden	65.70 +	75.00 +	69.50 (b)	65.05
Switzerland	26.00 (a)	25.30	22.64	26.63 (a)
Ukraine	81.40	87.40	75.20	84.90 *
United Kingdom	81.90	73.70	75.20 +	69.40 (d)
United States	764.00	789.00 (a)	782.00 +	787.00 +
OECD	2 129.00	2 227.87	2 230.64	2 254.83
TOTAL	**2 524.03**	**2 638.29**	**2 630.50**	**2 675.08**

* Secretariat estimate.

\+ *Nuclear Energy Data*, OECD, Paris, 2007.

(a) Generation record.

(b) Provisional data.

(c) The following data for Chinese Taipei are included in the World Total but not in the total for China: 37.4 TWh in 2003, 38.0 TWh in 2004, 38.4 TWh in 2005, 38.3 TWh in 2006.

(d) Gross capacity converted to net by Secretariat.

Western Europe (122.789 GWe net as of 1 January 2007)

As of 1 January 2007, 130 nuclear reactors were operating in Western Europe. No reactors were connected to the grid in 2005 or 2006 but one European Pressurised-water Reactor (EPR) was under construction in Finland and a second EPR was committed to construction in France. These advanced design plants are expected to commence operations in 2011 and 2012, respectively. One reactor each in Germany (about 0.3 GWe net), Sweden (about 0.6 GWe net) and Spain (about 0.1 GWe net) and four reactors in the United Kingdom (about 0.9 GWe net combined) were shut down in 2005 and 2006. Nuclear phase out policies have been implemented in Belgium, Germany, Spain and Sweden. However, in early 2007, the European Union proposed a common European energy policy that would see, among other things, a rapid increase in nuclear energy beginning in 2020 and accelerating after 2030.

In **Belgium**, the government's policy to phase out nuclear energy by limiting the operational lives of its seven reactors to 40 years and permitting no new construction continues, but the policy can be overridden if Belgian's security of supply is threatened. A report analyzing the country's current energy policy, commissioned by the Minister for Energy in 2006, will be submitted to the new government (a Christian Democrat – Liberal coalition that is expected to be formed as a result of the June 2007 election) following extensive review. The recommendations in this report, prepared by an expert group, are to be taken into consideration as the new government's energy policy is prepared.

In **Finland**, construction of the Olkiluoto 3 EPR (about 1.6 GWe net) nuclear power plant continues, but has been delayed by about a year due to issues associated with licensing validation of components and the quality of the concrete used in construction. It is now expected to be in operation in 2011. In 2007, Teollisuuden Voima Oy (TVO) began an Environmental Impact Assessment (EIA) on the possibility of building a fourth reactor at the Olkiluoto site and Fortum launched an EIA on the possibility of building a third reactor at the Loviisa site, with decisions on investment to follow. In late June 2007, a consortium of Finnish industrial and energy companies (Fennovoima) announced its intention to construct a new nuclear power plant (1.0 to 1.80 GWe) at an as yet undetermined site to begin operation in the 2016-2018 time frame.

In **France**, the industrial group AREVA announced its 100th reactor order, a 1.6 GWe net EPR destined to be built in Flamanville, Normandy. Construction was to begin in late 2007, with the unit scheduled to begin operating in 2012. One of the priorities laid out by the central government in the *Energy Planning Act* of 2005 is to keep the nuclear option open until 2020 by having an operational new reactor in service by 2015 so as to be able to replace the current generation of reactors.

In **Germany**, the April 2002 *Atomic Energy Act* (AEA) that governs the long-term phase out nuclear energy for commercial power generation has thus far resulted in the shutdown of two reactors (Stade in 2003 and Obrigheim in 2005). The AEA grants each plant operating as of 1 January 2000 a residual operating life that has been calculated based on a standard operating life of 32 calendar years from the commencement of commercial operation. This would lead to the elimination of nuclear power generation in Germany around 2023. The law also bans the reprocessing of spent fuel after 1 July 2005. In early 2007, an application by a utility to transfer capacity from a decommissioned reactor to the currently operating Biblis nuclear facility in order to extend its life from 2008 to 2011 was turned down by the Minister of Environment.

In the **Netherlands**, the planned 2005 shutdown of the Borssele nuclear power plant was changed and the plant is now expected to operate through a 20 year life extension to 2033. In December 2006 the plant's power was increased by 0.35 GWe by improvements to the blade design of the turbine. In 2006, the Dutch government set conditions required for new nuclear construction that include a decision on high level waste disposal before 2016.

In **Norway**, the state-owned energy company Stakraft announced in 2007 that it was to evaluate the possibility of building a nuclear power plant fuelled by thorium. Some of the world's largest deposits of thorium are found in Norway.

In **Spain**, the government's plan to phase out nuclear energy in an orderly and progressive way, without compromising security of electricity supply, continues. In April 2006, the Jose Cabrera nuclear power plant (about 140 MWe net) was permanently shut down after 38 years of operation as a result of this policy.

Sweden remains committed to the phase out of nuclear energy over the next 30-40 years and closure of the second plant under this policy, the Barseback-2 reactor (about 0.6 GWe net), took place in May 2005. However, power uprates to the remaining reactors in the Swedish fleet are expected to make up for the 1.2 GWe in net capacity lost with the shutdown of Barseback-1 and -2.

In **Switzerland**, two popular initiatives, "Moratorium Plus" and "Electricity Without Nuclear" – the first to extend the moratorium on the licensing of new nuclear power plants that lapsed in 2000 and the second to phase out nuclear altogether – were rejected in a national vote in 2003 by majorities of 58.4% and 66.3%, respectively. After two years of parliamentary debate, a new *Nuclear Energy Law* (NEL) was adopted in March 2003 and entered into force in February 2005. The NEL keeps the nuclear energy option open, addresses key issues related to radioactive waste management (including a ten-year moratorium on reprocessing spent fuel as of 1 July 2006) and empowers the Federal Government (Federal Council) to authorise the construction, operation and decommissioning of NPPs.

In the **United Kingdom**, the four oldest reactors (Sizewell A 1&2 and Dungeness A 1&2) were permanently shut down on 31 December 2006 after 40 and 41 years of operation, respectively. A review of energy policy earlier in 2006 signalled the government's desire to replace the country's nuclear power stations, principally due to energy security concerns and commitments to reduce carbon emissions. Any new nuclear power plants are to be financed and built entirely by the private sector (with internalised waste and decommissioning costs). In May 2007, the government published a white paper outlining how approval of major new infrastructure projects, like nuclear plants, would be streamlined. Westinghouse, EDF, General Electric and Atomic Energy Canada Limited (AECL) indicated shortly thereafter their intention to submit designs for Generic Design Acceptance (pre-licensing). Later in 2007, the government launched a round of public consultation on the nuclear option.

The reactor-related uranium requirements for Western Europe in 2006 were about 18 060 tU and are expected to increase to 19 180 tU in 2007.

North America (113.965 GWe net as of 1 January 2007)

At the beginning of 2007, there were 103 reactors operating in the United States, 18 in Canada and two in Mexico. No new reactors were under construction or shut down in 2005 and 2006, though one reactor in long-term shutdown was restarted in Canada and one reactor in long-term shutdown in the United States (Brown's Ferry-1) was in the process of being returned to service.

In **Canada**, the Government of Ontario confirmed in 2006 that nuclear power will be an important part of its plan to address looming energy shortages and both Ontario Power Generation and Bruce Power applied for licenses to prepare sites for the construction of as many as eight new reactors. A feasibility study on the refurbishment of the Pickering B nuclear power station was initiated and refurbishment of the Darlington nuclear power plant is under consideration. In January 2007, the regulatory authority accepted Bruce Power's application for new build and an environmental assessment process was initiated. A programme to restart Bruce A Units 1 and 2 and refurbish Units 3 and 4 was initiated in 2005, with the first unit expected to be restarted in 2009. In Alberta, Energy Alberta Corporation proposed building two Advanced CANDU (ACR) reactors to produce the electricity required for extraction of oil from the tar sands and AECL is conducting a USD 2.4 million feasibility study of building a second reactor in the province of New Brunswick, in this case a 1.2 GWe ACR Reactor. In July 2005, New Brunswick Power contracted AECL for the USD 1.4 billion refurbishment of the Point Lepreau reactor.

In **Mexico**, a feasibility study of building additional nuclear power plants at Laguna Verde and other sites on the coast of the Gulf of Mexico has been completed and a decision by the government of Mexico is pending. In 2007, a USD 600 million refurbishment programme of the two units at Laguna Verde was initiated. The refurbishment, expected to be completed in 2010, is designed to increase the power of the two units by about 20%.

In the **United States**, momentum continues to build toward the construction of new nuclear power plants stimulated, in part, by the enactment of the *Energy Policy Act* of 2005 that offers several incentives for new power plant construction. In September 2007, NRG Energy submitted an application for a full combined construction and operation licence to regulatory authorities, the first utility in the United States in over 30 years to do so. Extensions to the operating lives and uprates of existing power plants continue to increase installed capacity and projected uranium requirements. United States regulatory authorities granted approvals of license extensions and power uprates through May 2007 that cover a total of 113 reactors, comprising about 4.9 GWe of capacity. Ten applications (1.02 GWe) are pending. Additional capacity was added in May 2007 when the Browns Ferry-1 plant (shut down since 1985) was returned to service after a USD 1.8 billion restart programme. In August 2007, the plant's owner, the Tennessee Valley Authority, announced that it would embark on a five year, USD 2.49 billion construction project to complete construction of the second unit at the Watts Bar nuclear plant (1.18 GWe). This plant was about 60% complete when construction was halted in 1988.

Annual uranium requirements for North America were about 24 890 tU in 2006 and are expected to increase to 24 925 tU in 2007.

East Asia (77.041 GWe net as of 1 January 2007)

As of 1 January 2007, 85 reactors[5] were in operation in East Asia. In this region, which is undergoing the strongest growth in nuclear capacity in the world, five power plants were connected to the grid (about 4.3 GWe net) during 2005 and 2006 while none were shut down. Six reactors were under construction that will add about 5.5 GWe net to the grid.

In **China**, there were ten reactors in operation (about 7.57 GWe net) and three under construction (about 3.2 GWe net) as of 1 January 2007. Construction of the Lingao 3 reactor (about 1.0 GWe net) was initiated in 2005 and construction of the Qinshan II-3 (about 0.61 GWe net) and Lingao 4 (about 1.0 GWe net) reactors began in 2006. In late 2006, following a bidding process, the Chinese government selected Westinghouse to construct four AP 1000 reactors. In July 2007, it was agreed these units (1.1 GWe each) would be built in pairs at the Sanmen and Hayang sites beginning in 2009, with operation expected in 2013. The Tianwan-1 Russian designed pressurised water reactor (about 1.0 GWe net) was connected to the grid in May 2006 and began commercial operation in May 2007.

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5. There were also six nuclear power plants in operation in Chinese Taipei (about 4.9 GWe net) and two plants under construction (about 2.7 GWe net).

That same month the Tianwan-2 unit was connected to the grid and began commercial operation in August 2007. Construction was initiated in August 2007 at the Hongyanhe nuclear power station, where four (1.0 GWe each) reactors of Chinese design are to be built, the first expected to commence operation in 2012. The government of China continues to implement a plan to increase installed nuclear capacity to 40 GWe by 2020 (about 4% of electrical supply) and has expressed the desire to further increase it to between 120 GWe and 160 GWe, including a gradual development and phase-in of a closed fuel cycle with fast breeder reactors. To reach the near-term goal, 30 additional reactors of at least 1.0 GWe net each will need to be constructed by 2020.

In **Japan**, both the Hamaoka 5 boiling water reactor (1.38 GWe gross) and the Higashidori 1 boiling water reactor (1.10 GWe gross) were connected to the grid in 2005 and the Shika 2 advanced boiling water reactor (l.36 GWe gross) was connected to the grid in 2006. Construction of the Tomari 3 pressurised water reactor (0.912 GWe gross)**,** which is expected to begin operation in late 2009, continues. In early 2007 the Government of Japan approved the basic energy plan to enhance security of supply by placing greater importance on developing nuclear power, a nuclear fuel recycling system and fast breeder reactors.

In the **Republic of Korea**, the Ulchin 6 reactor (about 0.96 GWe net) was connected to the grid in 2005 and in addition to Shin Kori 1, which began construction in 2006, construction of three additional Korean standard nuclear power plants (OPR 1000; about 0.96 GWe net each) was initiated in 2007; Shin Kori 2, which along with Shin Kori 1 is scheduled to be completed in late 2010 or 2011, and Shin Wolsong 1 and 2, which are due to be completed by 2012 and 2013. Construction of the first pair of third-generation APR-1400 reactors (Shin Kori-3 and Shin Kori-4) has been authorised, with construction to be initiated in 2008 and operation expected by 2013 and 2014. Current plans also include the construction of two more APR-1400 units (Shin-Ulchin 1 and 2), which are expected to be completed in 2015 and 2016. As a result, there are expected to be 28 nuclear reactors operational by 2016 as compared to the 20 power plants in operation on 1 January 2007.

The 2006 reactor-related uranium requirements for the East Asia region were 13 170 tU and for 2007 are expected to increase to 14 320 tU.

Central, Eastern and South-eastern Europe (47.665 GWe net as of 1 January 2007)

As of 1 January 2007, 67 reactors were operating in 10 countries. This region is also undergoing strong growth with ten reactors under construction that will add about 9.05 GWe net when completed. During 2005 and 2006, no new plants were connected to the grid but three reactors were shut down (a total of about 1.25 GWe net). Entry into the European Union has been a driving factor in the recent shutdown of these older model reactors in Bulgaria and the Slovak Republic, as well as the reactor shutdown in Lithuania in 2004. These shutdowns may eventually be offset by new nuclear capacity as these governments and private industry are considering the construction of new nuclear power plants to meet growing energy demand while reducing carbon dioxide emissions. In August 2007, the Cernavoda 2 CANDU 6 reactor (about 0.65 GWe) was connected to the grid in Romania.

In **Bulgaria**, two of the four reactors at Kozloduy (about 0.41 GWe net each) were permanently shut down by the end of 2006 as part of Bulgaria's agreement for entry into the European Union. This leaves only the two larger units (about 0.95 GWe net each) in operation at the site that once had six operating reactors. To compensate for the loss of generating capacity, construction of two VVER reactors (about 0.95 GWe net each) is underway at the Belene site, with the first expected to begin operating in the 2013-2014 time frame. In mid-2007 the Government of Bulgaria was seeking partners for a 49% share in the Belene Power Company that will operate these units.

In the **Czech Republic**, six reactors were in operation on 1 January 2007 with an installed capacity of about 3.5 GWe net. Ongoing modernisation of the Dukovany nuclear power plant units (4 VVERs with a capacity of 0.41 GWe net each), including the already completed reconstruction of low pressure flow parts and the introduction of advanced fuel, is expected to increase generation capacity by about 14% in 2012. In 2007, replacement parts were installed to the turbines of both units at the Temelin nuclear power plant, resulting in a capacity increase of about 0.3 GWe and an extended turbine life span. At present, there are no plans to build additional nuclear power plants before 2030.

In **Hungary**, four VVER reactors were in operation at the Paks nuclear power plant on 1 January 2007 with a combined installed capacity of about 1.8 GWe net. In 2005, the Government of Hungary endorsed a plan to extend operating lives of all four units by 20 years. In 2006, a USD 26 million uprate programme was initiated that will see the combined capacity of Paks plant increased to a total of 2.0 GWe net by 2009.

In **Lithuania**, the only remaining operating reactor, Ignalina-2 (about 1.2 GWe net), is scheduled to be shut down at the end of 2009 in accordance with agreements made for entry into the European Union. Ignalina-1 was shut down on 31 December 2004 under the same agreement. In 2007, the three Baltic states (Lithuania, Latvia and Estonia) and Poland agreed in principle to build new nuclear generating capacity at Ignalina, initially adding two units with a combined generating capacity of 3.2 GWe. At least one unit is expected to be in operation by 2015. As of August 2007, representatives from each country in the project were negotiating partnership share arrangements.

In **Romania**, one reactor with an installed capacity of about 0.65 GWe net was in operation and one reactor was under construction on 1 January 2007. This unit, the second at the Cernavoda site, a CANDU 6 PHWR (about 0.65 GWe net), was connected to the grid in October 2007. That same month, the Romanian government launched a new tender for the USD 3 billion construction of Cernavoda units 3 and 4 (each with a capacity of 0.72 GWe) that are expected to start-up in the 2014-2015 time frame.

In the **Russian Federation,** 31 reactors (about 21.7 GWe net) were in operation as of 1 January 2007. Five reactors were under construction (about 4.5 GWe net combined), including the Beloyarsk 4 fast breeder reactor (about 0.75 GWe net) that was initiated in July 2006. In April 2007, construction of two reactors on the world's first floating nuclear power plant [Severodvinsk – Akademik Lomonosov 1&2 (2x30 MWe)] officially began. The government plans are to add 2-3 GWe/year of capacity each year from 2009 to 2030, and by 2050 to have inherently safe nuclear plants in operation using fast reactors with a closed fuel cycle and MOX fuel. Plans are also in place to upgrade existing power plants by using better fuels more efficiently and to extend operating lives.

In the **Slovak Republic**, five reactors at two sites with a combined capacity of about 2.03 GWe net were in operation as of 1 January 2007. Bohunice-1 (about 0.41 GWe net) was shut down on 31 December 2006 and Bohunice-2 is scheduled to be shut down at the end of 2008 in accordance with agreements made for entry into the European Union, despite a recently completed major refurbishment programme. In early 2007, the Slovak utility Slovenske Elektrarne announced that it would finalise construction of Mochovce-3 and 4 units (about 0.4 GWe net each) and upgrade the Bohunice-3 and Bohunice-4 units in an effort to extend operating lives to 40 years (until 2025). Construction of the Mochovce-3 and 4 reactors originally began in 1987 but was halted in 1992 due to lack of funding. Completion of the two reactors under the new programme is expected to begin in 2008 and be finalised by 2012 and 2013.

