International Symposium on

Uranium Raw Material for the Nuclear Fuel Cycle:

Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues

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ABSTRACTS

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Opening Session

Uranium and nuclear market, the horizon post-Fukushima

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Post-Fukushima, most countries have confirmed the importance of nuclear in their energy mix. We are seeing a level of new reactor construction unparalleled in decades with 61 nuclear power plants under construction and 5 plants under completion around the world. Global nuclear capacity is expected to increase by 50% over the next two decades. And more reactors mean more demand for uranium.

However, uranium industry is currently grappling with near-term challenges, particularly in the form of depressed uranium prices. Recently several uranium producers announced production delays or cancellations in response to low prices, including major suppliers. As the current price levels, including long-term prices, are not sufficient to stimulate new production, future supplies are in question due to the long-lead nature of uranium mine development.

Despite the near- to medium-term issues of our industry, the fundamentals of the uranium market remain strong over the long term - and these are the drivers of the Areva's mining growth strategy over the coming years.

Uranium markets and industry

IAEA study - uranium supply to 2060

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The IAEA is in the process of publishing a new study entitled: “Uranium Supply to 2060” (U2060). This report is a sequel to “Analysis of Uranium Supply to 2050”, published in 2001. Many changes to demand, supply and prices have occurred since that publication, including: complete suspension of operations within the Japanese fleet of nuclear reactors; conclusion of the Russian – US HEU agreement under which some 20,000 Russian nuclear warheads were converted into nuclear fuel; and significant uranium price volatility, i.e. <USD 23/Kg U (<USD 9.00/lb U_3O_8) in 2001, >USD 338/Kg U (>USD 130/lb U_3O_8) in 2007 and < USD 104/Kg U (<USD 40/lb U_3O_8) in 2013. U2060 incorporates these changes.

U2060 sets forth three demand cases that project reactor uranium requirements from 2010 to 2060. The middle or “reference” demand case forecasts moderate worldwide economic growth, accompanied by a modest growth in nuclear power that averages 1.8% per year. The high demand case envisions strong economic growth with accelerated growth in nuclear power averaging 2.4% per year, while the low demand case assumes that nuclear power will grow only slightly during the forecast period. It seems unlikely, at this time, that nuclear power would be phased out to any substantial degree within the foreseeable future. U2060 reviews the supply sources that are expected to be available to meet reactor uranium demand through to 2060. The structure of the report accommodates the fact that globalization of commodities is now a reality and that most uranium supply sources are now constrained by market economics. Non-market based supply, as was the case for example in the former Soviet Union, is expected to play a decreasing role in the fulfilment of nuclear fuel demand. Therefore, the main focus of this report is adequacy of market based production to meet that demand.

Uranium supply is divided into two broad categories: secondary and primary supply. Secondary supply sources include high enriched uranium from nuclear weapons, natural and low enriched uranium inventories, mixed oxide fuels and reprocessed uranium and re-enrichment of depleted uranium stockpiles (tails). Primary supply includes all newly mined and processed uranium, including small amounts of non-market-based supply such as may derive from China or India. Consideration is given to conventional resources as well as to high cost unconventional resources associated with phosphates, black shale, lignite, coal deposits and sea water. The requirement for primary supply is taken to be total demand, including increased inventories, less secondary supply.

The remainder of this report is largely devoted to assessing the adequacy of uranium resources to satisfy future nuclear fuel requirements and considers: confidence of the various resource categories, estimated production costs, and timing of new production capacity.

Uranium 2014: Resources, Production and Demand (the "Red Book") supply and demand projections to 2035

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Since the mid-1960s, with the co-operation of their member countries and states, the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) have jointly prepared periodic updates (currently every two years) on world uranium resources, production and demand. These updates have been published by the NEA in what is commonly known as the "Red Book". This 25th edition of the Red Book reflects information current as of 1 January 2013. The Red Book features a comprehensive assessment of uranium supply and demand in 2013 as well as projections of supply and demand to the year 2035. The basis of this assessment is a comparison of uranium resource estimates (according to categories of geological certainty and production cost) and mine production capability with anticipated uranium requirements arising from projections of installed nuclear capacity.

Since the accident at the Fukushima Dai-ichi nuclear power plant in 2011, Belgium, Germany and Switzerland have implemented policies to phase-out nuclear power. All countries with nuclear power facilities have conducted safety reviews of all facilities and most have implemented requirements to further strengthen safety, in particular with respect to beyond design basis natural events and station blackouts. Although no other countries with nuclear generating facilities have decided to phase-out nuclear power, development plans have been delayed in many countries because of the safety reviews, bringing about a decline in nuclear capacity projections to 2035. In addition to costs associated with implementing the strengthened safety features, capital intensive nuclear power construction programmes are experiencing difficulty in financing new build projects since the recession began in 2008 and the technology is facing stiff competition from natural gas generating plants with low fuel prices and subsidized renewable generating sources. Although these factors have reduced long-term nuclear generating capacity projections from those developed prior to the Fukushima accident, prospects for growth in global nuclear generating capacity remain positive, in particular in developing countries facing growing electricity demand with policies to reduce greenhouse gas emissions and poor air quality.

Uranium prices have declined by about 50% since the Fukushima accident as nuclear power plants in Germany were immediately closed all 48 operational reactors in Japan were progressively shut-down for regular maintenance and not re-started until new regulations governing re-starts were developed and implemented. The early retirements and the prolonged shut-downs led to an oversupplied uranium market, putting further downward pressure on uranium prices. In addition, enrichment facilities faced with excess capacity as demand declined have opted to run the plants with reduced tails assays to create additional uranium supplies, adding to the current market oversupply. As a result the current market oversupply and low uranium prices, market based producers have scaled back or deferred mine development plans. Due to these significant changes in the uranium market, projections of nuclear generating capacity and mine production have been scaled back from previous projections in the Red Book. This presentation summarizes the revised projection of supply and demand to 2035, as outlined in the recently released 2014 edition of the Red Book.

World Nuclear Association 2013 Fuel Market Report

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The presentation gives WNA views on nuclear capacity additions to 2030 and the likely adequacy of the fuel supply chain to meet the nuclear fleet's uranium requirements. A scenario approach is adopted resulting in three capacity projections based on the outlook for existing and new nuclear countries. Uranium resource estimations are taken from the IAEA's Red Book and the prospects for new and existing mines assessed on a site-by-site basis. Both prospective uranium requirements and primary uranium supply have decreased since the previous 2011 report, the latter markedly so from the mid-2020s. Secondary supply is also projected and expected to remain high to 2030.

Uranium exploration (2004-2014): New discoveries, new resources

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The last decade has demonstrated the dynamic of the mining industry to respond of the need of the market to explore and discover new deposits. For the first time in the uranium industry, the effort was conducted not only by the majors but by numerous junior mining companies, more than 800 companies where involved.

Junior miners introduced new methodologies, innovations and fresh approach. Working mainly on former prospects of the 70's and 80's they discovered new deposits, transformed historical resources into compliant resources and reserves and developed new large resources in Africa, North America and Australia.

In Australia, the Four Mile, Mt Gee, Samphire (SA), Mount Isa (Qld), Mulga Rock, Wiluna-Lake Maitland, Carley Bore-Yanrey-Manyingee (WA) projects were all advanced to compliant resources or reserves by junior mining companies.

In Canada, activity was mainly focused on Athabasca basin, Newfoundland and Québec, the results are quite amazing. In the Athabasca 2 new deposits were identified, Roughrider and Patterson South Lake, Whilst in Québec the Matouch project and in New Foundland the Michelin project are showing good potential.

In Namibia, alaskite and surficial deposits, extended the model of the Dalmaradian Central belt with the extension of rich alaskite of Z20, Husab, Omahola and large deposits of Etango and Norasa. A new mine commenced production Langer Heinrich and two are well advanced on way to production: Trekkopje and Husab.

The ISL model continues its success in Central Asia with large discoveries in Mongolia and China.

Europe has been revisited by some juniors with an increase of resources in Spain (Salamanca) and Slovakia (Kuriskova). Some countries entered into the uranium club with maiden resources namely Mali (Falea), Mauritania and Peru (Macusani caldeira).

The Karoo formation revitalised interest for exploration within Paraguay, South Africa (Rieskuil), Botswana (Lethlakane), Zambia (Mutanga, Chirundu) and the exploitation started in Malawi (Kayalekera) and planed in Tanzania (Mkuju).

The potential exploitability of uranium as by- or co-product has led to the innovative processes for extraction being aggressively developed around the World:

Known by its potential but with speculative resources, the black shale deposits of Korea, Colombia and especially in Sweden in the Östersund area have started to be quantified. Sweden reportedly has the second biggest uranium resources after BHP's Olympic Dam operation in Australia. Initial resources based on extraction via bioheap leaching have been calculated for Sweden. This technology for uranium was initially developed on metamorphic blackshales in Finland. The Sotkamo Project in Finland may commence uranium by product production in the near future.

The largest rare earths deposit in the world outside of China, Kvanefjeld in Greenland has the ability to be a uranium co-product.

All these discoveries or new resources must be tempered with the fact that scoping, prefeasibility and feasibility studies will be the true indicator of their economic viability.

The uranium supply strategy of China

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Currently there are 28 units of nuclear power plants (NPPs) under construction in China. Most of these plants will be put into operation sequentially in a couple years. The paper will present the operational and construction status of NPPs in China.

As the reactor fleet increases, the requirement for uranium will also substantially increase. Due to declining air quality, as atmospheric pollution spreads rapidly from northern parts to southern parts of China, the option to develop nuclear power has become the highest priority. Uranium demand will be the key to support the expanded nuclear power in the future. Current and future requirements of uranium and the envisaged supply strategy will be discussed.

Domestic production is seen as one of the channels to meet the increased requirement. As the uranium price remain low, there will be limited the expansion of domestic production in the short term. The exploration of economic resources is being promoted. Decreasing production costs is mandated in operations due to low uranium prices at present.

Development of overseas uranium resources is another channel to supply for the NPPs. Through acquisition of uranium mining projects, advanced uranium projects and exploration projects, China can meet the requirement of NPPs in the long-term. Joint venture partnership is also flexible option for developing uranium resources overseas.

Purchasing uranium in the market is the third option. Complementing the supply by domestic production and overseas development, purchase of uranium product in the market is a simple and easy option.

Advantages and disadvantages of these three channels and how these can be combined into an integrated strategy of supply and the proprotionate weightage of each channel for the potential future supply of uranium to the NNP fleet will be discussed.

World Nuclear Association (WNA) internationally standardized reporting (checklist) on the sustainable development performance of uranium mining and processing sites

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The World Nuclear Association (WNA) has developed internationally standardized reporting (‘Checklist’) for uranium mining and processing sites. This reporting is to achieve widespread utilities/miners agreement on a list of topics/indicators for common use in demonstrating miners’ adherence to strong sustainable development performance.

Nuclear utilities are often required to evaluate the sustainable development performance of their suppliers as part of a utility operational management system. In the present case, nuclear utilities are buyers of uranium supplies from uranium miners and such purchases are often achieved through the utility uranium or fuel supply management function. This Checklist is an evaluation tool which has been created to collect information from uranium miners’ available annual reports, data series, and measurable indicators on a wide range of sustainable development topics to verify that best practices in this field are implemented throughout uranium mining and processing sites.

The Checklist has been developed to align with the WNA’s policy document Sustaining Global Best Practices in Uranium Mining and Processing: Principles for Managing Radiation, Health and Safety, and Waste and the Environment which encompasses all applicable aspects of sustainable development to uranium mining and processing. The eleven sections of the Checklist are:

1. Adherence to Sustainable Development
2. Health, Safety and Environmental Protection
3. Compliance
4. Social Responsibility and Stakeholder Engagement
5. Management of Hazardous Materials
6. Quality Management Systems
7. Accidents and Emergencies
8. Transport of Hazardous Materials
9. Systematic Approach to Training
10. Security of Sealed Radioactive Sources and Nuclear Substances
11. Decommissioning and Site Closure

The Checklist benefits from many years of nuclear utility experience in verifying the sustainable development performance of uranium mining and processing sites. This Checklist is therefore not new and directly aims to share a common list with a view to standardize this reporting between utilities and miners at the international level.

IAEA geological classification of uranium deposits

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In 2009 a working group was created by the IAEA in order to review the various existing classifications and to propose a new or a modified classification to be used internationally. Abundant publications and company data became available with the increase of uranium prices starting in 2005 and the flurry of exploration work which followed. This provided a wealth of information on uranium deposit geology that has been used to revise the classification.

The previous IAEA classification, used in particular in the latest version of the NEA/IAEA 2012 Red Book, dates back to 1993. At this time, 582 uranium deposits were recorded in the IAEA UDEPO Database. At the end of 2013, 1525 uranium deposits were listed in the database.

Fifteen types of deposits have been retained in the new IAEA classification scheme. In contrast to previous IAEA classifications, they are not listed in order of economic importance, which has changed over time. Instead, they are listed in a geologically meaningful order from primary magmatic high temperature deposits to sedimentary and surficial low temperature deposits.

1. Intrusive
2. Granite-related
3. Polymetallic iron-oxide breccia complex
4. Volcanic-related
5. Metasomatite
6. Metamorphite
7. Proterozoic unconformity
8. Collapse-breccia pipe
9. Sandstone
10. Paleo-quartz-pebble conglomerate
11. Surficial
12. Lignite and coal
13. Carbonate
14. Phosphate
15. Black shale

Within the 15 types, 36 subtypes and 14 classes have been designated. The new classification is described in an IAEA document entitled “Geological classification of uranium deposits and description of selected deposits” to be published in 2014.

In comparison to the 1993 IAEA classification, the classic term “Vein type” has been abandoned. Veins are associated with various rock types, including granite, volcanic, metasomatites, metasedimentary rocks, sandstones and others, thus the term “vein” is only used to describe the configuration of ore bodies in any respective geological environment. “Vein-type” deposits have been reassigned to two types - “Granite-related” deposits (a new type) and “Metamorphite” deposits. “Breccia complex” has been renamed “Polymetallic iron-oxide breccia complex”, “Unconformity-related” deposits are called “Proterozoic unconformity”, “Quartz pebble conglomerate” has become “Paleo-quartz-pebble conglomerate” and “Phosphorite” deposits are renamed “Phosphate” to also include continental phosphate deposits. Lignite-coal, carbonate and black shale are now recognized as separate types.

The names of most deposit types are related to host rock type except for types 3, 7 and 8 which are related to structures, type 5 is related to metasomatic transformations and type 11 is associated with surficial processes. The deposit types can be regrouped into the three major classes of the rock.

It should be recognized that the 15 types have far greater significance than the simple names. Deposit types have fundamental characteristics and recognition criteria and in that respect, while mainly named by host rock, the types are essentially empirical models, based on observable characteristics. For each deposit types and subtypes a definition is given in the volume and the detailed characteristics of typical examples are presented as a reference with maps and cross sections.

Uranium geology

Felsic magmatism and uranium deposits

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Uranium strongly incompatible behaviour in silicate magmas results in its concentration in the most felsic melts and a prevalence of granites and rhyolites as primary U sources for the formation of U deposits. Despite its incompatible behaviour, U deposits resulting directly from magmatic processes are quite rare. In most deposits, U is mobilized by hydrothermal fluids or ground water well after the emplacement of the igneous rocks. Of the broad range of granite types, only a few have have U contents and physico-chemical properties that permit the crystallization of accessory minerals from which uranium can be leached for the formation of U deposits.

The first granites on Earth which crystallized uraninite appeared at 3.1 Ga, are the potassic granites from the Kaapval craton (South Africa) which were also the source of the detrital uraninite for the Dominion Reef and Witwatersrand quartz pebble conglomerate deposits.

Four types of granites or rhyolites can be sufficiently enriched in U to represent a significant source for the genesis of U deposits: peralkaline, high-K metaluminous calc-alkaline, L-type peraluminous ones and anatectic pegmatoids.

L-type peraluminous plutonic rocks in which U is dominantly hosted in uraninite or in the glass in their volcanic equivalents represent the best U source.

Peralkaline granites or syenites represent the only magmatic U-deposits formed by extreme fractional crystallization. The refractory character of the U-bearing minerals does not permit their extraction at the present economic conditions and make them unfavourable U sources for other deposit types. By contrast, felsic peralkaline volcanic rocks, in which U is dominantly hosted in the glassy matrix, represent an excellent source for many deposit types.

High-K calc-alkaline plutonic rocks only represent a significant U source when the U-bearing accessory minerals [U-thorite, allanite, Nb oxides] become metamict. The volcanic rocks of the same geochemistry may be also a favorable uranium source if a large part of the U is hosted in the glassy matrix. The largest U deposit in the world, Olympic Dam in South Australia is hosted by highly fractionated high-K plutonic and volcanic rocks, but the origin of the U mineralization is still unclear.

