The Nature and Extent of Uranium Reserves and Resources and their Environmental Development in the U.S. and Overseas

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A Report by the Uranium Committee
of the
Energy Minerals Division, AAPG

by

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Abstract

Uranium is an abundant element in the earth's crust and occurs in economic concentrations in a variety of geological environments ranging from Precambrian (Proterozoic) in age to sediments of Tertiary age. Uranium occurs in geographic locations ranging from the cold of the high latitudes of Canada and Russia to the heat of the tropics of Australia, Africa and Brazil. It also is available as by-products from nuclear devices, from processing phosphate deposits, and from other sources.

Reserve estimates are based on geophysical logs and an estimate of the physical dimensions of the mineralization. Reserve needs are based on industry estimates for new reactors and historical usage of older reactors, which depends on the reactor design. With the present expansion in the use of nuclear power expected to continue for the next 100 years, the dependence on overseas oil and gas will be reduced. This, along with reducing the use of coal over the next 30 years, will have a significant, positive impact on easing global warming and a marked impact on world political stability.

We assess the potential problems inherent in predicting uranium reserves and in developing these reserves, both from a technical point of view and a societal perspective, which must be combined by any company engaged in uranium exploration and recovery. Environmental considerations involving ground-water sampling of area water wells prior to in situ recovery (ISR) are an integral part of every uranium-development project and depend on the geographical location of the deposit under consideration. In some areas, uranium occurs naturally in aquifers and this is the reason for the need for comprehensive background ground-water studies before uranium recovery operations are undertaken. Socio-economic issues have become an important part of uranium recovery projects today.

Non-political State and Federal interests must be balanced between the interests of national needs and security and local protection with economic development. Without this balance, damage to society would occur at a time when we can least afford it. Filtered through industry perspectives, we evaluate these issues both in terms of developing uranium within the U.S. sphere of influence and of managing the environmental responsibilities associated with it.

Introduction

Uranium is an abundant element in the earth's crust and occurs in economic concentrations in a variety of geological environments. Uranium concentrations occur in rocks ranging from Precambrian (Proterozoic) in age to sediments of Tertiary age. Uranium occurs in economic concentrations on Earth at locations ranging from the cold of the high latitudes to the heat of the tropics. Some of the economic deposits can be developed by the ISR methods while others must be mined by either open pit or underground methods. With the anticipated expansion of nuclear power to supply the electrical power grids around the world, new uranium (and thorium) reserves must be located by expanding exploration around the globe, and elsewhere, and recycling of nuclear materials must be initiated in order to meet the needs of the latter 21st and early 22nd centuries.

Major Uranium Occurrences

The different types of uranium resources presently known to occur on Earth are described by the IAEA (2005a) and in North America by Finch (1996). A popular account of the development of the principal deposits is presented by Höök (2007). The following is a list of some of these deposits indicating their age, location and type of deposit, and recovery methods employed in Table 1:

Table 1
Age of Selected Uranium Deposits in the World
and
Method of Development

Cenozoic Deposits

Wyoming	(Roll-Fronts- Developed by In Situ Methods)
Nebraska	(Roll-Fronts – Developed by In Situ Methods)
South Dakota	(Roll-Fronts – Developed by In-Situ Methods)
Texas	(Roll-Fronts- Developed by In Situ Methods)
Kazakhstan	(Roll-Fronts- Developed by In Situ Methods)
Uzbekistan	(Roll-Fronts- Developed by In Situ Methods)
Australia	(Roll-Fronts- Developed by In Situ Methods)

Mesozoic Deposits

Canada	Western (Mining Only)
Canada	Eastern (In Situ and Surface Mining Methods)
Colorado	(Roll-Fronts- Developed by In Situ Methods & Surface Mining Methods)
New Mexico	(Redistributed Roll-Fronts – Developed by In Situ & Surface and Underground Mining Methods)

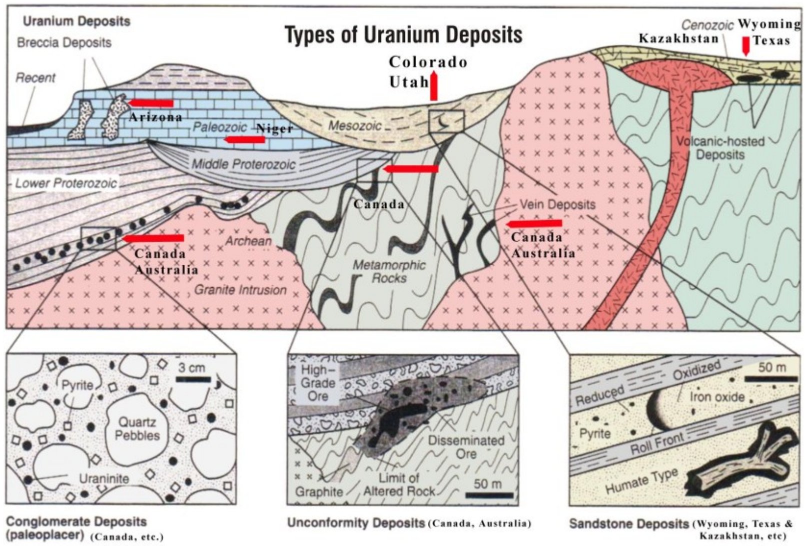
Paleozoic Deposits

Arizona	(Developed by Surface Mining Methods)
Niger	(Surface Mining)

Proterozoic Deposits

Canada	(Surface and Underground Mining)
Australia	(Surface Mining)
Africa – Gabon	(Surface and Underground Mining)

Figure 1 (After Kesler, 1994)



Calculating Uranium Resources

Resource Estimations in Sedimentary Deposits

Resource estimates are based on geophysical logs and an estimate of the physical dimensions of the mineralization, usually associated with roll-front deposits, which are typically "C"-shaped across the aquifer (see Figure 1 and 2A and Campbell, et al., 2007a). Gamma logs have traditionally been used to calculate both the grade and thickness for the boring. The grade X thickness (GT) estimates are then used to develop grade, thickness, and GT maps that are then used to determine the areal extent of the deposit.

