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ISR Symposium Keynote

KEY LESSONS LEARNED FROM THE APPLICATION OF ISR TO URANIUM

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ABSTRACT

In-Situ Recovery of Uranium has become a well-established mining method over the past 40 years. ISR offers a low-cost, environmentally sound process of extracting metals from deposits. ISR projects now populate the entirety of the top-third of the lowest uranium production cost facilities globally. Still, the technology has its limitations in scale and ore-types and it is unlikely to ever fully replace conventional uranium mining and production. This presentation will open with a brief overview of the advantages and limitations of the ISR mining process.

Over the last several decades, ISR technology has been advanced on two parallel paths. The US ISR industry has consistently pursued the application of alkaline lixiviant chemistry while Kazakhstan, Australia and other nations have consistently selected acidic lixiviant chemistries. In a broad view, the lixiviant preference appears to be influenced by geographical rather than technical factors. The choice of lixiviant influences uranium leachability, recovery rates and overall production costs. The lixiviant choice also impacts equipment and process selection in the recovery and concentration plant facilities.

This presentation will establish a renewed focus on the application of fundamental technical factors used to determine the proper lixiviant selection for an ISR project. Not all roll front deposits located in a region or country contain similar bulk mineral content or similar uranium mineralogy. Using the right techniques to understand the host rock and uranium speciation will lead to an improved process for the proper selection of ISR lixiviants. Selecting the proper lixiviant can have a large impact on the technical and economic success of a commercial operation.

The social expectation and standards for post-mining groundwater restoration have also been associated with lixiviant selection. It is commonly assumed that alkaline lixiviant is more benign and consequently the mined aquifer can more readily be restored to baseline conditions. Acidic lixiviant has been applied where there is a perceived lower technical standard for restoration. Current research efforts are being conducted to better understand the industrial capabilities of fully returning an aquifer to its pre-mining class of use following application of acidic lixiviants. The topic of groundwater restoration outcomes will be addressed.

Keywords: Uranium, In-Situ Recovery, Lixiviant, Geometallurgy, Groundwater Restoration

INTRODUCTION

In-Situ recovery of uranium evolved as an industry response for the need of a lower cost, environmentally friendly means to extract the important energy metal. Over the years, with various external events affecting the nuclear energy sector, the primary customer of uranium producers, the market price has experienced pronounced upward and downward swings along with prolonged periods of low values. It seems appropriate that we should context today's uranium market as a pathway to lead into our main objective of this paper, the key lessons learned from the application of ISR to uranium.

Uranium is traded in a spot market structure and through processes of longer term contracting. Historically, the term contract pricing is at a premium to the spot market to reflect the value of security of supply. Due to various factors which have led to a supply surplus, today the spot price is near its ten-year lows. With historically low spot prices, fuel buyers are attracted to the spot market and activity in the term market has been minimal. Both the spot and term prices are currently lingering at levels which are too low to invite investment into the development of new production capacity.

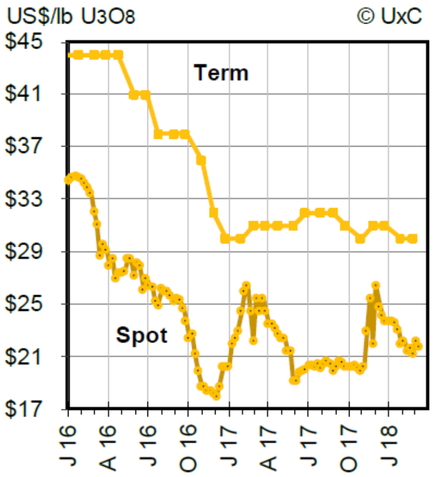

Figure 1: Uranium Market price trends
Source: The UX Consulting Company

The sustained weak market has not only led to reduced investment in uranium exploration and development in recent years, a substantial decline in uranium production has also occurred over the past several years. A long list of announcements has been made which signal producer capitulation to the soft market conditions. Production restraint has become a commonly proclaimed theme as illustrated in **Figure 2**.