Slovenia has a single nuclear reactor in operation (Krsko, 696 MWe) that is jointly owned by Croatia. Owned and operated by a joint Slovene-Croat company (NEK), Krsko entered commercial operation in 1983 and has an operational life designed for 40 years. Steam generators were replaced and the plant was uprated in 2001. The unit supplied 40% of the Slovenia's electricity in 2006.

In **Ukraine**, 15 reactors with a combined installed capacity of about 13.1 GWe net were in operation on 1 January 2007. The current Ukrainian government strategy calls for the nuclear share to be retained through 2030 at the current level of 45-50% of the total national electricity generation. This is expected to require the construction of twelve new reactors, ten of which with a capacity of about 1.5 GWe net.

Although other countries in the region do not currently have nuclear power plants, several governments, including **Armenia**, **Belarus**, **Georgia** and **Turkey**, are considering the possibility of building nuclear capacity to meet rising energy demand and to reduce greenhouse gas emissions.

Reactor-related uranium requirements in 2006 for the Central, Eastern and South-eastern European region were about 9 020 tU and are expected to increase to 9 310 tU in 2007.

Middle East, Central and Southern Asia (4.205 GWe net as of 1 January 2007)

As of 1 January 2007, 18 reactors were in operation and 8 were under construction (about 4.1 GWe net). During 2005 and 2006, two reactors were connected to the grid (about 1.0 GWe net) and no reactors were shut down.

In **India**, 16 reactors (about 3.58 GWe net) were operational on 1 January 2007 and seven reactors (four PHWRs, two light water reactors of Russian design and a prototype fast breeder reactor), with a total capacity of about 3.1 GWe net, were under construction. In April 2007, construction of one PHWR was completed and the Kaiga-3 reactor (about 0.2 GWe net) was connected to the grid. The total nuclear power generating capacity is expected to grow by about 6.7 GWe net by 2011 as units under construction are completed. Government plans call for the increase of the country's nuclear generation capacity to 20 GWe by 2020. The ongoing construction of a prototype fast breeder reactor (about 0.5 GWe) represents a major step forward in India's plans to introduce a thorium-based nuclear fuel cycle. Similarly, a prototype Advanced Heavy Water Reactor that would use thorium and uranium as fuel and generate more uranium than it consumes while producing electricity and desalinating water was undergoing pre-licensing review in 2007. In July 2007, India and the United States signed a civil nuclear co-operation agreement. If the agreement is approved by both governments and the Nuclear Suppliers Group, and India successfully negotiates an inspection regime with the IAEA for its civil nuclear facilities, India could access foreign nuclear fuel and equipment for the first time in three decades. At present, the scope of India's nuclear growth and the capacity of its currently operating reactors are periodically limited by indigenous uranium supply.

In **Iran**, the expected start-up of the Bushehr-1 reactor (about 0.9 GWe net) has been delayed until late 2008. Atomstroyexport, the Russian supplier of the reactor, has pushed back the start-up date of the reactor a number of times owing to technical difficulties. The Government of Iran has announced its intention to have 20 GWe net of installed capacity by 2026.

In **Pakistan**, two reactors (about 0.43 GWe net) were operational on 1 January 2007. In 2005, construction of a third reactor, Chasnupp-2 (about 0.3 GWe net), began under an agreement with the China National Nuclear Corporation. Completion is expected in 2011. In 2005, in order to meet rising demand for electricity, the Government of Pakistan approved a plan to increase nuclear generating capacity to 8.8 GWe by the year 2030, corresponding to a share of 5% in the total installed electricity generating capacity of the country at that time. The plan envisions gradually increasing local content to reduce the capital cost of nuclear power plants, as well as increasing unit capacity from 0.3 GWe to 0.6 GWe before eventually standardising it at 1.0 GWe.

In July 2006, the Government of **Kazakhstan** signed a USD 10 billion agreement with the Russian Federation for new reactors, uranium production and enrichment. To date, plans detailing the timing of the construction of new reactors have not been announced.

In May 2007, the Gulf Cooperation Council (**Saudi Arabia**, **Kuwait**, **United Arab Emirates**, **Qatar**, **Bahrain** and **Oman**) announced its intention to consider the construction of nuclear power plants for generating electricity and desalinisation in the 2020 to 2025 time frame. In August 2007, that Minister of National Infrastructures of **Israel** announced that he would submit a plan to the government to build a nuclear reactor. That same month, the government of **Yemen** also expressed interest in building nuclear capacity to meet the growing shortfall of electricity supply.

Reactor-related uranium requirements for the Middle East, Central and Southern Asia region were about 510 tU in 2006 and are expected to remain the same in 2007.

Central and South America (2.735 GWe net as of 1 January 2007)

At the beginning of 2007, there were four reactors operating in two countries in this region.

In **Brazil**, two reactors (Angra-1 and -2, about 0.6 GWe net and 1.2 GWe net, respectively each) were in operation on 1 January 2007. In May 2007, the President of Brazil approved the resumption of construction of the Angra-3 reactor (about 1.2 GWe net), which is expected to be completed in 2014. The government of Brazil is considering the possibility of building an additional four to eight units by 2030 in order to meet rising energy demand in the country.

In **Argentina**, two reactors (in total about 0.9 GWe net) were in operation on 1 January 2007. In May 2006, AECL signed an agreement with the state nuclear electrical utility to assist in completing the construction of the country's third reactor (Atucha-2), refurbish the Embalse PHWR and develop a feasibility study of building another PHWR for operation by 2015. Construction of the Atucha-2 reactor was suspended in 1984 because of a lack of funds when the reactor was about 80% complete.

The uranium requirements for Central and South America were about 570 tU in 2006 and are expected to remain the same in 2007.

Africa (1.84 GWe net as of 1 January 2007)

Nuclear capacity remained constant in Africa with the region's only two reactors located in **South Africa**. In order to meet rising demand for electricity, South Africa's state-owned utility Eskom approved the construction of a second nuclear power station in 2007 and issued an EIA of the construction of a new 4.0 GWe nuclear station. Should the project proceed as planned, it is estimated that construction could begin in 2009 or 2010 and the first unit of the station could be commissioned in 2016. This is the first step in Eskom's evaluation of adding 20.0 GWe of nuclear generating capacity by 2025. South Africa is also continuing to develop the Pebble Bed Modular Reactor, a high-temperature, helium-cooled reactor (about 0.1 GWe net). A demonstration plant is to be built in 2009 with operation expected to begin in 2013.

In July 2007, **Libya** signed a memorandum of understanding with France to build a nuclear powered desalinisation plant. The government of **Nigeria** expects to have its first nuclear power plant built and in operation by 2017, in order to meet rising demand for electricity. Other countries, including **Egypt**, **Ghana**, **Namibia** and **Uganda**, have also expressed interest in constructing nuclear power plants in order to meet rising electricity demand and for desalinisation.

Annual reactor-related uranium requirements for Africa were about 280 tU in 2006 and are expected to increase slightly to 290 tU in 2007.

South-eastern Asia (0 GWe net as of 1 January 2007)

This region has no current commercial nuclear power capacity. However, **Indonesia** and **Vietnam** are planning the construction of nuclear reactors to satisfy rising demand for electricity. Indonesia has announced its intention to start construction of a commercial nuclear power plant by 2010 with operation expected by 2016. Vietnam has established a nuclear power programme and approved a national energy plan that aims to construct two units (total capacity of 2.0 GWe) to be operational by 2020. The governments of the **Philippines** and **Thailand** are also considering the use of nuclear power to meet growing electricity demand.

Pacific (0 GWe net as of 1 January 2007)

This region currently has no commercial nuclear power capacity. Although current policy prohibits the development of commercial nuclear energy, the Government of **Australia** released in late 2006 a report on opportunities for Australia in uranium mining and nuclear energy. The results of this report have initiated a debate on the role nuclear power generation should play in Australia's future. Construction of the Open Pool Australian Light-water (OPAL) research reactor was completed and the first fuel loaded in August 2006. The government of **New Zealand** has a policy prohibiting the development of nuclear power but has recently discussed the possibility of building nuclear power plants for future electricity supply in light of greenhouse gas reduction targets and declining supply of natural gas.

B. PROJECTED NUCLEAR POWER CAPACITY AND RELATED URANIUM REQUIREMENTS TO 2030

Factors affecting capacity and uranium requirements

Reactor-related requirements for uranium, over the short-term, are fundamentally determined by installed nuclear capacity, or more specifically by the number of kilowatt-hours of electricity generated in operating nuclear power plants. As noted, the majority of the anticipated near-term capacity is already in operation, thus short-term requirements may be predicted with relative certainty.

Uranium demand is also directly influenced by changes in the performance of installed nuclear power plants and fuel cycle facilities, even if the installed base capacity remains the same. Over the past decade there has been a worldwide trend toward higher nuclear plant energy availability and capacity factors. In 2006, the average world nuclear energy availability factor (as defined by the IAEA) was 82.7%, compared to 71.0% [1] in 1990. Longer operating lifetimes and increased availability tend to increase uranium requirements. Other factors that affect uranium requirements include plant retirements, fuel-cycle length and discharge burn-up and the strategies employed to optimise the relationship between the price of natural uranium and enrichment services.[6] Recent high uranium prices have provided the incentive for utilities to reduce uranium requirements by specifying lower tails assays at enrichment facilities, to the extent possible in current contracts and the ability of the enrichment facilities to provide the increased services. As noted in the 2006 Annual Report of the Euratom Supply Agency, the trend toward lower tails assays has continued in the European Union (EU), with some utilities now specifying tails assays as low as 0.20% [2].

The strong performance and economic competitiveness of existing plants, chiefly because of low operating, maintenance and fuel costs, has made retention and improvement of these plants desirable in many countries. This has resulted in the trend to keep existing plants operating as long as can be achieved safely as well as upgrading their generating capacity, when possible. This strategy is especially pronounced in the United States but other countries (e.g. Canada, France, Hungary, Netherlands, the Russian Federation, Sweden and Switzerland) have or are planning to extend the lives of existing power plants and/or upgrade their generating capacities.

Installation of new nuclear capacity will increase uranium requirements, providing that new build capacity outweighs retirements. Many factors influencing decisions on building new nuclear generating capacity must be considered before any new significant building programmes will take place. These factors include projected electricity demand, security and cost of fuel supplies, the cost competitiveness of nuclear compared to other generation technologies and environmental considerations, in particular greenhouse gas emissions. With respect to nuclear, additional critical issues in need of resolution include public attitudes and acceptance of the safety of nuclear energy and proposed waste management strategies, as well as non-proliferation concerns stemming from the relationship between the civil and military nuclear fuel cycles.

Recent events indicate that many nations have decided that, on balance, objective analysis of these factors supports the construction of new nuclear power plants. Significant building programmes are underway in China, India, Korea, Japan and the Russian Federation and are planned in South Africa. Smaller programmes are also underway or planned in Canada, Finland and France and momentum is continuing to build in the United States, where the construction of 15 plants or more is currently under consideration. In September 2007, NRG Energy became the first nuclear utility in the United States in over 30 years to submit a full combined construction and operating license application to regulators.

Increased nuclear growth has also received support from key international organisations and political leaders. The 2006 World Energy Outlook, after noting that current energy development is underinvested, vulnerable and dirty, included an alternative policy scenario that, among other things, would result in a 10% increase in nuclear power generating capacity to address security of supply issues and reduce greenhouse gas emissions. In April 2007, G7 Finance Ministers endorsed nuclear energy as an increasingly attractive source of electricity as governments confront the issues of global climate change and an over-dependence on fossil fuels. They also recommended diversification of energy sources for both developed and developing countries, noting that such a strategy can include advanced energy technologies such as renewable, nuclear and clean coal. In May 2007, the Intergovernmental Panel on Climate Change acknowledged the role that nuclear energy could play in

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6. A reduction of the enrichment tails assay from 0.3 to 0.25% ^{235}U would, all other factors being equal, reduce uranium demand by about 9.5% and increase enrichment demand by about 11%. The tails assay selected by the enrichment provider is dependent on many factors including the ratio between natural uranium and enrichment prices.

reducing greenhouse gas emissions, although it noted that safety, proliferation and waste remain constraints to nuclear development. In June 2007, G8 leaders issued a statement noting that some of the group believed that the continued development of nuclear energy would contribute to global energy security, reduce harmful air pollution and address the climate change challenge.

On the other hand, nuclear phase-out programmes currently in place in several European nations will tend to reduce installed capacity over time in that region. However, construction programmes, particularly in east and central Asia, along with capacity upgrades and life extensions, are projected to outweigh reactor shutdowns and world installed nuclear capacity is expected to continue to increase through 2030, thereby increasing projected uranium requirements.

Projections to 2030[7]

Forecasts of installed capacity and uranium requirements, although uncertain due to the above-mentioned factors, point to future growth. Installed nuclear capacity is projected to grow from about 370 GWe net at the beginning of 2007 to about 509 GWe net (low case) or 663 GWe net (high case) by the year 2030. The low case represents growth of 38% from current capacity, while the high case represents a net increase of about 80% (Table 27 and Figure 9).

Nuclear capacity projections vary considerably from region to region. The East Asia region is projected to experience the largest increase that, by the year 2030, could result in the incorporation of 69-94 GWe of new capacity, representing 91% to over 124% increases over current capacity, respectively. Nuclear capacity in Central, Eastern and South-eastern Europe is also expected to increase considerably, with 40-74 GWe of new capacity projected by 2030 (increases of about 84-159%). Other regions projected to experience growth include the Middle East and Southern Asia; Central and South America; Africa and South-eastern Asia. For North America, the increase of projected nuclear capacity for 2030 varies from about 9% to 32%. Only in Western Europe is nuclear capacity expected to decrease significantly, despite new reactors being built or planned in Finland and France, as announced plans to phase out nuclear energy in Belgium, Germany, Spain and Sweden are implemented. Decreases in capacity of about 10-29% are projected for 2030 in Western Europe.

World reactor-related uranium requirements by the year 2030 (assuming a tails assay of 0.3%) are projected to increase to between 93 775 tU/year in the low case and 121 955 tU/year in the high case, representing about 41% and 83% increases respectively, compared to 2006 (Table 28 and Figure 10). As in the case of nuclear capacity, uranium requirements are expected to vary considerably from region to region. Uranium requirement increases are projected to be largest in the East Asia region, where expected increases in nuclear capacity would more than double the 2006 uranium needs by the year 2030. In contrast to steadily increasing uranium requirements in the rest of the world, requirements in North America are projected to remain fairly constant or increase by about 20% in the high case, whereas in the Western Europe region uranium requirements are expected to decline between 4% and 34% through the year 2030.

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7. Projections of nuclear capacity and reactor-related uranium requirements are based on official responses from member countries to questionnaires circulated by the Secretariat. For countries that did not provide this information, Secretariat projections are based on data from the IAEA *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030*. Because of the uncertainty in nuclear programmes in the years 2015, 2020, 2025 and 2030, high and low values are provided.

Table 27. **Installed nuclear generating capacity to 2030**
(MWe net, as of 1 January 2007)

COUNTRY	2006	2007	2010		2015		2020		2025		2030	
			Low	High	Low	High	Low	High	Low	High	Low	High
Argentina	940	940	940	1 625*	1 625*	2 320*	2 320*	2 320*	1 985*	3 700*	1 985*	4 060*
Armenia*	375	375	375	375	375	375	0	700	0	700	0	1 400
Belarus*	0	0	0	0	0	0	0	1 000	1 000	1 000	1 000	1 000
Belgium	5 825	5 825	5 825	5 825	5 825	5 825	4 035	5 825	2 025	5 825	0	5 825
Brazil	1 795[b]	1 795[b]	1 795[b]	1 795[b]	1 795[b]	3 905[b]	3905*	3 905	4 095*	5 095*	4 095*	8 095*
Bulgaria	2 720[b]	1 905[b]	1 905[b]	1 905[b]	2 905*	3 905[b]	3 905[b]	3 905*	3 905*	3 905[b]	3 905*	3 905[b]
Canada	12 500	12 500	14 000+	14 000+	14 000	14 000+	14 000	14 000+	15 000*	17 000*	17 000*	20 000*
China[a]	6 570[b]	7 570[b]	13 000	20 000	25 000	35 000	30 000	40 000	40 000	50 000	50 000	60 000
Czech Republic	3 490	3 490	3 500	3 550	3 540	3 600	3 550	3 750	3 600	3 750	3 600	3 750
Egypt*	0	0	0	0	0	0	0	600	0	1200	0	1800
Finland	2 680	2 680	2 680	2 680	4 280	4 280	4 280	4 280	4 280	4 280	4 280	4 280
France	63 260	63 260	63 130	63 130	63 130	64 700	63 130	64 700	64 700	64 700	64 700	64 700
Germany	20 336	20 339	12 500	16 700	8 000	12 000	1 300	4 000	0	0	0	0
Hungary	1 780	1 780[b]	1 920	1 920	1 920	1 920	1 920	1 920	1 920	1 920	1 920	1 920
India	3 575	3 780	6 220	6 690	9 180	13 130	13 725*	19 435	19 435*	27 665*	19 435*	35 425*
Indonesia*	0	0	0	0	0	0	0	900	900	1 800	900	3 600
Iran, Islamic Rep. of	0	0	915*	915*	915	915	6 000	6 000	11 000	11 000	16 000	20 000
Japan	47 100[b]	47 100[b]	48 545[b]	48 545[b]	49 830*	55 030*	56 355*	62 780*	62 780*	69 280*	62 980*	72 080*
Kazakhstan	0	0	0	0	0	600	0	600*	0	600*	0	600*
Korea, Republic of[b]	17 454	17 454	17 450	18 150	24 155	25 530	25 530	26 910	25 530	26 910	25 530	26 910
Lithuania	1 190[b]	1 190[b]	0	0*	0	1 500*	1 500*	1 500*	1 500*	3 000*	1 500*	3 000*
Malaysia*	0	0	0	0	0	0	0	0	0	0	0	900
Mexico	1 365+	1 365+	1 365+	1 570+	1 510*	1 580+	1 510*	1 580+	1 510*	1 580+	1 510*	1 580+

