An Introduction to Uranium

(Mining Methods & Locations, Supply, and U. S. Demand)

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Introduction

This white paper is a brief outline of Uranium mining methods and locations, world production and reserves, and United States civilian nuclear power plant demand. The paper presents a thumbnail of the following topics:

- Formation of Uranium Ore
- Current Major Uranium Mining Methods
- World Uranium Reserves and Production
- Past U. S. Uranium Mining and Current Locations
- U. S. Domestic Production and Importation of Uranium
- Summary

Because this is intended as an overview for quick digestion and understanding each topic includes references which provide more detailed information and discussion. This paper does not include any consideration of the issues pertaining to uranium ore mining and its reduction (milling) to a more concentrate form. This paper does not discuss best practices or regulation. These subjects will be addressed in a following paper..

Formation of Uranium Ore

The formation of uranium ore is a timeline of geological activities. The following technical description is taken from material presented by Steven H. Brown, CHP, Ref 1, Ronald L. Sass, Ph. D., Ref 2, and Wikipedia, Ref 3.

Uranium is a common constituent of the Earth's crust. It is commonly found in rock, soil, rivers, and oceans and is typically in the form of UO_2, called "uraninite" or UO_3 and U_2O_5, collectively designated as U_3O_8, called "pitchblende", a.k.a. "Yellow Cake". A square mile of earth (640 acres), one foot deep, will typically contain over a ton of radioactive uranium, or 1.15 mg/L, Ref 1. Shale and sandstone density ranges from 2.0 to 2.7 g/cc thus uranium is nominally about 0.49 mg/kg or 0.49 parts per million (ppm). Other estimates are as high as 2.5 ppm, Ref 4. Low-grade ore is on the order of 200 ppm (.02 %), average-grade at 1000 ppm (0.1 %), and extremely high ore grade at 150,000 - 200,000 ppm (15 % - 24 %), Ref 4 and Ref 4.5.

Uranium is thought to have been deposited at the surface of the Earth during volcanic activity some 4.5 billion years ago. During a later geological period, some 10 millions years in the past known as the Eocene and Miocene periods, sediment was carried by rivers and oceans during those periods and deposited during times of their normal flow as fine to coarse sands to form layers of sand and sandstone. Intermittently there were periods of abnormal elevated which brought silt and clay to form layers of shale, clay, and silt, thus forming intermittent layers of porous sand-based media and non-porous shale, etc. The porosity of the sand-based layers enabled the formation of aquifers within them. Within these layers the moving water acted as an oxidizer to leach out the uranium, which is highly soluble, and move it in the direction of the flow within the aquifer. Eventually the flow came to the shale/clay/silt layers where the uranium was reduced and trapped at the interfaces of the layers. Over time, these interfaces enlarged and extended over large distances thus forming large deposits of trapped, relatively-abundant amounts of uranium oxides. These are the deposits which are mined.

Current Major Uranium Mining Methods

Uranium is mined primarily by three methods, Open Pit, Conventional Underground, and In Situ Leaching/Recovery. World-wide approximately 28 % of the mining is by conventional underground, 25 % Open Pit, and 41 % In Situ Leaching, Ref 5.