Anatectic pegmatoids containing disseminated uraninite which results from the partial melting of uranium-rich metasediments and/or metavolcanic felsic rocks, host large low grade U deposits such as the Rössing and Husab deposits in Namibia.

The evaluation of the potentiality for igneous rocks to represent an efficient U source represents a critical step to consider during the early stages of exploration for most U deposit types. In particular a wider use of the magmatic inclusions to determine the parent magma chemistry and its U content is relevant to evaluating the U source potential of sedimentary basins that contain felsic volcanic acidic tuffs.

Granite-related hypothermal uranium mineralization in South China

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As one of the important geological types, granite-related uranium deposits account for about 29% of the total discovered natural uranium resources in China. Most of the granite-related uranium deposits located in Taoshan - Zhuguang uranium metallogenic belt, South China. In addition to the typical pitchblende vein-type uranium mineralization of epithermal metallogenic system, a new type of granite-related uranium mineralization with characteristics of hypothermal matallogenic system was discovered in South China by current studies. However, hypothermal is contact thermal to epithermal mineralization, and not the conventional intrusive high temperature mineralization.

Hypothermal uranium mineralization is presented by disseminated uraninite or pitchblende stockwork in fissures in granites normally with extensive alkaline alteration. The high temperature mineral assemblage of uraninite associate with scheelite and tourmaline was identified in hypothermal uranium mineralization. Fluid inclusion studies on this type mineralization indicated the middle to high temperature (>250℃) mineralization with the mixing evidence of ore forming solution derived from deep level, and the boiling and mixing of ore forming solution are regarded as the dominant mineralization mechanism for the precipitating of uranium. In contrast to the mineralization ages of 67 Ma to 87 Ma for typical pitchblende vein mineralization of epithermal metallogenic system, the mineralization age is older than 100 Ma for hypothermal uranium mineralization in granite.

In the Shituling deposit, Xiazhuang uranium ore field, uraninite and pitchblende micro veins with extensive potassic alteration, chloritization and sericitization are hosted in fissures of Indo-Chinese epoch granites with the uranium mineralization age of 130 Ma to 138 Ma with a mineralization temperature of 290℃ to 330℃ indicated. Other examples sharing the similar characters of hypothermal uranium mineralization have been recognized in Taoshan, Xiazhuang and Nanxuiang areas, South China. Preliminary geodynamic studies reveal that hypothermal uranium mineralization in granite predominantly occurs in areas with lithospheric extension in a crust thickening geological setting. This new type of uranium mineralization in granite is now considered as the new target for future exploration.

Recent advances about the unconformity-related U deposits

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Giant unconformity-related uranium deposits were formed during the Mesoproterozoic era, 1.6-1.0 Ga ago, in both the Athabasca (Canada) and Kombolgie (Australia) Basins. They are precious witnesses of protracted large-scale fluid flows at the interface between sedimentary basins and their crystalline basement, at conditions close to peak diagenesis (130-220°C). Although the Athabasca Basin hosts the world's largest high-grade uranium deposits, metallogenic models still bear important uncertainties. The objective of this contribution is to present new insights about the genetic model of these exceptional deposits.

The origin of the metals concentrated in the deposits has been investigated based on a systematic study of Hudsonian uranium mineralization in the basement rocks near the Athabasca Basin. This study shows that pre-Athabasca mineralization, expressed as uranium oxides, potentially represents a major uranium source for the unconformity related deposits.

The origin of the brines has been investigated based on coupled Cl/Br and $\delta^{37}Cl$ composition of fluid inclusions trapped in quartz-dolomite veins and $\delta^{11}B$ composition of Mg-tourmalines associated with U ores. These studies have shown that the brines initially derive from subaerial evaporation of seawater up to epsomite saturation (salt content of ca. 25-35 wt%) forming the Cl-Na-K-Mg-rich brines.

The original Cl-Na-K-Mg brines have percolated through the sedimentary pile and in the underlying basement, during tectonic reactivation, thanks to major faults and dense network of microfractures, partly inherited from late-orogenic deformation related to Trans-Hudson Orogen. Intensive brine/basement interaction was responsible for major chemical and isotopic changes (O, H, C) of the initial brines to form two chemically distinct NaCl-rich and $CaCl_2$-rich brines, both being highly enriched in metals. Their metal enrichment comparable with brines related to MVT Pb-Zn deposits supports the idea that the basement was the dominant source for metals, and especially for U.

The mineralizing brines have U concentrations between 1×10^{-6} and 2.8×10^{-3} $mol\cdot l^{-1}$, making them the U richest crustal fluids so far. This exceptional U content is related to the oxidizing and acidic nature of the brines and to the high availability of U sources. Synchrotron analyses show that U is present at the hexavalent sate in these brines. The mixing of the NaCl-rich and $CaCl_2$-rich brines is coeval with the UO_2 deposition but the reductant necessary for UO_2 precipitation remains enigmatic.

Basement to surface expressions of deep mineralization and refinement of critical factors leading to the formation of unconformity-related uranium deposits

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Under the Targeted Geoscience Initiative Four (TGI-4) program operated by the Geological Survey of Canada, a collaborative project between government, academia and industry is examining unconformity-related U ore systems in the Proterozoic Athabasca (Phoenix, Millennium McArthur River and Dufferin Lake zone), Thelon (Bong) and Otish (Camie River) basins in order to refine genetic models and exploration tools for these U deposits.

Examination of basement graphite-depleted zones underlying U-bearing zones at the Dufferin Lake zone has revealed the presence of low-ordered carbon species (carbonaceous matter) that may be interpreted as products of graphite consumption (± later carbon precipitation) by oxidizing Athabasca Basin fluids that migrated downward into the basement. This may have produced a mobile reductant (gas or fluid), which could then have played a role in deposition of UO_2. Alternatively, new numerical modelling supports a previous hypothesis that fluid overpressures may have caused hydrocarbons generated from oil shale at the top of the Athabasca Group to migrate downwards to the sites of U precipitation. A preliminary Fe and Mg isotopic study of the basement-hosted Bong deposit revealed that elevated $\delta^{57}Fe$ and $\delta^{26}Mg$ values are associated with U-bearing alteration and a red hematitic zone that is often ascribed to 'paleoweathering' in the literature. The higher isotopic values correlate with depletions in molar Fe^{2+}, indicating that the processes that formed both alteration zones mobilized Fe^{2+} while enriching the fluids in the lighter isotopes of Fe and Mg.

Petrological, geochemical and isotopic studies of intense alteration concentrated along the P2 fault hosting the McArthur River deposit reaffirm previous studies that the alteration overprinted earlier paleoweathered and diagenetic altered horizons along the unconformity and that the fault served as a conduit for basinal fluids to modify basement rocks through fluid-rock interactions. This fault-control is also manifested regionally, with new 3D modelling of the unconformity surface highlighting the influence of northeast-trending reverse faults in formation of a narrow ridge between the Phoenix and McArthur River deposits. Regional clay anomalies documented in previous studies, associated with the majority of deposits and prospects, are also broadly aligned with this feature.

Athabasca Group sandstones overlying the Phoenix deposits show relatively high concentrations of U, B, Pb, Ni, Co, Cu, As, Y and REEs above the deposit up to the uppermost sandstones and along the WS shear zone. In support of previous studies, some of the metals (U, Mo, Co, Ag and W) also occur in elevated concentrations in humus and B-horizon soil overlying the Phoenix and Millennium deposits. However, these new results enhance the sensitivity of these surficial geochemistry detection methods for deeply-buried (ca. 600–750 m) uranium deposits. The locations of these anomalous metal concentrations coincide with surface projections of the reactivated shear zones, consistent with the fault conduit model. Similar to elevated levels documented in earlier studies in the eastern Athabasca Basin, elevated levels of ^4He overlying the deeply-buried Millennium deposit indicate focused mobility of these gases within the water table.

Central Ukraine Uranium Province: The genetic model

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Ukraine produces ~1,100 t U per year from the Michurinske, Centralne, Novokostantynivske and Vatutinske U deposits in the Kirovograd U district of the Central Ukraine Uranium Province (CUUP) consisting of about 20 deposits and numerous showings related to ~1.8 Ga sodium metasomatites developed in the Lower Paleoproterozoic granite-gneiss and iron formations of the Ingul Megablock of the Ukrainian Shield. Two deposits (the Zhovta Richka and Pervomayske) were mined out tens kilometers eastward in iron formations of the Kryvy Rig – Kremenchug mining district. Na-metasomatite fields with scarce sub-economical U-mineralization were revealed by geophysical (magnetometry and gravimetry) and drilling programs northward in granitised gneisses around the younger Korsun-Novomyrgorod rapakivi pluton consisting of A2-type within plate granitoids which were emplaced during decompression melting at ~1.75 Ga. The present work aims to demonstrate structural and geochemical factors related to Na-metasomatism, and to mark out geochemical and tectonical parameters which were favorable for U-accumulation using data on deep seismic survey, geological structure analysis, and mineralogical and geochemical investigations of metasomatites.

In the Ingul Megablock, Na-metasomatites occur along shear fault zones mostly oriented N-S. Metasomatites form complicate systems of plate- and lens-like bodies of aegirine-riebeckite albitites surrounded by dequartzified host rocks. Elemental alteration during Na-metasomatism demonstrates simple exchange of Si, K, Rb, Ba and Cs by Na, Ca, and locally V and U. $\delta^{18}O$ H_2O (300-400ºC) for albitizing hydrothermal solutions is near “zero”, typically for surficial water. These data suggest host rock interaction with hot marine waters. Persistent Na-metasomatic alterations extend along major tectonic faults for several kilometres with variable thicknesses reaching some hundreds meters in the zones of intense brecciation developed in the places of fault ramifications or intersections. In such places albitites are often altered by superimposed calcic and potassic metasomatism resulting in the replacement of aegirine and riebeckite by garnet, epidote, actinolite, calcite and lamellar phlogopite accompanying U-mineralization. All types of the metasomatic alterations gradually pinch out with depth. U-mineralized metasomatites are enriched in a complex of elements typically accumulated in the crust during regional metamorphism, and partial melting as indicated by pegmatite dike swarms in the Ingul Megablock. From seismic data interpretation, all U deposits in the CUUP are located over latitudinal mantle “deeps” or in the zones where the base of the lithosphere contrastingly subsides. In conclusion, Na-metasomatism is interpreted as a regional process resulting from the deep penetration of marine waters down along crustal scale shear zones during an extensional tectonic regime causing the regional collapse of the Ingul Megablock. Calcic and potassic alterations and U-mineralization are possibly connected with the crust dehydration and probable hotspot partial melting in the mantle initiated by the most unstable P-T conditions within zones of contrasting thickness of the lithosphere. The proposed models of Na-metasomatism and U-accumulation are useful for delineation of prospective territories having the potential to host U deposits associated with Na-metasomatites in Proterozoic terrains.

Dynamics of uranium ore formation in the basement and frame of the Streltsovskaya Caldera

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The analysis of geological-geophysical, paleo-geodynamics, mineralogical, geochemical, isotope, geochronological, and thermo-baro-geochemical data allow us to offer a model of uranium ore formation dynamics in the basement and frame of the Streltsovskaya Caldera connected to activity of the fluid-conducting fault zones network with the aim to identify prospective areas The most ancient fluid-conducting structures are inter-block NE-SW, NNE-submeridional, NW-SE and, probably, WNW-sub-latitudinal faults. The oldest NE-SW faults and schistosity zones were formed during Proterozoic tectonic cycle (TC) with reactivation in T3-J2 time due to global reorganization of stress field and reactivation of tectonic movements. The NNE-submeridional and NW-SE faults were extended with increased fluid permeability during Caledonian and Variscan TCs. They also were reactivated in the process of Late Mesozoic tectonic and magmatic activation (TMA). Thus already at early stages of geotectonic evolution within the intersection of NE-SW (N-Urulyunguyevskiy fault) and NNE-submeridional (Chindachinskaya zone) faults the areas of increased fluid and magmatic activity were formed.

The dynamics of fault formation in the basement and frame of the Streltsovskaya caldera and its volcano-sedimentary cover differs. In the basement and granite framework NE-SW, NNE-submeridional and NW-SE faults are interblock structures of the I rank. Their intersection formed areas of long-term circulation of hydrothermal solutions and telescopic appearance of multi-age metasomatites that created conditions for localizing of vein-stockwork mineralization. In volcano-sedimentary cover the NE-SW and NNE-submeridional faults should be considered as interblock structures of the I rank where intersections provided inflow of ore-bearing solutions and their redistribution within the cover. Here the main ore distributing role belongs to NW-SE shears. They are intrablock II rank structures which were formed due to dextral strike-slip displacements along interblock faults during Late Mesozoic TMA. Within the intersections of NW-SE shears with stratified low-angle faults the conditions for forming of bedded deposits were created.

At the Paleozoic and Mesozoic border (T3-J2) into the caldera NW frame the pull-apart structure was developed. Dimension of the caldera and structure is comparable, and the latter is now hidden under K1-Q sediments of Sukhoy Urulunguy depression. Combination of paleotectonic analysis and data on dynamics of ore-forming processes and fluid-conducting fault zone formation allows us to identify three prospective areas. Two of them are located in Sukhoy Urulunguy depression in the intersection of NE-SW S-Urulyunguyevskiy fault with submeridional Gozogorsky and Meridional faults. The areas have prerequisites for detecting hidden Late Mesozoic mineralization both in volcano-sedimentary cover and basement. The third area is located in intersection of NE-SW N-Urulyunguyevskiy fault with meridional Chindachinskiy fault where prerequisites for detecting mineralization in Proterozoic-Early Paleozoic basement were found. It is inferred that these areas are prospective for identification of additional uranium resources within the Streltsovskoe ore field.

New Au-U deposit type in the weathering crust in tectonic-metasomatite zones of Pre-Cambrian shields

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Au-U mineralization is widely distributed in the tectonic-metasomatite zones of Pre-Cambrian shields (Aldan Shield, Ukraine Shield and others). The industrial ores are located only in several areas at depths of more than 150-300 m. Uranium mineralization is represented by uranotitnates and the gold mineralization by auriferous pyrite.

The zone of weathering is present to the depth of 100-150 m. The feldspars are replaced by the clay minerals, carbonates are dissovled, sulfides are oxidized and the secondary minerals of uranium replace uranotitanates.The golden mineralization in the envelope of weathering is represented by the fine-grained native gold. The particle size is 40-50 nm. Uranium mineralization is in the form of relict brannerite, tuyamunite, torbernite, carnotite. The gold content is 1-2 g/t, and uranium content 0.01-0.05% U.

Ore bodies of gold and uranium are located inside the tectonic-metasomatite zones. The zones of maximum concentration of these metals may not coincide. The gold ore bodies have the length of hundreds meters and a thickness of 1-5 m. The vertical extent of the secondary Au-U mineralization is 100-150 m.

20 laboratory samples of ore from the weathered zone were tested by the method of heap leaching. The first stage is the uranium leach by diluted sulfuric acid. The second stage is the cyanation of gold and silver.

The experimental data indicates leach rate of uranium 75%, gold 80-97%, silver 50-60%. Gold resources in the continous zone is estimated to be 80 t. Gold resources of the several other zones inside the area of 100 km^2 are estimated as 220 t.

The heap leach process can be used for profitable development of the low-grade deposits. This method helps to increase the resources of gold and uranium.

The genesis of Kurišková U-Mo ore deposit

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The U-Mo ores of the known uranium deposit Kurišková located in the Huta volcano-sedimentary complex (HVC) of lower Permian age belongs to the Petrova Hora Formation of the North-Gemeric tectonic unit (Western Carpathians). The HVC is built up by volcanic rocks of bimodal basalt-rhyolite association, intercalated with sandstones, mudstones and claystones. Based on the sedimentary facies reconstruction, it is supposed paleoenvironment of seasonally flooded shallow lakes of continental fluvial plain with transition to estuaries and shallow marine facies of continental shelf in the upper part of HVC.

The ore host rock complex was metamorphosed in conditions ~350°C (epizonal regional metamorphism). Consequently during tectonic uplift, HVC was mineralised by permeating U-Mo bearing ≤ 200°C hot water. Geochronology of uraninite crystals provided ages of the main ore forming processes within interval of 200-160 Ma. Consequent uranium remobilization and ore maturation is dated to 150-50 Ma and 40-10 Ma. However, these modification processes were active only within limited scale.