Table 27. **Installed nuclear generating capacity to 2030** (continued)
(MWe net, as of 1 January 2007)

COUNTRY	2006	2007	2010		2015		2020		2025		2030	
			Low	High	Low	High	Low	High	Low	High	Low	High
Netherlands	450	480	480	480	480	480	480	480	480	480	480	480
Pakistan*	425	425	725	725	600	725	900	1 975	1 850	3 750	1 850	6 000
Poland	0	0	0	0	0	0	0	0	1500	1500*	4500	4500*
Romania*	650	650	1 300	1 300	1 300	1 950	1 950	1 950	1 950	2 950	1 950	2 950
Russian Fed.	21 740[b]	21 740[b]	24 000	25 000	30 000	32 000	37 000	44 000	40 000	50 000	42 000	60 000
Slovak Republic	2 440	2 030	1 740	1 740	1 740	2 610	1 740	2 610	1 740	2 610	870	2 740
Slovenia	675	695	695	695	695	695	695	2 200	695	2 200	695	2 200
South Africa	1 800	1 840	1 840	1 840	2 005	8 420	10 500	15 340	16 000	25 000	20 000	25 000
Spain	7 450	7 450	7 450	7 450	7 450	7 450	7 450	7 450	7 300*	9 250*	7 300*	10 750*
Sweden	8 990	9 035	9 480+	9 480*	10 080+	10 080*	10 080+	10 080*	10 080+	10 080*	10 080+	10 080*
Switzerland	3 220	3 220	3 220	3 220	2 865	3 220	2 865	3 220	2 135	3 220	0	3 220
Turkey	0	0	0	0	1 500	4 500	4 500	4 500	4 500*	4 500*	4 500*	5 000*
Ukraine	11 800	13 800	13 800	13 800	15 800	17 900	16 600	20 200	18 800	26 200	20 000	26 200
United Kingdom	11 900	10 500	10 500	10 600+	6 000	6 000*	3 700	11 070*	1 200	11 660*	1 200	12 700*
USA	100 100	100 100	100 500	100 500	103 400	103 400	108 500	111 700	108 500	118 300	105 900	128 700
Vietnam*	0	0	0	0	0	0	0	1 000	1 000	2 000	1 000	3 000
OECD TOTAL	310 340	308 608	304 240	309 540	309 705	326 205	314 925	340 855	317 280	355 345	311 850	374 715
WORLD TOTAL	369 515	370 233	376 670	392 480	409 520	456 355	450 735	516 495	490 515	587 530	509 080	663 050

* Secretariat estimate based on *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030*, IAEA (Vienna), July 2007.
\+ Data from *Nuclear Energy Data*, NEA (Paris), 2007.
(a) The following data for Chinese Taipei are included in the World Total but not in the totals for China: 4 920 MWe net in 2006 and 2007, 4 920 and 6 270 MWe net for the low and high cases of 2010, 7 620 MWe net for the low and high cases of 2015, 7 620 and 8 920 MWe net for the low and high cases of 2020 and 2025, and 6 415 and 11 500 MWe net for 2030 low and high cases, respectively.
(b) MWe gross converted to net by the Secretariat.

Table 28. **Annual reactor-related uranium requirements to 2030**
(tonnes U, rounded to nearest five tonnes)

COUNTRY	2006	2007	2010		2015		2020		2025		2030	
			Low	High	Low	High	Low	High	Low	High	Low	High
Argentina	120	120	95*	250*	250*	475*	475*	475*	400*	750*	400*	825*
Armenia*	90	90	90	90	90	90	0	180	0	180	0	300
Belarus*	0	0	0	0	0	0	0	180	0	180	0	180
Belgium	880	1 065	1 075	1 075	750	1 075	750	1 075	375	1 075	0	1 075
Brazil	450	450	450	810	450	810	810*	810*	1000*	1200*	1 000*	2 000*
Bulgaria	505	505	1 320	1 320*	1 050	1 050*	1 050	1 050*	1 050	1 050*	1 050	1 050*
Canada	1 800	1 900	1 900	2 000	1 900	2 000	2 000	2 300	2 400*	2 600*	2 600*	2 900*
China[a]	1 200	1 500	2 340	3 600	4 500	6 300	5 400	7 200	7 200	9 000	9 000	10 800
Czech Republic	665	740	695	770	650	710	650	710	650	710	650	710
Egypt*	0	0	0	0	0	0	0	110	0	220	0	380
Finland	465	470	440	470	640	700	640	700	640	700	640	700
France+	7 185	9 000	8 500	9 500	8 000	9 000	8 000	9 000	8 000	9 000	8 000*	9 000*
Germany	3 710	3 490	1 800	2 000	1 100	1 500	200	350	0	0	0	0
Hungary	380	380	380	380	380	380	380	380	380	380	380	380
India*	445	445	880	880	1 140	1 400	2 825	2 825	2 825	4 060	2 825	5 200
Indonesia*	0	0	0	0	0	0	0	160	160	325	160	650
Iran, Islamic Rep. of	0	5	160	160	160	160	255	255	995	995	2 475	2 475
Japan	7 940	8 790	8 875	8 875*	11 340*	11 340	12 500*	13 940*	13 940*	15 380*	13 980*	16 000*
Kazakhstan	0	0	0	0	0	60	0	90*	0	90*	0	90*
Korea, Rep. of	3 200	3 200	3 200	3 600	4 400	5 000	4 800	5 300	4 800	5 300	4 800	5 300
Lithuania	60	90	0*	0*	0*	270*	270*	270*	270*	540*	270	540*
Malaysia*	0	0	0	0	0	0	0	0	0	0	0	160*
Mexico	200+	200+	210+	410+	210+	410*	215*	425+	215+	425*	215+	425*

Table 28. **Annual reactor-related uranium requirements to 2030** (continued)
(tonnes U, rounded to nearest five tonnes)

COUNTRY	2006	2007	2010		2015		2020		2025		2030	
			Low	High	Low	High	Low	High	Low	High	Low	High
Netherlands	65	70	70	70	70	70	70	70	70	70	70	70
Pakistan*	65	65	155	155	90	110	135	155	330	670	330	1180
Poland*	0	0	0	0	0	0	0	0	270	270	660	660
Romania*	100	200	200	200	200	300	300	300	300	455	300	455
Russian Federation	4 000	4 100	5 400	5 400	7 200	7 700	8 200	9 700	8 800	11 000	9 200	13 000
Slovak Republic	490	475	385	385	400	595	385	585	400	595	195	395
Slovenia	250	250	250	250	250	250	250	750	250	750	250	750
South Africa	280	290	290	290	295	1 310	1 570	2 145	2 100	3 235	3 175	3 235
Spain	1 725	1 310	1 830	1 830	1 010	1 010	1 400	1 400	1 400	1 755*	1 400	2 040*
Sweden+	1 600	1 600*	1 400	1 800	1 400	1 800	1 500	1 800	1 500	1 800	1 500	1 800
Switzerland	265	275	370	385	320	385	500	565	380	565	0	445
Turkey*	0	0	0	0	200*	650*	650*	650*	650*	650*	650*	700*
Ukraine	2 480	2 480	2 480	2 480	2 480	3 230	3 020	3 660	3 390	4 800	3 600	4 800
United Kingdom	2 165	1 900*	1 700	1 900	800	1 100	400	1 900*	300	2 000*	300	2 200*
United States	22 890	22 825*	22 625	22 625	23 860	23 865	24 510	25 245	23 855	25 865	22 265	26 615
Vietnam*	0	0	0	0	0	0	0	180	180	360	180	540
OECD TOTAL	55 625	57 690	55 455	58 075	57 435	61 590	59 550	66 395	59 955	68 870	57 645	70 755
WORLD TOTAL	66 500	69 110	70 395	75 020	76 870	86 385	85 390	98 600	90 935	110 510	93 775	121 955

* Secretariat estimate based on *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030*, IAEA (Vienna), July 2007.

\+ Data from *Nuclear Energy Data*, NEA (Paris), 2007.

(a) The following data for Chinese Taipei are included in the World Total but not in the totals for China: 830 tU/year in 2006 and 2007; 830 tU/year and 1 280 tU/year in the low and high cases in 2010, respectively, 1 280 tU/year in the low and high cases in 2015, 1 280 tU/year and 1 510 tU/year in the low and high cases in 2020 and 2025, respectively, and 1 075 tU/year and 1 930 tU/year in the low and high cases in 2030, respectively.

(b) Preliminary data.

Figure 9. **Projected installed nuclear capacity to 2030**
(low and high projections)

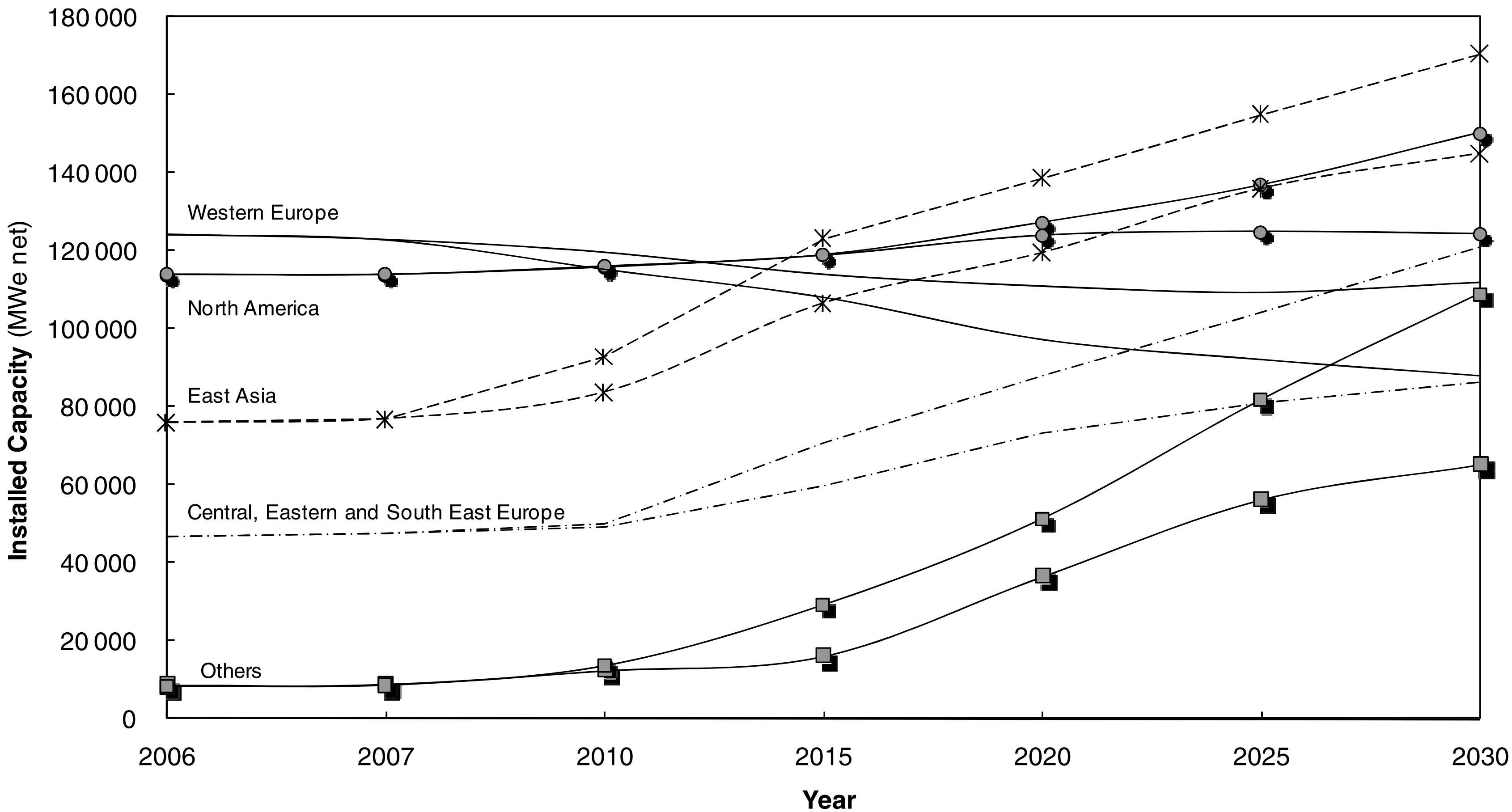
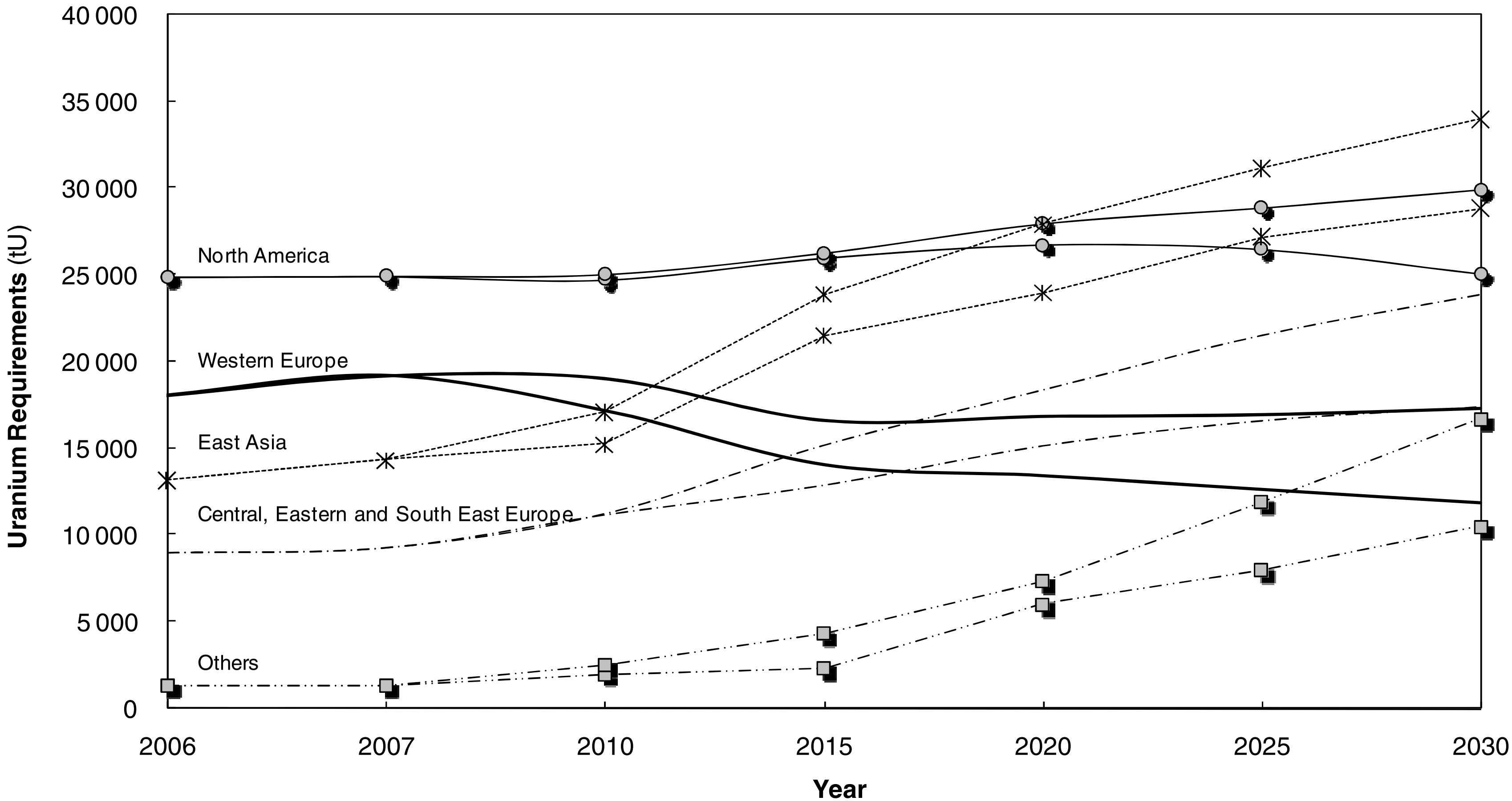


Figure 10. **Annual reactor uranium requirements to 2030**
(low and high projections)



C. URANIUM SUPPLY AND DEMAND RELATIONSHIPS

Uranium supply and demand remains in balance and there have been no supply shortages since the last report. However, a number of different sources of supply are required to meet demand. The largest is the primary production of uranium that, over the last several years, has satisfied some 50-60% of world requirements. The remainder has been provided or derived from secondary sources including stockpiles of natural and enriched uranium, the reprocessing of spent fuel and the re-enrichment of depleted uranium tails.

Primary sources of uranium supply

Uranium was produced in 20 countries in 2006, one more than in 2005, as the Islamic Republic of Iran started small-scale production in 2006. However, three of the 20 countries (France, Germany and Hungary) only produce uranium as a consequence of mine remediation efforts. Two countries, Australia and Canada, accounted for 44% of world production in 2006, and just eight countries, Canada (25%), Australia (19%), Kazakhstan (13%), Niger (9%), the Russian Federation (8%), Namibia (8%), Uzbekistan (6%) and the US (5%), accounted for 93% of the world's uranium mine output.

