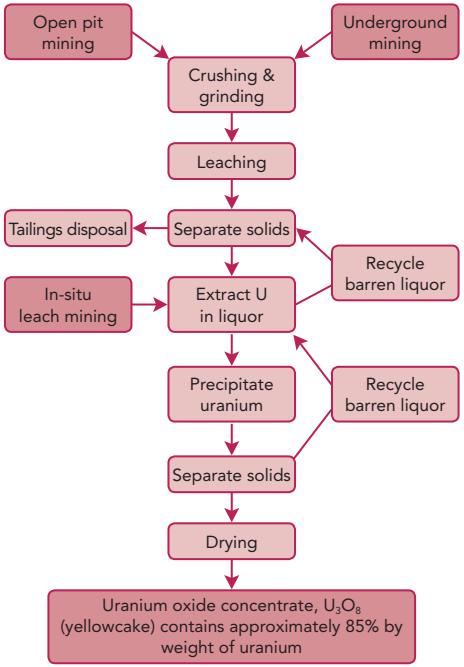
Milling

Simplified flow chart of uranium ore processing from mining to the production of concentrate. These processes are commonly known as milling and the product – uranium oxide concentrate – is the raw material for making nuclear fuel.



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Uranium production and resources

Country	2013 production (tU)	Uranium resources (tU)* <US$130/kg
Australia	6350	1,158,000
Brazil	198	155,700
Canada	9332	319,700
China	1450	109,500
Czech Republic	225	300
India	400	na
Kazakhstan	22,567	319,900
Malawi	1132	10,000
Namibia	4315	234,900
Niger	4528	339,000
Pakistan	41	na
Romania	80	3100
Russia	3135	172,900
South Africa	540	144,600
Ukraine	1075	86,800
USA	1835	207,400
Uzbekistan	2400	64,300
Other	27	129,400
Total	**59,637**	**3,455,500**

* OECD/NEA Reasonably Assured Resources category

Sources: WNA & OECD/NEA

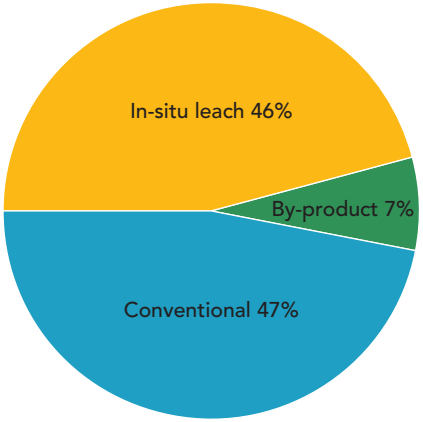
Uranium history

- In 1789 Martin Klaproth, a German chemist, isolated an oxide of uranium while analyzing pitchblende samples from silver mines in Bohemia.
- For over 100 years uranium was mainly used as a colorant for ceramic glazes and for tinting in early photography. Uranium was produced in Bohemia, Cornwall, Portugal and Colorado and total production amounted to about 300-400 tonnes.
- The discovery of radium in 1898 by Marie Curie led to the construction of a number of radium extraction plants processing uranium ore (radium is a decay product of uranium).
- Prized for its use in cancer therapy, radium reached a price of 750,000 gold francs per gram in 1906 (US$10 million). It is estimated that 754 grams were produced worldwide between 1898 and 1928. Uranium itself was treated simply as a waste material.
- With the discovery of nuclear fission in 1939, the uranium industry entered a new era. On 2 December 1942, the first controlled nuclear chain reaction was achieved in Chicago. Although nuclear fission was first used for military purposes, the emergence of civil nuclear power reactors in the 1950s demonstrated the enormous potential of nuclear fission for supplying electricity.
- From a small beginning in 1951, when four lightbulbs were lit with nuclear electricity, the nuclear power industry now supplies about 11% of world electricity.