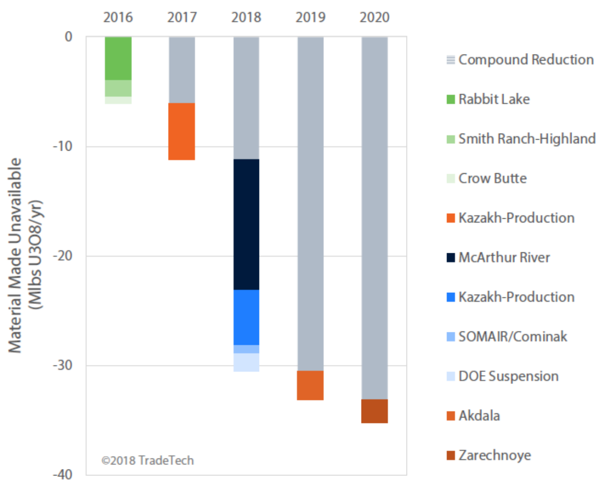

Figure 2: Uranium production decline
Source: Trade Tech

With annual production declines exceeding 30 million pounds per annum in 2018, which is over 20% of the worlds approximately 160 million pound primary uranium production level, how can a supply surplus be achievable, much less sustained? The answer lies in the actual growth of global production between the turn of the century and today as illustrated in **Figure 3**. In the year 2000, approximately 90 million pounds of U_3O_8 were produced globally. Kazakhstan was just a blip on the global production scene. In 2016, the estimated global production rate grew to 160 million pounds and Kazakhstan has grown into the world's number one producing nation accounting for 60 million pounds of annual production.

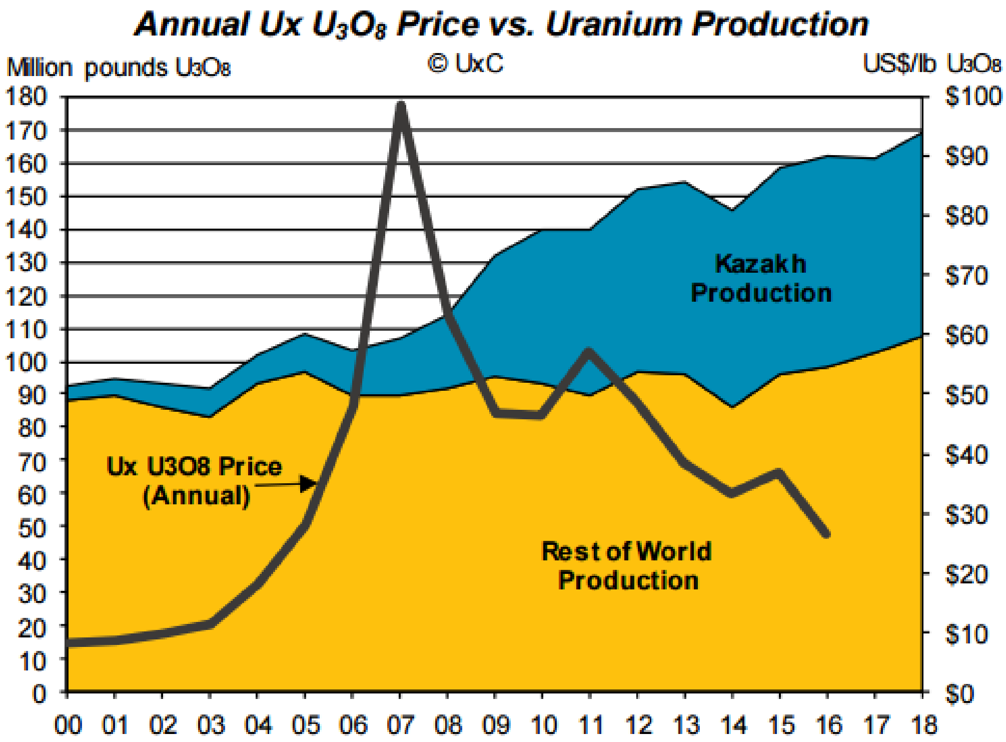

Figure 3: Annual Uranium production and spot price
Source: The UX Consulting Company

Production growth in Kazakhstan over the past two decades has been beyond the requirements of the market and is now effectively displacing other primary production sources. While there is no substitute for a good deposit, disproportionate growth on this scale must also have an economic explanation. How can Kazakh production be economically competitive? How did Kazakhstan accelerate their production from zero to 60 million pounds in under 20 years? Importantly, what mining method do they use? These questions bring us to Lesson #1.

LESSON #1: LOW PH ISR PRODUCTION LEADS THE WAY

Low pH (acid) ISR is the only uranium recovery method being utilized at Kazakh deposits today. It is the undisputed low cost production method champion. In 2015, ninety-six percent (96%) of the uranium recovered by ISR methods, about half of the global total, was produced at facilities employing low pH ISR solutions (WNA). The production technique generated 74 million pounds of primary mine production that year.

On the cost curve, all of the first quartile uranium operations globally are in-situ recovery facilities that utilize low pH (acidic) lixiviants. **Figure 4** presents the global production cost curve with low pH ISR facilities identified by color.