In comparison, 31 countries currently consume uranium in commercial nuclear power plants creating an uneven distribution between producing and consuming countries (Figure 11). In 2006, only Canada and South Africa produced sufficient uranium to meet domestic requirements. All others must use secondary sources or import uranium and, as a result, the international trade of uranium is a necessary and established aspect of the uranium market. Given the uneven geographical distribution between producers and consumers, the safe and secure shipment of nuclear fuel will need to continue without unnecessary delays and impediments. Difficulties that some producing countries, in particular Australia, have encountered with respect to international shipping requirements and transfers to international ports have therefore become a matter of some concern. However, efforts to better inform port authorities of the risks involved and the longstanding record of successful shipments of these materials have resulted in some improvements in the situation.

Primary uranium production alone is insufficient to meet world uranium requirements. In 2006, world uranium production (39 603 tU) provided about 60% of world reactor requirements (66 500 tU). In OECD countries, 2006 production of 19 705 tU provided only about 35% of demand of 55 625 tU (Figure 12). Remaining requirements were met by imports and secondary sources.

Secondary sources of uranium supply

Uranium is unique among energy fuel resources in that a significant portion of demand is supplied by secondary sources rather than direct mine output. These secondary sources include:

- Stocks and inventories of natural and enriched uranium, both civilian and military in origin.
- Nuclear fuel produced by reprocessing spent reactor fuels and from surplus military plutonium.
- Uranium produced by re-enrichment of ***depleted uranium*** tails.

Figure 11. **Estimated 2007 uranium production and reactor-related requirements for major producing and consuming countries**

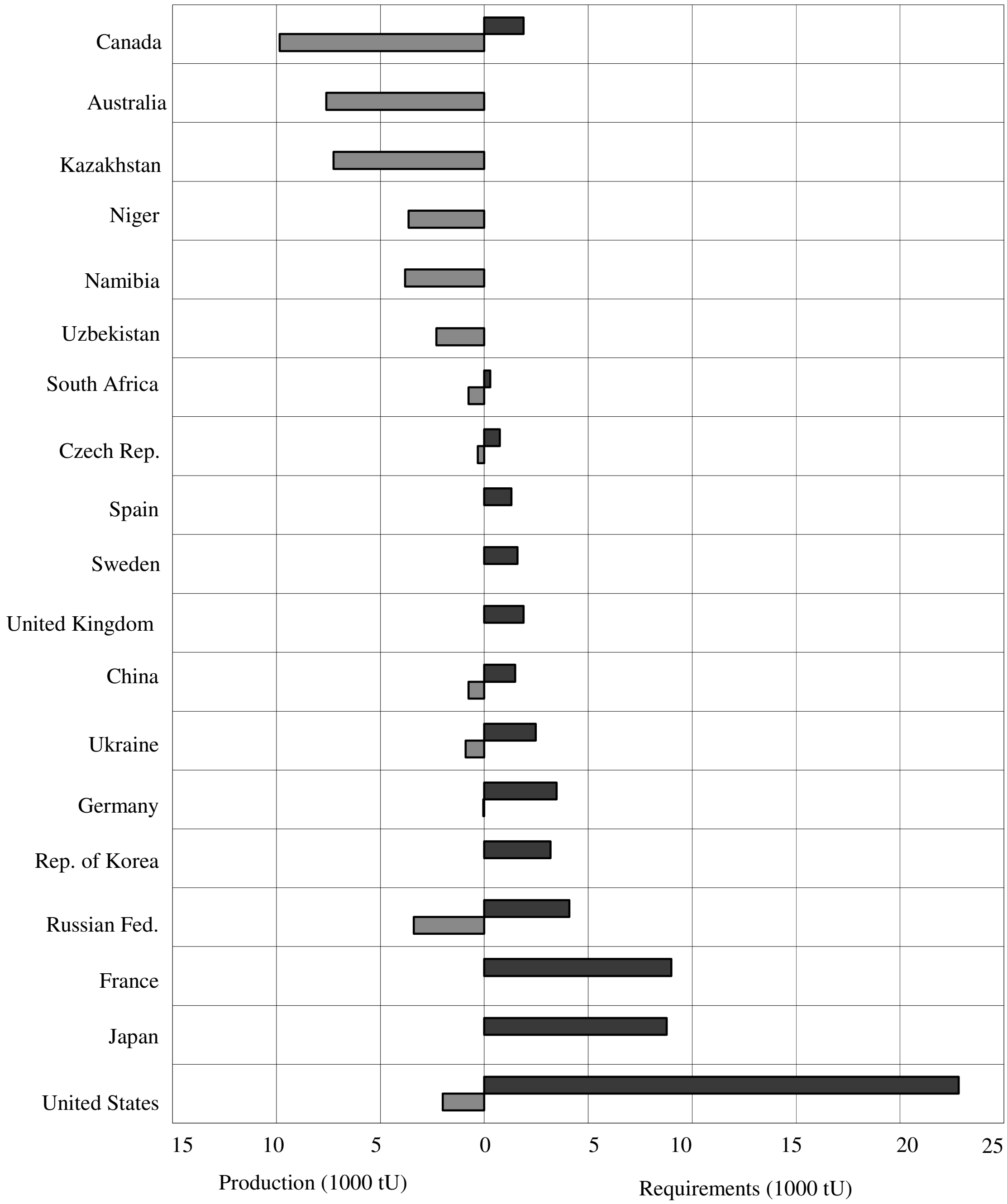
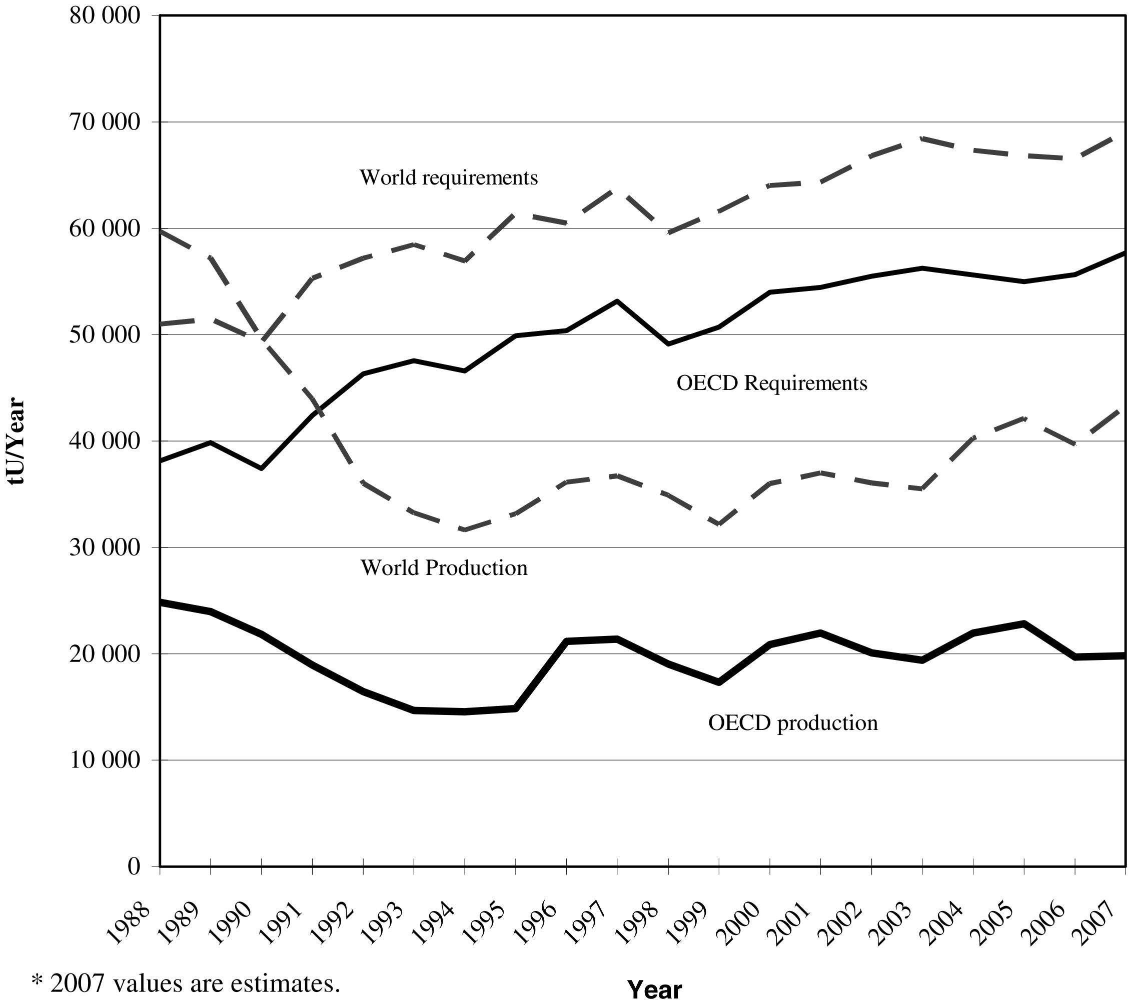


Figure 12. **OECD and world uranium production and requirements***
(1988-2007)

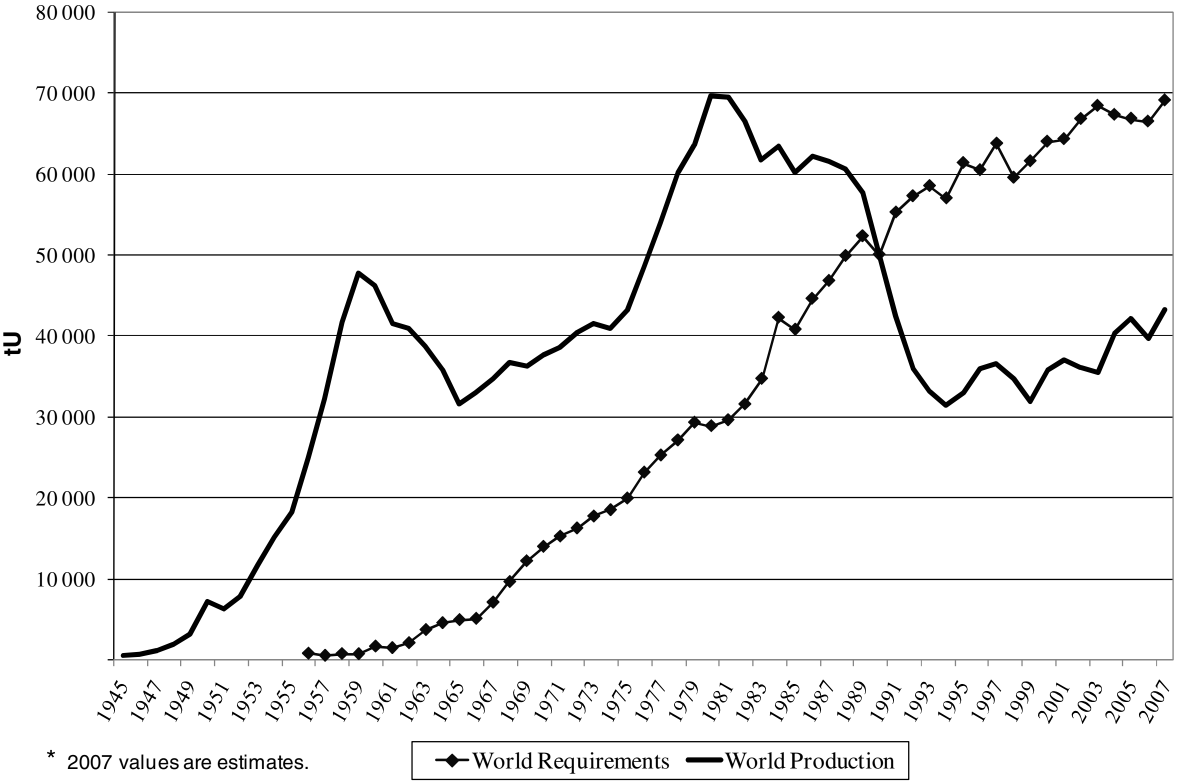


* 2007 values are estimates.

1. Natural and enriched uranium stocks and inventories

From the beginning of commercial exploitation of nuclear power in the late-1950s through to about 1990, uranium production consistently exceeded commercial requirements (Figure 13). This was mainly the consequence of a lower than expected nuclear electricity generation growth rate and high levels of production for military purposes. This over production created a stockpile of uranium potentially available for use in commercial power plants.

Figure 13. **Annual uranium production and requirements***
(1945-2007)

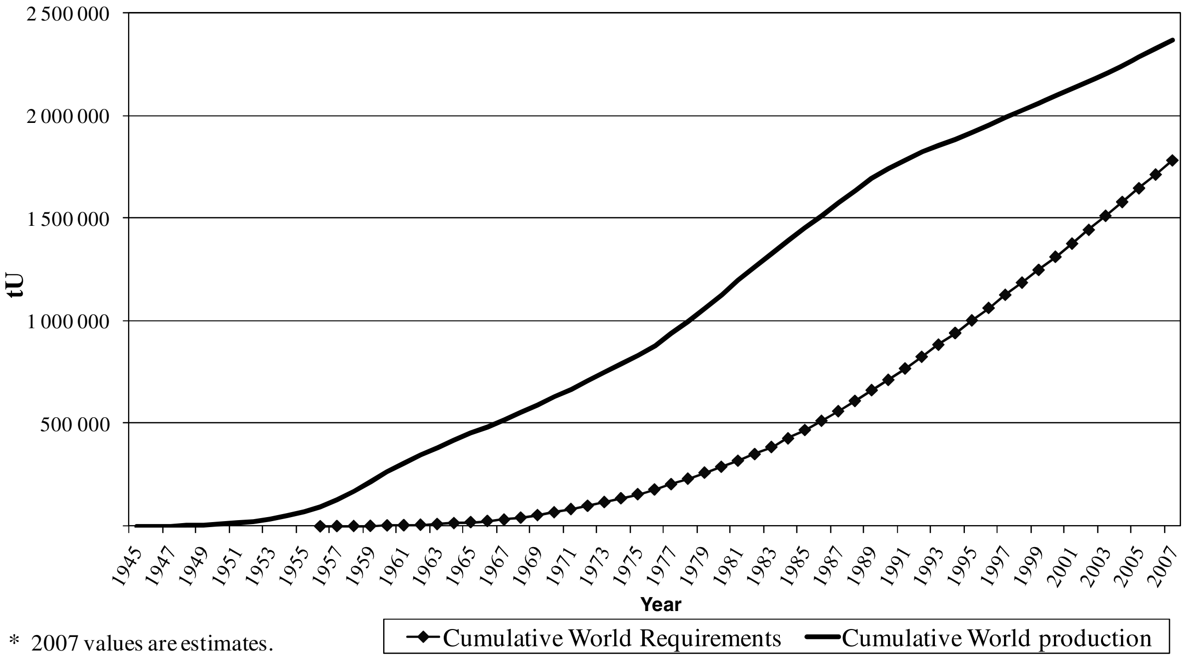


* 2007 values are estimates.

Following the political and economic reorganisation in Eastern Europe and the former Soviet Union in the early-1990s, major steps have been taken to develop an integrated commercial world uranium market. More uranium is now available from the former Soviet Union, in particular Kazakhstan, the Russian Federation and Uzbekistan, as is more information on the production and use of uranium in the former Soviet Union. Despite these developments and the increased availability of information regarding the amount of uranium held in inventory by utilities, producers and governments, uncertainty remains regarding the magnitude of these inventories as well as the availability of uranium from other sources. This, combined with uncertainty about the desired levels of inventories, continues to have significant influence on the uranium market.

However, data from past editions of this publication, along with information recently provided by member states, gives an indication of the possible upper bound of potentially commercially-available inventories. Cumulative production through 2006 is estimated to have amounted to about 2 325 000 tU, whereas cumulative reactor requirements through 2006 amounted to about 1 700 000 tU. This leaves an estimated remaining stock of about 625 000 tU, the upper limit of what could potentially become available to the commercial sector (Figure 14). This base of already mined uranium has essentially been distributed into two segments with the majority used and/or reserved for the military sector and the remainder used or stockpiled by the civilian sector. Since the end of the Cold War, increasing amounts of uranium, previously reserved for military purposes, have been released to the commercial sector. However, a significant portion of this will likely always remain reserved for military uses.

Figure 14. **Cumulative uranium production and requirements***
(1945-2007)



* 2007 values are estimates.

Civilian inventories include strategic stocks, pipeline inventory and excess stocks available to the market. Utilities are believed to hold the majority of commercial stocks because many have policies that require carrying the equivalent of one to two years of natural uranium requirements. Despite the importance of this secondary source of uranium, relatively little is known about the size of these stocks because few countries are able or willing to provide detailed information on stockpiles held by producers, consumers or governments due to confidentiality concerns (Table 29).

There is, however, evidence that some utilities have recently been building inventory. In the United States, 2006 year-end commercial uranium stocks (natural and enriched uranium equivalent) totalled 41 279 tU. This represents an increase of about 13% compared to the 2005 and 2004 levels of 36 068 tU and 36 622 tU, respectively. Utility stocks drove this upward trend, increasing by 12.4% between year end 2004 and 2005, and by 20.8% between 2005 and 2006, resulting in a total holding of 30 081 tU at year end 2006. In contrast, government stocks of natural uranium declined 11% from 19 326 tU at the end of 2004 to 17 179 tU at the end of 2006 in the United States.

The Euratom Supply Agency noted in its 2006 Annual Report [2] that uranium deliveries to the EU were slightly higher than the amount of uranium loaded into reactors, suggesting that uranium inventories were also being built in the EU, similar to the situation noted above in the case of utilities in the United States.

Available information suggests that no significant excess inventories are held in Eastern Europe and Central Asia, with the exception of the Russian Federation. The inventory of enriched uranium product and natural uranium held by the Russian Federation, though never officially reported, is believed to be substantial. However, these inventories have been drawn down for several years.

Large stocks of uranium, previously dedicated to military applications in both the United States and the Russian Federation, have become available for commercial applications introducing a significant source of uranium into the market. Highly enriched uranium (HEU) and natural uranium held in various forms by the military sector could total several years supply of natural uranium equivalent for commercial applications.