The main ore forming minerals are uraninite, coffinite and molybdenite. They occur in various metasedimentary and metavolcanic rock types of HVC, especially on the contact with the basaltic body. Mineralization is disseminated along sedimentary structures and tectonically driven fractures in both main rock types. In many cases, contemporaneous deformation of uranium mineralization together with the straight deposition of a new uranium ores is present. Some of the molybdenite-rich subvertical faults are likely to be remnants of the aqueducts transporting mineralised waters into the deposit space. U-Mo deposit shows $Th/U \ll 1$ and strong correlation between U-P-Pb ($r > 0.9$) and only weak correlation with Mo ($r \leq 0.6$). This suggests common geochemical history of U-P-Pb and separation of U-Mo during deposit forming processes.

The deposit is distributed into three ore bodies of semi-tabular shape. The main ore body is spatially closely linked to mylonitised metabasalt on the contact with sediments. It is showing a role of mechanical and geochemical barrier as a key factor for U-Mo precipitation in tectonic and lithological structures.

The presented genetic model operates with a series of step-by-step leaching and precipitation processes which resulted to present-day appearance of deposit. About 200 Ma ago, percolating ground waters had invaded the uppermost parts of buried HVC and started to leach U-Mo out of rhyolitic rocks of the upper Grúň rhyolite complex. Water-rock interaction integrated U-P-Pb-Mo-S geochemical streams changed water composition ($pH < 4\text{-}5$; $Eh > 0$) enabling transport of U and Mo complexes. As water stream proceeded through subvertical fault aqueduct, continual reduction responded to molybdenite precipitation and separation of Mo-S/U-P-Pb streams. The main stage of ore precipitation is related to alteration of infiltrated metamorphosed rocks synchronically with continual deformation of HVC. The reduction and increasing pH during alteration destabilised the dissolved U-Mo complexes and initiated the uraninite – coffinite precipitation.

Uranium potential in Greenland

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The uranium potential in Greenland is considered high with several known uranium occurrences. South Greenland is the largest uranium province in Greenland, containing the Kvanefjeld deposit, the Motzfeldt Centre and the Grønnedal-Ika complex, which are all large Mesoproterozoic alkaline Gardar intrusions. In the Puissattaq and Vatnaverfi areas, several U-rich veins follow the direction of the major fault zone. The Nordre Sermilik area is also rich in uranium occurrences related to faults and fractures. In the very southern part of Greenland, uranium mineralised veins occur at Illorsuit.

In West Greenland, several large carbonate intrusions (e.g. Sarfartoq, Qaqqaarsuk and Tikiussaq) contain elevated uranium concentrations. The Nuuk region also has a relatively-high level of background radiation due to numerous mineralised pegmatites. In East Greenland, mineralised zones are located in volcanic and granitic rocks of Devonian age at Randbøldal, Foldaelv and Moskusokseland. Uranium mineralisation associated with phosphorite occurs in the Devonian redbeds of southern Wegener Halvø. At Arkosedal, uranium mineralisation in hydrothermally altered breccia and veins, occur in fault zones between Caledonian complexes and Permian clastics. Uranium anomalies have also been detected at Hinks Land, Frænkel Land.

Given the very limited uranium exploration carried out in Greenland to date, a greater potential is presumed to exist based on spot observations and the knowledge of favourable geological environments. The 150 km² Ilímaussaq alkaline complex of South Greenland hosts the REE-U-Zn-F deposit referred to as Kvanefjeld. It is intruded into the Palaeoproterozoic Julianehåb Granite and the unconformably overlying Mesoproterozoic Eriksfjord formation comprising sandstone and basalt. Kvanefjeld represents the top of the Ilímaussaq intrusion and is composed of hyper-agpaitic lujavrites and naujaite. The last intrusive phase, the lujavrite, has an average U concentration of 273 ppm and approximately 3 times the amount of thorium. Most of the radioactive minerals are complex silicates and phosphates with rare earth elements, niobium, tantalum, zirconium and iron. Steenstrupine, a sodium-cerium-silico-phosphate is an important carrier of uranium (0.2–1.5% U) and thorium (0.2–7.4% Th). The thorium-silicate thorite (3.1% U, 40.5% Th) occurs only in the late stage differentiate lujavrite. In other rock types, eudialyte, a sodium-calcium- and iron-silicate with zirconium, is the dominant uranium- and thorium-bearing mineral.

The Kvanefjeld uranium deposit is unique in Greenland and has been described in great detail. Geological mapping and radiometric acquisition have been carried out from 1956 to 1985, and 12,455 m of core have been drilled and a 1 km long adit was constructed.

Since 2007, Greenland Minerals and Energy Ltd. (GME) has conducted REE-exploration activities in the Kvanefjeld area, including the drilling of an additional 57,710 meters of core. GME reports that the overall resource inventory for Kvanefjeld (0.127 ppm U or 150 U_3O_8 ppm cut-off) is 619 Mt of ore containing 135,626 t U (350 Mlbs U_3O_8) and 6.55 Mt TREO including 0.24 Mt heavy REO. Additional resources exist in Zone Sørensen and Zone 3.

A regional multi-scale 3-D geological model of the Eastern Sub-Athabasca Basement, Canada: Implications for vectoring towards unconformity-type uranium deposits

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The Proterozoic Athabasca Basin of northern Saskatchewan is one of the most important mining districts in Canada; hosting the world's highest grade uranium deposits and prospects. In the basin, many of the near-surface deposits have been discovered; hence new ore deposits at greater depths need to be discovered. To help make new discoveries, 3D geological modelling is being carried out.

Here, we present our multidisciplinary approach, whereby a 3D geological model of the eastern sub-Athabasca basement of northern Saskatchewan (i.e. the eastern and western Wollaston domains, the Wollaston-Mudjatik Transition Zone (WMTZ), and the Mudjatik Domain) was developed in the common earth environment. The project was directed towards building a robust 3D model(s) of the upper 3-5 km of the Earth's crust in three different scales: deposit-, district-, and regional-scale, using the GOCAD software platform (Paradigm). Our eastern sub-Athabasca basement model is constrained by both geological studies and geophysical techniques, such as topographic, outcrop, drill hole, petrophysical, and petrological data, along with geophysical potential field, electrical, and high-resolution regional seismic data, in order to better understand the regional- to district-scale tectonics and controls on the uranium mineral system(s) operating pre-, syn-, and post-Athabasca deposition. The resulting data were interpreted and visualized as 3D-surfaces and bodies in GOCAD. This model reveals a framework of key lithological contacts, major high-strain zones, and the setting of unconformity-type uranium deposits. As a result, this new knowledge is being used to identify key exploration vectoring criteria for unconformity-type, magmatic, and metamorphic/ metasomatic uranium deposits and to delineate new exploration targets in the basin. Hence, this regional-scale 3D GOCAD model can be utilized as a guide for exploration activities within the region (e.g. picking new drill targets).

As well, this 3D model reveals the complex crustal architecture of the sub-Athabasca basement underlying the Athabasca Basin and the complex structural-alteration features of its associated unconformity-type deposits (Figure 1). Eventually by adding a time component, our model will be used to construct a schematic 4D geological evolution model of the eastern Athabasca Basin.

In summary, the GOCAD common earth environment allows integration of multiple geological, geophysical, geochemical, and petrophysical data sets from surface to depth. As a result, we are able to manipulate and visualize the regional to district to mine scale architecture of the Wollaston fold-and-thrust belt (Figure 1) and its intersection with the Athabasca unconformity, especially with the aid of high-resolution seismic profiles. Most importantly, high-resolution seismic profiles and drilling constrain the 3rd dimension. In addition, the GOCAD model can be imported easily into other modeling applications (e.g. FLAC 3D, OST 3D) for gaining further knowledge about the mineral systems.

Exploration and discovery of the Pine Ridge uranium deposits, Powder River Basin, Wyoming, USA

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The Pine Ridge uranium deposits are named for a newly identified area between the Pumpkin Buttes and Southern Powder River Basin (PRB) mining districts. This regional prospect, covering nine contiguous townships, is northwest of the Cameco Smith Ranch mine and west of the Uranium One Allemand-Ross project in Converse County, Wyoming.

Surface mapping and 350+ measured sections of well exposed outcrops have identified 250 target sandstones and contributed to a model of the complex braided stream channel architecture within the Eocene Watsatch and Paleocene Fort Union Formations. The uranium-bearing sandstones occur in 3-D bundles of vertically aggrading river systems flowing into the PRB from distant uranium source areas of the Granite Mountains to the west and the northern Laramie Range to the south. Large volumes of mudstone overbank and swamp facies separate the individual river systems laterally, resulting in greater vertical reservoir continuity from sandstones stacking. At least five major paleo river systems have been identified and named.

High organic content, within the host formations, and rising veils of hydrocarbon gases from underlying oil and gas deposits have resulted in classic roll front uranium deposits in individual sandstones and intervals. Mineralization in stacked sandstone bundles several hundred feet thick show a crescent-shaped distribution within the shallow mineralized interval “attic”, the “cellar” at the base of the alteration cell, and the furthest basin-ward “front door”.

World-class uranium resource potential has been identified along 208 miles of redox boundary string length mapped from the 1522 control points consisting of outcrop data, pre-existing uranium drilling, oil and gas wells, and proprietary drilling in 2012 and 2013 by Stakeholder. All data is managed in ARC VIEW GIS with 3-D capability, which will be demonstrated.

Very few restrictions apply to the project area. Uranium holes are permitted solely by the Wyoming Department of Environmental Quality. There are no threatened and endangered species. There have been no surveys required for wildlife or archeological resources. There are only three surface and mineral owners involved in the project area, which are secured by long-term agreements amounting to 68,000 acres of mineral leases and surface use by Stakeholder.

Drilling in 2014 will concentrate on finding new ore bodies, and further definition of the size and quality of identified roll front deposits.

Education and training in uranium production cycle

Enabling sustainable uranium production: The Inter-regional Technical Cooperation experience

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Uranium production cycle activities are increasing worldwide, often in countries with little or no previous experience in such activities. Initial efforts in uranium exploration and mining were limited to a few countries, which progressed through a painful learning curve often associated with high socio-economic costs. With time, good practices for the sustainable conduct of operations became well established, but new projects in different regional contexts continue to face challenges.

Moreover, there have been highs and lows in the levels of activities and operations in the uranium industry, which has disrupted the stabilizing of the experiences and lessons learned, into a coherent body of knowledge. This collective experience, assimilated over time, has to be transferred to a new generation of experts, who have to be enabled to use this knowledge effectively in their local contexts in order to increase efficiency and reduce the footprint of the operations. This makes it sustainable and socially acceptable to local communities, as well as in the global context.

IAEA has implemented several projects in the last five years to address gaps in transferring a coherent body of knowledge on sustainable uranium production from a well experienced generation of experts to a new generation facing similar challenges in different geographical, technological, economic and social contexts. These projects focused on enabling the new practitioners in the uranium production industry to avoid the mistakes of the past and to apply good practices established elsewhere, adapted to local needs. The approach was intended to bring considerable cost savings while attracting elevated levels of social acceptance.

These projects were effective in introducing experts from different areas of the uranium production cycle and with different levels of experience to the availability of advanced tools that can make operations more efficient and productive, reduce footprint, increase competencies in control and management and make activities sustainable. Each uranium development project is technically, environmentally and socio-economically different from another, and a one-size-fits-all type of approach is not suitable.

Each person who interacted in one way or another with the project faced a unique challenge which they had to solve through an application of good practices appropriately applied to a new context. Use of informal on-line and social media communications was not intended at the start, but was quickly identified as a valuable tool for enabling the sharing of experiences.

The paper will discuss the lesson learned, key success factors and the results of these past activities in promoting a sustainable uranium production future in over 40 Member States of International Atomic Energy Agency.

Continuing education in radiation protection in the nuclear fuel cycle: The case of Nuclear Industries of Brazil

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This paper describes the pedagogical and technical concept that guided training in radiation protection implemented by the Indústrias Nucleares do Brasil (INB; Nuclear Industries of Brazil) to maintain the competence of its technical staff to perform activities with exposure to radiation, the staff responsible for the supervision of this work and as a form of dissemination of knowledge to the staff not involved in the use of ionizing radiation.

The groups of workers to be trained are here described, as well as the level of training, the frequency and types of training, the profile of trainers, the training programs, the forms of assessment and recording of training. It also describes the first general training performed in 2004. After this initial training no other general training was realized, and the option was to train small groups of workers, to avoid stopping the production as it occurred when general training was executed.

The overall training was conducted in three units: the Uranium Concentration Unit (URA) under production in the city of Caetité, state of Bahia, the Ore Treatment Unit (UTM) undergoing decommissioning at Poços de Caldas, state of Minas Gerais and the Unit of Heavy Minerals (UMP), at Buena, state of Rio de Janeiro. In the initial training at URA 79 workers were trained, distributed in 6 classes (average of 13 students per class); each class had nine hours training and the grades obtained ranged from 7.5 to 10. At UTM, 200 employees were trained distributed in 9 classes (average of 22 students per class); their notes ranged from 8.8 to 10. Finally, at UMP 151 employees were trained, in 5 classes (average of 31 students per class); their grades ranged from 8.6 to 9.0. That year, a total of 180 hours were spent for training 430 employees, with no effective rebuke.

Currently employees are trained when they arrive at their Units, and all along the year in small classes, as the general training has been definitely abolished.

Human resource development for uranium production cycle

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Nuclear fission energy is a viable option for meeting the ever increasing demand for electricity and high quality process heat in a safe, secured and sustainable manner with minimum carbon foot print and degradation of the environment. The growth of nuclear power has shifted from North America and Europe to Asia, mostly in China and India. Bangladesh, Vietnam, Indonesia, Malaysia and the United Arab Emirates are also in the priocess of launching nuclear power program. Natural uranium is the basic raw material for U-235 and Pu-239, the fuels for all operating and upcoming nuclear power reactors. The present generation of nuclear power reactors are mostly light water cooled and moderated reactor (LWR) and to a limited extent pressurized heavy water reactor (PHWR). The LWRs and PHWRs use low enriched uranium (LEU with around 5% U-235) and natural uranium as fuel in the form of high density UO_2 pellets. The uranium production cycle starts with uranium exploration and is followed by mining and milling to produce uranium ore concentrate, commonly known as yellow cake, and ends with mine and mill reclamation and remediation. Natural uranium and its daughter products, radium and radon, are radioactive and health hazardous to varying degrees. Hence, radiological safety is of paramount importance to uranium production cycle and there is a need to review and share best practices in this area. Human Resource Development (HRD) is yet another challenge as most of the experts in this area have retired and have not been replaced by younger generation because of the continuing lull in the uranium market. Besides, uranium geology, exploration, mining and milling do not form a part of the undergraduate or post graduate curriculum in most countries. Hence, the Technical Co-operation activities of the IAEA are required to be augmented and more country specific and regional training and workshop should be conducted at different universities with the involvement of international experts from leading public and private sector organizations involved in uranium exploration, mining and milling and mine remediation and reclamation. The Uranium Production and Safety Assessment Team (UPSAT) initiated by IAEA and tried first in the uranium mines in Caetite, Brazil, should be extended to more countries. The present paper summarizes the author's experience in IAEA and in India, highlighting the new courses that are required to introduced at the post graduate level in different universities as part of education and HRD in uranium production cycle.

Health, safety and environment

Responsible management for Health, Safety and Environment (HSE) in uranium mining and processing, starting from public support

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Seeking, gaining and maintaining public support is inherent to mining and to responsible management in this sector. In particular, it holds special relevance for remote mining sites for which the buy in from the regional and local workforce and populations is a necessity all along the life span of a mining project from exploration to development, commissioning, operation, closure and restoration. This paper briefly highlights some key features to be accounted for nowadays for the successful development, shaping and implementation of mining projects with a view to improve public support.

It is essential to address responsible management for health, safety and environment (HSE) in uranium mining and processing through key program elements such as policy; baseline; operational preparation for implementation; monitoring, reporting, review and continued improvements; as well as some insights on site closure and restoration. In particular, examples illustrate how these program elements are implemented in practice in uranium mining and processing. Some emphasis is put on radiation safety as responsible management for the other HSE dimensions tends to be analogous for all mines and mineral processing sites.

Institutional control of mine wastes in Saskatchewan, Canada

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Many jurisdictions around the world require mining operations to prepare closure plans and to post a bond or other financial assurances of sufficient value to cover the cost of closure. However, not all jurisdictions address the conditions under which they would accept the return of such properties, once the operator has fulfilled their obligations and is requesting release from further financial bonding. The issue is further complicated when it includes former uranium mill and tailings sites where international conventions and the national nuclear regulatory frameworks play an overriding and often defining role.

In Saskatchewan, a consultant led a team of provincial government departments in a process to develop an effective institutional control program (ICP). This required extensive consultations with industry, Aboriginal traditional users and other stakeholders to gain their support and inclusion. The entire policy development process culminated in 2007 with the implementation of the Reclaimed Industrial Sites Act and Regulations.

