WORLD URANIUM MINING PRODUCTION

СВЕТОВНО ПРОИЗВОДСТВО НА УРАН

Chief Assistant Professor PhD eng. Dolchinkov N. T.,

National Military University „Vasil Levski“, Veliko Tarnovo, Bulgaria,

National Research University "Moscow Power Engineering Institute", Moscow, Russia

n_dolchinkov@abv.bg

Abstract: *Uranium mines operate in some 20 countries, though in 2017 some 53% of world production came from just ten mines in four countries, with these four countries providing 77% of the world's mined uranium. Countries have different degrees of sovereign risk affecting their attractiveness for mining investment, different royalty and tax regimes, and different availability of skilled workers. These factors will have already influenced the mineral exploration which has led to the identification of an orebody before any mining issue has arisen.*

Keywords: uranium mines, uranium production, countries, factors, nuclear power

1. Introduction

Uranium mines operate in some 20 countries, though in 2017 some 53% of world production came from just ten mines in four countries (see Table 1), with these four countries providing 77% of the world's mined uranium.

2.1. Uranium mines

Over two-thirds of the world's production of uranium from mines is from Kazakhstan, Canada and Australia.

An increasing amount of uranium, now 50%, is produced by in situ leaching.

After a decade of falling mine production to 1993, output of uranium has generally risen since then and now meets almost all the demand for power generation.

Kazakhstan produces the largest share of uranium from mines (39% of world supply from mines in 2017), followed by Canada (22%) and Australia (10%).

Production from mines (tonnes U)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Kazakhstan	6637	8521	14,020	17,803	19,451	21,317	22,451	23,127	23,800	24,575	23,391
Canada	9476	9000	10,173	9783	9145	8999	9331	9134	13,325	14,039	13,116
Australia	8611	8430	7982	5900	5983	6991	6350	5001	5654	6315	5882
Niger	3153	3032	3243	4198	4351	4667	4518	4057	4116	3479	3449
Namibia	2879	4366	4626	4496	3258	4495	4323	3255	2993	3654	4224
Russia	3413	3521	3564	3562	2993	2872	3135	2990	3055	3004	2917
Uzbekistan (est)	2320	2338	2429	2400	2500	2400	2400	2400	2385	2404	2404
China (est)	712	769	750	827	885	1500	1500	1500	1616	1616	1885
USA	1654	1430	1453	1660	1537	1596	1792	1919	1256	1125	940
Ukraine (est)	846	800	840	850	890	960	922	926	1200	1005	550
South Africa	539	655	563	583	582	465	531	573	393	490	308
India (est)	270	271	290	400	400	385	385	385	385	385	421
Czech Republic	306	263	258	254	229	228	215	193	155	138	0
Romania (est)	77	77	75	77	77	90	77	77	77	50	0
Pakistan (est)	45	45	50	45	45	45	45	45	45	45	45
Brazil (est)	299	330	345	148	265	326	192	55	40	44	0
France	4	5	8	7	6	3	5	3	2	0	0
Germany	41	0	0	8	51	50	27	33	0	0	0
Malawi			104	670	846	1101	1132	369	0	0	0
Total world	**41,282**	**43,853**	**50,773**	**53,671**	**53,494**	**58,490**	**59,331**	**56,042**	**60,497**	**62,368**	**59,531**
tonnes U_3O_8	48,683	51,702	59,875	63,295	63,084	68,976	69,969	66,089	71,343	73,548	70,201
% of world demand*	64%	68%	78%	78%	85%	86%	92%	85%	90%	98%	92%

Table 1: *Uranium mines bay contry*

Data from the World Nuclear Association. NB: the figures in this table are liable to change as new data becomes available.

Mining methods have been changing. In 1990, 55% of world production came from underground mines, but this shrunk dramatically to 1999, with 33% then. From 2000 the new Canadian mines increased it again. In situ leach (ISL, or ISR) mining has been steadily increasing its share of the total, mainly due to Kazakhstan, and in 2017 accounted for half of production. In 2017 production was as follows:

In 2009 it became the world's leading uranium producer, with almost 28% of world production, then 33% in 2010, rising to 41% in 2014, and 39% in 2015 and 2016.