Table 29. **Uranium stocks in countries that have reported data**
(tonnes natural U equivalent as of 1 January 2007)

COUNTRY	Natural uranium	Enriched uranium
Argentina (a)	110	0
Australia (b)	NA	0
Belgium	NA	NA
Bulgaria	0	81
Canada (b)	NA	0
China	NA	NA
Czech Republic	< 200	NA
Egypt	0	0
Finland (c)	0	0
France (d)	NA	NA
Germany(e)	2 600	100
Hungary	1	0
India	NA	NA
Korea, Republic of (f)	NA	NA
Lithuania (g)	0	47
Mexico (h)	NA	NA
Netherlands	NA	NA
Niger	0	0
Poland	NA	NA
Portugal	168	0
Slovak Republic (i)	0	NA
South Africa (b)	NA	NA
Spain (j)	NA	611
Switzerland	1 609	1 422
Turkey	< 2	0
Ukraine	0	0
United Kingdom	NA	NA
United States (k)	39 154	8 722
Vietnam	0	0
TOTAL	> 43 844	> 10 983

NA Not available or not disclosed.
(a) Government data only. Commercial data are not available.
(b) Government stocks are zero in all categories. Commercial data are not available.
(c) The nuclear power utilities maintain reserves of fuel assemblies sufficient for 7-12 months use.
(d) A minimum of three years forward fuel requirements is maintained by EDF.
(e) Holdings also include 3 500 t (U equivalent) of depleted U.
(f) A strategic inventory is maintained along with about one year's forward consumption in pipeline inventory.
(g) A three month's stock of enriched fuel is generally maintained at the Ignalina NPP.
(h) Maintain one to two reloads of natural uranium at an enrichment facility.
(i) The government maintains a small stock of enriched uranium in the form of fuel assemblies.
(j) Regulations require a strategic inventory of at least 611 tU be maintained jointly by nuclear utilities.
(k) Government and utility stocks only; producer stocks amounted to an additional 11 197 tU but a breakdown into amounts of natural and enriched uranium is not available.

Highly enriched uranium from the Russian Federation

An Agreement between the Government of the US and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted from Nuclear Weapons (HEU Purchase Agreement) was signed on 16 October 1992 by the US and the Russian Federation providing for the blending down of 500 tons of HEU to low enriched uranium (LEU) over 20 years. USEC, Inc., the US Government's sole executive agent for implementing the HEU Purchase Agreement, receives deliveries of LEU from the Russian Federation for sale to commercial nuclear power plants. USEC purchases and sells only the enrichment component of this LEU under existing commercial contracts with purchasers of enrichment services. An agreement for the maintenance of a domestic uranium enrichment industry that was signed on 17 June 2002 by the Department of Energy and USEC, Inc. contained conditions for USEC, Inc. to continue as the US Government's sole executive agent for the HEU Purchase Agreement. In June 2006, the Russian Federation indicated that the HEU agreement will not be renewed when the initial agreement expires in 2013.

Under a separate agreement under the HEU programme, the natural uranium feed component is sold under a commercial arrangement between three western corporations (Cameco, AREVA, and Nukem) and Techsnabexport of the Russian Federation. Outside of the natural uranium feed component of HEU-derived LEU, imports of uranium from the Russian Federation have been limited by the *Agreement Suspending the Antidumping Duty Investigation on Uranium from the Russian Federation* (Suspension Agreement) signed between the US Department of Commerce (DOC) and the Ministry of Atomic Energy of the Russian Federation in 1992. As a result of the Suspension Agreement, DOC suspended antidumping investigations and the Russian Federation agreed to sell uranium to the United States under a quota system whereby Russian imports would have to be matched by an equivalent quantity of newly produced US uranium. A 1994 amendment to the suspension agreement contained language specifying an expected termination date of 31 March 2004. However, Russia did not request the DOC to undertake a termination review, a requirement for termination, and the DOC took the position that the Suspension Agreement had not expired. A second sunset review agreement was subsequently signed on 1 July 2005, maintaining the Suspension Agreement terms during the review.

In September 2005, the governments of the United States and Russian Federation issued a joint statement acknowledging that the implementation of the HEU Purchase Agreement had achieved its halfway point with 250 tonnes of HEU having been down-blended to low enriched uranium out of the total 500 metric tons of HEU covered in the agreement. As of 30 June 2007, 306 tonnes of HEU had been down-blended and 8 930 tonnes of low enriched uranium fuel have been delivered to the United States for use in commercial reactors. Deliveries as of 30 June 2007 represent the dismantlement of 12 231 nuclear warheads.

United States highly enriched uranium

The United States has committed to the disposition of 174.3 tonnes of surplus HEU with about 151 tonnes planned to be eventually blended down for use as LEU fuel in research and commercial reactors and 23 tonnes slated for disposal as waste. Through 2006, 94 tonnes of HEU were down-blended yielding 1 051 tonnes of LEU fuel.

The Department of Energy (DOE) and Tennessee Valley Authority (TVA) entered an Interagency Agreement in April 2001, whereby TVA will utilise LEU derived from blending down about 33 tonnes of US surplus HEU. In 2004 this agreement was modified to increase the total to 39 tonnes of HEU. This LEU is considered "off-spec" because it contains ^{236}U in excess of the specifications established for commercial nuclear fuel. Different portions of this material are being down-blended at DOEs Savannah River site (SRS) and at a TVA contractor. Down-blending began at SRS in 2003 and at the contractor facility in 2004. This down-blending programme will continue through 2007 and use of the resultant blended low enriched uranium (BLEU) fuel at TVA reactors is expected to continue until 2016.

About 10 tonnes of surplus HEU will be blended down to make low enriched research reactor fuel through approximately 2016. In addition, 17.4 tonnes of HEU will be down-blended to low enriched uranium fuel as part of the Reliable Fuel Supply initiative announced by DOE in September 2005. Under the Reliable Fuel Supply initiative, the United States will keep a reserve of low enriched uranium that, in the event of a market disruption, can be sold to countries that forgo enrichment and reprocessing. On 29 June 2007, the DOE's National Nuclear Security Administration (NNSA) awarded a contract to Wesdyne International, LLC (a subsidiary of Westinghouse Electric Company, LLC) and Nuclear Fuel Services, Inc. to down-blend the 17.4 tonnes of HEU between 2007 and 2010, producing about 290 tonnes of low enriched uranium fuel. The fuel will be available for use in civilian reactors by nations that are not pursuing uranium enrichment and reprocessing technologies. Qualifying countries will have access to the fuel at the current market price only in the event of an emergency that disrupts the normal flow of fuel supply.

In November 2005, the DOE announced that an additional 200 tonnes of HEU beyond the initially declared 174.3 tonnes of HEU would be permanently removed from further use by the United States in nuclear weapons. Of the additional 200 tonnes HEU, 160 tonnes will be provided for use in naval propulsion, 20 tonnes is to be blended down to low enriched uranium fuel for use in power or research reactors, and 20 tonnes reserved for space and research reactors that currently use HEU, pending development of fuels that would enable the conversion to low enriched uranium fuel cores. For power reactors, the LEU would become available gradually over a 25-year period.

2. *Nuclear fuel produced by reprocessing spent reactor fuels and surplus weapons-related plutonium*

The constituents of spent fuel from power plants are a potentially substantial source of fissile material that could displace primary production of uranium. When spent fuel is discharged from a commercial reactor it is potentially recyclable, since about 96% of the original fissionable material remains along with the plutonium created during the fission process. The recycled plutonium can be reused in reactors licensed to use mixed-oxide fuel (MOX). The uranium recovered through reprocessing of spent fuel, known as reprocessed uranium (RepU), is not routinely recycled; rather, it is stored for future reuse.

The use of MOX has not yet significantly altered world uranium demand because only a relatively small number of reactors are using this type of fuel. Additionally, the number of recycles possible using current reprocessing and reactor technology is limited by the build-up of plutonium isotopes that are not fissionable by the thermal neutron spectrum found in light-water reactors and by the build-up of undesirable elements, especially curium.

In January 2007 there were over 33 reactors, about 8% of the world's operating fleet,[8] licensed to use MOX fuel, including reactors in Belgium, France, Germany, India and Switzerland (Table 30).

8. In December 2002, Sweden authorised the limited use of MOX fuel at the Oskarshamn nuclear power plant. This decision allows the use of 900 kg of plutonium separated from spent fuel removed from Swedish reactors prior to 1982. Since 1982, Swedish used nuclear fuel has been placed in storage pending final disposal.

Additional reactors could be licensed to use MOX in China and the Russian Federation. The United States has licensed a reactor to use MOX as part of its weapons material disposition programme and initial tests of MOX fuel were loaded in 2005. In addition, the United States has proposed a new programme, the Global Nuclear Energy Partnership, which is intended to work with international partners to demonstrate the capability to safely recycle used nuclear fuel using more proliferation-resistant processes.

MOX reprocessing and fuel fabrication facilities exist or are under construction in China, France, India, Japan, the Russian Federation and the United Kingdom. Japan Nuclear Fuel Ltd. has been performing test separation of plutonium at the Rokkasho reprocessing plant since March 2006 and Japanese utilities are aiming to use MOX fuel in 16 to 18 reactors by 2010, following consultations and licensing processes. Initially, MOX fuel manufactured overseas will be used, followed by the use of MOX fuel produced at Rokkasho.

In September 2004, Cogema (now AREVA) filed an application with the French authorities to increase production at its Marcoule site from 145 tHM to 195 tHM. In July 2006, the MOX fuel plant in Belgium (Belgonucléaire) was shut down.

The Euratom Supply Agency (ESA) reported that the use of MOX fuel in the EU-15[9] reduced natural uranium requirements by an estimated 1 010 tU in 2005 and 1 225 tU in 2006. Since 1996, the ESA estimates that EU-15 reactors have displaced 11 515 tU through the use of 95.8 tonnes of plutonium in MOX fuel [2]. Since the great majority of world MOX use occurs in Western Europe, this figure provides a reasonable estimate of the impact of MOX use worldwide during that period.

Responses to the questionnaire provided some data on the production and use of MOX (Table 30).

Table 30. **MOX production and use**
(tonnes of equivalent natural U)

COUNTRY	Pre-2004	2004	2005	2006	Total to 2006	2007 (expected)
MOX production						
Belgium	437	86	0	0	523	0
France	8 600	1 110	1 160	1 160	12 030	1 160
Japan	583	15	0	0	598	9
United Kingdom	NA	0	11	22	NA	11
MOX use						
Belgium	437	29	28	26	520	0
France	NA	800*	NA	NA	NA	NA
Germany	4 560	480	480	320	5840	240
Japan	331	2	4	8	345	3
Switzerland	1 022	12	108	159	1 301	26
United States	0	0	0.1		0.1	0

NA Not available or not disclosed.

* Data from 2005 Red Book.

9. Data are for the fifteen EU countries prior to enlargement in May 2004. No MOX fuel is used in new member states.

Uranium recovery through reprocessing of spent fuel, known as RepU, has been conducted in the past in several countries, including Belgium and Japan. It is now routinely done only in France and the Russian Federation, principally because recycling of RepU is a relatively costly endeavour, in part due to the requirement for dedicated conversion, enrichment and fabrication facilities. Changing market conditions and non-proliferation concerns are, however, leading to renewed consideration of this recycling option. Very limited information is available concerning how much reprocessed uranium is used though available data indicate that it represents less than 1% of projected world requirements annually (Table 31).

Table 31. **Re-processed uranium production and rse**
(tonnes of equivalent natural U)

COUNTRY	Pre-2003	2004	2005	2006	Total to 2006	2007 (expected)
Production						
France	NA	1 100	1 100	1 100	NA	1 100
Japan (a)	595	50	0	0	645	0
Russian Federation*	NA	1 300	1 300	1 300	NA	1 300
United Kingdom	~50 000	NA	1 270	NA	~51 270	NA
Use						
Belgium	508(b)	0	0	0	508	0
France*	NA	275	275	275	NA	275
Japan (a)	64	28	46	27	165	54
Switzerland	1 009	254	281	244	1 788	289
United Kingdom	~15 000	NA	NA	NA	~15 000	NA

NA Data not available.
* Secretariat estimate.
(a) For fiscal year.
(b) From 1993 to 2002.

Mixed-oxide fuel produced from surplus weapons-related plutonium

In September 2000, the United States and the Russian Federation signed an agreement for the disposition of surplus plutonium. Under the agreement, both the United States and the Russian Federation will each dispose of 34 tonnes of surplus weapon-grade plutonium at a rate of at least two tonnes per year in each country once facilities are in place. Both countries agreed to dispose of surplus plutonium by fabricating it into MOX fuel for irradiation in nuclear reactors and the development of MOX fuel fabrication facilities is underway in both countries. This approach will convert the surplus plutonium to a form that cannot be readily used to make a nuclear weapon.

On 3 March 2005, the NRC announced that it had issued a license amendment that authorises Duke Power to use four mixed-oxide (MOX) fuel lead assemblies fabricated in France at its Catawba nuclear power plant near Rock Hill, S.C. On 1 August 2007, DOE's NNSA initiated construction of a MOX fuel fabrication facility at the US Department of Energy's Savannah River site near Aiken, South Carolina. It is expected to begin producing MOX fuel in 2016 for use in four specially licensed commercial reactors.

The 68 tonnes of weapons-grade plutonium would displace about 14 000 to 16 000 tonnes of natural uranium over the life of the programme. This represents about 1% of world annual uranium requirements over the period of the programme.

3. *Uranium produced by re-enrichment of depleted uranium tails*[10]

Depleted uranium stocks represent a significant reserve of uranium that could displace primary uranium production. However, the re-enrichment of depleted uranium has been limited as a secondary source of uranium since it is only economic in centrifuge enrichment plants that have spare capacity and low operating costs.

At the end of 2005 the inventory of depleted uranium is estimated at about 1 600 000 tU and to be increasing by about 60 000 tU annually based on uranium requirements of 66 000 tU per annum [3]. If this entire inventory was re-enriched to levels suitable for nuclear fuel it would yield an estimated 450 000 tU of equivalent natural uranium, which would be sufficient for about seven years of operation of the world's nuclear reactors at the 2006 uranium requirement levels.[11] However, this would require significant spare enrichment capacity that is not currently available.

Deliveries of re-enriched tails from the Russian Federation are a significant source of uranium for the EU, representing 3-8% of the total natural uranium delivered annually to EU reactors between 2001 and 2006 (Table 32). However, in 2006, the Russian Federation indicated that it will stop the re-enrichment of depleted uranium tails once the existing contracts come to an end.

Table 32. **Russian Federation supply of re-enriched tails to European Union end users**

Year	**Re-enriched tail deliveries** (tU)	**Percentage of total natural uranium deliveries**
2001	1 050	7.6
2002	1 000	6.0
2003	1 200	7.3
2004	900	6.2
2005	500	2.8
2006	700	3.3

Sources: Euratom Supply Agency (2007), *Annual Report 2006*, Luxembourg.

In the United States, the DOE and the Bonneville Power Administration have initiated a pilot project to re-enrich 8 500 tU of the DOE tails inventory. The pilot project is anticipated to produce, over a two-year period, a maximum of 1 900 tonnes of natural uranium equivalent for use by the Columbia Generating Station between 2009 and 2017.

Additional information on the production and use of re-enriched tails is not readily available. The information provided, however, indicates that its use is relatively limited (See Table 33).

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10. Depleted uranium is the by-product of the enrichment process having less ^{235}U than natural uranium. Normally, depleted uranium tails will contain between 0.25 and 0.35% ^{235}U compared with the 0.711% found in nature.
11. OECD Nuclear Energy Agency, (2007) *Management of Recyclable Fissile and Fertile Materials*, Paris, France. This total assumes 1.6 million tU at 0.3% assay is re-enriched to produce 420 000 tU of equivalent natural uranium, leaving 1 080 000 tU of secondary tails with an assay of 0.14%.

Table 33. **Re-enriched tails use**
(tonnes of equivalent natural U)

COUNTRY	Pre-2003	2004	2005	2006	Total to 2006	2007 (expected)
Belgium	345	0	0	0	345	0
Finland	287	140	60	108	595	140
France (a)	NA	0	0	0	NA	0

NA Data not available.
(a) A small amount of tails are re-enriched in the Russian Federation and recycled within the Georges Besse enrichment plant.

Uranium market developments

Uranium price developments

Some national and international authorities, i.e., Australia, United States and the Euratom Supply Agency, make available price indicators to illustrate uranium price trends. Additionally, spot price indicators for immediate or near-term delivery (typically less than 15% of all uranium transactions) are regularly provided by industry sources such as the TradeTech, Ux Consulting Company LLC (UxC) and others. Figure 15 shows a comparison of annual average delivered prices reported by various government sources.