The program addresses all aspects of conventional closed mines, as well as uranium specific issues of radioactive waste management, including all applicable articles of the IAEA's Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the requirements of the federal Nuclear Safety and Control Act, the expectations of the Canadian Nuclear Safety Commission, and all applicable provincial Acts and regulations.

Cameco Corporation was the first company to successfully register a decommissioned gold site, as well as five former uranium sites into the program. Following acceptance of a site into the program and a financial deposit from the operator, each site is monitored and maintained under provincial responsibility.

Calibration of a PHREEQC-based geochemical model to predict surface water discharge from an operating uranium mill in the Athabasca Basin

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A PHREEQC based geochemical model has been developed to predict impacts from the McClean Lake Mill discharges through three lakes in the Athabasca Basin, Saskatchewan, Canada. The model is primarily a mixing calculation that uses site specific water balances and water compositions from five sources: 1) two water treatment plants, 2) waters from pit dewatering wells, 3) run-off into the lakes from surface waters, 4) ambient lake compositions, and 5) precipitation (rain and snow) onto the pit lake surface. The model allows for the discharge of these waters into the first lake, which then flows into another nearby lake and finally into a third larger lake. Water losses through evaporation and the impact of subsequent evapoconcentration processes are included in the model.

PHREEQC has numerous mass transfer options including mixing, user specified reactions, equilibration with gas and solid phases, and surface complexation. Thus this program is ideally suited to this application. Preparation of such a complicated model is facilitated by an EXCEL Spreadsheet, which converts the water balance into appropriately formatted mixing proportions and to prepare portions of the PHREEQC input file in a format directly useable by PHREEQC. This allows for a high level of flexibility, while reducing transcription errors. For each scenario, the model path involves mixing of the waters in the first lake, followed by evapoconcentration, equilibration of the resulting solution with gas phases, including carbon dioxide and oxygen and with minerals and surfaces. The resultant composition is mixed in the second lake with more surface water, lake water and precipitation, and then re-equilibrated. This water represents the flow into the final lake; further mixing/dilution is accommodated; chemical equilibration may also occur. Because of the numerous steps and processes that define the pathway, each annual step requires approximately 200 lines of input in PHREEQC.

Models used in the initial calibration used annual water balances and compositions from 2000 to 2011. The calibration indicated that a simple mixing approach could explain the behavior of conservative elements such as sodium, potassium and chloride. For calcium and sulfate, the precipitation of gypsum ($CaSO_4 \cdot 2H_2O$) may occur in the holding ponds. This lowers the calcium and sulfate discharge from this source term, but also improves the fit in the downstream lakes. Even though most of the major ions are conserved and attenuated through dilution, many of the chemicals of concern such as molybdenum, uranium and arsenic have lower measured concentrations than predicted by the initial mixing models. Attenuation processes beyond simple dilution and typically related to mineral precipitation or surface complexation are responsible for these drops in concentrations. This modeling effort provides insights into the geochemical behavior of trace metals that would not be readily apparent without the model.

Methodological approach on uranium mill tailings decommissioning designing

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A distinctive feature of uranium mining and milling facilities is potential environmental contamination with solid, liquid and gaseous radioactive waste. The wastes are the largest volume in the nuclear fuel cycle and major contributors to the formation of a radiation-dangerous situation for the population and the environment despite their relatively low radioactivity. In the past the remediation of uranium mining and milling sites including tailings was not considered in detail. Current analysis of the collected materials allows the establishment of features that are valid for post-operational uranium mines.

A procedure to estimate the condition of non-exploited tailings and other former facilities was developed in the course of scientific researches for various climatic zones and highlands. On the basis of field observations and laboratory studies an atlas on technogenic deposits typical for the uranium mining industry has been created. It was developed and implemented using a penetration technique survey of decommissioned tailings which avoids unnecessary risk to personnel when samling tailings.

Through scientific research it was determined that a specific approach and technological scheme of remediation should be applied for each climatic zone. According to the conducted studies a particular approach should be used in arid areas.

As to tailings features, the moisture condition inside the tailings bulk is the main difference between the arid area and areas of continental and acutely continental climate. A water lens may be formed in the tailings body. According to the studies the nature of water lens formation partly corresponds to desert groundwater unsaturated recharge regimes.

Analysis shows that for a very long period a water-saturated zone may be formed in a tailings body. The zone is isolated from the surface by a mulch layer preventing evaporative processes. Actual data of tailings deposits condition, especially on particle size, density and time of tailings stabilization, permit the creation of a long-term prediction methodology of their humidity condition. These predictions it should be used to developed technical regimes suitable to a particular tailings pond.

A “methodology on environmental pollution damage evaluation of decommissioned uranium mining and milling facilities and estimation of remediation economic efficiency” has been developed and implemented for assessment the remediation works efficiency. In this methodology a determination of social damage (damage to health), environmental damage to natural resources (air, water, territory, etc.) and property damage (property losses of individuals and legal persons) can be carried out.

Economic efficiency of remediation is confirmed if the benefit of the performed works is positive.

The assessment and use of all the above proposed procedures means a methodical approach to the decommission designing of milling plants tailings.

Radiation requirements for uranium project approvals

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Uranium mining projects in Australia must receive approval under both state and national laws based on a wide ranging impact assessment of the project. The process may take a number of years and involves multiple levels and parts of government and public consultation and scrutiny.

The impact assessment is broad and usually covers; environmental, social, health, public safety and economic aspects. Information provided in the approvals documentation needs to be presented in a credible and understandable manner for all audiences. This means making complex information simpler, while making sure that it maintains its technical integrity.

Poorly communicated information, which is overly complex, overly simplified or incomplete, can result in significant delays to the project approval which can potentially impact on project timelines.

For uranium projects, along with other projects involving radioactive materials, such as minerals sands and rare earths, radiation and its impacts usually draw a disproportionate amount of both government and public scrutiny compared to other potential impacts and risks.

It is therefore of key importance that radiation assessments are properly performed and results clearly presented and communicated with sufficient detail for stakeholders to make informed decisions. It is also important to ensure that the radiation risk is presented in perspective with other risks of the project.

This presentation outlines a structure for a radiation impact assessment based on experience from a number of projects in Australia. The structure aims to be clear and simple and ensure the right balance between scientific fact, digestible information and demonstrable competence.

Uranium mine regulation and remediation in Australia's NorthernTerritory

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The Northern Territory of Australia (NT) has a long association with uranium mining extending back over 70 years. Although currently there is only one active mine, the Ranger Uranium Mine operated by Energy Resources of Australia, there is plenty of uranium-related activity with several on-going exploration operations and a number of remediated and legacy sites. The regulation of Ranger is complex as it involves both NT and Australian Federal Governments in addition to other significant stakeholders and consideration of exacting, site specific, administrative requirements. The paper describes the current regulatory systems for Ranger and the other uranium operations in the NT, including the recent changes to the remediation security bonding process and the concurrent introduction of a remediation levy on all aspects of the NT mining industry.

The paper also reports briefly on the progress of remediation at some significant former uranium mine sites in the NT, including the major project at the former Rum Jungle mine site.

Regulation of activities producing uranium as a by-product: South African perspective

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In South Africa, enhanced levels of NORM are associated with many mining and industrial processes. Exploitation and mining of ores that contain NORM can result in radiation exposure to the workforce involved particularly through the underground pathway being regarded as the dominant pathway as a result of radon exposure. The regulatory processes under which non-uranium mines operates, determined by the National Nuclear Regulator, ensures that people and environment remain protected from the effects of non-uranium mining through a strict monitoring and reporting.

This paper provides summarised analysis of radiation protection measures in employed for the monitoring of the workers and environment at the mine and mineral processing facilities. A further summary of available monitoring survey of selected area where the operations are taking place will be discussed and compared with the regulatory limits.

Risk-based environmental assessment for uranium mines – some Canadian and Australian experience

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The uranium producing countries of Canada and Australia have independently developed regulatory frameworks emphasising the importance of human health and ecological risk assessments as core tools for ensuring protection of the environment and public. The value of such an approach is presented as well as practical lessons learned through recent applications of this regulatory model.

In May 2000, the Canadian Atomic Energy Control Act was replaced by the Nuclear Safety and Control Act (NSCA). This law created the Canadian Nuclear Safety Commission, whose mission is to protect the health, safety and security of persons and the environment; and to implement Canada's international commitments on the peaceful use of nuclear energy. From an environmental perspective, the new law added a requirement for the protection of the environment and non-human biota, and a responsibility over hazardous substances in addition to nuclear ones. The NSCA requires the prevention of unreasonable risk to, and adequate provision for the protection of, the environment and the health and safety of the public. It was decided that environmental and public protection would recognize the principles of pollution prevention and ALARA, and that it would be risk based. For Class 1 facilities and uranium mines and mills, Ecological and Human Health Risk Assessments are the core of both the Environmental Assessment process and the licensing process under the Nuclear Safety and Control Act. The Ecological Risk Assessment informs the Effluent and Environmental Monitoring Programs with the resultant monitoring data used to reinforce the risk assessments on a cyclical basis throughout the lifespan of the facility. A number of standards and regulatory documents have been completed supporting this environmental protection framework. In this presentation, a case study is used to illustrate the use of ERA for decision making.

In the last decade or so in Australia uranium mining proposals normally require assessment under the Federal Environment Protection and Biodiversity Act 1999, as well as a parallel State or Territory approvals. The previous generation of mines were approved under the former Environment Protection (Impact of Proposals) Act 1993 or earlier arrangements. In recent years various guidelines, both generic and developed for individual proposals have been issued by State, Territory and Federal governments.

Recent Australian guidelines, for uranium and other mining, all include a risk-based approach to environmental impact assessment, including consideration of design and operating measures to minimize impacts, and associated environmental monitoring programmes to assess actual against expected outcomes and provide early-warning of potentially adverse trends. Some recent guidelines and their application to new uranium projects or extensions of existing operations in three jurisdictions are reviewed and the usefulness of the approach discussed.

Social Licensing in uranium mining: Experiences from the IAEA review of the planned Mukju River Uranium Project, Tanzania

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The IAEA Uranium Production Site Appraisal Team (UPSAT) programme is designed to assist Member States to enhance the operational performance and the occupational, public and environmental health and safety of uranium mining and processing facilities across all phases of the uranium production cycle. The scope of the appraisal process includes exploration, resource assessment, planning, environmental and social impact assessment, mining, processing, waste management, site management, remediation, and final closure. An UPSAT review was requested in 2010 by the United Republic of Tanzania (URT) to address the challenges the country is currently facing in developing its uranium mining and processing capability for the first time. The review that was carried out from 27 May to 5 June, 2013 had the objective to to appraise URT's preparedness for overseeing the Uranium Production Cycle in general, at the same time focusing on the planned Mkuju River Project (MRP) in the south of the country in particular. The UPSAT team was tasked to report its findings according to five primary areas:

1. Regulatory system
2. Sustainable uranium production life cycle
3. Health, Safety and Environment (HSE)
4. Social licensing
5. Capacity building.

The paper will discuss the key findings and suggestions that were provided to governmental stakeholders and the operater to improve the planned operations.

Experience of IAEA UPSAT mission to Tanzanian uranium sites as a means of sustaining best practice for uranium production in Tanzania

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Utilization of nuclear power has been escalating, hence the growing demand for Uranium for the world nuclear power worldwide and in particular Asia and Middle East. This has influenced uranium exploration, development and investment in different countries in the world. In 2007, Tanzania witnessed extensive uranium exploration investment and discovery of several sites with economically viable uranium deposits at Bahi, Manyoni and Mkuju River. The most advanced project is Mkuju River Project located in the Selous Game Reserve, which is a classified UNESCO World Heritage site. At a time of discovery, the country had no previous experience managing uranium production cycle, hence the necessity for cooperation with national and international stakeholders to ensure safe, secure and safeguarded Uranium mining. This development pressed a need to quickly and efficiently setting up of an internationally accepted best practice for uranium mining in the country.

Preparations and stakeholder involvement in setting regulatory framework for uranium mining were initiated. Therefore, the request was submitted to International Atomic Energy Agency (IAEA) Uranium Production Site Appraisal Team (UPSAT) mission to review the country's regulatory readiness for uranium governance. The review mission aimed at appraising the country's preparedness for overseeing the Uranium Production Cycle in general and with emphasis on the planned Mkuju River Project (MRP) in the south of the country in particular.

The mission comprehensively reviewed the regulatory system, sustainable uranium production life cycle, health, safety and environment, social licensing and capacity building and gave objective recommendations based on best practice. Therefore, this paper briefly reviews the impact of the first UPSAT mission in African soil for fostering sustainable best practice for uranium life cycle in Tanzania.

Social licensing in uranium production cycle

Product stewardship for uranium: A way for the industry to demonstrate its high performance

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The future of nuclear energy and the nuclear fuel cycle are inextricably linked and the performance of any sector has an immediate and direct effect on all other sectors. With the exception of major incidents such as Chernobyl and Fukushima, uranium mining has historically been regarded as the “bad boy” of the nuclear fuel cycle and this has been one of the impediments to the green credentials which are inherent in nuclear power. The reality is that the health, safety, environment and social credentials of uranium mining are class leading and reflect a mature industry with a strong licence to operate. Major producers, such as Rio Tinto, recognise that this performance is essential for both current and future operations. Product stewardship is a tool to help demonstrate this performance across the industry and extend this through the rest of the fuel cycle. Uranium is unique in product stewardship terms with effectively one end user for all the production combined with strong tracking and control throughout its cycle. These unique aspects give extra importance to how the industry interacts internally and externally to provide a strong base for its customers. Product stewardship of uranium is essential for the continued development of uranium as a source of minimal environmental impact, low emissions and clean energy.

The Namibian uranium mining model: Voluntary sector initiatives underpinned by a regulatory safety net ensures best practice - an update

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Namibia has extensive deposits of low-grade uranium and is regarded as a region of global importance for this source of energy. Namibia also has a long history of uranium mining, dating back to 1976, when Rio Tinto's Rössing uranium mine opened.

The Namibian Government’s position on uranium mining is clear. His Excellency Hifikepunye Pohamba, President of the Republic of Namibia, reaffirmed that “Namibia’s mineral resources (including uranium) are to be strategically exploited and optimally beneficiated, providing equitable opportunities for all Namibians to participate in the industry, while ensuring that environmental impacts are minimized and investments resulting from mining are made to develop other sustainable industries and human capital for long-term national development.”.

Building on a presentation at URAM in 2009, this paper shares Namibia’s experiences from the past five years: discusses the challenges faced by the Namibian Government and the uranium industry in with the development of a robust, independent national regulatory and monitoring framework.

• How Namibia has implemented the two necessary levels of independence: capable government oversight and third-party evaluation of industry’s sustainable development practices.

• How Namibia implemented mutually-beneficial partnerships to ensure that adequate capacity exists. Voluntary product stewardship schemes have arisen out of the need for the industry to balance their pursuit of economic gain with environmental and social concerns.

• How industry has built on WNA standards in developing voluntary product stewardship schemes to gain majority sector participation.

• How the Namibian Government has taken important steps in responding to the dearth of inadequate legislation with the promulgation of The Minerals (Prospecting & Mining) Act, No 33 of 1992 ,the Minerals Policy (2005), Atomic Energy and Radiation Protection Act, 5 of 2005 and the Environmental Management Act, 7 of 2007.

• How the Government and Industry development of a cross-sectoral, government-led “Strategic Environmental Assessment” (SEA), crucial for the Government to fully understand how the mines, both on their own and in combination, will impact upon the receiving environment.

• How the Environmental and Radiation Regulations were rolled out with the creation of the Strategic Environmental Management Plan (SEMP) office at the Ministry of Mines and Energy, Namib Ecological Restoration and Monitoring Unit (NERMU) and the Namibian Uranium Institute (NUI)

• How the full implementation of the Atomic Energy and Radiation Protection Act was achieved with a fully operational National Radiation Protection Authority (NRPA) and Environmental Commissioners Office. The NRPA and Environmental Commissioner conduct multiple inspections every year at all uranium mines and mills to ensure that radiation levels are kept well below regulatory limits, protect workers and the public from other potential hazards, and verify that all activities are environmentally responsible and safe.

The Namibian approach is an example of voluntary sector initiatives underpinned by a regulatory safety net to ensure environmental and social sustainability and internationally accepted health standards across the board.

The model of interaction with the National Operator when doing uranium mining in Kazakhstan

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The report presents a model of organizational and production interaction with the National Operator, NAC Kazatomprom JSC, with regard to uranium mining in Kazakhstan by means of mechanism of joint management of mining, processing and service companies. NAC Kazatomprom JSC is the world's largest producer of uranium, and Uranium One Holding is the largest foreign partner of the National Operator. The mining assets of Uranium One Holdings include the following joint ventures: Betpak Dala LLP (South Inkai and Akdala Mines), Karatau LLP, Akbastau JSC, Kyzylkum LLP and KRC Zarechnoye JSC. It shows that the project management in the form of joint ventures allows for minimization of investment risks in Kazakhstan. The practice of corporate communication with NAC Kazatomprom JSC goes far beyond the “investment– receipt of dividends” scheme when the investment guarantees mean control over the enterprise activities through participation in the meetings of enterprise management bodies.