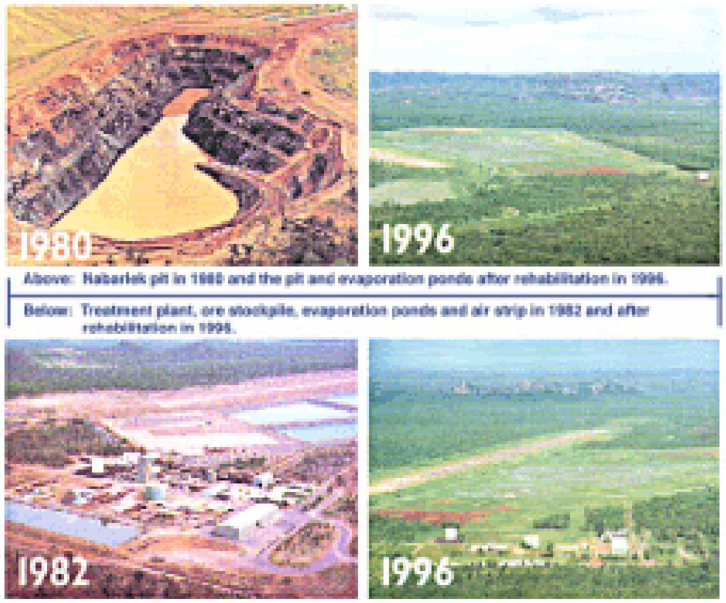
<u>Open Pit</u>

Open Pit mining is a surface mining that tends to be a concave terraced hole in the ground with one or more ramps at locations around the edge that enable transport by gigantic truck-carriers of the excavated content to an adjacent refining site where the uranium oxide is extracted (milled). Images of examples are shown in Figure 1, Ref 6.

(a) Rossing Mine, Nambia **(b) Lodeve Mine, France**

Figure 1 – Examples of Open Pit mines, Ref 6.

Generally some attempt is made to restore the site to per-mine conditions once the mine is no longer productive. Restoration tends to be a major aspect of regulation. Figure 2 provides two examples of restoration, Ref 7.



Above: Nabarlek pit in 1980 and the pit and evaporation ponds after rehabilitation in 1996.

Below: Treatment plant, ore stockpile, evaporation ponds and air strip in 1982 and after rehabilitation in 1996.

Photos Above: Australia's Nabarlek uranium pit in 1980 and the pit and evaporation ponds after rehabillitation in 1996.

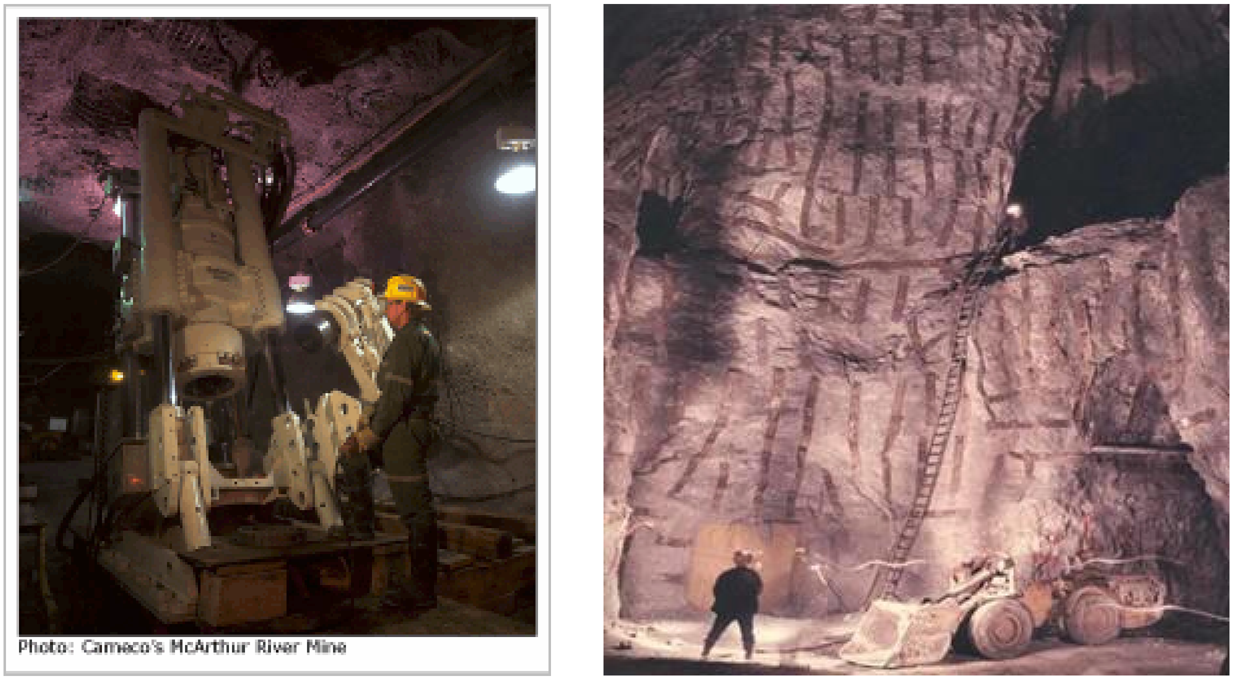
Photos Below: Treatment plant, ore stockpile, evaporation ponds and air strip in 1982 and after rehabillitation in 1996.