The thickness of the radiometric zone is indicated by the half-amplitude points of the flanks of the associated total gamma curve (Figure 2). The upper boundary of the radiometric zone is determined by measuring the distance from the base to the top of the curve of the first curve of the upper flank and dividing by two (E_1 and T_1).

The area under the total gamma curve is determined by taking half-foot values in successive order beginning at E_1, (I_1, I_2, I_3, etc.). This procedure is continued down to T2 and then continued for one more 0.5-foot interval past Tx from the last I intercept above T2. The tail areas of a radiometric curve are those areas bordering the general area under the curve representing the thickness of the radiometric zone. These tail areas specifically extend from the outer limits of the anomalous curve to a point halfway between an E point and the adjacent I point. The value of the sum of the two tail areas is approximated by adding together the counting-ratio values of E_1 and E_2 and then multiplying by a tail factor, typically 1.38 for 0.5-foot intervals. As long as both end values, E_1 and E_2, are read at or below the half-amplitude levels of the adjacent peaks on the logs, the error of this approximation is usually less than two percent of the total area under the curve.

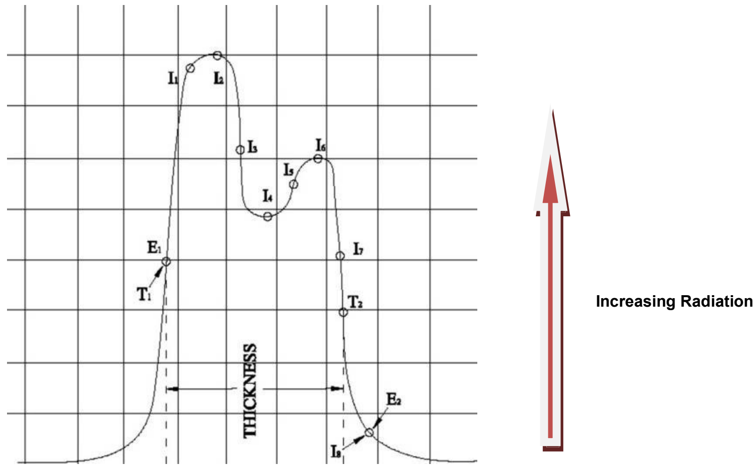


Figure 2
Calculations on Natural Gamma Log

After determining the proper E_1-E_2 and T_1-T_2 intercepts for a curve, the procedure for calculating the GT value is:

$$[1.38 * (E_1 + E_2)] + \sum I = S$$

$$\frac{S}{1-(S*DT)} * (\text{Mud factor}) * (\text{K factor}) = GT$$

$$\frac{GT}{\text{Thickness}} = \text{Grade}$$

S	=	unadjusted sum of the counts
DT	=	dead time (from well log)
Mud factor	=	is also known as water factor (from well log)
K factor	=	is the calibration for the probe, as determined from a test pit

The total number of radiometric pounds of uranium (eU_3O_8) is determined from the GT contour map. It is strongly recommended that grade and thickness maps also be developed, along with a model map prior to reserve estimation so that a "best estimate" for the size of the deposit may be determined. All of the maps should be in agreement before determining reserves.

Using the GT map, the areal extent of each individual contour interval should be determined. Unless specific density measurements have been made for the sediments within the ore zone, an estimate of 2,000 pounds per 18 cubic feet (~ 111 lbs. per cubic foot) is typically used for the density of unconsolidated sands. Therefore, the calculation for the reserves in pounds of uranium is:

$$\text{Volume} = \text{Area} * \text{Average GT}$$

$$\text{lbs. } eU_3O_8 = \text{Volume} * \frac{2{,}000 \text{ lbs.}}{18 \text{ cu. ft.}} * \frac{1}{100}$$

(Grades are used as a portion of 1%, thus the necessity for the factor 1/100)
or lbs. eU_3O_8 = Volume * 1.111)

When the reserve calculations are for GT contours made between contour intervals, the average GT for that interval is:

$$\frac{\sum \text{Upper + Lower Contour Levels}}{2}$$

In the case of the area within the uppermost contour value:

$$\frac{\sum \text{All GTs in that Interval}}{\text{Number of values Used}}$$

The average thickness for a deposit is determined by:

$$\frac{\Sigma \text{ All Thickness Values}}{\text{Number of Values Used}}$$

The weighted average grade for a deposit is then determined by:

$$\frac{\mathbf{\Sigma} \text{ All GTs}}{\text{Number of Values Used}}$$

Typical gamma logging tools measure radioactive decay products which develop in the uranium decay chain rather than the ^{235}U of interest. After a long period of geologic time the decay products measured by gamma logging tools will be directly proportional to the uranium in the ore zone provided that geologic processes have not caused the uranium to be separated from the gamma emitters being measured, such as ^{214}Bismuth ^{226}Radium and ^{222}Radon and others. The uranium and decay products naturally separate down gradient, with a higher percent of the latter remaining behind in the tails of the roll-front and the uranium (in higher percent than the decay products) moving ahead in the nose of the ore body, albeit slower than the ground-water flow rate (see Figure 3). The gamma log does not indicate the correct grade (actual chemical content) neither up gradient nor down gradient of the ore zone. The grade calculation made from the gamma log can be either higher or lower that that actually present in these areas.