The sustainable model has been developed for the interaction with the National Operator and with state authorities of the Republic of Kazakhstan through or together with the National Operator, whereby various projects have been implemented starting with the joint support of social development of Kazakhstan regions in excess of the minimum amounts established by the government in subsoil use contracts (through Kazatomprom-Demeu LLP, specially established for this purpose) and ending with the implementation of such major projects as the “Atomic Ring” or innovative projects on the construction of alternative energy sources (solar power plant) on sites of joint industrial projects.

Effective cooperation with the National operator Kazatomprom allowed to successfully establish and run at the jointly owned mines the program of efficiency improvement which stimulates continuous improvement of current operations and results in considerable cost reduction. The key ideas of the Efficiency Improvement Program introduced at the ISL mines, its milestones and achievements are reported.

Why jurisdiction and uranium deposit type are essential considerations for exploration and mining of uranium

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Uranium is a relatively abundant element, being 25 times more common than silver, and having the same crustal abundance as tin. Economically minable uranium grades vary greatly, from a low of 0.01% U to over 20% U. What are the factors that allow mining of these very low grade ores that are only 50 times background concentrations? Why don't the high grade deposits of the world exclusively supply all of the worlds newly mined uranium needs? There are two main reasons that the high grade deposits of the world do not exclusively supply all of the worlds newly mined uranium needs: 1) jurisdictional issues, the favorability or lack thereof of governmental policies where the deposit is located and the delays caused by an ineffective or corrupt policy and 2) the deposit type, which has a great influence on the recovery cost of the uranium. The quality of a deposit can override more difficult political jurisdictions if recovery of the investment occurs quickly and in an environmentally friendly way.

1. Political Jurisdiction:

a. Some political jurisdictions around the world are unstable. Because of instability it would not be smart to begin an exploration program or an actual uranium mine in a politically volatile area.

b. Multiple political jurisdictions do not allow mining of radioactive materials. There exists a law or a ban on exploration and/or mining of radioactive materials. Some jurisdictions that currently fall into this category is the State of Virginia, U.S.A. and British Colombia, Canada. Some past examples that have recently changed laws are Queensland, Australia and Greenland (Denmark).

c. Permitting uncertainties. While many areas of the world allow uranium mining, the permitting process can delay a project for years. Nearly all of the Western Countries would fall under this scenario; U.S.A, Canada, Australia and Western Europe. There are two related principle issues that affect permitting and the economics of a uranium deposits.

i. Time value of money: Delays cost money.
ii. Lost market opportunity: Market prices move up and down.

2. Mining Cost:

a. Open Pit Mining: Large, economy of scale projects, mining 50,000 tonnes/day of uranium ore can operate at very low unit cost, in the order of 1 US$/tonne.

b. Small Scale Underground Mining: Small, extremely high grade deposits mining <100 tonnes/day but at grades of 10-20%U.

c. "In-Situ" Recovery (ISR): Has multiple variables, acid leach, alkaline leach, depth to orebody, among others, that affect the recovery cost. Basically, water wells do the mining in ISR.

In conclusion one should consider the jurisdiction, stability of the government, and permitting regulations when considering an investment in uranium exploration, mining, or signing a long term contract for the delivery of uranium. In an uncertain world with changing political dynamics it would be wise to have a mix of jurisdictions and sources for a countries future uranium supply.

The role of public consultation in leading practice uranium mining

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As the raw material used to fuel nuclear power plants to generate significant amounts of electricity with life cycle carbon emissions as low as renewable energy sources, uranium is a valuable energy commodity. Yet the mining of uranium remains controversial, principally because of the environmental and health impacts created in the early years of the industry when uranium mining was conducted by governments to meet military requirements during the Cold War. At the time, maximising production in the face of rapidly rising demand was the principal goal and little concern was given to properly managing environmental and health impacts or community relations.

Uranium mining is now conducted under significantly different circumstances than those in the early era of production for military purposes. Since then, societal expectations of environmental protection and the safety of workers and the public have evolved as the outcomes of the early era of mining became apparent, driving changes in regulatory oversight and mining practices. Leading practice uranium mining is now the most regulated and arguably one of the safest forms of mining in the world.

Public consultation was seldom, if ever, undertaken in the early stages of uranium mining. As with other forms of mining, societal attitudes about health and safety and environmental protection have been accompanied by an expectation that public participation should be an integral part of planning and approval processes for uranium mines along with transparency and assurances of performance throughout the entire life cycle of the facility. Leading practice uranium mining includes repeated opportunities for public consultation throughout the life of a mining facility.

Major milestones for public consultation in the mine life cycle include the environmental impact assessment process that engages the interested public and special interest groups, such as local native and aboriginal populations. In order to demonstrate that facilities are performing as designed, the collection of baseline environmental data to objectively assess ecosystem impacts through the life of the mine by environmental monitoring programmes is essential to provide assurance of performance. Public consultation opportunities in presenting the results of the environmental monitoring programmes have proven critical to maintaining trust that the operations are preforming as planned.

Communication with neighbouring communities in decisions that affect them is critical to maintaining a social license to mine. An ongoing dialogue among the main stakeholders: the community, the mining company and the government has proven critical in this regard. With careful execution and participation of the main stakeholders, and adequate funding set aside for site remediation by mining companies, public funding for uranium mine site legacies and remediation should no longer be required and the goal of ensuring that no additional legacy uranium mining and milling issues are created will be assured.

Included in this presentation are examples of public consultation in uranium mine operations that illustrate some of the challenges faced when undertaking public consultation and how such programmes can effectively increase public confidence and support of uranium mining, strengthening the social license to conduct the mining activity.

Evaluation of uranium resources

The Wiluna Uranium Project, Western Australia: Bringing a new project to the market

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The Wiluna Uranium Project is the first uranium mine in Western Australia to receive Government environmental approval since government policy was changed in 2008 to allow uranium mining in Western Australia. Located 960 km northeast of Perth in remote central Western Australia, the Wiluna Project comprises 76.5 million pounds U_3O_8 [~29,000 tU] in six shallow, calcrete-hosted carnotite uranium deposits. Mining is planned at a rate of 1.3 million tonnes annually to produce 2 million pounds U_3O_8 [~770 tU] production using an alkali leach process. The Project requires initial capital investment of AUD$315M and has an operating cost of US$29-31 per pound [~75-~80 USD/kgU].

During the four years it has taken to gain environmental approval, Toro also progressed technical studies to validate the economic and technical viability of the Project. These included the initial Preliminary Feasibility (PFS) to define the processing train; mining optimisation studies, a Resource Evaluation Pit (REP) and a commercial scale Pilot Plant to verify the mining and processing technologies; and finally, Phase 1 of the Definitive Feasibility Study (DFS) which focussed on the processing plant design.

The REP and Pilot Plant demonstrated Toro's commitment to developing a technically robust mine, based on proven mining practices and rigorous metallurgy. The 45,000 t REP was constructed in the Centipede deposit at the margin of the Lake Way salt pan, to demonstrate the successful use of a continuous surface miner in shallow (<10 m deep) deposits, to test various water barriers to control groundwater ingress into the mining envelope, and to evaluate a new in-pit grade control technique for 300 mm mining benches.

From the REP, a 15 t blended metallurgical sample and a 40 tonne groundwater sample were then used in the Pilot Plant to demonstrate the technical viability of the alkaline leach process across both calcrete and clay dominant ore types. The Plant confirmed that the process is technically viable with a consistent recovery of 85% using a fully integrated hydrometallurgical circuit. Lessons from the REP and Pilot Plant were incorporated into the Phase 1 DFS, from which the process design, mass balance and process model, plant layout and preliminary costs were determined.

Since 2009, Toro has acquired further regional resources around Wiluna to strengthen the mine's value proposition. Through the addition of Dawson Hinkler, Millipede, Nowthanna and Lake Maitland to the original Centipede and Lake Way deposits, Toro was able to grow the resource base from 24 to 76.5 million pounds [~920 to ~29,000 tU]. More importantly, this resource now includes 36.7 million pounds of U_3O_8 [~14,000 tU] at an average grade of 930 ppm (500 ppm cut-off) [~790 and ~420 ppmU respectively], which places Wiluna as an attractive and competitive proposition for calcrete-hosted deposits world-wide.

The combination of the strong technical viability, local community and government support and environmental permits for Wiluna means that the Project is ready to become a new uranium supply to meet global demand when the uranium market stabilises and a price recovery appears. The major lessons in bringing a new Australian mine to market have been to maintain a transparent approach with all stakeholders, use robust science to test the technical veracity of the proposal and be patient and diligent in all technical, regulatory and community aspects of the Project.

An overview of uranium, rare metal and REE mineralisation in the crystallines of Sonbhadra district, Uttar Pradesh, India

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Uranium and REE mineralisation hosted by the Proterozoic migmatites and younger intrusives is identified over 350 km^2 in Son Valley area, Sonbhadra district, Uttar Pradesh, which forms the northwestern extension of Chotanagpur Granite Gneiss Complex (CGGC). The rocks exposed include banded gneisses and metasedimentary enclaves, overlain by the Mahakoshal supracrustals and sediments of the Vindhyan Supergroup in the north and Gondwana Supergroup in the south. The craton had undergone repeated rifting, giving rise to intracratonic rift basins for the development of cover rock sequences of arkosic to psammo-pelitic metasediments, which now occur as migmatites comprising pegmatoid leucosomes and biotite melanosomes and associated mesosomes. These intracratonic zones are parallel to the Lower Proterozoic Mahakoshal supracrustals. Anorogenic, rift related plutons of alkali granite of middle Proterozoic age are seen emplaced within Mahakoshal supracrustals, which at places like Kundabhati and Sonwani are episyenitised.

Extensive exploration carried out by AMD has established a potential province in the terrain for U, Nb-Ta and REE mineralisation with complex metallogeny associated with the evolution of migmatites. Consistent uranium mineralisation has been established at Naktu, Kudar, Lakhar, Sirsoti, Nawatola, Dhanbhadua, Kudri and Anjangira, where the host rock is essentially albite-rich pegmatoid leucosome mobilizate (PLM) and to a lesser extent, biotite melanosome/melanosome mobilizate (MM). The lensoidal mineralisation is disposed in an en-echelon manner with variable dimensions along the strike and dip, and varying grades from 0.010-1.00%eU_3O_8. Development of thick PLM is observed in Naktu-Kudar tract, whereas the migmatites at Kirwil-Kudri-Anjangira tract occur as thin veneer over basement and contain thin PLM bands. The anorogenic alkali feldspar granites within Mahakoshal supracrustals at Kundabhati, Sonwani and Chitwar also host uranium mineralisation.

Three major types of uranium mineralisation are identified based on the host-rock characteristics, viz. (a) Pegmatoid Leucosome Mobilizate (PLM) and Biotite Melanosome (BMM) hosted mineralizaion, (b) Potassic granite/episyenite hosted mineralisation and (c) Magmatic Pegmatite hosted mineralisation. Uraninite, samarskite, fergusonite and xenotime are identified in the PLM and BMM hosted mineralisation at Naktu, Kudar, Kudri, where soda metasomatism in the form of albite replacing the alkali feldspars is ubiquitously seen. The mineralisation at Kundabhati, Sonwani and Chitwar are hosted by potassic granites and episyenites, which are characterized by K-metasomatism, desilicfication and concomitant release of iron, rendering a deep red colouration to the mineralized rock. Magmatic pegmatite hosted mineralisation is at Jaurahi, where columbite, samarskite, aescheynite, thorite, xenotime, fluorite, fluorapatite and zircon occur as segregations in the pegmatites.

The present geological milieu in the Son Valley area has the imprints of repeated thermal, tectonic and metamorphic reactivation. The profuse occurrence of migmatites is the resultant product of ultra-metamorphism of arkosic to psammopelitic sequence deposited in ensialic extensional basins. Thermal regime in the course of ultra-metamorphism leading to anatexis had led to the remobilization of intrinsic uranium in sediments and subsequent concentration within the albite rich pegmatoid leucosome and biotite rich melanosome. Syn-tectonic plutonic activity also has contributed towards the mobilization and subsequent concentration of U. The mineralized episyenites are the product of shearing, brecciation and desilicification of the anorogenic alkali granites, and associated metasomatism. The multimetal-mineralisation associated with magmatic pegmatites has resulted due to pneumatolytic/metasomatic activity at a later stage.

International standardisation for the reporting of resources and reserves

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The mining industry is a vital contributor to national and global economies and yet it is very different from other industries. It is based on depleting finite mineral resources, the knowledge of which is imperfect prior to the commencement of mining or extraction. It is an industry with a colourful history of success and failure, entrepreneurs and opportunists, visionaries and short sightedness. These aspect or traits were both positive, it fostered innovation, and negative for the industry. Negative in that the merit of certain projects or results was difficult to assess, it created a credibility issue and consequently investment in the industry was impacted.

In 1989 the first JORC code was released (Joint Ore Reserves Committee) in Australia. It was incorporated into the Australian Stock Exchange (ASX) listing rules thereby becoming binding on companies listed on the ASX it was also adopted by the Australian Institute of Mining and Metallurgy (AusIMM) and became binding on its members. Essentially JORC was the pre-cursor or model for an international standard for the reporting of exploration results, mineral resources and ore reserves.

A trend towards tighter corporate governance and regulation demanded an international standard to "good practice" in mineral reserve management as well as high standards of public reporting by responsible, experienced persons. In 2006 CRIRSCO (Committee for Mineral Reserves International Reporting Standards)released an International Reporting Template (the Template), the purpose of which is to assist with the dissemination and promotion of effective, well-tried, good practice for public reporting of Exploration Results, Mineral Resources and Ore Reserves already widely adopted through national reporting codes and standards. CRIRSCO's members are National Reporting Organisations (NROs) that are responsible for developing mineral reporting codes, standards and guidelines in Australasia (JORC), Chile (National Committee), Canada (CIM), Europe (PERC), Russia (NAEN), South Africa (SAMREC) and the USA (SME). The member NROs nominate representatives to the Committee.

The top 5 listed mining companies in the world all report their resources and reserves in accordance with the CRIRSCO family of codes. Two of which, BHP Billiton and Rio Tinto are uranium producers. It is noteworthy that prior to the inclusion in 2010 of the Russian NAEN code in the CRIRSCO family the combined value of mining companies listed on stock exchanges of CRIRSCO member countries accounted for more than 80% of the listed capital of the mining industry.

Mineral resource and Ore Reserve codes are the basic building block underpinning the confidence required for investment in the mineral resources sector. They are the basis for our decisions when evaluating or selling projects

Application of United Nations Framework Classification – 2009 (UNFC-2009) to nuclear fuel resources

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Nuclear energy currently provides approximately 15% of the world’s electricity, utilized in about 30 countries. As many countries are planning to expand capacity or introduce nuclear power into the energy mix, the demand for uranium fuel is expected to increase. Reactors suitable for utilizing thorium as fuel are also being developed for deployment in the long-term.

Since nuclear power is capital intensive and uranium feedstock is required for a nuclear reactor life of between 40 and 60 years, operators need assurance of a reliable uranium supply. Comprehensive and up-to-date information on the worldwide supply of nuclear fuel resources is therefore essential for planning and implementation of nuclear power programmes. Information on resources are provided through the bi-annual Organisation for Economic Co-operation and Development / Nuclear Energy Agency – International Atomic Energy Agency (OECD-NEA/IAEA) report “Uranium: Resources, Production and Demand” (the “Red Book”) and the online datasets of World Distribution of Uranium Deposits (UDEPO) and World Thorium Deposits and Resources (ThDEPO).

Two international classification and reporting systems have been used for uranium and thorium deposits. These systems are 1) the Committee for Mineral Reserves International Reporting Standards

(CRIRSCO) Template, and 2) the OECD-NEA/IAEA resource classification schema. The CRIRSCO Template is the most recently developed international standard for the reporting of exploration results, mineral resources, and mineral reserves. The Template is based on a number of compatible and consistent national or regional reporting standards and represents the current international best practice for public reporting by companies.The NEA/IAEA schema was developed for classifying and reporting individual, regional, national and international uranium/thorium resource estimates. The NEA/IAEA schema reports uranium resource estimates in different categories based on geological confidence and the expected cost of recovery. The UNFC system is an alternative to these two systems, and has been developed to be compatible with both energy mineral and oil and gas resource reporting schema.

