



## Uranium Nuclear Fuel

By CK Wong 2005.11.15

<http://www.ck-wong.ca/Energy/uranium%20nuclear%20fuel%20cycle%2020051115.pdf>

### Introduction

There are two types of atomic energy generator. The first type is commonly known uranium fuel generator. The second type uses the heavy water. The heavy water reactor does not create radioactive hazard residue. The waste management is simple. This is different in uranium fuel generator. This article discuss the life cycle of uranium nuclear fuel. Observations and trends are presented on the future of uranium fuel.

### Uranium Source

Uranium is very common in nature on land and seawater. It is not a scarce mineral. Wherever you find rock, most likely you will find the trace of uranium at about 2 - 4 part per million (ppm). This is a fairly small number but it is comparable to gold. Production grade gold ore is usually at the concentration of 2.5 – 6 gram per ton which is about 2.5 – 6 ppm. Because uranium is almost everywhere, it is about 500 time more abundant than gold. Therefore it is a good supply although it is not renewable.

The grade of uranium ore can be ranging from 1,000 ppm to 200,000 ppm. High grade uranium reduces the cost of production. As the price of uranium moving from US\$10 at the beginning of 2000 to \$33 in November 2005, lower grade may be considered.

There are 16 isotopes of uranium. Each isotope has the same 92 negatively charged electron outside and 92 positively charged protons in the nucleus. The difference is the number of neutron in the nucleus. All isotopes have the same chemical property. For nuclear fuel, we are only interested in  $U_{235}$  and  $U_{238}$ . In the natural environment,  $U_{235}$  is about 0.7% in the uranium found. For nuclear reactor, most designs need  $U_{235}$  above 0.7% of  $U_{235}$  concentration except Canadian's CANDU. The rest of the uranium is mostly made up of the  $U_{238}$ .

$U_{235}$  is not highly stable which could be split into smaller chunks of nuclei and release energy.  $U_{238}$  is radioactive but at a very low intensity which is about 0.1 watt/ton. All the  $U_{238}$  on earth generates radiation heats up the core of earth. In a way, the earth is powered by uranium. If you worry about radiation, you may relax a bit because human being has been subject to uranium radiation for thousands of years.

When uranium is mined and sold, the producer uses either the chemical or water process to extract uranium and its isotopes. The merchandize is sold as the oxide form  $U_3O_8$ . To extract the  $U_{235}$ , the oxide is gone through a process of concentration so that the  $U_{235}$  could produce effective nucleus reaction. The process converts the  $U_3O_8$  to a gas form  $UF_6$ . The objective is to improve the  $U_{235}$  concentration from the natural occurrence of 0.7% to 2-4%. Later the  $UF_6$  is converted to  $UO_2$  which is used to create the fuel pallets.

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## World Reserve Distribution

Although uranium exists everywhere, some country has higher concentration. Australia is believed to have the highest reserve of 660,000 ton or 28% of the world concentration with Canada second. Canada's reserve is estimated to be about 320,000 ton or 14% of the world. Kazakhstan has 15% of world total while American only holds the meager 3%. The numbers could be adjusted when more new exploration data from Mongolia, Russia and Africa is available.

## Nucleus Chemistry

To appreciate the nuclear reactor, we may want to understand what happens in the core of the reactor where the nucleus chemistry occurs.

$U_{235}$  which has 3 neutrons less than  $U_{238}$  has an unstable nucleus structure. When a neutron is traveling slowly through the nucleus, the  $U_{235}$  trigger fission: it splits into several fragments. The total mass of what is formed is less than the original nucleus (reduction of neutron). The disappeared mass is converted to energy.

## Fuel Requirement

Not all reactors require the same mix of  $U_{238}$  and  $U_{235}$ . The different creates the differentiator of different nuclear reactor.

The following is some samples:

Reactor	Uranium Mix	Moderator
<b>Magnox</b>	Natural uranium metal (0.7% $U_{235}$ ) Magnesium alloy cladding	Graphite
<b>AGR</b>	Uranium dioxide enriched to 2.3% $U_{235}$ Stainless steel cladding	Graphite
<b>PWR</b>	Uranium dioxide enriched to 3.2% $U_{235}$ Zirconium alloy cladding	Light Water
<b>BWR</b>	Uranium dioxide enriched to 2.4% $U_{235}$ Zirconium alloy cladding	Light Water
<b>CANDU</b>	Unenriched uranium dioxide (0.7% $U_{235}$ ) Zirconium alloy cladding	Heavy Water
<b>RBMK</b>	Uranium dioxide enriched to 1.8% $U_{235}$	Graphite

