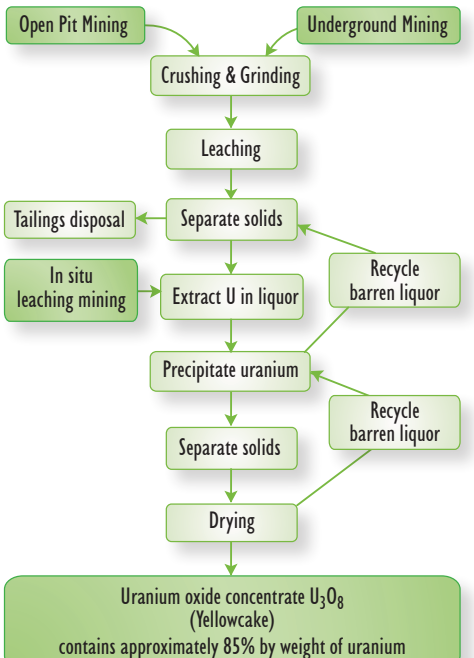
## Milling

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 or area | 2008 production (tU) | Capacity (tU) at 31.12.08 | Uranium resources (tU)* <US£80/kg |
|---|---|---|---|
| Australia | 8430 | 9550 | 714 000 |
| Brazil | 330 | 400 | 157 400 |
| Canada | 9000 | 11 810 | 329 200 |
| China † | 769 | 1000 | 44 300 |
| Czech Rep | 263 | 440 | 600 |
| France | 5 | n/a | n/a |
| India † | 271 | 300 | n/a |
| Kazakhstan | 8521 | 10 000 | 344 200 |
| Namibia | 4366 | 5000 | 145 100 |
| Niger | 3032 | 3500 | 44 300 |
| Pakistan † | 45 | 50 | n/a |
| Romania † | 77 | 100 | n/a |
| Russia | 3521 | 3750 | 172 400 |
| South Africa | 655 | 2000 | 205 900 |
| Ukraine | 800 | 1000 | 126 500 |
| USA | 1430 | 2000 | 99 000 |
| Uzbekistan | 2338 | 2500 | 55 200 |
| **Total** | **43 853** | **53 400** | **2 438 100** |

*Sources: WNA, OECD/NEA*

*OECD/NEA Reasonably Assured Resources Category

† World Nuclear Association estimate

NB Many other countires have also known uranium resources

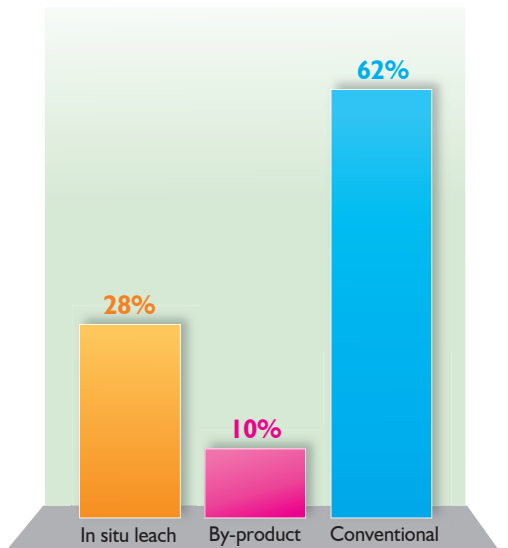
## Uranium history

- In 1789 Martin Klaproth, a German chemist, isolated an oxide of uranium while analysing pitchblende samples from the Joachimsthal 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 simply dumped 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. The first nuclear explosion in 1945 demonstrated the enormous power potential of nuclear fission.
- From a small beginning in 1951, when four lightbulbs were lit with nuclear electricity, the nuclear power industry now supplies some 15% of world electricity.