Figure 2 – Examples of Restoration of Open Pit mines, Ref 7

No examples of current productive Open Pit uranium mining in the United States were found in the course of assembling information for this paper. The largest producing current Open Pits include Ranger (3216 tonnes, 2010) in Australia and Rossing (3077 tonnes, 2010) in Nambia, both shown in Figure 1, and Langer Heinrich (1419 tonnes, 2010) in Nambia, Kayelekera (684 tonnes, 2010) in Malawi, and McClean Lake (666 tonnes, 2010) in Canada, Ref 5.

Conventional Underground

Conventional Underground mining of uranium is in most respects is no different than underground mining of other minerals or coal. United States mines evolved from small scale operations in Colorado and Utah. In the 1960's and 1970's larger scale underground mining operations opened in Colorado, Utah, New Mexico, Arizona, Wyoming, Washington, and South Dakota, Ref 8 and Ref 9. The earlier mines resembled something not unlike classic silver mines, whereas the modern ones are of an entirely different scale as shown in Figure 3, Ref 7 and Ref 9.



(a) Cameco's McArthur River Mine, Canada, Ref 7 (b) Not identified, Ref 9

Figure 3 – Examples of conventional Underground Mines

Modern conventional underground mines use a range of equipment, including small loaders and trucks. Rubber-tired diesel equipment has replaced rail-mounted. The ore is usually extracted by drilling small diameters holes and blasting the ore. The broken ore is transported to the surface where it is sent to an ore processing mill to extract the contained metals. Uranium deposits nowadays are typically outlined by drilling from the surface. Access into ore deposits is through vertical shafts or inclined openings (called “drifts” or “declines”). In the U.S., shaft mines typically range from a few hundred feet deep to more than 3,000 feet deep.

In Situ Leaching

An increasingly preferred method, world-wide and in the United States, is In-Situ Leaching (ISL), also called In-Situ Recovery (ISR). ISL is a relatively low-cost method that is executed at above ground and is used for other minerals such as copper. It consists of drilling encased holes (wells) down into the ore deposit, one or more as input wells and additional ones for production and monitoring such as depicted in Figure 4, Ref 10. The pattern and spacing differs from location to location depending on ore richness and geology, Ref 8. The method requires a penetrable geology, as in the case of shale. This method is used in the United States (Nebraska, Texas, and Wyoming) and in foreign countries such as Kazakhanstan and Uzbekistan, and Australia.