McArthur River – world's top producing uranium mine in 2013

World Nuclear Association

URANIUM FROM MINE TO MILL



World uranium production by mining method, 2013

Top ten uranium mines in 2012-2013

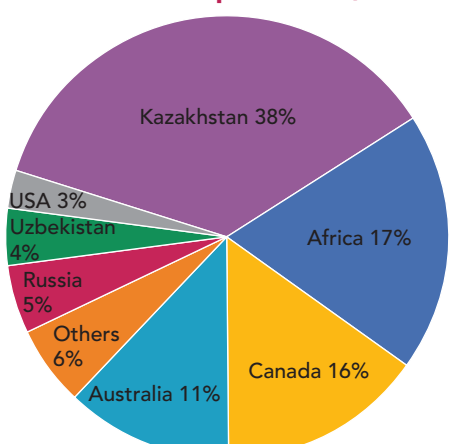
Mine	Country	Main owner	Mine type	Production (tU)		% of world production	
				2012	2013	2012	2013
McArthur River	Canada	Cameco	Conventional	7520	7744	13	13
Olympic Dam	Australia	BHP Billiton	By-product (copper)	3386	3399	6	6
Somair	Niger	Areva	Conventional	3065	2730	5	5
Tortkuduk	Kazakhstan	Katco JV/Areva	ISL	2661	2563	5	4
Ranger 3	Australia	ERA/Rio Tinto	Conventional	3146	2510	5	4
Priargunsky	Russia	ARMZ	Conventional	2011	2133	3	4
Karatau/Budenovskoye 2	Kazakhstan	Kazatomprom/Uranium One	ISL	2135	2115	4	4
Langer Heinrich	Namibia	Paladin	Conventional	1955	2098	3	4
Inkai	Kazakhstan	Cameco/Kazatomprom	ISL	1870	2047	3	3
Rössing	Namibia	Rio Tinto	Conventional	2289	2031	4	3
Total from top ten mines				**30,038**	**29,370**	**51**	**50**

Leading uranium mining companies

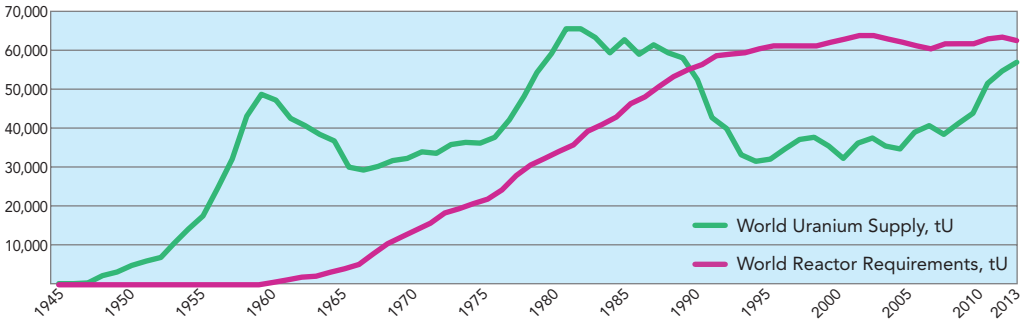
(based on marketing share of production)

Company	2013 production	
	Actual (tU)	World share (%)
Kazatomprom	9402	16
Cameco	9144	15
Areva	8768	15
ARMZ-Uranium One	8160	14
Rio Tinto	4541	8
BHP Billiton	3399	6
Paladin	3230	5
Navoi	2400	4
Sub-total	49,044	~83
World total	**59,637**	**100**

World uranium production, 2013



World historic uranium production



The gap between reactor requirements and production since 1985 has been filled by secondary supplies, mostly from stockpiles including military inventory. Going forward, the gap will increasingly be filled by higher primary production, as secondary supplies diminish.

Mineralogy and ore grade

- **Uraninite** is the most common primary uranium mineral: others of economic interest include coffinite and brannerite. The most common form of uraninite is **pitchblende**, which is sometimes associated with colourful secondary uranium minerals derived from weathering.
- The average abundance of uranium in the Earth's crust is 2.7 parts per million, making it more common than tin.
- The concentration of uranium needed to form an economic mineral deposit varies widely depending on its geological setting and physical location. Average ore grades at operating uranium mines range from 0.03% U to as high as 24% U, but are most frequently less than 1% U. Lower uranium grades are viable as by-product.

Mining methods

- **Open pit:** used to mine relatively shallow deposits. Economics depend on the ratio of ore to waste, higher grade ores having lower ratios.
- **Underground:** used to mine deposits too deep for open pit mining. For mining to be viable, these deposits must be comparatively high grade.
- **In-situ leach:** this method is applicable only to sandstone-hosted uranium deposits located below the water table in a confined aquifer. The uranium is dissolved in acid or alkali injected into and recovered from the aquifer by means of wells. The geology remains undisturbed.
- **By-product:** uranium often occurs in association with other minerals such as gold (Witwatersand), phosphate (USA and elsewhere) and copper (Australia).

Processing and extraction

- **Crushing and grinding:** breaks down the ore to fine particles.
- **Leaching:** acid or alkali dissolves the freed uranium, and the uranium-bearing solution is separated from the leached solids.
- **Extraction:** ion exchange or solvent extraction methods are used to separate the dissolved uranium.
- **Precipitation and drying:** uranium is precipitated from solution using one of several chemicals. Dewatering, filtration and drying complete the process. The final product is sometimes known as yellowcake, although it is typically khaki in colour.