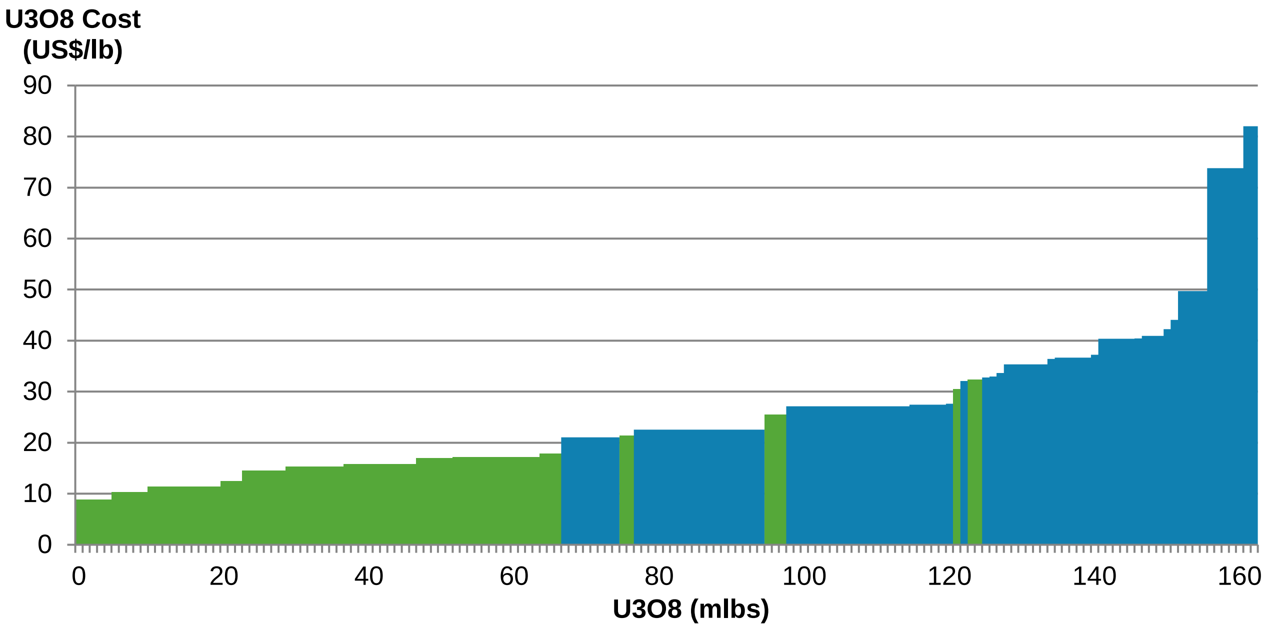

Figure 4: Global Production Cost Curve. Green = Low pH ISR, Blue = All other methods
Data Source: The UX Consulting Company

ISR ADVANTAGES

From **Figure 4** we can easily recognize the primary advantage of ISR for the uranium mining industry, that being low overall production costs. The conditions that support that overall result are also important to understand.

After over 40 years of practical application, ISR is now a very established mining method. Many facets of the ISR uranium recovery method are now tried and true industry standards. Factors which determine a deposit's amenability to the ISR process are well understood. Additionally, the necessary process controls that can assure successful environmental protection outcomes have been demonstrated and can be duplicated at multiple sites. In short, the ISR method has successfully transitioned from an experimental technology to a proven commercial scale, environmentally sound process of extracting metals from deposits.

As expected during early stage development, ISR applications today result in limited environmental impacts. In comparison to other mining methods, ISR offers low overall water consumption rates, very low noise levels, minimal dust emissions, and minimal impact to local air quality. Post mining, ISR offers excellent mine closure opportunities as no long term legacy sites are created. Numerous ISR project sites have been fully rehabilitated and returned to the landowners for unrestricted use. This is true even in the United States where environmental standards are known to be high and legacy issues from conventional uranium mining in the 1950's and 1960's persist even today.

A properly suited uranium ore deposit can be placed into production via the ISR method with a remarkably low up front capital cost. ISR techniques do not require the use of a mining fleet. Further, because the ore is left in place, there is no bulk material handling equipment and the mill facilities are relatively low cost hydrometallurgical process facilities. Finally, there is no upfront capital costs associated with mill tailings storage facilities. Only small quantities of solid waste are generated during the commercial operations. Non-radioactive solid waste quantities may be economically disposed of at commercial landfills.

ISR also provides for highly flexible mining plans. When product demand is high, new well field areas can be quickly developed and activated without a proportionate increase in labor and other incremental costs. During low pricing periods, production rates can be scaled back without substantial impact to the unit production costs.