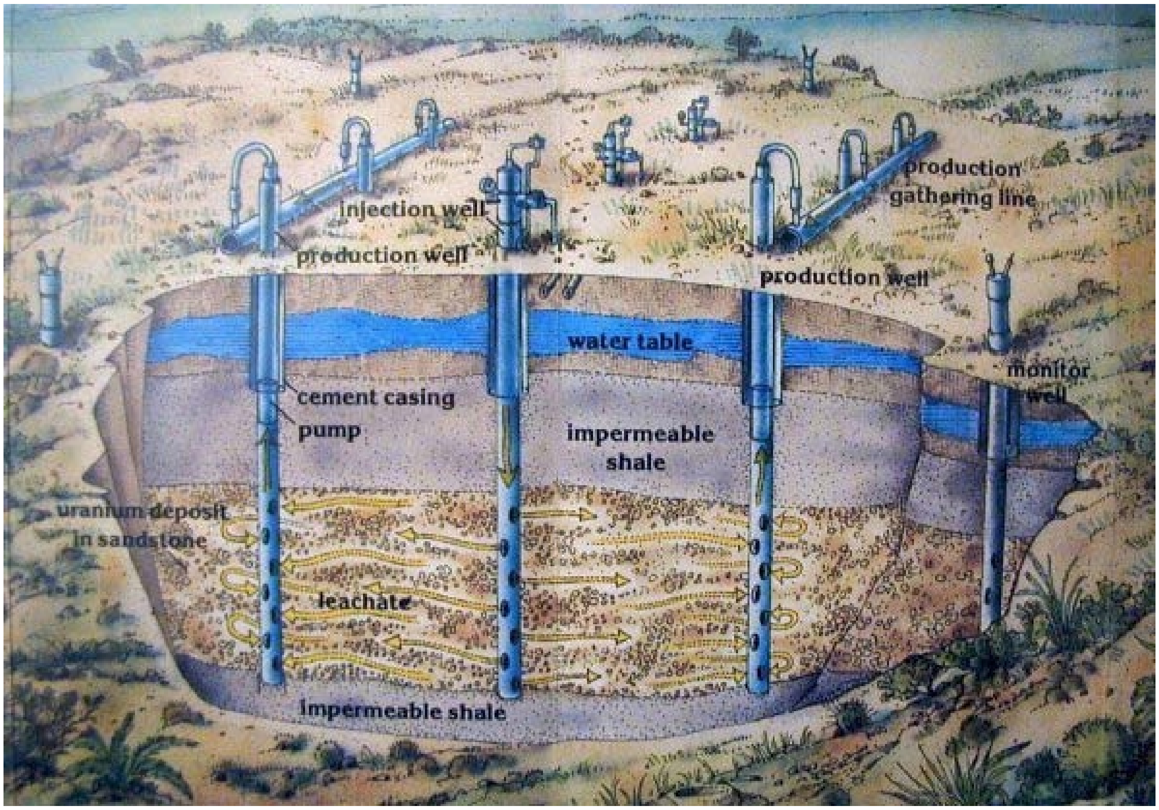


Figure 4 – A depiction of In-Situ Leaching for uranium, Ref 10

Hydraulic fracturing can be used to open pathways for the leaching fluids to penetrate. Whether those fluids are acidic or alkalic depends on the nature of the strata in which the uranium is located. The carrier of the fluid is native groundwater, Ref 8.

World Uranium Reserves and Production

Tables I and II provide values for world reserves and production, country by country. Table I is for 2009 reserves and up-to-2008 productions estimated by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, Ref 11. Table II is for 2007 reserves and 2006 production by the World Nuclear Association and the European Nuclear Society, Ref 12. In both tables the countries with the largest reserves are Australia, Kazakhstan, Canada, Russia, and South Africa. In Table I the United States 9th behind Nambia, Brazil, and Niger, and 6th in Table II in front of the same three. The differences are likely accredited to economics and methods of accounting, but in any case the U.S. does have considerable reserves. At present rates of use the reserves in Table I will be used in the next 72 years, Ref 4. According to France's Organisation for

Economic Co-operation and Development's Nuclear Energy Agency there is about twice that amount yet to be discovered for a total supply life of approximately 240 years, Ref 13. Obviously with an increase of nuclear plants to meet larger demand for energy that length of time will decrease.