*McArthur River – world's top producing uranium mine in 2008*



# Uranium - from mine to mill



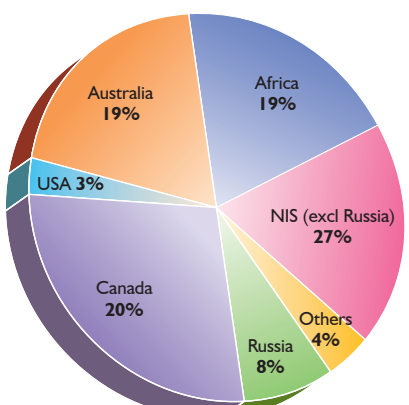

*World uranium production by mining method, 2008*

World Nuclear Association

www.world-nuclear.org

## Top ten uranium mines in 2007 - 2008

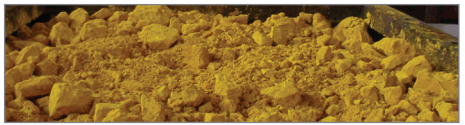
| Mine | Country | Main owner | Mine type | Production (tU) | | % of world production | | Rank | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2007 | 2008 | 2007 | 2008 | 2007 | 2008 |
| McArthur River | Canada | Cameco | Conventional | 7199 | 6383 | 17 | 15 | 1 | 1 |
| Ranger | Australia | ERA (Rio Tinto 68%) | Conventional | 4589 | 4527 | 11 | 10 | 2 | 2 |
| Rössing | Namibia | Rio Tinto (69%) | Conventional | 2583 | 3449 | 6 | 8 | 5 | 3 |
| Olympic Dam | Australia | BHP Billiton | By-product (copper) | 3388 | 3344 | 8 | 8 | 3 | 4 |
| Priargunsky | Russia | ARMZ | Conventional | 3037 | 3050 | 7 | 7 | 4 | 5 |
| Arlit | Niger | Areva | Conventional | 1790 | 1743 | 4 | 4 | 6 | 6 |
| Rabbit Lake | Canada | Cameco | Conventional | 1544 | 1368 | 4 | 3 | 7 | 7 |
| Akouta | Niger | Areva | Conventional | 1403 | 1289 | 3 | 3 | 8 | 8 |
| McClean Lake | Canada | Areva | Conventional | 734 | 1249 | 2 | 3 | 11 | 9 |
| Akdala | Kazakhstan | Uranium One | ISL | 1000 | 1034 | 2 | 2 | 9 | 10 |
| **World total from top ten mines** | | | | **27 297** | **27 436** | **64** | **62** | | |




*World uranium production, 2008*

## Leading uranium mining companies

| Company | 2008 production | |
|---|---|---|
| | Actual (tU) | World share (%) |
| Rio Tinto | 7975 | 18 |
| Cameco | 6659 | 15 |
| Areva | 6318 | 14 |
| KazAtomProm | 5328 | 12 |
| ARMZ | 3688 | 8 |
| BHP Billiton | 3344 | 8 |
| Navoi | 2338 | 5 |
| Uranium One | 1107 | 3 |
| Paladin | 917 | 2 |
| General Atomics | 636 | 1 |
| Sub total | 38 310 | 87 |
| **World total** | **43 930** | **100** |



*Yellowcake*

## 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. These figures do not apply to by-product operations.

## Mining methods

• **Open pit:** used to mine relatively shallow deposits. Economics depend on the ratio of ore to waste, higher grade ores being able to produce higher 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 a mildly alkaline or acidic solution that is 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 (United States and elsewhere) and copper (Australia).

## Processing and extraction

• **Crushing and grinding:** breaks down the ore to sand/silt sized particles, thereby freeing the uranium minerals.

• **Leaching:** acid or alkali dissolves the freed uranium, allowing the uranium-bearing solution to be separated from the leached solids by solid-liquid separation device, resulting in a clarified uranium-bearing solution.

• **Extraction:** ion exchange or solvent extraction methods are used to separate the dissolved uranium from the aqueous solution.

• **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.

## Western world historic uranium production