Finally, ore grade has been demonstrated to be less of a factor for ISR than for other mining methods. ISR is typically employed on ores that are low grade due to the nature of their formation. In the USA, one of the lowest cost production centers today addresses an ore body that has such a low grade that most outsiders could not imagine it would be successful. The Company that developed the project understood the importance of other deposit characteristics over the importance of grade. This brings me to Lesson #2, a most unexpected thought.

LESSON #2: IN ISR, GRADE IS NOT KING

An ore body that is a candidate for ISR needs to have several characteristics, high grade not being among the top three. To be a good candidate ore body, the target mineralization needs to be accessible to the injected mining solution (lixiviant), readily soluble in that solution and wide spread throughout the host formation.

Uniform host formation permeability is a key criterion. In ISR, also known as solution mining, your solution is your “miner”. Your miner must be able to contact the ore. If your lixiviant cannot come in contact with your target mineral, there is nothing you can do to change your predictably poor mineral recovery outcome.

Often times, the factors which cause uranium to concentrate at relatively high grades in epigenetic sandstone deposits will be the very same factors that prevent you from accessing the mineral. Sometimes this is an organic component like an old tree trunk or another sedimentary debris feature that absorbs metals in concentrations and will not be susceptible to the oxidation reaction that solubilizes uranium into the lixiviant. High uranium grades in a roll front environment should be viewed with a cautionary eye. Something is providing a strong trap that will be difficult to overcome without an aggressive chemistry to counter the strong trap.

Mineralized width and thickness are often an excellent indicator of a good ISR candidate orebody. Wide deposits with substantial thickness can be host to abundant quantities of mineral without being high grade. Significant widths and thicknesses are indicative of a broad sand channel with a classical roll front type of deposition. High uranium grades are unusual in a classical role front deposit because the uranium mineral is deposited as oxidized groundwater is consumed in a reducing environment. Strongly reducing environments are difficult to overcome and do not easily give up their prized mineralization.

ISR LIMITATIONS

There are several known factors that will determine that a host deposit is not amenable to the ISR process. For lixiviant confinement, it is important to have an overall sedimentary stratification system that controls the vertical migration of the mining solution. Equally important, the host formation must be saturated (below the water table). The host rock must be naturally broken & permeable to allow solution flow from well to well. Finally, well drilling technology and costs place a limitation on the economic viability of deep formations.

Figure 1: a) Hard rock core, and b) Sandstone core

Mineralogy and geochemistry influences also place limitations on the in-situ recovery method. The project developer must have a detailed understanding of the uranium mineralogy to ensure that the proper lixiviant chemistry is applied. The mineralogical aspects extend to the host rock which may contain reactive minerals which can either interfere with the extractive process or add value as a coproduct or byproduct.

LESSON #3: LIXIVIANT SELECTION IS A KEY FACTOR

There is a certain duality that defines the development of ISR lixiviant chemistry. The US ISR industry has consistently pursued the application of alkaline lixiviant chemistry while Kazakhstan, Australia and other nations have consistently selected acidic lixiviant chemistries. In a broad view, the lixiviant preference appears to be influenced by geographical rather than technical factors. Clearly, that should not be the case. Proper lixiviant selection should be based on the host rock and mineralization criterion, not geographic or social norms.

The alkaline lixiviant chemistry employed in the USA has been touted as being a more benign approach. To the layman, the term acid infers danger and undesirable risks. Alkaline ISR has been a much easier "sale" to stakeholders because household chemicals like baking soda and oxygen can be discussed as the primary chemical agents. Post-mining groundwater rehabilitation advantages have also been claimed for the alkaline ISR process. Those ideas will be discussed further in the next section of this paper.

Outside of the USA, the uranium ISR industry has generally embraced acidic or low pH ISR chemistry. A broader range of uranium minerals are susceptible to the more aggressive leaching agents and oftentimes the extraction rates and overall recovery rates are measurably higher. Adversely, the acidic chemistry is perceived to be riskier on a health and environmental basis and therefore the application has been limited where challenging regulatory processes are expected.

Not all ore deposits located in a region or country contain similar bulk mineral content or similar uranium mineralogy. Pre-design metallurgical test work should include extensive mineralogical characterization to understand both the uranium and host rock mineralogy. Using the right techniques to understand the host rock and uranium speciation will lead to an improved process for the proper selection of ISR lixiviants.

Host rock factors that should be evaluated include the presence of acid consuming constituents such as carbonate minerals, the presence of carbonate consuming constituents such as gypsum, the abundance and type of clays present which can affect permeability, and the presence of chemically reducing constituents such as pyrite which will affect oxidant requirements. The presence of carbonaceous (organic) materials can also be deleterious to the ISR process and must be closely evaluated.