A single Russian nuclear power reactor operated from 1972 to 1999, generating electricity and desalinating water.

Kazakhstan has a major plant making nuclear fuel pellets and aims eventually to sell value-added fuel rather than just uranium. A fuel fabrication plant is being built with 49% Chinese equity.

The government is committed to a high level of uranium exports, and plans in 2018 to complete a feasibility study for a reactor, probably to be sited at Kurchatov.

Kazakhstan has been an important source of uranium for more than 50 years. Over 2001 to 2013 production rose from 2022 to about 22,550 tonnes U per year, making

Kazakhstan the world's leading uranium producer. Capacity is around 25,000 tU/yr, but in October 2011

Kazatoprom announced a cap on production of 20,000 tU/yr, which was evidently disregarded. Of its 17 mine projects, five are wholly owned by

Kazatomprom and 12 are joint ventures with foreign equity holders, and some of these are producing under nominal capacity. In 2016, 12,986 tU was attributable to Kazatomprom itself – 21% of world production, putting it ahead of Cameco, followed by Areva and ARMZ-Uranium One.

The country's total production in 2016 was 24,575 tU, and in 2017 was 23,600 tU. In January 2017 Kazatomprom said that production would be reduced by about 10%, due to low prices; in December 2017 Kazatomprom announced that the reduction would be 20% from 2017 levels, enacted over a period of three years. The announced cuts amount to a producton deferral of 11,000 tonnes of natural uranium. In May 2018 the country's energy minister announced that the production target for 2018 is set at 21,600 tU.

Canada was the world's largest uranium producer for many years, accounting for about 22% of world output, but in 2009 was overtaken by Kazakhstan.

Production comes mainly from the McArthur River and Cigar Lake mines in northern Saskatchewan province, which are the largest and highest-grade in the world.

With known uranium resources of 582,500 tonnes of U3O8 (493,900 tU), as well as much continuing exploration, Canada has a significant role in meeting future world demand.

Method	tonnes U	%
In situ leach (ISL)	29,492	50%
Underground & open pit (except Olympic Dam)*	27,350	46%
By-product*	2689	4%

Table 2: *World distribution of uranium mining methods*

Canada is a country rich in uranium resources and a long history of exploration, mining and generation of nuclear power (for coverage of nuclear power, see information paper on Nuclear Power in Canada). To 2014, more uranium had been mined in Canada than any other country – 485,000 tU, about one-fifth of world total.

Early uranium mining

In Canada, uranium ores first came to public attention in the early 1930s when the Eldorado Gold Mining Company began operations at Port Radium, Northwest Territories, to recover radium. A refinery to produce radium was built the following year at Port Hope, Ontario, some 5000 km away.

Exploration for uranium began in earnest in 1942, in response to a demand for military purposes. The strategic nature of such material resulted in a ban on prospecting and mining of all radioactive materials across Canada. In 1944, the federal government took over the Eldorado company and formed a new Crown corporation which later became Eldorado Nuclear Ltd. Uranium exploration was restricted to the joint efforts of Eldorado and the Geological Survey of Canada.

Postwar, uranium exploration gathered pace when the wartime ban on private prospecting was lifted in 1947. Deposits around the Bancroft, Ontario, area were discovered by the early 1950s, and the first discovery in Ontario's Elliot Lake region was in 1953. The northern Saskatchewan uranium province was also discovered in the 1950s and Eldorado Nuclear began mining at Beaverlodge in 1953.

By 1956 thousands of radioactive occurrences had been discovered. Several proved to be viable deposits, and by 1959, 23 mines with 19 treatment plants were in operation in five districts. Of these 19, about 11 in the Elliot Lake area, including the largest plants, would come to be operated by Rio Algom and Denison Mines. Three other plants were located near Bancroft, three in northern Saskatchewan and two in Northwest Territories.