Table I – World Locations and percentages of uranium 2009 reserves and up-to-2008 production and reserves based on $135 US/kg, Ref 11

Country	Reserves as of 2009, metric tons	World Share, %	Historical Production to 2008 , metric tons (tones)	World Share, %
Australia	1,673,000	31.00%	156,428	6.50%
Kazakhstan	651,800	12.10%	126,900	5.30%
Canada	485,300	9.00%	426,670	17.70%
Russia	480,300	8.90%	139,735	5.80%
South Africa	295,600	5.50%	156,312	6.50%
Namibia	284,200	5.30%	95,288	4.00%
Brazil	278,700	5.20%	2,839	0.10%
Niger	272,900	5.00%	110,312	4.60%
United States	207,400	3.80%	363,640	15.10%
China	171,400	3.20%	31,399	1.30%
Uzbekistan	114,600	2.10%	34,939	1.40%
Jordan	111,800	2.10%	0	0.00%
Ukraine	105,000	1.90%	124,397	5.20%
India	80,200	1.50%	9,153	0.40%
Mongolia	49,300	0.90%	535	0.00%
Algeria	19,500	0.40%	0	0.00%
Argentina	19,100	0.40%	2,513	0.10%
Malawi	15,000	0.30%	0	0.00%
Central African Republic	12,000	0.20%	0	0.00%
Spain	11,300	0.20%	5,028	0.20%
Sweden	10,000	0.20%	200	0.00%
Slovenia	9,200	0.20%	382	0.00%
Turkey	7,300	0.10%	0	0.00%
Portugal	7,000	0.10%	3,717	0.20%
Romania	6,700	0.10%	18,419	0.80%
Japan	6,600	0.10%	84	0.00%
Gabon	4,800	0.10%	25,403	1.10%
Indonesia	4,800	0.10%	0	0.00%
Italy	4,800	0.10%	0	0.00%
Peru	2,700	0.00%	0	0.00%
Finland	1,100	0.00%	30	0.00%
Czech Republic	500	0.00%	110,427	4.60%
France	100	0.00%	75,982	3.20%
Belgium	0	0.00%	686	0.00%
Bulgaria	0	0.00%	16,362	0.70%
Democratic Republic of the Congo	0	0.00%	25,600	1.10%
Germany	0	0.00%	219,517	9.10%
Hungary	0	0.00%	21,052	0.90%
Iran	0	0.00%	17	0.00%

Madagascar	0	0.00%	785	0.00%
Mexico	0	0.00%	49	0.00%
Pakistan	0	0.00%	1,159	0.00%
Poland	0	0.00%	660	0.00%
Zambia	0	0.00%	86	0.00%
Soviet Union	NA	NA	102,886	4.30%
Total	5,404,000	100%	2,409,591	100%

Table II – World Locations and percentages of uranium 2007 reserves and 2006 production and reserves based on $130 US/kg, Ref 12

Estimated 2007 reserves and 2006 production				
Country	2007 Reserves, metric tons		2006 Production	
	WNA estimate	ENS estimate	Metric tons (tones)	Percent
Canada	423,000	329,200	9,862	25
Australia	1,243,000	725,000	7,606	20
Kazakhstan	817,000	378,100	5,279	14
Niger	274,000	243,100	3,434	9
Russia	546,000	172,400	3,262	8
Namibia	275,000	176,400	2,782	7
Uzbekistan	111,000	72,400	2,270	6
United States	342,000	339,000	1,579	4
Ukraine	200,000	135,000	800	2
China	68,000	N/A	750	2
South Africa	435,000	284,400	542	1
Brazil	278,000	157,400	190	0
India	73,000	N/A	177	0
Jordan	112,000	N/A	0	0
Other	272,000	287,600	200	1
Total	5,469,000	3,300,000	38,733	100
WNA	World Nuclear Association			
ENS	European Nuclear Society			