Thorough hydrometallurgical test work is another important aspect in the evaluation and selection of the proper ISR lixiviant. Unfortunately, large quantities of ore samples are rarely available for metallurgical testing. Most testing is done on limited quantities of core samples which are generally expensive to obtain. Commonly, initial leachability screening work is performed in bottle roll tests. The effect of varying leach conditions can be economically ascertained for both acid and alkaline systems with properly managed bottle roll testing. Column leach tests more closely simulate in-situ conditions although the required ore handling steps mean a sample will never really be preserved in its natural condition. Column leach tests can be used to refine and confirm the preliminary data obtained through bottle roll testing. Post-test analysis of the unreacted uranium species adds a substantial opportunity to improve overall leach efficiency and is often overlooked during the test design process.

Selecting the optimal lixiviant conditions through proper laboratory examinations can have a large impact on the technical and economic success of a commercial operation. The choice of lixiviant influences reagent consumption, uranium extraction, recovery rates and consequently overall production costs. For the technically minded individual, it seems preposterous that lixiviant selection would be based on geographic and social norms.

LESSON #4: GROUNDWATER RESTORATION CAN BE ACHEIVED

Groundwater within the ore zone is invariably impacted during ISR operations. Modern regulatory standards hold mining projects including ISR to an objective of creating no lasting environmental impacts. Of the available mining methods, ISR holds the promise of creating the lowest levels surface disturbance, air quality impacts and impacts to flora and fauna. The necessary level of impact to groundwater quality during mining has elevated the level of concern over the long term destruction of the groundwater resource to alarming and sometimes debilitating levels. Upon scientific scrutiny however, those concerns are determined to be largely unfounded.

Groundwater restoration objectives vary from location to location and correctly so. The natural water quality associated with many uranium deposits dictates that the water is unsafe for human or livestock consumption and is generally unsuitable for most other applications prior to any human activity. The restoration objective for this category of groundwater should and commonly is to ensure that any human impact from ISR is contained to the local area and cannot spread beyond the control area. Natural attenuation is often an effective long term strategy for control of these waters. Supplemental water treatment to achieve certain objectives such as a pH target level can be economically accomplished to enhance the success of natural attenuation.

In some locations, the majority of groundwater quality parameters suggest that with a modest level of treatment, the water could be beneficially used. Although not a first choice in most cases, radionuclides associated with uranium deposits can be economically removed from groundwater if other sources of water are scarce or unavailable. Waters in this category should be given consideration for protective schemes that enhance the opportunity for future use.

One of the most effective methods of protecting groundwater sources from long term impacts is to control the extent of lixiviant migration during mining. Planning of effective countermeasures to avoid lixiviant excursions during wellfield operations is one of the best practices available to reduce the effort and cost required to restore the groundwater quality after mining. Hydrogeological flow modeling techniques have significantly advanced alongside computer speed and capabilities. Implementing a program of routine usage of flow modelling can greatly enhance any hydraulic control strategy. That said, hydrologic models are built from geologic models and it is important for ISR operators to develop a detailed an accurate understanding of the structural framework of the stratigraphy of the formation. Major features like stratigraphic divisions, faulting and unconformities must be identified and accounted for in the geologic and hydrologic models.

At Peninsula Energy's Lance Project in Wyoming today, a considerable laboratory program is underway with the objective of demonstrating the capacity to fully restore the groundwater quality to pre-mining conditions following low pH ISR operations without the reliance on natural attenuation. Results to date indicate that pH-reliant soluble constituents like uranyl-sulfates can be fully remediated with the effective return to baseline pH conditions. Uranium is one of the more difficult restoration parameters at alkaline/oxidation ISR projects. The results of this research hold promise that the societal misunderstanding that low pH ISR operations cannot be effectively remediated may soon be addressed by scientific research.

There are many examples of successful groundwater remediation following in-situ recovery operations. Minor variances in a parameter concentration that still falls within the original class of use of the aquifer should not be cited as a reason to disqualify this statement. The record of success in meeting restoration objectives is well established and should not present a barrier to future ISR operations.

CONCLUSIONS

In-Situ Recovery today is a well-established mining method. After more than 40 years of commercial applications, significant advances have been realized in understanding the technical factors that drive a successful ISR operation. With the history of uranium ISR as a basis, four key lessons were presented here;

1. Low pH uranium ISR is the lowest cost uranium mining method available
2. In ISR, ore grade is not the most important indicator of success
3. Proper lixiviant selection will determine economic results
4. Groundwater restoration can and has been achieved with modern ISR methods

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