The United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) is a project-based system that applies to all fossil energy and mineral reserves and resources. It has been designed to meet, to the extent possible, the needs of applications pertaining to energy and mineral studies, resource management functions, corporate business processes, and financial reporting standards. Bridging documents have been developed to explain the relationship between UNFC-2009 and the other classification schema such as the CRIRSCO Template and the NEA/IAEA schema.

It is desirable that uranium resource estimates are reported in a manner that are universally understood and accepted. The bridging document between NEA/IAEA and UNFC-2009 explains the relationship between these two systems and provides instructions on how to classify estimates generated by the NEA/IAEA scheme using UNFC numerical codes. The bridging document will facilitate mapping of results between the two schemes in a consistent manner. Alignment with UNFC-2009 will assist in communications, especially where issues of socio-economic viability of a resource is considered. The alignment of company reporting to UNFC-2009 will also ensure consistent aggregation of quantities in national governmental and international reporting. Application of UNFC-2009 is expected to support the accurate and transparent management of resources throughout the uranium production life-cycle.

Roll-front uranium occurrences of the South Texas Mineral Belt: Development of a database for mineral potential modelling and quantitative resource assessment

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The South Texas Mineral Belt in the United States is a broad curvilinear region of marginal-marine roll-front sandstone uranium occurrences. Located ~130 km inland, the belt parallels the Gulf of Mexico coastline and extends from southeast Texas to Mexico. It trends northeast-southwest and is about 400 km long and 10-50 km wide as delineated by alignments and clusters of occurrences, but ~100 km wide if outlying occurrences are included. The occurrences are hosted in coastal plain sediments and rocks of Tertiary age that dip gently towards the Gulf. These include the Lower Eocene Wilcox Group, Middle Eocene Claiborne Group, Upper Eocene Jackson Group, Upper Oligocene–Miocene Catahoula Tuff, Lower Miocene Oakville Sandstone, and Pliocene Goliad Sand. Older sequences are mixed fluvial-beach facies, whereas younger are dominantly fluvial. Occurrence distribution is controlled by host unit strike and dip, and permeable sequences therein, and by a combination of growth faults and locations of reductants.

The U.S. Geological Survey is conducting a quantitative assessment of roll-front uranium resources in the South Texas Mineral Belt using geospatial mineral potential modeling and 3-Part Assessment methodologies. The objectives are to (1) delineate permissive, favorable, and prospective tracts, (2) estimate the number of undiscovered deposits, and (3) estimate the resource endowment of each tract. A roll-front uranium resources database has been compiled for the assessment detailing occurrence location, size, operation type, U_3O_8 production and reserves, and host unit.

The database contains 253 occurrences, including 165 deposits (sites with recorded production or reserves), 75 prospects (sites with some level of exploration), 6 showings (sites of interest that have been investigated), and 5 anomalies (sites with indications of mineralizing processes). Of the deposits, ~52% are open-pit operations, ~29% are ISR, and the remainder unknown. These include 102 past-producers, 41 unmined, 2 operating, and 1 under development, as well as 11 deposits and prospects with exploration status. Through 2013, an estimated total resource of ~134.862 Mlbs U_3O_8 (~81.239 Mlbs production, ~53.623 Mlbs reserves) [~51,800, ~31,200 and ~20,600 tU respectively] are contained in 122 occurrences, mainly in past-producing, unmined, and operating deposits. The Goliad Sand hosts ~7% of the occurrences, with resources of ~44.9067 Mlbs U_3O_8 [~17,300 tU] in ISR past-producing, operating, and exploration and development phase deposits. The Oakville Sandstone hosts ~18% of the occurrences, with resources of ~48.6351 Mlbs U_3O_8 [~18,700] mainly in ISR and open-pit past-producing and some unmined deposits. The Catahoula Tuff hosts ~25% of the occurrences, with resources of ~14.8701 Mlbs U_3O_8 [~5,700 tU] mainly in ISR and open-pit past-producing and unmined deposits. The Jackson Group hosts ~46% of the occurrences with resources of ~26.2766 Mlbs U_3O_8 [~10,100 tU] mainly in open-pit and past-producing deposits. The Claiborne Group, Wilcox Group, and unidentified units host the remaining occurrences. Grades range 0.04% - 0.3% U_3O_8 (0.11% average) [~0.034-~0.25%U and average ~0.093%U] for open-pit operations, and 0.03% - 0.34% (0.09% average) [~0.025-~0.29%U and average ~0.076%U] for ISR (higher grades have been reported).

Geological 3-D modelling and resources estimation of the Budenovskoye uranium deposit (Kazakhstan)

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The Budenovskoye deposit is the biggest sandstone-hosted, roll front type uranium deposit in Kazak hstan and in the world. Uranium mineralization occurs in the unconsolidated lacustrine-alluvial sediments of Late Cretaceous Mynkuduk and Inkuduk horizons. The Budenovskoye deposit was split into four areas for development with the present Karatau ISL Mine operating No. 2 area and Akbastau ISL Mine Nos. 1, 3 and 4 areas. Mines are owned by Kazatomprom and Uranium One in equal shares.

CSA Global was retained by Uranium One to update in accordance with NI 43-101 the Mineral Resource estimates for the Karatau and Akbastau Mines.

The modelling Reports shows a significant increase in total uranium resources tonnage at both mines when compared to the March 2012 NI 43-101 resource estimate: at Karartau measured and indicated resources increased by 586% while at Akbastau by 286%. It has also added a 55,766 tonnes U to the Karatau Inferred Mineral Resource category.The new estimates result from the application of 3-D modelling techniques to the extensive database of drilling information, new exploration activities.

The modelling of roll front type uranium deposits to be developed using ISL methods has its own specific requirements, which have been fully accounted. Mineral resources estimation was based on 0.04 m% grade x thickness cut-off. The relationships between geophysical logging data and laboratory analyses were identified in order to define resource estimation parameters based on gamma log, electrical logging methods and disequilibrium studies.

The interpretation of roll front type uranium deposits amenable to in-situ leaching consists of: modelling of mineralized-bearing horizons (Inkuduk and Mynkuduk); interpretation of mineralized bodies and interpretation of clay horizons in order to define mineralization that cannot be extracted from impermeable sediments by ISL methods.

Mineralized envelopes were divided into three morphological elements – rolls nose, wing, and residual parts as well as into mineralized horizons. The intervals where mostly reduced rocks are developed were attributed to the nose; the intervals where reduced and oxidised rocks are developed were attributed to the wings; and the intervals where there are mainly oxidised rocks developed were attributed to the residual part. The nose parts of rolls trace regional redox front zones.

The resources estimation methodology for ISL amenable sandstone type deposit is based on GT (grade × thickness) modeling as a main parameter. First a gridded model is generated where the vertical dimension for each block corresponds to the thickness of mineralised ore body. After that uranium productivity (grade × thickness) is calculated by multiplying the cell vertical size by uranium grade. Finally the productivity of each two-dimensional gridded model cell is compared with the corresponding column of cells in the classical three-dimensional block model.

How effective project management will add value to your uranium project

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Up until the recent Fukushima incident in March 2011 project activity in the uranium sector was driven by high uranium prices and merger and acquisition corporate activity. Soon after the incident, project development in the uranium sector collapsed and capital slowly dried up as Uranium prices dropped. New projects were put on hold, significantly reducing growth in the small to medium capital markets. Existing brownfield growth plans were halted as corporate strategies focused on improving the efficiency of existing assets.

Recent positive sentiment supported by positive commentary in the uranium market, driven by an improved understanding of the supply and demand fundamentals and the restart of Japan's nuclear reactors, has seen renewed corporate merger and acquisition activity. Developers are again taking an interest in new uranium project development.

Uranium projects, like most other commodities, have a critical "to do list" which is part of project feasibility and is essential to complete in order for these uranium projects to be desirable packaged world class projects ready for construction.

Understanding and correctly interpreting the complexities of the deposit geology and the application of this to mining and processing. Determining the optimum construction methods and design. Ensuring effective in-country management, determining the timing on when to recruit an owners team, effective product marketing, resolution of environmental, community and legal issues. These all contribute to the effective management of shareholder capital and create the growth in value required to support the next phase in the development.

This paper will present the authors experience based on case studies from a number of recent uranium projects in Australia, Africa and Europe, either developed through to construction or at different phases of feasibility. The presentation will focus on the experience gained and the lessons learnt when managing the development of these uranium projects. The presentation will include examples of where projects have suffered, both in value and unplanned delays, due to lack of appropriate understanding of what is required to ensure the work is completed to achieve the desired results on time and on budget. Other examples will demonstrate where projects have exceeded expectations and delivered exceptional value, due to factors which are often underrated or ignored in the management of the exploration and mine development industry.

The type of uranium projects discussed include near surface tertiary sedimentary mineralisation, sandstone hosted mineralisation, alaskite style mineralisation and in-situ leach roll front mineralisation. Issues covered include: corporate management; in-country management; technical

support; technical issues relating to geology, grade determination and database management; metallurgy and processing test work; EPCM relationships and financial arrangements.

Advances in exploration and uranium mineral potential modelling - 1

Genetic model for roll-front uranium deposits in the Gulf Coast Uranium Province, Texas, USA

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The U.S. Geological Survey is re-assessing the undiscovered uranium resource potential of roll-front mineralization in thick sequences of Paleogene and Neogene siliciclastic strata deposited along the U.S. Texas Gulf Coast. In southern Texas, 249 roll-front sandstone-hosted uranium occurrences have been identified. Of these, 102 were mined producing 31 156 t U (81 million lbs of U_3O_8). Fifty-nine known deposits remain containing reserves of an estimated 20 771 tU (54 million lbs of U_3O_8). A genetic model describing the most probable source, transport mechanisms, and depositional controls of these deposits was developed to estimate undiscovered resources in the region.

Most evidence points to rhyolitic volcanic ash beds interbedded with host sandstones as the uranium source. These tuffs probably originated in the Trans-Pecos volcanic field, which is located in southwestern Texas and adjacent Mexico. The most active period of Trans-Pecos volcanism, 46 to 16 Ma, corresponds with uranium mineralized sequences in adjacent Tertiary strata. Uranium transport is hydrologically controlled by oxidation gradients established in coastward dipping sedimentary facies. Important deposit clusters are found within large, permeable paleochannel systems, and other deposits are controlled by facies variations in ancient barrier bar systems. There is localized association of uranium deposits with offlap sequences caused by lowered sea level that rejuvenated groundwater flow, and increased erosion and oxidations depths. The Duval mineral trend, which contains about 25% of the total uranium found in the region, formed along the axis of the major Rio Grande paleochannel system that was active from the Eocene through the Miocene. Thick tuffs interbedded with sediments in this paleochannel provided a source for uranium that locally remobilized to form deposits within the Catahoula Formation. This uranium was remobilized and further concentrated downdip into the overlying Miocene Oakville Sandstone and Pliocene Goliad Sand. This newly recognized recycling and enrichment of uranium into younger sandstones down gradient along paleochannels may be important throughout the basin, but it has not been adequately tested. Both intrinsic and extrinsic reductants control deposition of uranium in roll-fronts. Most deposits appear to be controlled by extrinsic reductants that seeped upward from underlying gas fields. These gasses, or dissolved H_2S, or organics in oil field brines, may have migrated upward via faults as many deposits are found adjacent to fault zones. Other economic deposits are found associated with intrinsic reductants, in the form of organic-rich reduced sediments that interfingered with the paleochannel and barrier bar systems. In east Texas, where more humid conditions resulted in greater amounts of organic matter in sediments, uranium is found associated with humates and rarely forms economic deposits. Almost all the roll-front deposits in Texas have been identified in western Texas, where arid conditions predominated and organic facies are less common than in eastern Texas.

Recent exploration progresses on sandstone-hosted uranium deposits in north-western China

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The metallogenic target selection using multiple exploration techniques and drilling program for sandstone-hosted uranium deposits have been intensively carried out for recent years, and big progresses on new discoveries of uranium reserve/resource have been made in the Mesozoic sedimentary basins such as in Yili, Ordos etc. in North-western China

The Yili basin is a depression one within the Tianshan Mountain belt in the western part of China. Its basement is composed of Proterozoic-Paleozoic metamorphic and sedimentary rocks, and covers of Mesozoic sediments. The early-middle Jurassic Shuixigou Group is major uranium-productive beds which are composed of three Formations such as Badaowan, Sangonghe, Xisanyao and eight sedimentary cycles. Uranium deposits are found in the south margin of the Basin and controlled by the redox zone. The combined exploration techniques of detailed sedimentary facies study, Rn-survey, high-precision magnetic and soil geochemical and seismic surveys have been successfully used to have locate the potential targets and mineralization zones. The enlargement of uranium reserve/resources in the known deposits and new resources in the selected new targets and cycles have been achieved through further drilling programs.

The Ordos basin is a large Meso-Cenozoic basin developed in North China Platform, with its size of approximately 250,000 km^2 and is well known as an important “energy resources basin” because of abundance of coal, oil and gas deposits. The Dongsheng sandstone type uranium deposit is a large one discovered in recent years in northeastern Ordos basin. It is a special kind of sandstone type uranium deposit, different from other ordinary sandstone type deposits because of its unique signatures. It is generally controlled by a transitional zone between greenish and grayish sandstones, both of those two kinds of sandstones now indicate reduced geochemical environments. The greenish color of the paleo-oxidized sandstones mainly results from chloritization and epidotization related to oil and gas secondary reduction processes. The metallogenic superposition model for this kind of uranium deposit has been put forward, and exploration indications summarized. Based on the exploration model, indications and using techniques such as detailed sedimentary facies study, Rn-survey, high-precision magnetic and soil geochemical and seismic surveys, new metallogenic targets have been selected and a big progresses on enlargement of reserve/resources have been made to have discovered new uranium deposits such as Nalinggou and Daying deposits and new ore beds as well in the north-western part of the north Ordos Basin.

Novel geochemical techniques integrated in exploration for uranium deposits at depth

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Mineral deposits are in fact geochemical anomalies, and as such their detection and assessment of their impact on the environment should be facilitated using geochemical techniques. Although geochemistry has been used directly in the discovery of uranium deposits and more indirectly in shaping deposit models, the novel applications of geochemistry and integration with other data can be more effective in formulating exploration and remediation strategies. Recent research on the use of geochemistry in detecting uranium deposits at depth include: (1) more effective integration of geochemical with geophysical data to refine targets, (2) revealing element distributions in and around deposits to adequately assess the total chemical environment associated with the deposit, (3) the use of element tracing using elemental concentrations and isotopic compositions in the near surface environment to detect specific components that have migrated to the surface from uranium deposits at depth, (4) understand the effects of both macro- and micro-environments on element mobility across the geosphere-biosphere interface to enhance exploration using select media for uranium at depth. Geophysical data used in exploration can identify areas of conductors where redox contrasts may host mineralization, structures that act to focus fluids during formation of the deposits and act as conduits for element migration to the surface, and contrasts in geology that are required for the deposits. However, precision of these data is greatly diminished with depth, but geochemical data from drill core or surface media can enhance target identification when integrated with geophysical data.

Geochemical orientation surveys over known unconformity-related deposits at depth clearly identify mineralization 900m deep. Drill core near the deposit, clay-size fractions separated from soil horizons and vegetation over and far from the deposit record element migration from the deposit as radiogenic He, Rn and Pb unique to uranium-rich sources. Isotopic compositions of C and N indicate microbial interactions with the uranium deposits, which is the likely process by which elements are mobilized out of the deposits and into the surrounding environment for us to use as vectors to ore. Correlations among pathfinder elements occur in fractures in core, but also in various surface media. Multi-element analyses including Pb isotopes of the clay-sized fractions of all soil horizons and vegetation provide compelling evidence that a robust geochemical signature exists. All of the processes that operate to produce geochemical anomalies at the surface above unconformity-related deposits are applicable to all other types of uranium deposits and should be integrated into learning curves for effective exploration of uranium.

Methods of mineral potential assessment of uranium deposits: A mineral systems approach

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Mineral potential represents the likelihood (probability) that an economic mineral deposit could have formed in an area. Mineral potential assessment and prospectivity analysis use a probabilistic concepts to mineral deposits, where the probability of an event (formation of a mineral deposit) is conditional on two factors : i) geological processes occurring in the area, and ii) the presence of geological features indicative of those process. For instance, one of the geological processes critical for the formation of sandstone-hosted uranium deposits in an area is transport of uranium in groundwaters. Geological features indicative of this process in an area comprise, i) presence of leachable source rocks of uranium; ii) presence of highly permeable sandstone; and iii) suitable hydrogeological gradient driving flow groundwaters.