Due to biogeochemical processes, uranium may have moved into an area of low gamma, thus increasing the grade, or out of an area of high gamma, thus decreasing the grade. When this occurs over a wide area, the ore body, or a part thereof, is said to be in disequilibrium. In order to determine chemical reserves (cU_3O_8), a representative number of core samples will need to be obtained for laboratory analysis and compared to the eU_3O_8 results for each core hole. This will determine the amount of disequilibrium in the ore zone of the particular deposit, such as:

$$cU_3O_8 = \text{disequilibrium} * \text{lbs. } eU_3O_8$$

The Prompt Fission Neutron (PFN) logging tool overcomes the problem of disequilibrium by measuring the ^{235}U in the formation. Spectral gamma logs are no longer used to determine grade. In the PFN tool, a pulsed neutron source electronically generates 10^8 14 MeV neutrons per second which ultimately cause fission of ^{235}U in the formation. The thermal and epithermal neutrons returning to the tool from the formation are counted in separate detector channels to provide a measure of ^{235}U free from variations in neutron output and borehole factors common to both channels. The tool also contains a standard scintillation gross gamma counter. The tool has no electric logs (resistivity and self-potential) and so must be run after these logs have been run. The lowest practical grade measurement is about 0.02%. Like the standard gamma tool, the PFN tool must be calibrated by taking measurements in test pits of known grade and porosity.

An acceptable test pit is of one-meter diameter and one-meter deep polyethylene tank, usually installed in an excavation so that only the top of the tank is exposed. This tank is filled with a specific grain-size of sand into which is poured a solution of uranium dissolved in nitric acid. From this, one can calculate the weight of uranium/volume. Multiple pits are required to establish a calibration curve. The minimum is three grade pits (high, medium, and low) and one barren pit. Other useful pits are those with varying bore diameters to establish hole-size factors. Tools have been very stable for long periods of time but users should establish a regular program (after 1,000 hrs of operation) to verify the tool's calibration. Assaying the mineralized zones in a borehole can be done either in a parked mode where the tool is stopped and an assay taken or in a continuous mode. The continuous mode is typically used, logging at 1 meter per minute. The regular gross gamma-logging tool is used to identify the mineralized zones of interest. The PFN tool is then used to assay those zones. Contour maps based on PFN-developed GTs typically take disequilibrium into account. This will need to be confirmed.

Over geological time, changes in the sediments' mineralogy occur within the once-reduced minerals such as pyrite, marcasite and the others being altered to oxidized minerals containing high concentrations of radioactive decay products. This change is also illustrated in Figure 3 for Wyoming sediments. Texas uranium occurrences have similar but also different relationships in certain areas that involve methane (and H_2S?) as likely reductants in place of the carbonaceous materials associated with lignite, as in Wyoming, New Mexico, Nebraska, southern Australia, and elsewhere (Rubin, (1970); Rackley, (1975); Freeman and Stover, (1999); Arnold and Hill, (1981); Collings and Knode, (1984); Campbell, *et al.,* (2007a), and McKay and Miezitis, (2001).

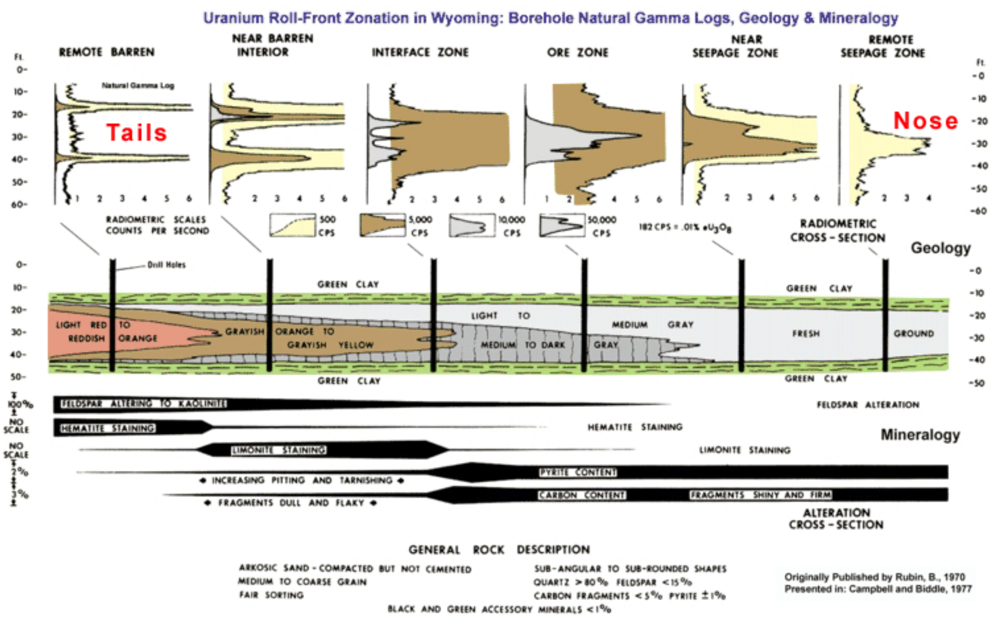


Figure 3
Natural Gamma Log Zonation & Associated Geology
(After Campbell and Biddle, (1977)

Standards for Resource Estimations

The Canadian Institute of Mining and Metallurgy (CIM) National Instrument 43-101 is becoming the standard for estimating resources. This standard requires that all disclosures of scientific or technical information made by an issuer, including disclosure of a mineral resource or mineral reserve, concerning a mineral project on a property material to the issuer. This must be based upon information prepared by or under the supervision of a qualified person.