Source: IEE Nuclear Power in UK – Reactor Types

## Nuclear Plants Data

Nuclear power plants in commercial operation

Reactor type	Main Countries	Number	GWe	Fuel	Coolant	Moderator
Pressurised Water Reactor (PWR)	US, France, Japan, Russia	263	237	enriched UO <sub>2</sub>	water	water
Boiling Water Reactor (BWR)	US, Japan, Sweden	92	81	enriched UO <sub>2</sub>	water	water
Gas-cooled Reactor (Magnox & AGR)	UK	26	11	natural U (metal), enriched UO <sub>2</sub>	CO <sub>2</sub>	graphite
Pressurised Heavy Water Reactor 'CANDU' (PHWR)	Canada	38	19	natural UO <sub>2</sub>	heavy water	heavy water
Light Water Graphite Reactor (RBMK)	Russia	17	13	enriched UO <sub>2</sub>	water	graphite
Fast Neutron Reactor (FBR)	Japan, France, Russia	3	1	PuO <sub>2</sub> and UO <sub>2</sub>	liquid sodium	none
	<b>TOTAL</b>	<b>439</b>	<b>361</b>			

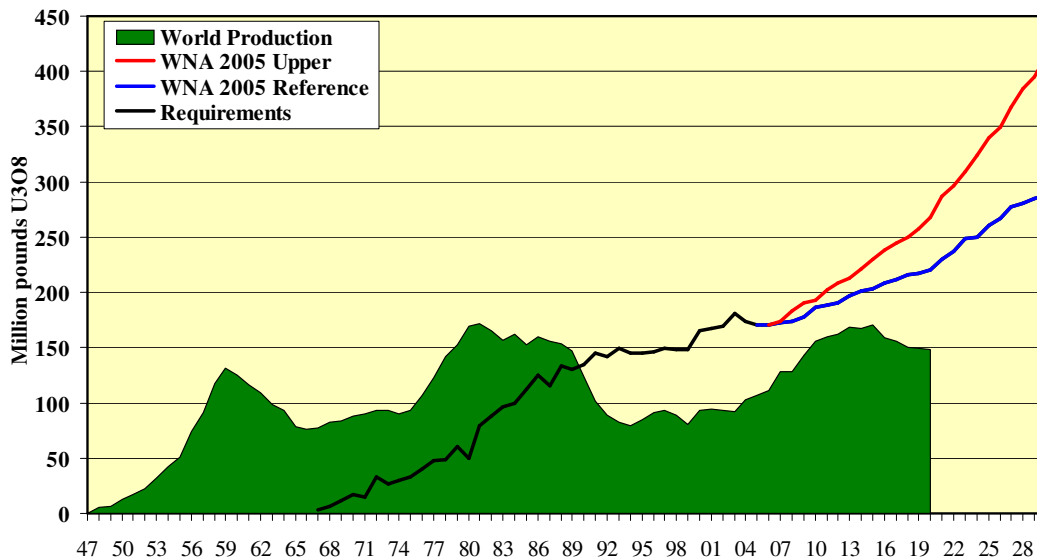
GWe = capacity in thousands of megawatts.

Source: IAEA April 2004, *Nuclear Power Reactors in the World (at 31/12/03)*.

## Supply and Demand

The following chart from Ux Consulting presents a general trend of uranium shortage that similar to the oil.

### Western Production vs. Requirements, 1947-2030



Complement of Ux Consulting. From the presentation by Jeff Combs, President, in the 2005 Toronto Resources Investment Conference

In the past when cheap oil is at \$1/barrel, the world's energy industry developed the energy industry based on oil. Now the cheap oils are gone. The oil based energy industry infrastructure has to adapt to the heavy oil which is also non-renewable. The transition is painful and the world economy is shocked. In the long run, the oil will be finished.

Nuclear energy is one of the viable solutions that can complement the oil. However, we need to manage the supply of uranium better than the oil to reduce the shock due to shortage. Reviewing the history of nuclear fuel supply, it follows the similar pattern of oil. At the very beginning, the supply is in excess. The excess drove the price down. The cheap price pushed the application. In the nuclear application, there is always the fear factor to slow down the growth. The EU's vigorous regulation of the old nuclear plan is in fact doing a good thing for the nuclear energy industry. A radio leaky nuclear plan is not just danger but also not economical from the energy generation and maintenance perspective.

One special aspect of nuclear fuel is that the current technology only uses a small fraction of the uranium. The supply chain should include the recycle seriously. The most recent price increase should be a good motivation for recycle. However, from the long term perspective, the nuclear reactor should evolve to higher degree of perpetual.

## Resource

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