Mineral deposits can also be conceptualised as mineral systems with more emphasis on mineralising processes. This concept has some clear parallels with the petroleum systems approach which has proven to be a useful in oil and gas exploration. Mineral systems are defined as 'all geological factors that control the generation and preservation of mineral deposits'. Seven important geological factors are outlined to define the characteristics of a hydrothermal mineral system. These factors include: i) source of the mineralising fluids and transporting legends; ii) source of metals and other ore components; iii) migration pathways which may include inflow as well as outflow zones; iv) thermal gradients; v) source of energy to mobilised fluids; vi) mechanical and structural focusing mechanism at the trap site; and vii) chemical and/or physical cause for precipitation of ore minerals at the trap site. This approach, commonly known as the 'source', 'transport' and 'trap' paradigm has been redefined to introduce five questions as a basis to understand spatial and temporal evolution of a mineral system at all scales (regional to deposit). The five questions include: i) what is the architecture and size of the system; ii) what is P-T and geodynamic history of the system; iii) what is the nature of the fluids and fluid reservoirs in the system; iv) what is the nature of fluid pathways; and v) what is the chemistry of metal transport and deposition in space as well as time.

Analysis of fertile mineral systems can provide useful information on geological processes essential to form an economic mineral deposit in an area. Mappable features of these processes in geological datasets can then be used to estimate probabilities visualised in the form of mineral potential, prospectivity and favourability maps. The probabilities (levels of mineral potential, favourability index) can be either shown using non-numerical (high, moderate and low), ordinal (numbers expressing ranking) and cardinal (numbers expressing quantities) scales.

This paper will discuss advantages and disadvantages of various GIS-based methods of qualitative assessment and will also present a number of case studies illustrating mineral potential assessment of uranium deposits carried out in Geoscience Australia.

The future of uranium - focus on greenfields

Sandstone uranium deposits of Eurasia – from genetic concepts to forecasting and new discoveries

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Along the Eurasian continent's southern borders lie uranium ore provinces and regions controlling medium-sized and, on rare occasions, large sandstone deposits. Central French, Eastern Rhodope and other regions are known in the west. Large uranium ore provinces were discovered in the south of the Turan Plate and in the depressions of South Kazakhstan, viz. Central Kyzyl Kum, Syr Darya, Chu Sarysu. A common criterion has been established for all objects of the sandstone type, located in oil and gas, coal etc. sedimentary basins – the zone of interlayer or ground-interlayer oxidation, controlling uranium mineralization.

In 2003 we were able to justify the concept that the formation of giant deposits in Chu Sarysu province was caused by the collision between the Indian Plate and the southern part of the Eurasian continent. Within the limits of Pacific ore belt there is a zonal distribution of ore deposits. Ordinary mineralization is drawn towards its eastern fringe: gold, tin, copper, tungsten etc. Volcanic and tectonic structures of central type of Mesozoic age are located further west, from the north to the south, that is large calderas – Streltsovskaya (Russia), Dornot (Mongolia), Sian Shan (China), which control large and unique endogene uranium deposits. In the far west, in the region of subsiding tectonic tensions, there are sandstone deposits of uranium in Transbaikalia, Mongolia and Yunnan, which are spacially connected to young basalts. Infiltration deposits of Vitim region are adjacent to endogene deposits of Streltsovsky region in the southern-easterly direction, and to the east of the deposits of Yunnan at the same latitude lay the Sian Shan caldera with geothermal deposits of uranium and other metals. We combined them into the unified submeridional Baikal-Southern China uranium ore belt.

After examining the southern extremities of the Eurasian continent, the region of the collision of the Indian Plate, a distinct similarity can be percieved between the location of infiltration uranium deposits of the Tien Shan megaprovince and the pattern of development of the Pacific Plate subduction. In both cases young sandstone deposits tend to be situated close to the zone of subsiding geodynamic activity. Endogene uranium bodies can be found near the contact area of collision plates. The size of both endogene and exogene objects in the south and east of the Eurasian Plate differ considerably.

The given material bears evidence of a close spacial connection between part of sandstone uranium deposits and endogene uranium deposits. Both types of uranium deposits belong to the same ore metallogenic zoning which is entirely dependent on the global geodynamic processes taking place in the crust and mantle on the fringes of the Eurasian continent. This makes it possible to increase the prospects for the future of many parts of the world.

Undiscovered resource evaluation: Towards applying a systematic approach to uranium

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Evaluations of potential mineral resource supply range from spatial to aspatial, and everything in between across a range of scales. They also range from qualitative to quantitative with similar hybrid examples across the spectrum. These can compromise detailed deposit-specific reserve and resource calculations, target generative processes and estimates of potential endowments in a broad geographic or geological area. All are estimates until the ore has been discovered and extracted. Contemporary national or provincial scale evaluations of mineral potential are relatively advanced and some include uranium, such as those for South Australia undertaken by the State Geological Survey. These play an important role in land-use planning as well as attracting exploration investment and range from data- to knowledge-driven approaches. Studies have been undertaken for the Mt Painter region, as well as for adjacent basins.

The process of estimating large-scale potential mineral endowments is critical for national and international planning purposes but is a relatively recent and less common undertaking. In many cases, except at a general level, the data and knowledge for a relatively immature terrain is lacking, requiring assessment by analogy with other areas. Commencing in the 1980s, the United States Geological Survey, and subsequently the Geological Survey of Canada evaluated a range of commodities ranging from copper to hydrocarbons with a view to security of supply. They developed innovative approaches to, as far as practical, reduce the uncertainty and maximise the reproducibility of the calculations in information-poor regions. Yet the approach to uranium was relatively ad hoc and incomplete (such as the US Department of Energy NURE project). Other historic attempts, such as the IAEA-NEA International Uranium Resource Evaluation Project (IUREP) in the 1970s, were mainly qualitative.

While there is still no systematic global evaluation of undiscovered uranium resources, attempts are being made to calculate uranium supply up to and beyond 2030-2060. In part, these projections are based upon expanding known resources either currently in advanced exploration, feasibility or production. However given that lead-in times from exploration to discovery and exploitation, are relatively long for uranium projects, and few mines have currently projected lives beyond a decade or two, the supply calculations are necessarily partly based upon resources that are not yet known with any confidence. Few countries report undiscovered resources to the OECD-NEA/IAEA “Redbook”, but how these figures are calculated is unknown and likely involves a range of techniques with variable degrees of robustness. Surprisingly these figures for undiscovered resources only marginally exceed those for known resources, and this has profound implications for long-term security of supply. There is a requirement for an integrated and consistent approach that is best done using statistically and geoscientifically robust methods already proven successful for other commodities (such as copper) using existing uranium databases (such as the IAEA UDEPO database). Very few countries, such as China and the United States have started this process independently on a country scale.

Case study: financing growth in uranium production despite today's serious challenges – from concept to production in five years

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Uranium Energy Corp (UEC) is an NYSE-listed uranium exploration, development and production company headquartered in Corpus Christi, Texas. The Company was launched in late 2005 and commenced production in November 2010 using low-cost, environmentally friendly in-situ recovery (ISR) methods. The Company's assets include a pipeline of exploration and development properties, with ISR operations in Texas built around a hub-and-spoke expansion model. Assets include significant conventional uranium mining properties in Arizona and Colorado, as well as potentially world-class exploration/development projects in an emerging uranium district in the Parana Basin, Paraguay, South America. Securing financing for an array of uranium projects in various stages of development is clearly challenging in a volatile economic environment. Yet, the potential of a compelling long-term uranium supply/demand deficit has attracted contrarian investors despite the difficulties. Since going public in 2006, UEC has relied primarily on raising capital through public equity offerings. UEC has raised over $130M in equity capital since going public as well as recently arranging a $20M debt financing with a group of lenders led by Sprott Resources and Li Ka Shing, one of Asia's wealthiest and most influential investors. In addition to traditional equity and debt offerings, UEC has benefited from a variety of non-equity vehicles utilized by many metals and mining companies including timely acquisitions and timely divestitures. With a volatile uranium price over this period, as possible, the company has been making acquisitions during periods of low prices, and raising cash through divestitures when prices are higher, while reviewing royalty and streaming opportunities. With a plan to combine cash flow from operations and strategic partnerships, UEC is expanding production while advancing its diversified portfolio for maximum financial and sector flexibility.

The outlook on potential uranium ISL Mining at Nyota Deposit (Tanzania)

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The Nyota Deposit, located in the Karoo sedimentary basin in south-western Tanzania, is currently the subject of a detailed feasibility study by the Uranium One subsidiary, Mantra Tanzania.

The Nyota deposit has JORC compliant resources of 152 Mlbs of U_3O_8 (at a 100 ppm cut-off) [~58,500 tU and ~85 ppm U], at an average grade of 286 ppm [~243 ppmU]. The original mining and extraction philosophy was based around an open cast mining operation, and a conventional IX, resin in pulp processing plant, producing up to 7 Mlb of U_3O_8 [~2,700 tU] per year over life of mine of 11 years.

With their extensive ISL experience worldwide, Uranium One recognised that an opportunity might exists to convert a larger portion of the resource to reserves by extending the extraction options to include ISL. Preliminary work done in 2012 on the water table and mineral resource revealed that approximately one third of the resource (up to 50 Mlbs U_3O_8) [~19,000 tU] both within and outside the current pit designs, are situated in permeable sediments below the groundwater level and potentially amenable to ISL.

Due to the undulating topography, densely forested area and large proportion of shallow resource above the groundwater table, ISL as an extraction philosophy has not been considered seriously in the past. Furthermore there is no history of successful ISL mining within the regional Karoo basin.

A systematic, toll gated ISL testing program was initiated in 2012 at one of the areas where mineralisation occur below the water table. The first step was a preliminary hydrological study, conducted in 2012. The results demonstrated that major geological, hydrological and technical parameters are favorable for ISL mining. However, comparing to known roll front type sandstone type uranium deposits for ISL mining, the ore hosting aquifer horizon is unconfined and free flow.

This was followed up with a very successful push-pull test, conducted in 2013, which revealed the suitability of the mineralisation to leaching with acidic solutions. Uranium leaching with sulphuric acid concentrations of 5, 10 and 20 g/L, with exposure times ranging from 1 to 3 days, demonstrated positive leaching dynamics. Commercial grade uranium content was obtained in the solutions which ranged from 30 to 124 mg/L U.

These successes have led to an increase in confidence that ISL could work, and the planned follow-up work for 2014 consists of an ISL specific resource estimate, a more advanced hydrological study and a 5-spot ISL field leaching trial.

The concept of ISL at Nyota is not without its technical environmental and approvals challenges. Uranium mining is a fairly new concept for Tanzania. It will remain important to work closely with the Tanzanian regulators during the testing. Should ISL prove to be viable, it holds the potential to unlock the region as an ISL production centre.

Uranium production based on in situ leaching

Worldwide ISL uranium mining outlook

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ISL uranium mining technology was developed independently in the USSR and USA in the early 1960s. The Soviets adopted the acid while the US alkaline leaching system. The major advantages of ISL over conventional mining are: little surface disturbance, no tailings or waste rock, economical mining of lower grade ores, minimal radiation exposure, lower capital and operational costs. The principal geological and technical criteria of ore hosting sediments which determine mineralisation amenability for ISL are: ground water static level above mineralisation, water abundance, hydraulic conductivity or permeability above 1m/day, carbonate content below 2% for acid ISL, water confining horizons above and below mineralisation, ore productivity above 1 kg/m^2, and an easily leachable uranium mineralisation.

The worldwide ISL production has been steadily increasing during the last decade from 7,926 tU in 2005 to 26,304 tU in 2012 which is 45% of the world total. Kazakhstan has increased ISL production during this period from 3,603 tU to 20,900 tU which is a 35% of the world total. Other six ISL producing countries produced 5404 tU in 2012. Acid technology contributes 95% of the total. The main advantages of acid ISL are higher uranium recovery, lower leaching period and possibility of natural attenuation for aquifer restoration.

Most of ISL mines demonstrate low capital, operation and production costs. Nine or the eleven operating uranium producing centers with production cost below 80$/kgU are represented by ISL mines. The approximate CAPEX for a 1000 t U capacity ISL mine construction is $80M.

The major technical parameters which determine production cost are: uranium concentration in pregnant solution, acid consumption, wells flow rate, wellfield drilling and construction costs. The selection of wellfield development pattern configuration and wells spacing depends on the ore body geological setting and sediments permeability. The main areas of ISL effectiveness increase and cost reduction are: uranium resources, hydrology and leaching systems 3D modeling, leaching intensification by adding specific oxidants, wellfield and pumping systems optimization, wells design.

The ISL production is expected to grow to the level of 37,000 tU in 2020 and after that will decline to 30,000 tU in 2030 due to resources depletion. Sandstone type ISL amenable uranium resources amount 26% of world total Identified resources and 24% of the most economically viable cost category <80$/kgU. Aggregated uranium production during 2012 - 2030 is estimated at 1.5 MtU and will deplete 40% of all resources below 80$/kgU. By 2030 resources of existing primary uranium mines will be depleted more than two fold, including about 75% of ISL mines resources. After 2020, uranium market may face shortage of low cost resources and exploration aimed at new deposits discovery is vital.

The methodology for roll front sandstone type deposit requires systematic multistage exploration starting from greenfield regional metallogenic studies to detailed delineation drilling. Most favorable regions for new sandstone type deposits are located in Chu Sarysu basin in Kazakhstan, Vitim region in Russia, sedimentary basins in China and Mongolia, the Karoo basin in Africa and the Parana basin in South America.

Development of ISL uranium mining in Kazakhstan

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In the second half of the 1960s production of uranium from low-grade ores by in-situ leaching (ISL) feasibility was proved. It fundamentally changed the situation in the raw material base in Kazakhstan.

Rapid development of ISL uranium mining in Kazakhstan was promoted by the availability of large sandstone type deposits.

As of 1 January 2014, identified and prognosticated in situ uranium resource in Kazakhstan is about 1.7 million tU, with 77% of them available for ISL production.

Kazakhstan has not only a tremendous resource base, but also state of the art technologies of uranium mining and processing, and is being marketed by the full nuclear fuel cycle. It became the world leader in uranium ISL mining technology.

Technological know-how enables to start uranium mining capacities in record time, during the one year.

Uranium mining in Kazakhstan today is being conducted at 22 sites. During last 10 years uranium production in Kazakhstan has increased 6 times and reached 22,500 tU in 2013.

Since the first ISL site launch, the technology and uranium-containing solutions processing is being constantly improved. Uranium deposits development today is associated with a set of sophisticated technological approaches.

More and more complicated fields are being involved for processing, requiring a new fields design approach and screen positions. New methods for modeling and uranium mining forecasting are being successfully implemented.

For direct uranium determination problem solution there is offered logging prompt fission neutrons that expands the application scope of the quantitative uranium determination method in its situ.

Kazakh experts are the only in the world who successfully process suspended uranium deposits (not having a lower aquiclude), and deposits with uranium ore occurring at more than 700 m occurrence, and herewith minimal ore mining mass volumes are being involved for refinement.

There is extensive experience gained in the advanced acidification application (leaching solutions feeding to the ore-bearing horizon without pumping), what gives the opportunity to get rich uranium-containing solution at an early stage mining block reprocessing, as well as reduces colmatation. Solutions for advanced editing of acidification come from refining blocks that allows to start remediation of aquifers at the blocks finalizing stage.

New polymeric and glass-reinforced materials were successfully implemented for storage equipment and pipe products manufacturing, which improves the tightness and reduces earth surface contamination to a minimum. The use of such materials in piping blocks allows mining for deposits with significant groundwater head above the ground.

Sorbtion-desorbtion U-shaped columns application allowed us to radically change the approach to the processing complex design. There are being designed modules, consisting of one U-shaped column and 3 sorption columns. Modular approach to the engineering and construction allows us to refine the process of capacity expansion and gradual processing complex capacity increasing to more than 2 million tonnes of uranium per year.

Nichols Ranch ISL Uranium Mine - a case history

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The Nichols Ranch ISL Uranium Mine is located in the Powder River Basin of Wyoming, U.S.A. The mine is owned and operated by Uranerz Energy Corporation (Uranerz), a U.S. corporation headquartered in Casper, Wyoming. Nichols Ranch started operations in February 2014 and is the newest uranium mine to go into production in the USA. The uranium being extracted is hosted in a sandstone, roll-front deposit at a depth ranging from 400 to 800 feet [~120 to ~240 m). The In-Situ Recovery (ISL) mining method is employed at the Nichols Ranch mine which is the method currently being utilized at most uranium mines in the USA. Environmental permit applications for the Nichols Ranch mine were submitted to the appropriate regulatory agencies in late 2007. It required more than three and a half years to obtain all the necessary permits and licenses to construct and operate the mine. Construction of the mining facilities and the first wellfield started in late 2011 and was completed in late 2013. Mining results to date have been better than anticipated and Uranerz expects to reach its 2014 production target. The most challenging part of getting a new uranium mine in production in the United States of America was the three plus years it took to get through the environmental permitting process. Uranerz was one of three companies in 2011 that applied for permits to construct and operate uranium mines in Wyoming at essentially the same time. The Nichols Ranch mine is licensed to produce up to two million pounds per year of uranium (as U_3O_8) [~770 tU] ready for shipment to the converter. At this time only the ion exchange portion of the central processing plant has been installed at Nichols Ranch with uranium loaded resin being shipped to Cameco's nearby Smith Ranch – Highland ISL uranium mine for elution, precipitation, drying and packaging under a toll processing agreement. Cameco provides Uranerz with dried and drummed yellowcake that Uranerz owns which is shipped to the converter for delivery to the company's customers.