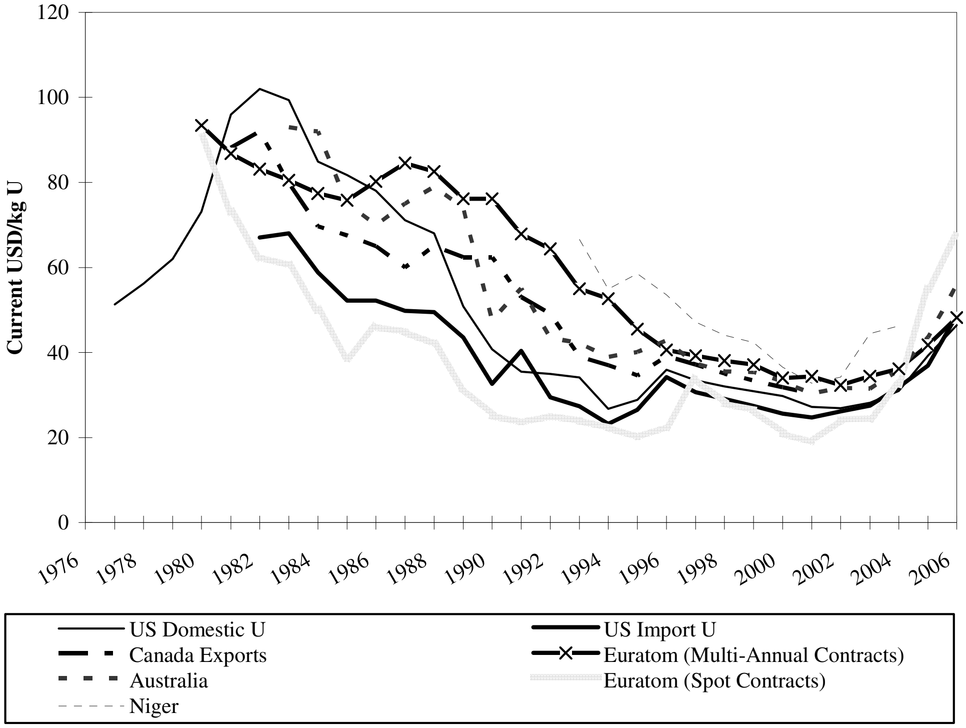
The over-production of uranium, which lasted through 1990 (Figure 13), combined with the availability of secondary sources, resulted in uranium prices trending downward from the early-1980s until 1994 when they reached their lowest level in 20 years. Between 1990 and 1994 there were significant reductions in many sectors of the world uranium industry including exploration, production and production capability. This decreasing supply situation combined with growing demand for uranium and the bankruptcy of an important uranium trading company resulted in a modest recovery in uranium prices from October 1994 through mid-1996. This trend, however, reversed as increasingly better information about inventories and supplies maintained downward pressure on uranium prices until 2001.

Beginning in 2001, the price of uranium began to rebound from historic lows to levels not seen since the 1980s and continued to rise through 2006. Price information from a limited number of government sources all display this trend (Figure 15). Depending on the nature of the purchases (long term contracts versus spot market), the limited information available on uranium purchases in 2006 indicate that purchase prices ranged between USD 45/kgU and USD 75/kgU (USD 17/lbU_3O_8 and USD 29/lbU_3O_8).

While the trend of increasing prices has also been characteristic of information available on purchases made on the spot market since 2001, and in particular after 2003, the price has been much more volatile. In June 2007, the spot market price reached as high as USD 136/lb U_3O_8 (USD 354/kgU) before declining to USD 85/lb U_3O_8 (USD 221/kgU) in October 2007 (Figure 16).[12] Note that Figure 15 reflects mostly long-term contracts and thus the dynamic changes of the past two years are not as evident as the changes shown in Figure 16.

12. Spot price data courtesy of TradeTech (www.uranium.info).

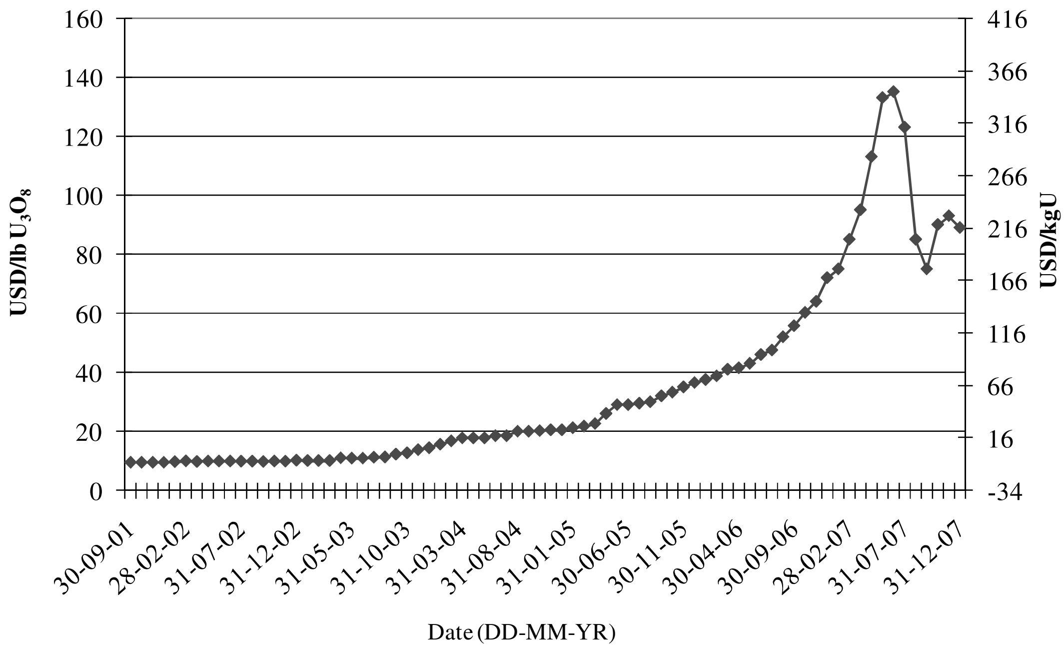
Figure 15. **Uranium prices: 1976-2006**



Notes: 1. Euratom prices refer to deliveries during that year under multi-annual contracts.
2. Beginning in 2002, Natural Resources Canada (NRCan) suspended publication of export price for 3-5 years pending a policy review.

Sources: Australia, Canada, Euratom Supply Agency, Niger, United States.

Figure 16. **NUEXCO exchange value trend** (30 September 2001 – 31 December 2007)



A variety of reasons have been put forward to account for the price changes experienced in the last few years, including problems experienced in nuclear fuel cycle production centres in 2003 and weakness of the United States dollar, the currency used in many uranium transactions, which began a significant decline against the major world currencies in 2002. While these events likely did not, in themselves, cause the price increase, all combined to create uncertainty about the robustness of the supply chain. An increasing sense of the finite nature of inventories, the expansion of nuclear power generation in countries such as China and Russia, the recognition by many governments that nuclear power can produce competitively priced base load electricity that is essentially free of greenhouse gas emissions and the role nuclear can play in enhancing security of energy supply have all likely contributed to the strengthening market. The appearance of speculators in the market has also impacted uranium prices by introducing demand from sources outside the electricity generation industry. In fact, purchases by speculators may have been an important factor in the rapid upward ascendancy of price since early 2007. The downturn in price since June 2007 has alternately been attributed to a market correction or a seasonal slow-down in activity. Regardless of the cause, the uranium spot market price has gone through more rapid and significant changes in 2007 than it has in decades, creating great interest in the commodity and injecting much needed investment into the industry.

Other market developments

On 13 February 2002, the Department of Commerce (DOC) issued determinations in antidumping and countervailing duty investigations involving LEU from France, Germany, the Netherlands, and the United Kingdom. The DOC placed an antidumping duty order on LEU imports from France while all four countries were issued countervailing duty orders. The decision resulted in countervailing duties being assessed against France, but not against Germany, the Netherlands, and the United Kingdom. The DOC determinations were challenged at the US Court of International Trade (CIT). The US Court of Appeals for the Federal Circuit (CAFC) affirmed in March 2005 a ruling by the US Court of International Trade (CIT) that contracts for the purchase of enrichment services, quantified by separative work units, were contracts for the sale of services, not goods. US antidumping law applies only to the sale or purchase of goods, not services. The CAFC further affirmed that CIT was correct in ruling that the Department of Commerce's approach to defining the word "producer" was in accordance with law. This provides USEC the ability to trigger the antidumping and countervailing subsidy investigations. This ruling, if confirmed, could impact the imposition of duties on LEU imported from the European Union, as well as, the Russian Suspension Agreement on Uranium, which is based on US antidumping law and covers uranium enriched in Russia. Pending a final resolution that may involve further appeals and re-hearings, the import duties now imposed will continue to be collected.

Policy measures in the European Union

Since its establishment in 1960 under the Euratom Treaty, the Euratom Supply Agency (ESA) has pursued a policy of diversification of sources of nuclear fuel supply in order to avoid over-dependence on any single source. Within the European Union, all uranium purchase contracts by EU end-users (i.e. nuclear utilities) have to be approved by the ESA. In approving such contracts, the ESA is seeking to maintain a sufficient diversity of supply sources, with the aim of enhancing security of supply. The main effect of this policy in recent years has been to generally reduce the market share of supplies from the Russian Federation (even though the enlargement of the EU added some Russian designed nuclear power plants to the EU and supplies from the Russian Federation correspondingly increased in 2006, compared to 2005). The results of the application of the supply diversification policy are set out in the ESA Annual Reports, which showed that in 2006 the total supply of natural uranium and feed contained in EUP from the Russian Federation comprised about 26% of the EU market (including a proportion of the material derived from ex-military HEU).

In November 2003, the European Commission received negotiating directives from the European Council to start negotiations with the Russian Federation for a nuclear trade agreement. The agreement will have to take into account the new market conditions in the enlarged EU and the special relations between the new member states and the Russian Federation in this field. The agreement will also take into consideration the interests of European consumers and the need to maintain the viability of EU industries at the front end of the fuel cycle. A draft agreement was presented to the Russian Federation in 2004. As of 2006, however, negotiations with the Russian Federation on the draft agreement have not progressed.

The Euratom Supply Agency continues to stress the importance for utilities to maintain an adequate level of strategic inventory and to use market opportunities to increase their inventories, consistent with their circumstances. Furthermore, it recommends that utilities cover most of their needs under long-term contracts with diversified supply sources.

Supply and Demand to 2030

Market conditions are the primary driver of decisions to develop new or expand existing primary production centres. As market prices have increased significantly, plans for increasing production capability have developed rapidly. A number of countries, notably Australia, Canada, Kazakhstan and South Africa, have reported plans for significant additions to planned future capability. Moreover, in some African countries production centres not anticipated in the 2005 Red Book have been developed that are either in production or are expected to be producing in the near future. These developments are indeed timely as demand is rising and secondary sources are declining in availability.

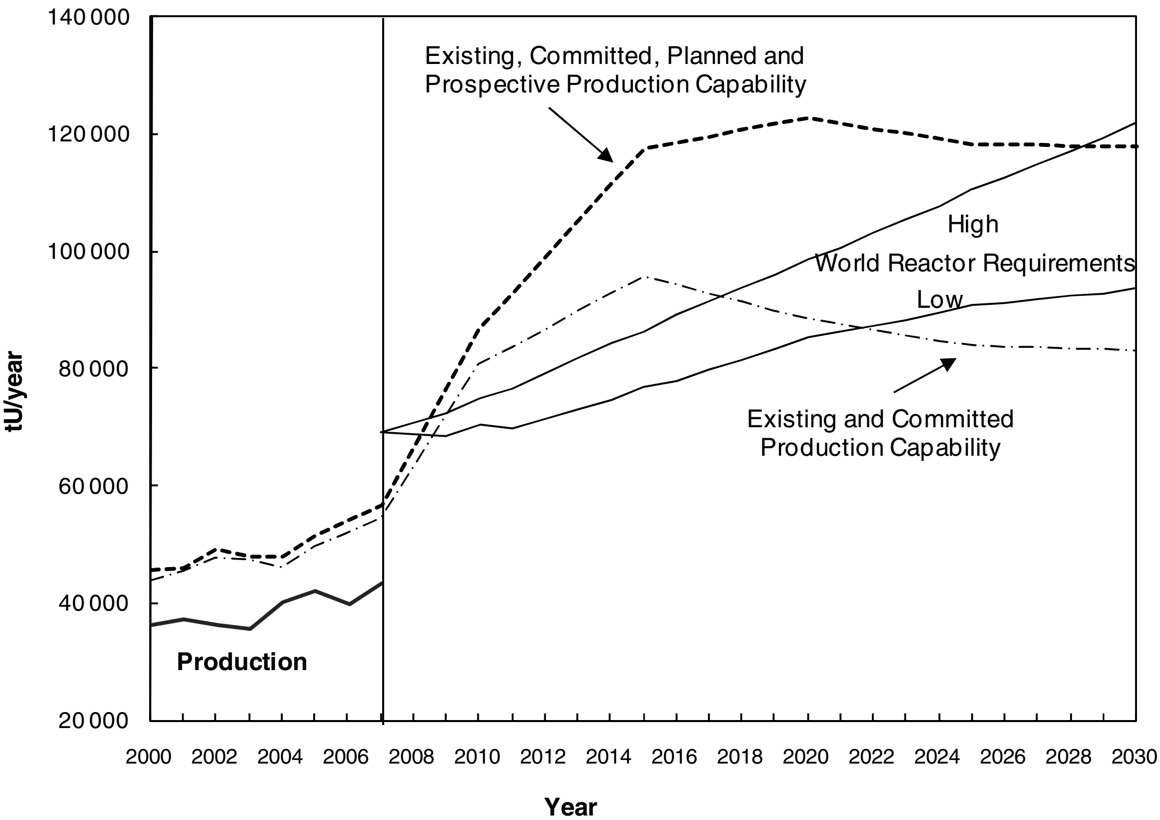
The supply and demand picture is evolving rapidly as strong market conditions are stimulating heightened activity. Not only is demand to 2030 projected to rise, but a dynamic expansion of production capability has significantly altered the supply – demand relationship of the recent past, such that even requirements stemming from the high case demand scenario could be met through 2028 if all Existing, Committed, Planned and Prospective production centres are developed on time and full production capability is achieved (Figure 17). In contrast, planned capability from all reported Existing and Committed production centres, although potentially exceeding high case demand requirements between 2010 and 2017, is projected to satisfy about 89% of the low case requirements but only about 68% of the high case requirements in 2030. With Planned and Prospective production centres, primary production capability would be adequate to satisfy low case requirements to 2030, but in the high case primary production capability would fall short (97% of high case requirements in 2030).

Although it may be tempting to interpret projections of production capability portrayed in Figure 17 as indicating an oversupplied market, past experience shows that this is not likely to be the case. Production capability is not production. To the left of the vertical line demarcating 2007 (Figure 17), world production (including expected production in 2007) has been plotted to illustrate the difference existing today between production and production capability. The challenge will be closing the gap between world production and high and low reactor requirements in the coming years.

World production has never exceeded 89% of reported production capability [4] and since 2003 has varied between 75% and 84% of production capability. Given the recent record of mine development, delays in the establishment of new production centres can reasonably be expected, reducing and/or delaying anticipated production from Planned and Prospective centres. Hence, even though the industry has responded vigorously to the market signal of high prices, additional primary production and secondary supply will be required, supplemented by uranium savings achieved by specifying low enrichment tails assays, to the extent possible. After 2013, secondary sources of uranium are expected to decline in availability and reactor requirements will have to be increasingly met by primary production [5]. Therefore, despite the significant additions to production capability reported here, there remains pressure to bring facilities into production in a timely fashion. To do so, strong market conditions will be required to bring the necessary investment to the industry.

A key element in the uranium market continues to be the availability of secondary sources, particularly the level of stocks available and the length of time remaining until those stocks are exhausted. As Table 29 shows, accurate information on secondary sources of uranium, especially inventory levels, is not readily available. This hampers effective decision making on new production capability. However, it is clear that the strong market of late has spurred increased exploration and the development of production capability.

Figure 17. **Projected annual world uranium production capability through 2030 compared with projected world reactor requirements***



Sources: Tables 17 and 21.

* Includes all Existing, Committed, Planned and Prospective production centres supported by RAR and Inferred Resources recoverable at a cost of <USD 80/kgU.

D. THE LONG-TERM PERSPECTIVE

Uranium demand is fundamentally driven by the number of operating nuclear reactors, which ultimately is driven by the demand for electricity. World demand for electricity is expected to double from 2002 through 2030 to meet the needs of an increasing population and sustained economic growth. The International Energy Agency reference scenario projection indicates that 5 087 GW of new capacity will be needed by 2030 to meet the projected increase in electricity demand and to replace ageing infrastructure [6]. Growth is expected to be strongest in nations seeking to improve their standard of living, led by India and China. The significance of the role that nuclear energy will play in future electrical generation will depend on how effectively a number of factors discussed earlier are addressed (economics, safety, non-proliferation concerns, security of supply, waste disposal, environmental considerations, etc.) and how public acceptance of nuclear energy evolves.

The extent to which nuclear energy is seen as beneficial in meeting greenhouse gas reduction targets could potentially increase the role of nuclear energy in future electrical generation. As noted by the Intergovernmental Panel on Climate Change (IPCC), electricity generated from fossil fuels has been by far the biggest culprit in terms of emissions growth since 1970, exceeding by two times the next largest energy contributor and growing at a much faster rate [7]. Highlighting the role that this environmental issue could play in future development, the IEA alternative policy scenario envisions slightly lower growth in electricity generation overall, but an increasing share of nuclear generating capacity in order to reduce greenhouse gas emissions. Recent sustained increases in fossil fuel prices have also increased interest in nuclear energy because of the significant role that fuel costs play in fossil energy generation costs compared to nuclear energy, thereby improving the relative economic competitiveness of nuclear energy [8]. Dependence on imported fossil fuels in some countries has also raised concerns about the security of energy supplies. However, in countries where public concerns about safety, security, non-proliferation and waste disposal are not convincingly addressed, the contribution that nuclear energy makes to the future energy mix could be limited. Yet, if only 10% of this projected increase in capacity is met by nuclear energy this would more than double the current installed capacity with a corresponding impact on uranium requirements.

Several alternative uses of nuclear energy have the potential to heighten its role worldwide, such as the desalination of seawater, heat production for industrial or residential purposes and ultimately, the production of hydrogen. While heat production will likely remain a niche use, the potential exists for desalination and hydrogen production to become significant roles for nuclear energy. The increasing need for fresh water has led to plans being announced for the use of nuclear desalination plants in several countries, such as China, India, Korea, Morocco, Pakistan and the Russian Federation. If these plans come to fruition they could significantly increase uranium requirements.