A **Qualified Person** is defined as an individual who is an engineer or geoscientist with at least five years of experience in mineral exploration, mine development or operation or mineral project assessment, or any combination of these; has experience relevant to the subject matter of the mineral project and the technical report; and is a member or licensee in good standing of a professional association, such as the AIPG, AEG, SME or licensed in the State of operations.

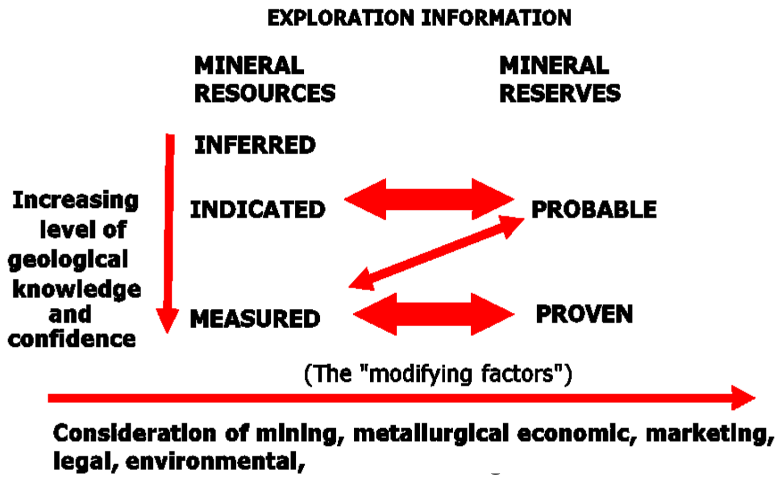
The CIM has also defined Mineral Resources as follows:

> A **Mineral Resource** is a concentration or occurrence of diamonds, natural solid inorganic material, or natural solid fossilized organic material including base and precious metals, coal, and industrial minerals in or on the Earth's crust in such form and quantity and of such a grade or quality that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge.
>
> An **Inferred Mineral Resource** is that part of a Mineral Resource for which quantity and grade or quality can be estimated on the basis of geological evidence and limited sampling and reasonably assumed, but not verified, geological and grade continuity. The estimate is based on limited information and sampling gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes.
>
> An **Indicated Mineral Resource** is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics can be estimated with a level of confidence sufficient to allow the appropriate application of technical and economic parameters, to support mine planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes that are spaced closely enough for geological and grade continuity to be reasonably assumed.
>
> A **Measured Mineral Resource** is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are so well established that they can be estimated with confidence sufficient to allow the appropriate application of technical and economic parameters, to support production planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes that are spaced closely enough to confirm both geological and grade continuity.
>
> A **Mineral Reserve** is the economically mineable part of a Measured or Indicated Mineral Resource demonstrated by at least a Preliminary Feasibility Study. This Study must include adequate information on mining, processing, metallurgical, economics and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified. A Mineral Reserve includes diluting materials and allowances for losses that may occur when the material is mined.
>
> A **Probable Mineral Reserve** is the economically mineable part of an Indicated and, in some circumstances, a Measured Mineral Resource demonstrated by at least a Preliminary Feasibility Study. The required Reserve Study must include adequate information on mining, processing, metallurgical, economic, and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified.
>
> A **Proven Mineral Reserve** is the economically mineable part of a Measured Mineral Resource demonstrated by at least a Preliminary Feasibility Study. This Study must include adequate information on mining, processing, metallurgical, economic, and other relevant factors that demonstrate, at the time of reporting, that economic extraction is justified.

The relationship between mineral resources and mineral reserves are illustrated in Figure 4.

Figure 4

Relation between Mineral Resources and Mineral Reserves
(after CIM Council, December 11, 2005)



New Resources

The current enrichment process is about 50% efficient but is based mostly on the relationship of feed stock cost to enrichment cost. The enrichment process has new, more efficient centrifuges coming on-line, at least in Iran. Other processes may be in the works. With more efficient processes, the 0.30% ^{235}U left in the "spent" uranium will be reprocessed and recycled into the fuel cycle. Recycling is the logical step toward handling nuclear wastes but that will require government support to proceed (Campbell, *et al*., (2007b). France conducts some recycling but so-called “fast breeder” reactors are still on the drawing boards.