This first phase of Canadian uranium production peaked in 1959 when more than 12,000 tonnes of uranium were produced. The uranium yielded C$ 330 million in export revenue, more than for any other mineral export from Canada that year. However, this period marked the end of cost-plus production for export, and over the next few years the number of mines declined to four. Uranium production in the Bancroft area and at Beaverlodge ceased in 1982 and the last of the labour-intensive, lower-grade Elliot Lake mines closed in 1996.

During the 1960s the federal government supported the domestic uranium industry by initiating a stockpiling program which ended in 1974, after some 7000 tonnes of uranium were purchased at a cost of C$ 100 million. Uranium exploration was revived by expectations of nuclear power growth, and as a result several new uranium deposits were discovered in northern Saskatchewan's Athabasca Basin, starting in the late 1960s.

Conventional mines have a mill where the ore is crushed, ground and then leached with sulfuric acid to dissolve the uranium oxides. At the mill of a conventional mine, or the treatment plant of an ISL operation, the uranium then separated by ion exchange before being dried and packed, usually as U3O8. Some mills and ISL operations (especially in the USA) use carbonate leaching instead of sulfuric acid, depending on the orebody. Where uranium is recovered as a by-product, eg of copper or phosphate, the treatment process is likely to be more complex.

During the 1990s the uranium production industry was consolidated by takeovers, mergers and closures, but this has diversified again with Kazakhstan's multinational ownership structure. Over half of uranium mine production is from state-owned mining companies, some of which prioritise secure supply over market considerations. In 2017, the top 10 companies by production marketed 86% of the world's uranium production:

2.2. Uranium production

Company	tonnes U	%
Kazatomprom	12,488	21
Cameco	9155	15
Orano	8031	13
Uranium One	5102	9
CNNC & CGN	3897	7
ARMZ	2917	5
Rio Tinto	2558	4
Navoi	2404	4
BHP Billiton	2381	4
Energy Asia	2218	4
General Atomics/Quasar	1556	3
Sopamin	1188	2
Paladin	970	2
Other	4667	7
Total	**59,532**	**100%**

Table 3: *Uranium production by companies*

Note that these figures are based on marketed share of production, not joint venture shares.

Australia's uranium has been mined since 1954, and three mines are currently operating. More are planned.

Australia's known uranium resources are the world's largest – almost one-third of the world total.

In 2017 Australia produced 6937 tonnes of U3O8 (5882 tU). It is the world's third-ranking producer, behind Kazakhstan and Canada. All production is exported. Uranium comprises about one-quarter of energy exports.

Australia uses no nuclear power, but with high reliance on coal any likely carbon constraints on electricity generation will make it a strong possibility.

In May 2016 the South Australian government's royal commission on the nuclear fuel cycle reported. Its main recommendation was for an international high-level nuclear waste repository, though this was not accepted.

The Australian economy is unique in the OECD in that about 20% of GDP is accounted for by mining and mining services (in 2012). Uranium is a small part of this economically, but in energy terms, uranium (4200 PJ in 2015-16) comprises about one-quarter of energy exports.

In the 1930s ores were mined at Radium Hill and Mount Painter in SA to recover radium for medical purposes. As a result a few hundred kilograms of uranium were also produced.

Uranium ores as such were mined and treated in Australia initially from the 1950s until 1971. Radium Hill, SA, Rum Jungle,

NT, and Mary Kathleen, Queensland, were the largest producers of uranium (as yellowcake). Production ceased either when ore reserves were exhausted or contracts were filled. Sales were to supply material primarily intended for USA and UK weapons programs at that time. However, much of it was used for electricity production.

The development of civil nuclear power stimulated a second wave of exploration activity in the late 1960s. A total of some 60 uranium deposits were identified from the 1950s through to the late 1970s, many by big companies with big budgets. (Since then only two significant new ones have been found: Kintyre and Beverley Four Mile. The minor exploration boom 2002-07 was driven by small companies focused on proving up known deposits.)