Energy use for transportation, which is projected to continue to grow rapidly over the coming decades, is also a major source of greenhouse gas emissions. Hydrogen is seen as a potential replacement for fossil fuels, as a means of reducing emissions. Nuclear energy offers the potential of producing hydrogen that could make this alternate energy carrier available with significantly less greenhouse gas emissions compared to current methods of hydrogen production. Any electricity-producing reactor can produce hydrogen through the process of electrolysis. As the market for hydrogen continues to develop more commercial reactors may install electrolysis equipment to permit them to produce hydrogen during off-peak hours, thus permitting optimal usage of the baseload generating capability of the reactor and maximising revenue. The overall efficiency of production of hydrogen in this way, however, is relatively low. Some existing reactors and high-temperature reactors under development hold the promise to generate hydrogen at much higher efficiencies using high-temperature steam electrolysis or thermo-chemical processes.

Recently launched multilateral fuel cycle initiatives also have the potential to alter uranium demand. Driven by rising energy needs, non-proliferation and waste concerns, governments and the IAEA have made a number of proposals that could accelerate the development of a closed fuel cycle and lead to the establishment of multilateral enrichment and fuel supply centres. As of December 2007, 19 nations (Australia, Bulgaria, Canada, China, France, Ghana, Hungary, Italy, Japan, Jordan, Kazakhstan, Lithuania, Poland, the Republic of Korea, Romania, the Russian Federation, Slovenia, Ukraine and the United States) further promoted development of the Global Nuclear Energy Partnership (GNEP) by signing a "Statement of Principles". The GNEP programme promises to aid the expansion of the peaceful use of nuclear energy through enhanced safeguards, international fuel service frameworks, and advanced technologies, including reprocessing and the development of fast breeder reactors. The Uranium Enrichment Centre created by the Russian Federation and Kazakhstan is an alternative approach to address non-proliferation concerns by allowing international partners access to enriched nuclear fuel without having to deploy the technology locally.

Technological advancements also promise to be a factor in defining the long-term future of nuclear energy and uranium demand. Advancements in reactor and fuel cycle technology not only promise to address economic, safety, security, non-proliferation and waste concerns, but also to radically increase the efficiency with which uranium resources are utilised. The introduction and use of advanced reactor designs would also permit the use of other materials as nuclear fuel, such as uranium-238 and thorium, thereby expanding the available resource base. Moreover, breeder reactors could produce more fuel than they consume, since spent fuel could be recovered, reprocessed and reused to produce additional energy.

Many national and several major international programmes are working to develop advanced technologies, for example, the Generation IV International Forum (GIF) and the IAEA International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). The objective of INPRO is to help to ensure that nuclear energy is available to contribute, in a sustainable manner, to the energy needs in the 21st century. As of July 2007, 27 countries (Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Japan, Republic of Korea, Morocco, Netherlands, Pakistan, the Russian Federation, Slovakia, the Republic of South Africa, Spain, Switzerland, Turkey, Ukraine, and the United States) and the European Commission were working together in the INPRO Project.

Argentina, Brazil, Canada, France, Japan, the Republic of Korea, the Republic of South Africa, Switzerland, the United Kingdom, the United States and Euratom are members of GIF. In 2002, the GIF selected six nuclear energy system concepts to be the focus of continued collaborative research and development. The reactor concepts are a sodium-cooled fast reactor, a very high-temperature reactor, a supercritical water reactor, a lead-cooled fast reactor, a gas-cooled fast reactor and a molten-salt reactor. All but the very high-temperature reactor involves recycling fuel and several may be suitable for hydrogen production.

As documented in this volume, sufficient resources exist to support significant growth in nuclear capacity for electricity generation in the long-term. Identified Resources[13] are sufficient for over 80 years, considering 2006 uranium requirements of 66 500 tU. If estimates of current

13. Identified resources include all cost categories of RAR and Inferred Resources for a total of about 5 468 800 tU (Table 2).

(2006) rates of uranium consumption in power reactors[14] are used (a more realistic approach, since uranium requirements are government expectations of annual national uranium purchases; not the uranium consumed in nuclear fuel), the Identified Resource base would be sufficient for about 100 years of reactor supply, without considering uranium savings achieved by for example, specifying lower tails assays or using MOX fuel. Exploitation of the entire Conventional Resource[15] base would increase this about 300 years, though significant exploration and development would be required to move these resources into more definitive categories. Given the limited maturity and geographical coverage of uranium exploration worldwide, there is considerable potential for discovery of new resources of economic interest.

As noted in the Uranium Supply chapter, there are also considerable Unconventional Resources, including uranium contained in phosphate rocks, that could be utilised to significantly lengthen the time that nuclear energy could supply energy demand using current technologies. However, considerable effort and investment would need to be devoted to better defining the extent of this potentially significant source of uranium.

Deployment of advanced reactor and fuel cycle technologies could also significantly add to world energy supply in the long-term. Moving to advanced technology reactors and recycling fuel could increase the long-term availability of nuclear energy from hundreds to thousands of years. In addition, thorium, which is more abundant than uranium in the earth's crust, is also a potential source of nuclear fuel, if alternative fuel cycles are developed and successfully introduced. Thorium-fuelled reactors have already been demonstrated and operated commercially in the past.

Thus, sufficient nuclear fuel resources exist to meet energy demands at current and increased demand well into the future. However, to reach their full potential considerable exploration, research and investment is required, both to develop new mining projects in a timely manner and to facilitate the deployment of promising technologies.

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14. Uranium usage per TWh is taken from OECD/NEA (2001), *Trends in the Nuclear Fuel Cycle*, Paris [9]. These were used to define how much electricity could be generated for the given levels of uranium resources. Years of generation were then developed by factoring in the 2006 generation rate (2 675 TWh net, Table 26) and rounding to the nearest five years.

15. Total conventional resources includes all cost categories of RAR, Inferred, Prognosticated and Speculative Resources for a total of about 16 008 900 tU (Tables 2 and 11). This total does not include secondary sources or unconventional resources, e.g. uranium from phosphate rocks.

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[9] NEA (2001), *Trends in the Nuclear Fuel Cycle*, OECD, Paris, France.

Appendix 4

GLOSSARY OF DEFINITIONS AND TERMINOLOGY

UNITS

Metric units are used in all tabulations and statements. Resources and production quantities are expressed in terms of tonnes (t) contained uranium (U) rather than uranium oxide (U_3O_8).

1 short ton U_3O_8	= 0.769 tU
1 percent U_3O_8	= 0.848 percent U
1 USD/lb U_3O_8	= USD 2.6/kg U
1 tonne	= 1 metric ton

RESOURCE TERMINOLOGY

Resource estimates are divided into separate categories reflecting different levels of confidence in the quantities reported. The resources are further separated into categories based on the cost of production.

a) Definitions of resource categories

Uranium resources are broadly classified as either conventional or unconventional. Conventional resources are those that have an established history of production where uranium is a primary product, co-product or an important by-product (e.g., from the mining of copper and gold). Very low-grade resources or those from which uranium is only recoverable as a minor by-product are considered unconventional resources.

Conventional resources are further divided, according to different confidence levels of occurrence, into four categories. The correlation between these resource categories and those used in selected national resource classification systems is shown in Figure A.

Reasonably Assured Resources (RAR) refers to uranium that occurs in known mineral deposits of delineated size, grade and configuration such that the quantities which could be recovered within the given production cost ranges with currently proven mining and processing technology, can be specified. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. Reasonably Assured Resources have a high assurance of existence. Unless otherwise noted, RAR are expressed in terms of quantities of uranium recoverable from mineable ore (see Recoverable Resources).

Inferred Resources refers to uranium, in addition to RAR, that is inferred to occur based on direct geological evidence, in extensions of well-explored deposits, or in deposits in which geological continuity has been established but where specific data, including measurements of the deposits, and knowledge of the deposit's characteristics, are considered to be inadequate to classify the resource as RAR. Estimates of tonnage, grade and cost of further delineation and recovery are based on such sampling as is available and on knowledge of the deposit characteristics as determined in the best known parts of the deposit or in similar deposits. Less reliance can be placed on the estimates in this category than on those for RAR. Unless otherwise noted, Inferred Resources are expressed in terms of quantities of uranium recoverable from mineable ore (see Recoverable Resources).

Figure A. **Approximate Correlation of Terms used in Major Resources Classification Systems**

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES		
NEA/IAEA	REASONABLY ASSURED		INFERRED	PROGNOSTICATED	SPECULATIVE	
Australia	DEMONSTRATED		INFERRED	UNDISCOVERED		
	MEASURED	INDICATED				
Canada (NRCan)	MEASURED	INDICATED	INFERRED	PROGNOSTICATED	SPECULATIVE	
United States (DOE)	REASONABLY ASSURED		ESTIMATED ADDITIONAL		SPECULATIVE	
Russian Federation, Kazakhstan, Ukraine, Uzbekistan	A + B	C 1	C 2	P1	P2	P3
UNFC*	G1 + G2		G3	G4	G4	

* United Nations Framework Classification correlation with NEA/IAEA and national classification systems is still under consideration.

The terms illustrated are not strictly comparable as the criteria used in the various systems are not identical. "Grey zones" in correlation are therefore unavoidable, particularly as the resources become less assured. Nonetheless, the chart presents a reasonable approximation of the comparability of terms.

Prognosticated Resources refers to uranium, in addition to Inferred Resources, that is expected to occur in deposits for which the evidence is mainly indirect and which are believed to exist in well-defined geological trends or areas of mineralisation with known deposits. Estimates of tonnage, grade and cost of discovery, delineation and recovery are based primarily on knowledge of deposit characteristics in known deposits within the respective trends or areas and on such sampling, geological, geophysical or geochemical evidence as may be available. Less reliance can be placed on the estimates in this category than on those for Inferred Resources. Prognosticated Resources are normally expressed in terms of uranium contained in mineable ore, i.e., *in situ* quantities.

Speculative Resources (SR) refers to uranium, in addition to Prognosticated Resources, that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The location of deposits envisaged in this category could generally be specified only as being somewhere within a given region or geological trend. As the term implies, the existence and size of such resources are speculative. SR are normally expressed in terms of uranium contained in mineable ore, i.e., *in situ* quantities.

b) Cost categories

The cost categories, in United States dollars (USD), used in this report are defined as: <USD 40/kgU, <USD 80/kgU, and <USD 130/kgU. All resource categories are defined in terms of costs of uranium recovered at the ore processing plant

NOTE: It is not intended that the cost categories should follow fluctuations in market conditions.

Conversion of costs from other currencies into USD is done using an average exchange rate for the month of June in that year except for the projected costs for the year of the report, which uses the exchange rate of 1 January 2007 (Appendix 8).

When estimating the cost of production for assigning resources within these cost categories, account has been taken of the following costs:

- The direct costs of mining, transporting and processing the uranium ore.
- The costs of associated environmental and waste management during and after mining.
- The costs of maintaining non-operating production units where applicable.
- In the case of ongoing projects, those capital costs that remain non-amortised.
- The capital cost of providing new production units where applicable, including the cost of financing.
- Indirect costs such as office overheads, taxes and royalties where applicable.
- Future exploration and development costs wherever required for further ore delineation to the stage where it is ready to be mined.
- Sunk costs are not normally taken into consideration.

c) Relationship between resource categories

Figure B illustrates the inter-relationship between the different resource categories. The horizontal axis expresses the level of assurance about the actual existence of a given tonnage based on varying degrees of geologic knowledge while the vertical axis expresses the economic feasibility of exploitation by the division into cost categories.

Figure B. **NEA/IAEA Classification Scheme for Uranium Resources**

		IDENTIFIED RESOURCES		UNDISCOVERED RESOURCES	
Recoverable at costs	<USD 40/kgU	REASONABLY ASSURED RESOURCES	INFERRED RESOURCES	PROGNOSTICATED RESOURCES	SPECULATIVE RESOURCES
	USD 40-80/kgU	REASONABLY ASSURED RESOURCES	INFERRED RESOURCES		
	USD 80-130/kgU	REASONABLY ASSURED RESOURCES	INFERRED RESOURCES	PROGNOSTICATED RESOURCES	

Decreasing economic attractiveness (↓)

Decreasing confidence in estimates (→)

d) Recoverable resources

RAR and Inferred Resource estimates are expressed in terms of recoverable tonnes of uranium, i.e. quantities of uranium recoverable from mineable ore, as opposed to quantities contained in mineable ore, or quantities *in situ*, i.e., not taking into account mining and milling losses. Therefore both expected mining and ore processing losses have been deducted in most cases. If a country reports its resources as *in situ* and the country does not provide a recovery factor, the Secretariat assigns a recovery factor to those resources based on geology and projected mining and processing methods to determine recoverable resources. The recovery factors that have been applied are:

Mining and milling method	**Overall recovery factor** (%)
Open-pit mining with conventional milling	80
Underground mining with conventional milling	80
ISL (acid)	75
ISL (alkaline)	70
Heap leaching	70
Block and stope leaching	75
Co-product or by-product	70
Unspecified method	75

SECONDARY SOURCES OF URANIUM TERMINOLOGY

a) Mixed-oxide fuel (MOX): MOX is the abbreviation for a fuel for nuclear power plants that consists of a mixture of uranium oxide and plutonium oxide. Current practice is to use a mixture of depleted uranium oxide and plutonium oxide.

b) Depleted uranium: Uranium where the ^{235}U assay is below the naturally occurring 0.7110%. (Natural uranium is a mixture of three isotopes, ^{238}U – accounting for 99.2836%, ^{235}U – 0.7110%, and ^{234}U – 0.0054%). Depleted uranium is a by-product of the enrichment process, where enriched uranium is produced from initial natural uranium feed material.

PRODUCTION TERMINOLOGY[1]

a) Production centres: A production centre, as referred to in this report, is a production unit consisting of one or more ore processing plants, one or more associated mines and uranium resources that are tributary to these facilities. For the purpose of describing production centres, they have been divided into four classes, as follows:

1. IAEA (1984), *Manual on the Projection of Uranium Production Capability,* General Guidelines, Technical Report Series No. 238, Vienna, Austria.

i) **Existing** production centres are those that currently exist in operational condition and include those plants which are closed down but which could be readily brought back into operation.

ii) **Committed** production centres are those that are either under construction or are firmly committed for construction.

iii) **Planned** production centres are those for which feasibility studies are either completed or under way, but for which construction commitments have not yet been made. This class also includes those plants that are closed which would require substantial expenditures to bring them back into operation.

iv) **Prospective** production centres are those that could be supported by tributary RAR and Inferred, i.e., "Identified Resources", but for which construction plans have not yet been made.

b) Production capacity and capability

Production capacity: Denotes the nominal level of output, based on the design of the plant and facilities over an extended period, under normal commercial operating practices.

Production capability: Refers to an estimate of the level of production that could be practically and realistically achieved under favourable circumstances from the plant and facilities at any of the types of production centres described above, given the nature of the resources tributary to them. Projections of production capability are supported only by RAR and/or EAR-I. The projection is presented based on those resources recoverable at costs <USD 80/kgU.

Production: Denotes the amount of uranium output, in tonnes U contained in concentrate, from an ore processing plant or production centre (with milling losses deducted).

c) Mining and milling

***In situ* leaching (ISL)**: The extraction of uranium from sandstone using chemical solutions and the recovery of uranium at the surface. ISL extraction is conducted by injecting a suitable uranium-dissolving leach solution (acid or alkaline) into the ore zone below the water table thereby oxidising, complexing, and mobilising the uranium; then recovering the pregnant solutions through production wells, and finally pumping the uranium bearing solution to the surface for further processing.

Heap leaching (HL): Heaps of ore are formed over a collecting system underlain by an impervious membrane. Dilute sulphuric acid solutions are distributed over the top surface of the ore. As the solutions seep down through the heap, they dissolve a significant (50-75%) amount of the uranium in the ore. The uranium is recovered from the heap leach product liquor by ion exchange or solvent extraction.

In place leaching (IPL): involves leaching of broken ore without removing it from an underground mine. This is also sometimes referred to as stope leaching or block leaching.

Co-product: Uranium is a co-product when it is one of two commodities that must be produced to make a mine economic. Both commodities influence output, for example, uranium and copper are co-produced at Olympic Dam in Australia. Co-product uranium is produced using either the open-pit or underground mining methods.

By-product: Uranium is considered a by-product when it is a secondary or additional product. By-product uranium can be produced in association with a main product or with co-products, e.g., uranium recovered from the Palabora copper mining operations in South Africa. By-product uranium is produced using either the open-pit or underground mining methods.

Uranium from phosphates: Uranium has been recovered as a by-product of phosphoric acid production. Uranium is separated from phosphoric acid by a solvent extraction process. The most frequently used reagent is a synergetic mixture of Tri-m-Octyl Phosphine Oxide (TOPO) and Di 2-Ethylhexyl Phosphoric Acid (DEPA).

Ion exchange (IX): Reversible exchange of ions contained in a host material for different ions in solution without destruction of the host material or disturbance of electrical neutrality. The process is accomplished by diffusion and occurs typically in crystals possessing – one or two – dimensional channels where ions are weakly bonded. It also occurs in resins consisting of three-dimensional hydrocarbon networks to which are attached many ionisable groups. Ion exchange is used for recovering uranium from leaching solutions.

Solvent extraction (SX): A method of separation in which a generally aqueous solution is mixed with an immiscible solvent to transfer one or more components into the solvent. This method is used to recover uranium from leaching solutions.

DEMAND TERMINOLOGY

a) Reactor-related requirements: Refers to natural uranium acquisitions *not* necessarily consumption during a calendar year.

ENVIRONMENTAL TERMINOLOGY[2]

a) Close-out: In the context of uranium mill tailings impoundment, the operational, regulatory and administrative actions required to place a tailings impoundment into long-term conditions such that little or no future surveillance and maintenance are required.

b) Decommissioning: Actions taken at the end of the operating life of a uranium mill or other uranium facility in retiring it from service with adequate regard for the health and safety of workers and members of the public and protection of the environment. The time period to achieve decommissioning may range from a few to several hundred years.

c) Decontamination: The removal or reduction of radioactive or toxic chemical contamination using physical, chemical, or biological processes.

d) Dismantling: The disassembly and removal of any structure, system or component during decommissioning. Dismantling may be performed immediately after permanent retirement of a mine or mill facility or may be deferred.