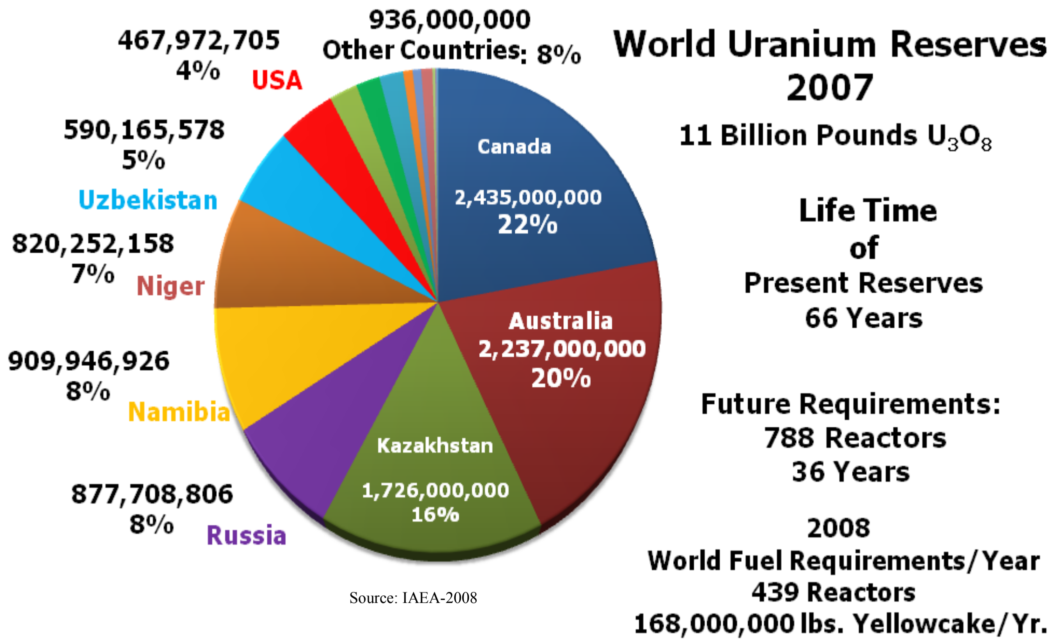
Mixed fuel, already in some reactors, will become more widely used and eventually plutonium will be a possible, or even a probable, fuel. The nuclear plant operators are currently running their plants well beyond their initially planned refueling needs. To increase the available supply, in situ recovery operations are going to have to do better than 70% recovery, which may come mainly from a much closer definition of the ore configuration. Recoveries are similar throughout the world in roll-front deposits.

World Uranium Resources

There are many factors involved in estimating yearly yellowcake needs over the next 90 years, including regaining the general public’s support regarding the expansion of the use of nuclear power to supply the electricity needs within the American power grid. (Campbell, *et al.,* (2005). The resources are numerous and occur in many countries, (see IAEA, (2005a). Presently, Canada, Australia, and Kazakhstan contain almost 60% of the uranium reserves known to date (Figure 5). Exploration is underway in numerous other areas in the U.S. and overseas (Figure 6). We have gathered the available information and have concluded that the known reserves are adequate to supply the anticipated expansion well into the latter part of the this the 21st Century, but this is based on a number of assumptions that must be defined, beginning with the definition of reserves and resources as we have discussed above.

Geopolitical factors will also emerge regarding uranium exploration and development as it has with oil and gas exploration and development over the past century. We, therefore, should focus on potential resources within the American sphere of influence. It is imperative that the American public realize the importance of this need, sooner than later. Environmental issues surrounding exploration and development of the uranium resources in the U.S. must be placed in context with the need for development. Ignorance and conflicting agenda inherent within a small but vocal segment of the general public have introduced potential road blocks to energy security at a reasonable price in the U.S. Reasonable environmental controls also are required and have been updated as new information becomes available by State and Federal agencies and adopted by the mining industry within the U.S. today.

Figure 5



Source: IAEA-2008

Figure 6

Source: IAEA-2008

Environmental Issues

To a large extent, in-situ recovery of uranium is both a natural resource development project and a natural, contaminant-remediation project. Renninger, *et al.,*(2004), illustrate how bacteria are not only involved in the formation of uranium deposits of economic interest, but also in the removal of heavy metals and actinides from contaminants in the subsurface. Furthermore, although uranium ore is a natural energy resource, it is also a bacterial waste product that was formed within the bio-geochemical cell of the mineralizing roll-front. In other terms, uranium ore is a by-product of anaerobic bacterial respiration that forms within the bio-geochemical cell. Both rely heavily on, and are driven by, geological and hydrogeological processes including: the hydraulic conductivity of the sands involved either within the ore zone or in the monitored sands above and below the ore zone; the hydraulic gradient prevailing within, below, and above each of the ore-bearing sands; and the porosity of the ore-bearing sands involved. Also important is the hydrochemistry of the fluids within the ore zone and of the fluids to be injected (both within the ore zone and at proximal and distal parts of the aquifer designated by the State as a uranium production zone).

It is the responsibility of the uranium company (and required by state regulatory agencies) to install strategically located ground-water monitoring wells to be sampled periodically for fluids that may have escaped the production zone. These wells are designed to monitor not only the perimeter of the production area, but also both the overlying and underlying aquifers. The company's hydrogeological staff is responsible for monitoring the behavior of the fluids and associated hydrochemistry during and after operations involved in the in situ recovery of the uranium ore zones and for monitoring the data generated from sampling the surrounding monitoring wells (Figure 7).

Figure 7 - Monitoring Well Nest

Protecting upper and lower aquifers from incursions of the production fluids requires understanding the hydrogeological conditions in and around the production site. Regulatory personnel work with the company's staff to ensure that the operations meet the regulations written to protect the aquifers that are located some distance outside and away from designated production areas (Campbell, *et al*., (2007A).

Environmental Requirements and Company Policies

Uranium exploration area permits in Texas, for example, are granted by the Railroad Commission of Texas (RRC). ISR recovery operations in Texas are regulated by the Texas Department of State Health Services (DSHS) and Texas Commission on Environmental Quality (TCEQ) for the processing plant (and the radioactive materials license) and the latter for the underground injection control (UIC) aquifer exemption, the Class III UIC permit and production area authorizations (PAA) for uranium recovery operations, and the Class I UIC nonhazardous well permit for wastewater disposal. The TCEQ also oversees cleanups of releases and spills of the leaching solution from the well field and associated pipelines. TCEQ applications for conducting in situ recovery of uranium and production area authorization are available on the TCEQ website under Rulemaking and Concepts (Here).