Mary Kathleen began recommissioning its mine and mill in 1974. Other developments were deferred pending the findings of the Ranger Uranium Environmental Inquiry, and its decision in the light of these. Mary Kathleen's second production phase was1976 to the end of 1982.

The largest-producing uranium mines in 2017 were:

Mine	Country	Main owner	Type	Production (tonnes U)	% of world
Cigar Lake	Canada	Cameco (50%)	underground	6924	12
McArthur River	Canada	Cameco (69.8%)	underground	6193	10
Tortkuduk & Myunkum	Kazakhstan	Katco JV/Areva	ISL	3519	6
Olympic Dam	Australia	BHP Billiton	by-product/ underground	2381	4
Budenovskoye 2	Kazakhstan	Karatau JV/Kazatomprom-Uranium One	ISL	2352	4
Inkai	Kazakhstan	Inkai JV/Cameco	ISL	2116	4
SOMAIR	Niger	Areva (63.6%)	open pit	2116	4
South Inkai	Kazakhstan	Betpak Dala JV/Uranium One	ISL	1982	3
Ranger	Australia	Rio Tinto (68%)	open pit	1945	3
Budenovskoye 1, 3 & 4	Kazakhstan	Akbastau JV/Kazatomprom-Uranium One	ISL	1931	3
Top 10 total				**31,458**	**53%**

Table 4: *Uranium production by companies*

Most of the uranium ore deposits at present supporting these mines have average grades in excess of 0.10% of uranium – that is, greater than 1000 parts per million. In the first phase of uranium mining to the 1960s, this would have been seen as a respectable grade, but today some Canadian mines have huge amounts of ore up to 20% U average grade. Other mines however can operate successfully with very low grade ores, down to about 0.02% U.

Some uranium is also recovered as a by-product with copper, as at Olympic Dam mine in Australia, or as by-product from the treatment of other ores, such as the gold-bearing ores of South Africa, or from phosphate deposits such as Morocco and Florida. In these cases the concentration of uranium may be as low as a tenth of that in orebodies mined primarily for their uranium content. An orebody is defined as a mineral deposit from which the mineral may be recovered at a cost that is economically viable given the current market conditions. Where a deposit holds a significant concentration of two or more valuable minerals then the cost of recovering each individual mineral is reduced as certain mining and treatment requirements can be shared. In this case, lower concentrations of uranium than usual can be recovered at a competitive cost.

Generally speaking, uranium mining is no different from other kinds of mining unless the ore is very high grade. In this case special mining techniques such as dust suppression, and in extreme cases remote handling techniques, are employed to limit worker radiation exposure and to ensure the safety of the environment and general public.

Searching for uranium is in some ways easier than for other mineral resources because the radiation signature of uranium's decay products allows deposits to be identified and mapped from the air.

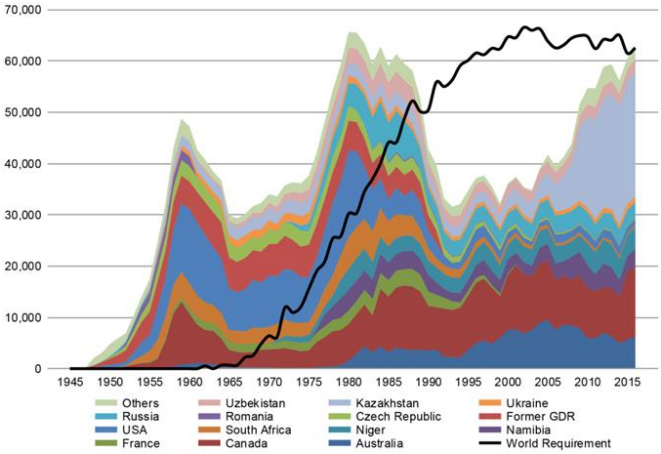

Fig 1: *Uranium production by contry*

	tonnes U	percentage of world
Australia	1,818,300	30%
Kazakhstan	842,200	14%
Canada	514,400	8%
Russia	485,600	8%
Namibia	442,100*	7%
South Africa	322,400	5%
China	290,400	5%
Niger	280,000*	5%
Brazil	276,800	5%
Uzbekistan	139,200*	2%
Ukraine	114,100	2%
Mongolia	113,500	2%
Botswana	73,500*	1%
Tanzania	58,200*	1%
USA	47,200	1%
Jordan	43,500	1%
Other	280,600	4%
World total	**6,142,600**	