2. Definitions based on those published in OECD (2002), *Environmental Remediation of Uranium Production Facilities*, Paris.

e) Environmental restoration: Cleanup and restoration, according to predefined criteria, of sites contaminated with radioactive and/or hazardous substances during past uranium production activities.

f) Environmental impact statement: A set of documents recording the results of an evaluation of the physical, ecological, cultural and socio-economic effects of a planned installation, facility, or technology.

g) Groundwater restoration: The process of returning affected groundwater to acceptable quality and quantity levels for future use.

h) Reclamation: The process of restoring a site to predefined conditions, which allows new uses.

i) Restricted release (or use): A designation, by the regulatory body of a country, that restricts the release or use of equipment, buildings, materials or the site because of its potential radiological or other hazards.

j) Tailings: The remaining portion of a metal-bearing ore consisting of finely ground rock and process liquids after some or all of the metal, such as uranium, has been extracted.

k) Tailings impoundment: A structure in which the tailings are deposited to prevent their release into the environment.

l) Unrestricted release (or use): A designation, by the regulatory body of a country, that enables the release or use of equipment, buildings, materials or the site without any restriction.

GEOLOGICAL TERMINOLOGY

a) Uranium occurrence: A naturally occurring, anomalous concentration of uranium.

b) Uranium deposit: A mass of naturally occurring mineral from which uranium could be exploited at present or in the future.

c) Geologic types of uranium deposits[3]

Uranium resources can be assigned on the basis of their geological setting to the following categories of uranium ore deposit types (arranged according to their approximate economic significance):

1. Unconformity-related deposits.
2. Sandstone deposits.
3. Hematite breccia complex deposits.
4. Quartz-pebble conglomerate deposits.
5. Vein deposits.
6. Intrusive deposits.
7. Volcanic and caldera-related deposits.
8. Metasomatite deposits.
9. Surficial deposits.
10. Collapse breccia pipe deposits.
11. Phosphorite deposits.
12. Other types of deposits.
13. Rock types with elevated uranium content.

3. This classification of the geological types of uranium deposits was developed by the IAEA in 1988-89 and updated for use in the Red Book.

1. **Unconformity-related deposits**: Unconformity-related deposits are associated with and occur immediately below and above an unconformable contact that separates a crystalline basement intensively altered from overlying clastic sediments of either Proterozoic or Phanerozoic age.

   The unconformity-related deposits include the following sub-types:

   - *Unconformity contact*
     1. Fracture bound deposits occur in metasediments immediately below the unconformity. Mineralisation is monometallic and of medium grade. Examples include Rabbit Lake and Dominique Peter in the Athabasca Basin, Canada.
     2. Clay-bound deposits occur associated with clay at the base of the sedimentary cover directly above the unconformity. Mineralisation is commonly polymetallic and of high to very high grade. An example is Cigar Lake in the Athabasca Basin, Canada

   - *Sub-unconformity-post-metamorphic deposits*
     Deposits are strata-structure bound in metasediments below the unconformity on which clastic sediments rest. These deposits can have large resources, at low to medium grade. Examples are Jabiluka and Ranger in Australia.

2. **Sandstone deposits:** Sandstone uranium deposits occur in medium to coarse-grained sandstones deposited in a continental fluvial or marginal marine sedimentary environment. Uranium is precipitated under reducing conditions caused by a variety of reducing agents within the sandstone, for example, carbonaceous material, sulphides (pyrite), hydrocarbons and ferro-magnesium minerals (chlorite), etc. Sandstone uranium deposits can be divided into four main sub-types:

   - *Roll-front deposits*: The mineralised zones are convex down the hydrologic gradient. They display diffuse boundaries with reduced sandstone on the down-gradient side and sharp contacts with oxidised sandstone on the up-gradient side. The mineralised zones are elongate and sinuous approximately parallel to the strike, and perpendicular to the direction of deposition and groundwater flow. Resources can range from a few hundred tonnes to several thousands of tonnes of uranium, at grades averaging 0.05-0.25%. Examples are Moynkum, Inkay and Mynkuduk (Kazakhstan); Crow Butte and Smith Ranch (United States) and Bukinay, Sugraly and Uchkuduk (Uzbekistan).

   - *Tabular deposits* consist of uranium matrix impregnations that form irregularly shaped lenticular masses within reduced sediments. The mineralised zones are largely oriented parallel to the depositional trend. Individual deposits can contain several hundreds of tonnes up to 150 000 tonnes of uranium, at average grades ranging from 0.05-0.5%, occasionally up to 1%. Examples of deposits include Westmoreland (Australia), Nuhetting (China), Hamr-Stráz (Czech Republic), Akouta, Arlit, Imouraren (Niger) and Colorado Plateau (United States).

   - *Basal channel deposits*: Paleodrainage systems consist of several hundred metres wide channels filled with thick permeable alluvial-fluvial sediments. Here, the uranium is predominantly associated with detrital plant debris in ore bodies that display, in a plan-view, an elongated lens or ribbon-like configuration and, in a section-view, a lenticular or, more rarely, a roll shape. Individual deposits can range from several hundreds to 20 000 tonnes uranium, at grades ranging from 0.01-3%. Examples are the deposits of Dalmatovskoye (Transural Region), Malinovskoye (West Siberia), Khiagdinskoye (Vitim district) in Russia and Beverley in Australia.

- *Tectonic/lithologic deposits* occur in sandstone related to a permeable zone. Uranium is precipitated in open zones related to tectonic extension. Individual deposits contain a few hundred tonnes up to 5 000 tonnes of uranium at average grades ranging from 0.1-0.5%. Examples include the deposits of Mas Laveyre (France) and Mikouloungou (Gabon).

3. **Hematite breccia complex deposits:** Deposits of this group occur in hematite-rich breccias and contain uranium in association with copper, gold, silver and rare earths. The main representative of this type of deposit is the Olympic Dam deposit in South Australia. Significant deposits and prospects of this type occur in the same region, including Prominent Hill, Wirrda Well, Acropolis and Oak Dam as well as some younger breccia-hosted deposits in the Mount Painter area.

4. **Quartz-pebble conglomerate deposits:** Detrital uranium oxide ores are found in quartz-pebble conglomerates deposited as basal units in fluvial to lacustrine braided stream systems older than 2.3-2.4 Ga. The conglomerate matrix is pyritiferous, and gold, as well as other oxide and sulphide detrital minerals are often present in minor amounts. Examples include deposits found in the Witwatersrand Basin where uranium is mined as a by-product of gold. Uranium deposits of this type were mined in the Blind River/Elliot Lake area of Canada.

5. **Vein deposits:** In vein deposits, the major part of the mineralisation fills fractures with highly variable thickness, but generally important extension along strike. The veins consist mainly of gangue material (e.g. carbonates, quartz) and ore material, mainly pitchblende. Typical examples range from the thick and massive pitchblende veins of Pribram (Czech Republic), Schlema-Alberoda (Germany) and Shinkolobwe (Democratic Republic of Congo), to the stockworks and episyenite columns of Bernardan (France) and Gunnar (Canada), to the narrow cracks in granite or metamorphic rocks, also filled with pitchblende of Mina Fe (Spain) and Singhbhum (India).

6. **Intrusive deposits:** Deposits included in this type are those associated with intrusive or anatectic rocks of different chemical composition (alaskite, granite, monzonite, peralkaline syenite, carbonatite and pegmatite). Examples include the Rossing and Trekkopje deposits (Namibia), the uranium occurrences in the porphyry copper deposits such as Bingham Canyon and Twin Butte (United States), the Ilimaussaq deposit (Greenland), Palabora (South Africa), as well as the deposits in the Bancroft area (Canada).

7. **Volcanic and caldera-related deposits**: Uranium deposits of this type are located within and nearby volcanic caldera filled by mafic to felsic volcanic complexes and intercalated clastic sediments. Mineralisation is largely controlled by structures (minor stratabound), occurs at several stratigraphic levels of the volcanic and sedimentary units and extends into the basement where it is found in fractured granite and in metamorphites. Uranium minerals are commonly associated with molybdenum, other sulphides, violet fluorine and quartz. Most significant commercial deposits are located within Streltsovsk caldera in the Russian Federation. Examples are known in China, Mongolia (Dornot deposit), Canada (Michelin deposit) and Mexico (Nopal deposit).

8. **Metasomatite deposits**: Deposits of this type are confined to the areas of tectono-magmatic activity of the Precambrian shields and are related to near-fault alkali metasomatites, developed upon different basement rocks: granites, migmatites, gneisses and ferruginous quartzites with production of albitites, aegirinites, alkali-amphibolic and carbonaceous-ferruginous rocks. Ore lenses and stocks are a few metres to tens of metres thick and a few hundred metres long. Vertical extent of ore mineralisation can be up to 1.5 km. Ores are uraninite-brannerite by composition and belong to ordinary grade. The reserves are usually medium scale or large. Examples include Michurinskoye, Vatutinskoye, Severinskoye, Zheltorechenskoye and Pervomayskoye deposits (Ukraine), Lagoa Real, Itataia and Espinharas (Brazil), the Valhalla deposit (Australia) and deposits of the Arjeplog region in the north of Sweden.

9. **Surficial deposits:** Surficial uranium deposits are broadly defined as young (Tertiary to Recent) near-surface uranium concentrations in sediments and soils. The largest of the surficial uranium deposits are in calcrete (calcium and magnesium carbonates), and they have been found in Australia (Yeelirrie deposit), Namibia (Langer Heinrich deposit) and Somalia. These calcrete-hosted deposits are associated with deeply weathered uranium-rich granites. They also can occur in valley-fill sediments along Tertiary drainage channels and in playa lake sediments (e.g., Lake Maitland, Australia). Surficial deposits also can occur in peat bogs and soils.

10. **Collapse breccia pipe deposits:** Deposits in this group occur in circular, vertical pipes filled with down-dropped fragments. The uranium is concentrated as primary uranium ore, generally uraninite, in the permeable breccia matrix, and in the arcuate, ring-fracture zone surrounding the pipe. Type examples are the deposits in the Arizona Strip north of the Grand Canyon and those immediately south of the Grand Canyon in the United States.

11. **Phosphorite deposits**: Phosphorite deposits consist of marine phosphorite of continental-shelf origin containing syn-sedimentary stratiform, disseminated uranium in fine-grained apatite. Phosphorite deposits constitute large uranium resources, but at a very low grade. Uranium can be recovered as a by-product of phosphate production. Examples include New Wales Florida (pebble phosphate) and Uncle Sam (United States), Gantour (Morocco) and Al-Abiad (Jordan). Other type of phosphorite deposits consists of organic phosphate, including argillaceous marine sediments enriched in fish remains that are uraniferous (Melovoe deposit, Kazakhstan).

12. **Other deposits**

Metamorphic deposits: In metamorphic uranium deposits, the uranium concentration directly results from metamorphic processes. The temperature and pressure conditions, and age of the uranium deposition have to be similar to those of the metamorphism of the enclosing rocks. Examples include the Forstau deposit (Austria) and Mary Kathleen (Australia).

Limestone deposits: This includes uranium mineralisation in the Jurassic Todilto Limestone in the Grants district (United States). Uraninite occurs in intra-formational folds and fractures as introduced mineralisation.

Uranium coal deposits: Elevated uranium contents occur in lignite/coal, and in clay and sandstone immediately adjacent to lignite. Examples are uranium in the Serres Basin (Greece), in North and South Dakota (United States), Koldjat and Nizhne Iliyskoe (Kazakhstan) and Freital (Germany). Uranium grades are very low and average less than 50 ppm U.

13. **Rock types with elevated uranium contents:** Elevated uranium contents have been observed in different rock types such as pegmatite, granites and black shale. In the past no economic deposits have been mined commercially in these types of rocks. Their grades are very low, and it is unlikely that they will be economic in the foreseeable future.

    Rare metal pegmatites: These pegmatites contain Sn, Ta, Nb and Li mineralisation. They have variable U, Th and rare earth elements contents. Examples include Greenbushes and Wodgina pegmatites (Western Australia). The Greenbushes pegmatites commonly have 6-20 ppm U and 3-25 ppm Th.

    Granites: A small proportion of un-mineralised granitic rocks have elevated uranium contents. These "high heat producing" granites are potassium feldspar-rich. Roughly 1% of the total number of granitic rocks analysed in Australia have uranium-contents above 50 ppm.

    Black Shale: Black shale-related uranium mineralisation consists of marine organic-rich shale or coal-rich pyritic shale, containing syn-sedimentary disseminated uranium adsorbed onto organic material. Examples include the uraniferous alum shale in Sweden and Estonia, the Chatanooga shale (United States), the Chanziping deposit (China), and the Gera-Ronneburg deposit (Germany).

Appendix 5

ACRONYM LIST

AGR	Advanced gas-cooled reactor
AL	Acid leaching
ALKAL	Alkaline atmospheric leaching
BWR	Boiling water reactor
CANDU	***Can***adian ***d***euterium ***u***ranium
CWG	Crush-wet grind
DOE	Department of Energy (United States)
EC	European Commission
EIA	U.S. Energy Information Administration
EU	European Union
EUP	Enriched uranium product
FLOT	Flotation
Ga	Giga-years
GDR	German Democratic Republic
GIF	Generation IV International Forum
GNSS	Global Nuclear Services and Supply
GWe	Gigawatt electric
HEU	Highly enriched uranium
HL	Heap leaching
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INPRO	International project on innovative nuclear reactors and fuel cycles
IPL	In-place leaching
ISL	*In situ* leaching
IX	Ion exchange
kg	Kilograms
km	Kilometre
LEU	Low enriched uranium
LWR	Light water reactor
MAGNOX	Magnesium oxide
MOX	Mixed oxide fuel
MWe	Megawatt electric

NEA	Nuclear Energy Agency
OECD	Organisation for Economic Co-operation and Development
OP	Open-pit
ppm	Part per million
Pu	Plutonium
PHWR	Pressurised heavy-water reactor
PWR	Pressurised water reactor
RAR	Reasonably assured resources
RBMK	Water-cooled, graphite-moderated reactor (Russian acronym)
SWU	Separative work unit
SX	Solvent extraction
t	Tonnes (metric tons)
Th	Thorium
tHM	Tonnes heavy metal
TOE	Tonnes oil equivalent
tU	Tonnes uranium
TVA	Tennessee Valley Administration
TWh	Terrawatt-hour
U	Uranium
UG	Underground mining
USSR	Union of Soviet Socialist Republics
VVER	Water-cooled, water-moderated reactor (Russian acronym)

TABLE OF CONTENTS

PREFACE 3

EXECUTIVE SUMMARY 9

I. URANIUM SUPPLY 13

A. URANIUM RESOURCES 13
- Identified Resources (previously “Known Conventional Resources”) 13
- Distribution of Identified Resources by Categories and Cost Ranges 13
- Distribution of Resources by Production Method 19
- Distribution of Resources by Deposit Type 19
- Proximity of Resources to Production Centres 23
- Undiscovered Resources 24
- Other Resources and Materials 26
- Thorium 28

B. URANIUM EXPLORATION 29
- Current Activities and Recent Developments 33

C. URANIUM PRODUCTION 37
- Present Status of Uranium Production 41
- Ownership 42
- Employment 44
- Production Methods 45
- Projected Production Capabilities 46
- Changes in Production Facilities 47

II. URANIUM DEMAND 51

A. CURRENT COMMERCIAL NUCLEAR GENERATING CAPACITY AND REACTOR-RELATED URANIUM REQUIREMENTS 51

B. PROJECTED NUCLEAR POWER CAPACITY AND RELATED URANIUM REQUIREMENTS TO 2030 62
- Factors Affecting Capacity and Uranium Requirements 62
- Projections to 2030 64

C. URANIUM SUPPLY AND DEMAND RELATIONSHIPS 71
- Primary Sources of Uranium Supply 71
- Secondary Sources of Uranium Supply 71
- Uranium Market Developments 82
- Supply and Demand to 2030 85

D. THE LONG-TERM PERSPECTIVE 87

III. NATIONAL REPORTS ON URANIUM EXPLORATION, RESOURCES, PRODUCTION, DEMAND AND THE ENVIRONMENT 91

Algeria 92
Argentina 94
Australia 103
Belgium 114
Brazil 118
Bulgaria 126
Canada 135
Chile 148
China 153
Colombia 163
Czech Republic 166
Egypt 176
Finland 179
France 186
Germany 191
Hungary 197
India 204
Iran, Islamic Republic of 218
Japan 223
Jordan 229
Kazakhstan 234
Korea, Republic of 249
Lithuania 252
Malawi 254
Namibia 256
Niger 268
Peru 276
Poland 279
Portugal 283
Russian Federation 289
Slovak Republic 300
Slovenia 303
South Africa 310
Spain 322
Sweden 328
Switzerland 332
Turkey 335
Ukraine 338
United Kingdom 352
United States of America 357
Vietnam 375

APPENDICES

1. Members of the Joint NEA-IAEA Uranium Group 379

2. List of Reporting Organisations and Contact Persons 383

3. The Uranium Mining Remediation Exchange Group (UMREG) 387

4 Glossary of Definitions and Terminology 391

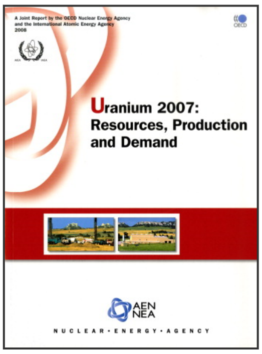
5. Acronym List 403

6. Energy Conversion Factors 405

7. Listing of all Red Book Editions (1965-2008) and National Reports 409

8. Currency Exchange Rates 417

9. Grouping of Countries and Areas with Uranium-related Activities 419



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