Drinking water aquifer exemptions are granted by the U. S. EPA and mine safety is overseen by Mine Safety Health Administration (MSHA), mining's equivalent of the Occupational Safety Health Administration (OSHA). Other agencies that may need to be consulted are the Texas Parks and Wildlife, the Texas Historical Office, and the U.S. Army Corp of Engineers. In order to conduct ISR operations, a complete environmental assessment of the site must be conducted. This assessment includes both surface and ground-water characterization to be used to establish monitoring baselines and ground-water restoration concentration levels. The environmental assessment has become more important as the general public has become more environmentally aware. ISR uranium recovery operations are also under increased public pressure to prove that they are safe operations and that any required remediation of the aquifer to pre-recovery conditions can be accomplished in a reasonable period of time. A properly conducted assessment can be used to show that, despite the general public's impression, the aquifer that contains the uranium mineralization contained both suitable and unsuitable drinking water quality for millions of years before uranium recovery was contemplated.

While the aquifer may contain suitable drinking water quality, in some areas the aquifer contains uranium mineralization that has been present long before humans could drill water wells. The fact that the aquifer contains uranium mineralization has been misunderstood by a few landowners, which has resulted in numerous protests and added costs that uranium companies must spend to respond to this misunderstanding. Establishing baseline environmental conditions are essential to provide reasonable mine closure guidelines. These are conducted over the course of years to determine seasonal variations well before uranium recovery operations begin and during and after the operations have been concluded. A number of investigations are usually conducted on a variety of physical, biological, and socio-economic investigations. See Campbell, *et al*., (2007A), and Davis and Curtis, (2007), for a discussion of these issues. Recently, the IAEA, (2005b) has turned its attention to the methods employed to meet the environmental requirements in the U. S. and overseas as well.

Socio-Economic Issues

Socio-economic issues have become increasingly important over the recent decades. Impacts on local populations may disrupt local lifestyles, but there also may be positive impacts by providing employment and local business in support of such operations. An assessment of current resource use, such as agriculture, wildlife harvesting, fishing, and tourism is important. Cultural issues also must be considered, including current conditions, history, and archaeology. The costs and benefits must be carefully weighed. Knowledge of these factors will help to reinforce community relations.

Some of the more important issues that should be considered or accepted are:

- What type of uranium recovery methods should be used? There are pros and cons to each of the methods available.

- What is a reasonable cleanup goal? Remediating a site to drinking water levels is no longer required by the state because this action was deemed unreasonable since the site was already naturally contaminated. The general public will need to understand how and why the cleanup goals have been set. In more than one case companies have been criticized about the cleanup levels set, even though these levels were well below the human health risk levels approved by the state regulatory agency. Good community relations through communication are an important function of the uranium company's management.

- Are there any abandoned wells that need to be plugged? Identification of old boreholes may be required to make sure they are properly sealed before ISR operations begin. Because many of the new deposits were discovered in the 1980s, it is entirely possible that, by today's standards, the exploratory borings were improperly sealed. It has been common practice to simply fill the hole with drilling mud and then insert a 10-foot concrete plug three feet below the surface. These plugs were known to slip, and old boreholes that were thought to be properly abandoned would cave-in and remain open to the surface for many years. These open borings serve as routes for the migration of uranium production fluids to both higher and lower aquifers. There have been cases reported of these old boreholes being discovered by the fluid geyser that resulted when the nearby injection wells were initially operated.

- What is the best way to dispose of excess wastewaters, by evaporative ponds or disposal well? Evaporative ponds are thought to be more environmentally friendly, but may be unfeasible in areas of high humidity or low temperatures. Ponds such as these often leak, creating cleanup problems during closure, so ponds should be avoided if possible. In some uranium recovery operations, above ground storage tanks are used to temporarily contain wastewaters. The use of reverse osmosis will reduce the volume of fluids requiring injection well disposal. Disposal wells may be uneconomic if they need to be drilled too deep to reach an appropriate brine disposal injection zone. It has also been suggested that two disposal wells should be installed, in case a problem develops with one of them.

- Have all neighboring water wells been identified? All water wells within a regulatory distance of 0.25 miles from the uranium-recovery area need to be included in any monitoring program for periodic sampling and laboratory analysis. Some uranium companies are extending this radius to insure that the coverage is suitable, and to placate neighbors.

Is a well-established emergency-response procedure in place and are all employees skilled in its use? This should be an established function of company management. With the general public becoming more environmentally conscious, it is imperative that an ISR uranium company be prepared to respond to all spills and releases immediately and answer any and all questions from concerned persons openly and honestly. This may not insure that problems and misunderstandings will not occur, but a community approach should prevent most of the associated problems. A lingering problem involves local media reporting on uranium company activities often employing "fear" words to make a particular impact on the reader, or making statements that have no basis in fact or appropriate reference, or combining and confusing subjects in the article to encourage the reader to draw certain conclusions that the general public might not otherwise make (Campbell, *et al.,* (2005). There are also problems with paid activists who are credentialed in one academic field but who claim knowledge in another and attempt to influence others on subjects about which they know very little.