Production raises other considerations. According to the Northwest Mining Association 21 percent of U. S. electricity is generated by nuclear power which requires 55 million lbs (~ 24,947 tonnes) per year, Ref 14. According to this same reference and Ref 15 the United States produces on the order of 4 million pounds(1814 tonnes) of Yellow Cake (U3O8). [This production amount is a similar to that in Table II.] So the U. S. produces only 7 % of what is currently needed for electricity production. The other 93 % is imported. From a tonnage perspective this requires all of Australia's and Canada's production (5900+9783 tonnes) plus 43 % of Kazakhstan's, the current largest producer, Ref 5. Some relief could be found in reducing the tails essay in enrichment and reprocessing used fuel, Ref 4, thus extending the total supply life to ~ 310 years. New designs of Light Water Reactors could increase fuel-use efficiency. Fast neutron reactors could substantially increase supply life, Ref 16, and the use of Fast Breeder Reactors could extent the supply life to ~12,000 years, Ref 4 and Ref 16.

Past U. S. Uranium Mining and Current Locations, Ref 17

Most uranium ore in the United States comes from deposits in sandstone, which tend to be of lower grade than those of Australia and Canada. Because they are lower grade many uranium deposits in the United States became uneconomic when the price of uranium declined sharply in the 1980s.

Regular production of uranium-bearing ore in the United States began in 1898 Colorado and Utah. The discovery of radium by Marie Curie, also in 1898, made the ore also valuable for radium. Uranium was a byproduct. By 1913, the Colorado Plateau uranium-vanadium province was supplying about half of the world supply of radium. Production declined sharply after 1923, when low-cost competition from radium from the Belgian Congo and vanadium from Peru. Mining revived in the 1930s with higher prices for vanadium. American uranium ores were in very high demand by the Manhattan Project during World War II, although the mining companies did not know that the by-product uranium was suddenly valuable. The late 1940s and early 1950s saw a boom in uranium mining in the western US.

Uranium mining declined with the last open pit mine (Shirley Basin, Wyoming) shutting down in 1992. United States production occurred in the following states (in descending order): New Mexico, Wyoming, Colorado, Utah, Texas, Arizona, Florida, Washington, and South Dakota. The collapse of uranium prices caused all conventional mining to cease by 1992. ISL mining has continued primarily in Wyoming and Nebraska as well as in Texas. Rising uranium prices since 2003 have increased interest in uranium mining in the United States.