Table 5*: Uranium resources by country in 2017*

Identified resources recoverable (reasonably assured resources plus inferred resources), to US$ 130/kg U, 1/1/17, from OECD NEA & IAEA, Uranium 2018: Resources, Production and Demand ('Red Book'). The total recoverable identified resources to US$ 260/kg U is 7.989 million tonnes U.

Identified resources in situ to US$ 130/kg U are 8.122 Mt, and to US$ 260/kg U, 10.653 Mt.

* IAEA estimate.

Uranium supplies for the EU

Euratom reported that in 2017, 14,312 tonnes of uranium was delivered to EU-28 utilities. This represented about one-quarter of world supply from mines. Nearly all of this (96%) was under long-

term contracts. In addition, MOX fuel containing 10.7 tonnes of plutonium was used, representing a saving of 993 tonnes of natural uranium and 0.69 million SWU.

The main sources of 2017 uranium deliveries were: Canada 29%, Russia, 15%, Niger 15%, Australia 15%, and Kazakhstan 14%. The 2017 average price for deliveries under long-term contracts was €80.55/kgU, 7% lower than in 2016. In 2017 enrichment was supplied by: EU (Areva and Urenco), 7.69 million SWU; Russia (Tenex), 2.52 million SWU; and others, 0.65 million SWU.

In 2017 inventories declined to 49,004 tonnes of natural uranium equivalent, about three years' requirements. Projections by utilities for Euratom suggest that this will diminish to about 2025.

Euratom reported that in 2017, 2232 tU of fresh fuel was loaded into commercial reactors in the EU-28. It was produced using 16,084 tU of natural uranium and 460 tU of reprocessed uranium as feed, enriched with 12.10 million SWU. In 2017, the fuel loaded into EU reactors had an average enrichment assay of 3.92% and an average tails assay of 0.23%.

3.Conclusions:

1. Kazakhstan produces the largest share of uranium from mines (39% of world supply from mines in 2017), followed by Canada (22%) and Australia (10%).;
2. In 2017, the top 10 companies by production marketed 86% of the world's uranium production;
3. In the 1930s ores were mined at Radium Hill and Mount Painter in SA to recover radium for medical purposes. As a result a few hundred kilograms of uranium were also produced;
4. The main sources of 2017 uranium deliveries were: Canada 29%, Russia, 15%, Niger 15%, Australia 15%, and Kazakhstan 14%. The 2017 average price for deliveries under long-term contracts was €80.55/kgU, 7% lower than in 2016. In 2017 enrichment was supplied by: EU (Areva and Urenco), 7.69 million SWU; Russia (Tenex), 2.52 million SWU; and others, 0.65 million SWU.

4.Literature:

1. Josephson, Paul R, 1999, Red Atom - Russia's nuclear power program from Stalin to today.
2. Minatom 2000, Strategy of Nuclear Power Development in Russia,
3. O. Saraev, paper at WNA mid-term meeting in Moscow, May 2003.
4. Rosenergoatom Bulletin 2002, esp. M.Rogov paper.
5. Perera, Judith 2003, Nuclear Power in the Former USSR, McCloskey, UK.
6. Kamenskikh, I, 2005, paper at WNA Symposium.
7. Kirienko, S. 2006, paper at World Nuclear Fuel Cycle conference, April and WNA Symposium, Sept.
8. Shchedrovitsky, P. 2007, paper at WNA Symposium, Sept.
9. Panov et al 2006, Floating Power Sources Based on Nuclear reactor Plants
10. Rosenergoatom website
11. Rosatom website
12. nuclear.ru6.
13. http://www.world-nuclear.org/information-library.aspx;
14. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/uranium-mining-overview.aspx