The general public is unaware of how some public servants, activists, and news media are sowing the seeds of misinformation, creating unnecessary controversy and mistrust around the U.S. This includes the dissemination of shoddy and blatantly-biased articles related specifically to inhibiting the expansion of nuclear power and associated uranium exploration and recovery. For additional information on these public relations issues and on our efforts to provide meaningful information to the affected general public, see:

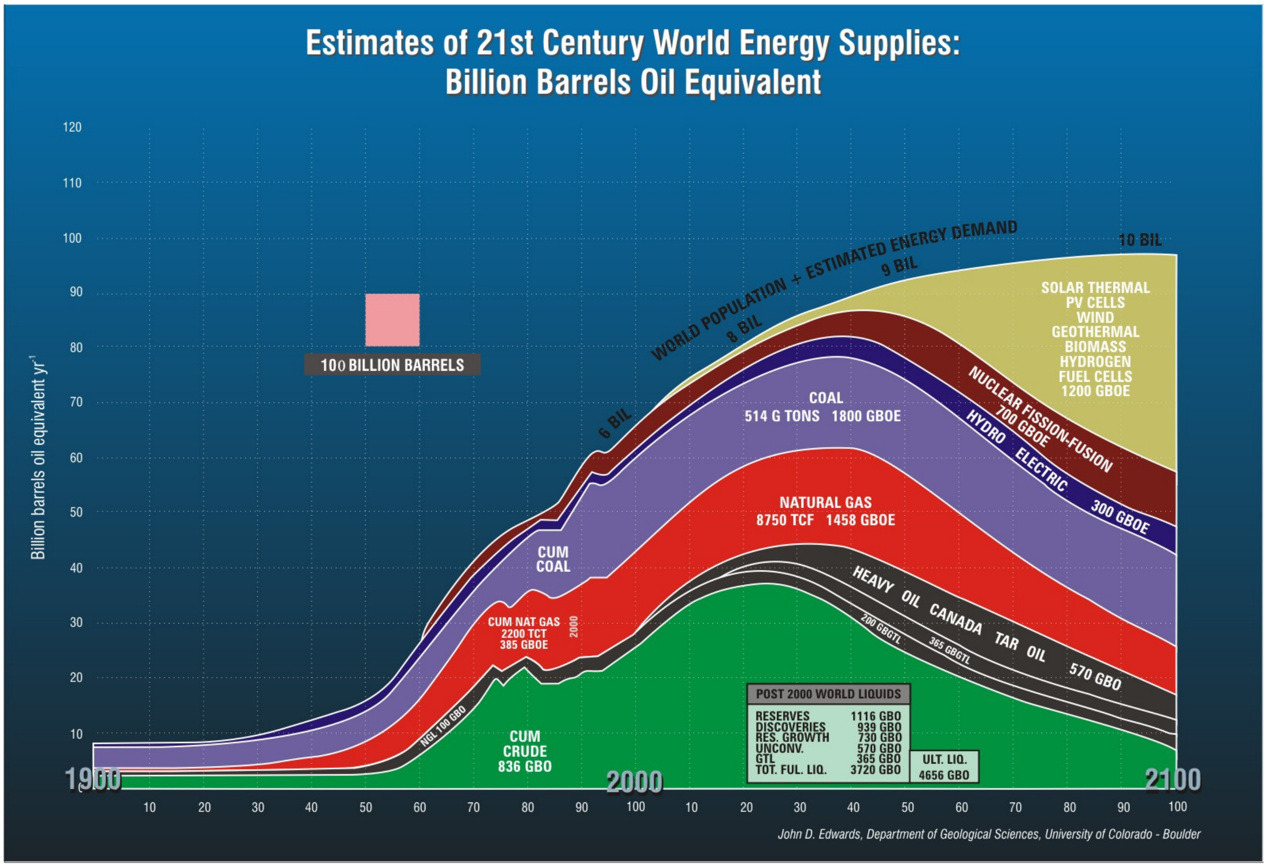
http://mdcampbell.com/CAReviewszz/careviews.htm

As mentioned earlier, in many respects, the recovery of uranium from an aquifer is similar to environmental remediation programs. The latter involves anthropogenic contaminants that have been released and then recovered by industry as part of environmental clean-up. Similar in-situ pumping and recovery methods are used, but in the case of uranium, this is a natural contaminant formed millions of years ago, not a contaminant released by industry. Like oil recovery, uranium and associated natural constituents cannot be completely removed from the aquifer.

Needs of the Future

The need for viable energy fuel will become critical by mid-century. According to the present paradigm, all conventional energy sources are predicted to peak during this period and alternative resources are anticipated to fill the gap, as indicated in Figure 8. Nuclear power utilities have sufficient identified reserves to last well past the year 2074. Even with the anticipated nuclear power expansion from 436 to 766 reactors over the next 30 years, present reserves still meet the need of the expansion; reserves expand as the fuel price rises and as demand stimulates exploration (Figure 5).