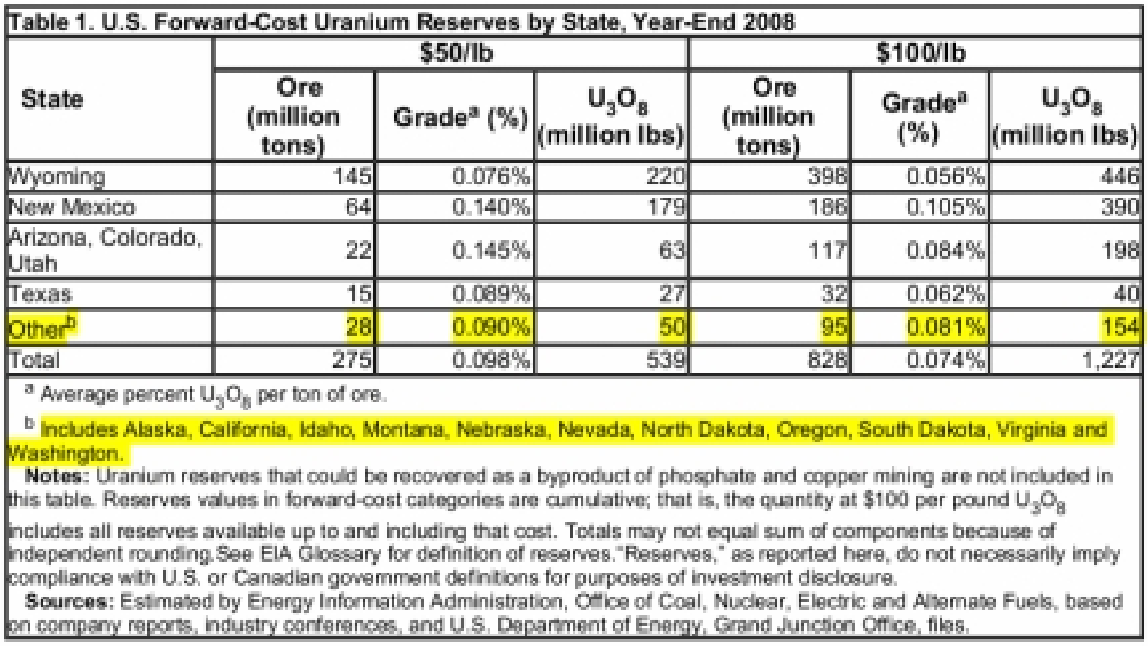


Table 1. U.S. Forward-Cost Uranium Reserves by State, Year-End 2008

State	$50/lb			$100/lb		
	Ore (million tons)	Grade[a] (%)	U_3O_8 (million lbs)	Ore (million tons)	Grade[a] (%)	U_3O_8 (million lbs)
Wyoming	145	0.076%	220	398	0.056%	446
New Mexico	64	0.140%	179	186	0.105%	390
Arizona, Colorado, Utah	22	0.145%	63	117	0.084%	198
Texas	15	0.089%	27	32	0.062%	40
Other[b]	28	0.090%	50	95	0.081%	154
Total	275	0.098%	539	828	0.074%	1,227

[a] Average percent U_3O_8 per ton of ore.

[b] Includes Alaska, California, Idaho, Montana, Nebraska, Nevada, North Dakota, Oregon, South Dakota, Virginia and Washington.

Notes: Uranium reserves that could be recovered as a byproduct of phosphate and copper mining are not included in this table. Reserves values in forward-cost categories are cumulative; that is, the quantity at $100 per pound U_3O_8 includes all reserves available up to and including that cost. Totals may not equal sum of components because of independent rounding.See EIA Glossary for definition of reserves."Reserves," as reported here, do not necessarily imply compliance with U.S. or Canadian government definitions for purposes of investment disclosure.

Sources: Estimated by Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, based on company reports, industry conferences, and U.S. Department of Energy, Grand Junction Office, files.

Figure 5 – United States uranium reserves, 2008, Ref 18

The U. S. Energy Information's 2008 data, released 2010, for U. S. domestic uranium reserves is provided in Figure 5, Ref 18. In Figure 5, "Other" was compiled for Virginia and 10 other States to be a total reserve of 95 million tons (86 million tonnes) of ore at a grade of 0.081 %. A recent report estimated Virginia's portion to be ~ 32,000 tons (29,000 tonnes) at 0.06 % grade, or approximately 0.08 % of the total for "Other" in Figure 5, Ref 19. In terms of the total amount estimated for the entire U. S. it is 0.008 %.

U. S. Uranium Domestic Production and Importation of Uranium

Figure 6 plots U. S. uranium domestic production and importation from 1949 to 2010, Ref 20. Production grew until about 1960, held somewhat steady until 1980 and then began a decline until now it is on the order of 1900 Tonnes, which is approximately 7 %, as noted in an above section, of the total for production and importation. (The production curve is similar in history as noted in the prior section.) This is about half of that indicated in Figure 7 which shows a dependence on Australia, Canada, and countries belonging to the former Soviet Union, the latter providing on the order of 20 % of domestic consumption by U. S. civilian nuclear power reactors. (The discrepancy is not explainable herein.)

Figure 6 – Historical levels of domestic production and importation of Uranium, Ref 20

Figure 7 – Distribution of sources of uranium for Domestic U. S. Nuclear Power, Ref 17

The largest, high-grade uranium mine in the world is McArthur River in Canada, Ref 21. McArthur River is a conventional underground mine. It provided 14 % of the world supply in 2010, making it the largest-producing mine in the world, Ref

5. McArthur River is 70 % owned by Cameco and 30 % by AREVA, a French company. Cameco is headquartered in Saskatoon, Saskatchewan. AREVA headquartered in the Tour Areva in Courbevoie, Paris. Cameco owns two ISL uranium mines in the United States: Crow Butte in Nebraska and Smith Ranch-Highlands in Wyoming.