Figure 8
(From Campbell and Campbell, (2005)

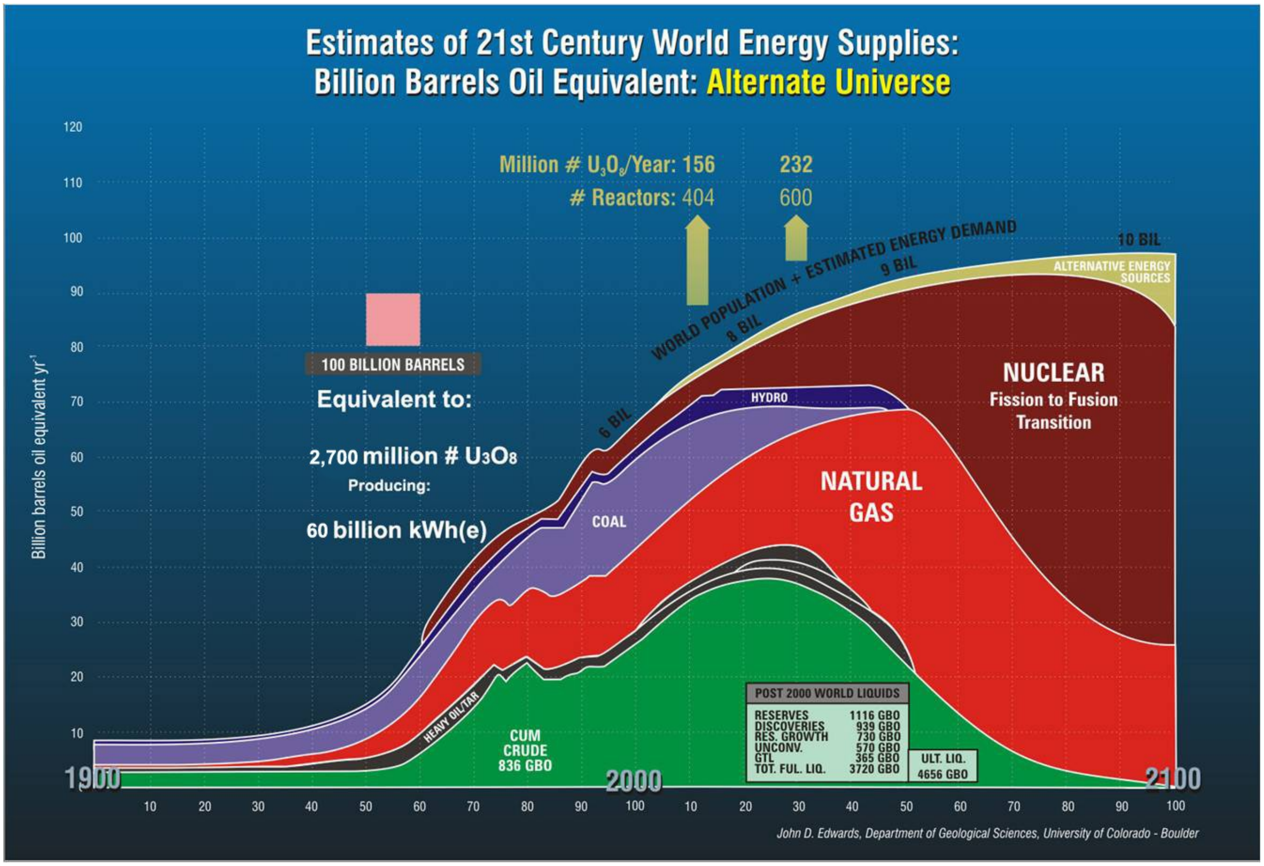


An alternative future energy scenario that phases out coal, fuel oil, and dams for electrical generation, combined with expanding the use of nuclear and natural gas, while postponing the use of alternative methods of electrical generation, is illustrated in Figure 9 as in an alternate universe. This scenario includes nuclear power providing most of the electricity production while natural gas will likely be used for transportation. Less-developed countries may use the remaining carbon-based fuels for some time to come. Wind and solar energy have roles to play in remote areas where the national power grid has not yet reached.

Conclusions: Looking into the Future

The economic and social fabric of America depends on how rapidly the U.S. can develop and implement a viable energy plan (see Kucewicz, (2007). With the declining oil & gas resources, and with coal becoming an unacceptable energy source on the basis of its socio-economic limitations extending over the next 30 years, nuclear power appears to be the most viable source of energy to generate the large quantities of electrical power that will be required. Also, as uranium reserves are consumed in the early 22nd Century, there is no reason to conclude that additional resources will not be discovered. Also, recycling of uranium (and plutonium) almost certainly will be re-instated for development (Campbell, *et al*., (2007b); U.S. Department of Energy, (2007); Leventhal and Dolley, (1994). The use of thorium as a fuel to generate electricity also will play an increasing role (see summary information on thorium (here) and older, but still relevant information (here)).

Figure 9
(Modified from Limerick, *et al*, (2003)



Lastly, it is not unreasonable to assume that economic uranium (and thorium) deposits will be discovered elsewhere in the solar system, i.e., on other planets, moons, or asteroids. The environmental processes that form the younger types of uranium mineralization (of Tertiary age) require the presence of water, bacteria and associated enzymes, and may not be present on many of these distant bodies. However, water may be more pervasive than originally assumed. Geologically older types of uranium mineralization associated with igneous and metamorphic rocks similar to deposits that occur in Proterozoic gneiss and amphibolites (Christopher, (2007) and to the younger rocks in the U.S. (Armbrustmacher, *et al*., (1995), as well as the well-known, developed uranium deposits in Canada and northern Australia and those under development in Africa, would be analogues for the types of deposits that would be expected to occur elsewhere in the solar system. Some early speculations about uranium, thorium, and associated geochemistry have already begun (Surkov, *et al*., (1980); Zolotov, *et al*., (1993). With the number of unmanned probes planned in the next few years, additional information should be available to begin looking actively for resources in our solar system, hopefully within the next 20 years, supported by solar and nuclear power (Campbell, *et. al*, In Prep).

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