Summary

The content of this section reflects impressions held from material in the references of this report, a small portion of which has been provided above.

There are two aspects of energy production that do not remain constant, the amount of resource and the status of technology. For the most part technology drives what we believe to be the amounts of resource for all forms of energy production. As technology is created and developed larger quantities of energy resources (gas, oil, and uranium) are found and the economy of production of each discovery becomes better. Hence not only are more resource locations discovered but those already discovered become more economically feasible. The circumstances for uranium are strikingly similar to those for gas and oil, especially so because a portion of the underlying technology and methods are similar. Gas and oil use hydraulic fracturing technology to cause orders of magnitude higher production, as can In-Situ Leaching/ In-Situ Recovery (ISL/ISR). ISL/ISR is becoming a well-mining technology not unlike gas and oil. It does not take much imagination to understand that in coming years ISL/ISR technology will be further developed and refined to make uranium and other mineral extraction even more economical, thus enabling production from even lower grade ore that is in production today. One method of uranium recovery not mention here is extraction from the oceans. The uranium in ocean water is about 3 ppb which is three orders of magnitude less than medium grade land-based ore, Ref 22. In today's economy, using today's technology, that is not a viable alternative, but probably, not possibly, it will be.

Both ISL/ISR and shale gas and oil recovery use large volumes of water and both do have a potential to contaminate local supplies of drinking water in underground aquifers. There is no doubt that potential contamination, and that of near-by surface water, is a reasonable and realistic concern. But such concern all too frequently, if not consistently, used by environmental advocates to prevent production whether or not it is reasonable or realistic. From a responsible engineering and scientific point of view there is requirement to protect the well-being of the population and all of its resources. There is no argument that Water is the most valuable because it is essential for life. But the flag of potential threat to water should not be use to frighten the population to a state of neurotic anxiety simply as a means to prevent production of valuable resources of energy. The key is “best practices” and “responsible practices” and the key to these is two-fold: (1) the best use and development of available technology and (2) incentive, not punitive, regulation.

If we, mankind, are to continue advancing our societies we will consume more and more energy, both in terms of amount per person and amount as a growing population. Knowingly or not, with the ever-increasing use of computers, ipads, smart phones, and other such devices we daily use more energy per person, including the environmentalists who oppose the recovery of gas and oil and the production of uranium. Like it or not, windmills and solar farms are not now and will less so in the future, be capable of keeping pace with increasing energy demands.

So whether or not to lift a ban on uranium mining is a consideration that will not go away. In many respects Virginia's ban on uranium mining makes no more sense than the present potential of a Federal Government ban on shale-gas wells in the George Washington Forest. Perhaps it is appropriate that the ban not be lifted in haste but it is not appropriate to let the politics of lobbying drive the decision. The driver is technology to provide the recovery of the resource and the knowledge of how to best employ the technology, both which will make progress.

Three reports are presently available for consideration of whether or not to lift the ban, Ref 19, 23, and 24. They provide a broad field of consideration. At this point their collective content should be brought into a whole and to it more added, such as national security and the technologies on the horizon. Hopefully intelligent and realistic decisions can be made in spite of the inevitable color of the politics embedded with all these reports and the politics of the producers, the environmentalists, and the politicians.

A second white paper is planned to follow this one. It will have a three-fold goal:
- An objective, rational, and realistic gathering and assessment of concerns relating to contaminations associated with conventional underground and ISL/ISR recovery of uranium.
- A gathering and assessment of existing best-practice technology and methods.
- A study of existing uranium mining/processing regulations where uranium production now occurs.

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