ISR mining of uranium in the permafrost zone, Khiagda Mine (Russian Federation)

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The "Khiagda" mine in the Republic of Buryatia is the only ISR mine in the world where ore mining is performed in a permafrost region. Its raw material source is deposits of the Khiagdinsky ore field having geological reserves of uranium to 48 thousand tonnes. The ore field is a part of the Vitimsky Uranium ore district with reserves of 100 thousand tonnes. This is the most promising region in Russia where the deposits may be extracted by the ISR technique.

Throughout a year, the air temperatures varies from +35 to –50°C. Permafrost is developed everywhere to a depth of 90 m.

The Khiagdinsky ore field includes 8 deposits. The ore-bearing paleovalleys down-cut the slopes of the granite rise. The ore accumulations are localised in alluvial sandy water-saturated Miocene deposits overlaying the crust formations of the granite basement. They are overlapped by the cover of basalts and volcanogenic sedimentary deposits. The ore accumulations occurrence under the cover of frozen basalts at the depths 90 to 280 m.

Uranium in ores is presented by ningyoite; it is significantly reduced, comprising up to 90-100% U(IV). Mining of such ores by the acidic ISR without an oxidant is of low effectiveness. The ore-bearing sands are quartz-feldspar and practically noncalcareous. The acid consumption caused by chlorites and montmorillonites is at the medium level, 90 kg/tonne.

The ore-bearing deposits, according to the filtration tests, have the filtration coefficient (hydraulic conductivity) of 2.1 (1.4–3.7) m/day and water transmissivity of 50 (24–105) m^2/day. The accumulations are inundated irregularly. In the lower reaches of the paleovalleys, the output of the pumping-out wells varies from 5 to 9 m^3/hour, and in the upper reaches it ranges from 2 to 5 m^3/hour. The temperature of the formation waters is 1 to 4°C.

The rigorous climatic conditions, high degree of uranium reduction in ores, complicated hydrogeological conditions and high viscosity of the very cold groundwater caused low uranium recovery at the initial stage of development. The extensive scientific and research works carried out to increase the uranium content in the productive solutions, and in particular, the use of an oxidant, gave the possibility to bring the Khiagda mine to the world second place in terms of this indicant.

Research is planned aiming to improve the control of groundwater resources inside the paleovalleys and between the paleovalleys, decrease the leaching solutions viscosity and improve the design of the technological wells.

Implementation of the planned researches, despite the harsh climate and complicated geological and production settings, will bring the Khiagda mine to a world-leading position, and it will gain competitiveness with the ISR enterprises of Kazakhstan and Uzbekistan.

Rational ore deposit drilling pattern with construction of cluster pumping wells in the artesian flow conditions

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Drilling pattern and quantity of technological (injection and production) wells in the uranium in-situ leaching is determined by the projection of ore deposit to the daylight surface, structure and hydrogeological characteristics of ore-bearing deposits and given well field productivity. The difference between the structure of production and injection wells lies in that the upper part of production well has a submersible pump which, compared to injection wells, requires installation in its the upper part of the casing string with larger diameter pipes to allow for the pump installation. As a result, the production wells can be operated in pumping and injection mode and injection wells only in injection mode.

The essence of the new scheme is as follows:

• All wells on the block are constructed as injection wells, i.e. without a larger diameter pipe being installed in the upper part of the string.

• The wells selected for operation as production wells, are leak-proof connected with “cluster” pumping wells by plastic pipelines.

• “Cluster” pumping wells up to 100 m deep equipped with dead-end string with no screen are constructed near the power sources. Submersible pumps are installed in such wells with the total capacity to be determined by the design flow rate of the block and to ensure the steady, directional flow from injection to production wells. The minimum number of such "cluster" pumping wells is one per a well field, which well can be piped to up to seven wells designed for production.

As a result, the expenses on procurement of cable products and submersible pumps are reduced and funds for well drilling and their piping are saved.

The proposed scheme of well field development used under the artesian flow conditions allows not only for the cost reduction on operating block piping but also for the use of injection wells as production wells at different stages of block development by selecting any necessary combinations of technological wells. The preliminary calculations show that the operating costs go down and more uranium is extracted from the subsoil.

In 2013, the pilot block was built on Budenovskoye deposit and at this stage the technical and economic parameters of its operation are in line with the estimated parameters.

Advancements in exploration and In-Situ Recovery of sedimentary-hosted uranium

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This paper describes recent advancements in exploration technologies for sedimentary-hosted uranium deposits as basis for improved model-based planning and optimization of in-situ recovery (ISR).

High-resolution shallow (<500 m depth) seismic in combination with refraction tomography is used for high-fidelity imaging of true-depth stratigraphy of sedimentary formations, tectonic faults and specific structures for the improved understanding of (hydro)geology in general and as potential indicator for uranium mineralization in particular.

A new-generation geophysical downhole-wireline tool with pulsed neutron generator has been developed (i) to accurately measure U grade (PFN [prompt fission neutron] method with important *in-tool* corrections for systematic influences), (ii) to determine geophysical parameters including porosity, density, macroscopic neutron cross section (clay content) and deduced permeability, and (iii) to log the mineral composition (based on element-specific gamma ray spectroscopy applied to natural gamma rays as well as gamma rays from inelastic neutron scattering, thermal-neutron capture and neutron activation) – all by one tool.

This new data - together with conventional geophysical and geochemical information – provides an excellent aid to the assessment of ISR feasibility, the design of wellfields and plan-ning of wellfield operation.

A new kinetic leaching model (reactive transport) has been specifically adjusted to acidic leaching conditions considering kinetic rates of the main neutralizing and redox reactions as function of both pH and oxidation potential (balance of e- acceptor species). It is used as an effective tool for predicting wellfield recovery curves, estimating chemicals' consumption and optimizing leaching chemistry (i.e. dosage of chemicals to injection lixiviant) in dependence on mineralogical conditions (abundance of main reactants).

The methods for performance improvement of technological wells at in-situ uranium leaching

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Operational efficiency of in-situ leaching (ISL) deposits essentially depends on the geotechnical well conditions. In most cases, during operation of such wells the decrease of well flow rate and injectability is observed, which is caused by the new formation of salts and clay particles that are deposited on the screen and in the near-screen area. In this connection, there is a need for various activities to restore the flow rate of geotechnical wells.

Zarechnoye and Kharassan Mines performed works to adapt the techniques for well performance improvement that are used in the oil and gas industry. The method is based on the specific acid treatment of host rocks with a special solution to ensure both cleaning of the pore space and creation of new solution flow channels and enlargement of the existing ones, and clay cake removal in the well bottom zone.

When the well flow rate cannot be restored by conventional method, the developed method allows achieving exceptional results. Thus, in the period from May to November 2013 the well workover was performed on 19 production wells at Zarechnoye deposit with the average flow rate before the repair being 5.6 m^3/h. The repair of these wells by conventional methods managed to restore the flow rate to 12.7 m^3/h on average. The use of new method at the final stage of well workover, airlift washing, resulted in achievement of 33.9 m^3/h on average. The initial performance of submersible pumps after the well workover was 17.3 m^3/h while at the initial operation stage the average flow rate, with no evidence of clogging, was 17.1 m^3/h. As a result, the interrepair cycle more than doubled, and the average performance of production wells increased by 309%.

Thorium and rare-earth element-associated resources

Thorium: Geology, occurrence, deposits and resources

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The average content of thorium in the upper crust of the earth reaches 6 to 10 g/t, about 3 to 4 times that of uranium. Thorium is widely distributed, however not as metal, but in mineral form as oxides, silicates, phosphates, and lesser in various other minerals.

Thorium deposits, in simplified form, are divided into four major types, which are: placers, carbonatite-hosted, vein-type and alkaline rock-hosted deposits.

Placer deposits are formed by weathering of country rocks, transportation and wave/current action near shore. Commonly they are known as black sands or heavy mineral sands. The main thorium mineral is the rare earth phosphate monazite with generally less than 10% Th. Other commercial minerals are e.g. ilmenite, rutile, magnetite etc. Monazite can be separated and, if thorium is required, it can be extracted as by-product. Placers range in age from Archean to Tertiary and to Recent deposition.

Carbonatite rocks are of magmatic origin, consisting of more than 50% carbonate minerals (calcite, dolomite, ankerite), often enriched in magnetite, apatite fluorite and accessory Nb-Ta minerals, containing Th. Other economic minerals may be present. Carbonatite deposits are common world-wide. Presently commercial interest is primarily on Nb and Ta, thorium may be recovered as by-product, if required.

Vein-type deposits are wide-spread too and mainly of hydrothermal origin occurring in spatial relation to intrusive or extrusive igneous rocks, often related to carbonatite intrusions. They are generally elongated, vein-and lense-like in shape or in sheets, filling joints and fissures. Common thorium minerals are thorium oxide and thorium silicate. Veins are frequently polymetallic. Thorium could be a by-product, if required.

Alkaline rocks are of igneous origin characterized by high amount of alkali feldspar (alkali granite, syenite). Frequently delimitation to peralkaline rocks cannot be drawn. Alkaline and peralkaline rocks are often spatially related to carbonatite intrusions. Mineral composition is various. Similar to other deposits types, thorium may be a by-product.

Thorium resources can be classified according to confidence in estimates of tonnages. In many cases official figures are either not available or not in agreement with established standards. Therefore uncertainties remain in reporting numbers. However, latest estimates for the world indicates more than 6.2 million t Th.

Thorium recovery as a co-product of processing rare earth element deposits

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Intrusion-related deposits of rare earth elements (REEs) are typically enriched in thorium (Th). The REEs and Th are “incompatible elements”, so-named because they form high-charge ions that do not readily fit into common igneous minerals. They concentrate in differentiated magmas, such as melts that form alkaline intrusions and carbonatites, common hosts for REEs. Thus, high-grade Th deposits are often high-grade REE deposits. Consequently, Th can be a co-product of developing REE deposits if a market emerges for Th as a nuclear fuel. Currently, Th within REE deposits in the United States is treated as a radioactive contaminant, not as a potential commodity.

Three examples presented here illustrate the potential for obtaining Th from residue streams of REE production. First are the Mountain Pass operations of MolyCorp in southeastern California, the only active REE mine and processing facility in the United States. The orebody is a carbonatite reportedly containing 16.7 Mt of proven and probable reserves grading 7.98% total REE oxides. The primary ore mineral is bastnaesite. Monazite (REE-Th-phosphate) is an accessory mineral, imparting an average Th content of about 0.03%. After the carbonatite is processed and REEs separated, the Th moves with other residues into the tailings impoundment.

A second example is the Bear Lodge project of Rare Element Resources in north-eastern Wyoming, currently in an advanced stage of permitting for their mine and processing plant. The deposits occur in a hydrothermally altered carbonatite-alkaline intrusive complex, with total measured and indicated resources of 15.2 Mt of ore averaging 3.11% total REE oxides. The primary REE ore minerals are ancylite and REE-fluorocarbonates. Important Th-bearing accessory minerals are monazite and cerianite (Ce-Th-oxide). The ore averages about 0.12% Th. In a press release of January 23, 2014, the company announced their processing technology will “selectively isolate and economically remove thorium”.

As a third example, UCore Rare Metals plans to mine REE-rich vein deposits within the Bokan Mountain alkaline intrusive complex in southern Prince of Wales Island, southern Alaska. The target vein deposits are enriched in the heavy REEs, which comprise about 40% of the total REEs. Inferred resources for the veins are 5.2 Mt averaging 0.65% total REE oxides. These structurally controlled "vein-dikes" show evidence of early alkaline magmatic injection followed by later hydrothermal alteration. Detailed mineralogical study of this vein-dike system by the USGS revealed that Th and U are dominantly sited in thorite and a complex suite of Th±U±Ti±Nb±Y oxide minerals, including fergusonite, polycrase, and aeschynite. The oxide minerals along with Y-silicates are the primary heavy REE-bearing minerals of the deposit. Limited sampling revealed Th contents of about 0.15%. In the processing of these ores, Th and its radioactivity will need to be addressed. Separation and stockpiling of Th from the residue streams provide a possible economic solution in all three examples.

Thorium as a new commodity: Th resources in Brazil

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President Eisenhower's speech "Atoms for Peace" established in 1953 the basis for peaceful power generation via nuclear reactors, somewhat pursuing to "counterbalance" the moral effects of the Hiroshima and Nagasaki´s horrors. In his own words "...this greatest of destructive force can be developed into a great constructive force for the benefit of all mankind."

U based experimental power reactors came into play in earlier 1950s as a consequence and evolution of Fermi´s "Chicago Pile-1". However, it was sooner realized that no U mines were available for the building and expansion of such power plants and geological prospecting began for that purpose.

Since Th mines were known and Th is more abundant than U, Th based reactors were also studied and developed during the 1960s and they had quite promising beginnings in those days.

Such developments on Th based reactors, were, however, abandoned in favour of U-based power plants, but have resurged today due to several possible advantages on the safety and proliferation issues.

Moreover, with the renewed interest on rare earth element (REE) production, due to the well-known Chinese moratorium on production, Th related issues came into play again, as a result of how to utilize or dispose of Th by-products.

This paper presents and discusses the potential geological and mine resources and reserves of Th-containing ores and minerals in Brazil as gathered throughout the several discussions and meetings held on behalf of the IAEA Thorium Group during these last years.

Separation of rare earths from uranium and thorium

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Kvanefjeld is an emerging multi-element deposit hosted within marginal phases of the Ilimaussaq Intrusive Complex, located near the southwest tip of Greenland. The deposit is exposed at surface along a series of undulating bluffs on a broad peninsula surrounded by deep-water fjords that run directly out to the Atlantic Ocean.

Delineated resources to date include 367 7223 tU (956 million lb U_3O_8) at 232 ppm U (273 ppm U_3O_8), 1.08% TREO and 0.24% Zn. The project is a truly world class resource for the strategic future metals of uranium and rare earth elements. In addition the deposit typically contains thorium concentrations of 600 ppm.

The Project is currently Feasibility Study stage with process development essentially complete. The Feasibility Study is evaluating a concentrator and refinery treating 3 million tonnes year of ore. The concentrator will produce a rare earth mineral concentrate which increases the grade of the rare earths by an order of magnitude.

The mineral concentrate is refined using an atmospheric sulphuric acid leach which extensively leaches the uranium from the concentrate. Additional atmospheric treatment stages are used to allow the extensive extraction of rare earths while controlling other radionuclides. Refining of this mineral concentrate is expected to produce approximately 23 000 tonnes per annum of contained Rare Earth Oxide (REO) in a mixed carbonate and 423 t U (1.1 million lb) per year of U_3O_8.

Rare earth elements are commonly associated with naturally occurring radioactive materials. In particular Thorium is often found in the same minerals as rare earth elements making their combined treatment necessary. This paper discusses the metallurgical flowsheet developed for the Kvanefjeld rare earth and uranium deposit located in southern Greenland.

Metallurgical studies have been successful using flotation to produce a high grade concentrate which consists of 14% REO, 0.21% U (0.25% U_3O_8) and 0.8% thorium. Due to the unique nature of the minerals contained within the deposit a customised hydrometallurgical flowsheet was developed to treat the concentrate. The hydrometallurgical flowsheet has been well tested and is capable of producing a high grade mixed rare earth product which is very low in uranium and thorium. A separate uranium oxide product can also be produced using commercially established solvent extraction.

Process engineering designs of both the concentrator and hydrometallurgical plant are well advanced and suitable for Feasibility level studies. The paper and presentation will discuss the customised metallurgical flowsheet and show how uranium is selectively recovered away from the rare earth elements. The issues of Naturally Occurring Radioactive Material (NORM) deportment and strategies for removal and safe disposal are also discussed.

Thorium and uranium separation from Rare Earth complex minerals in Turkey

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In the southern part of Turkey there is a complex minerals deposit which contains rare earth elements (REEs), Ti, Zr, U and thorium. Physical beneficiation operations and hydrometallurgical processes allow to the separation of U along with Zr and Ti. The obtained [REEs and Th] oxalate concentrate is submitted to metathesis in order to convert oxalates to their respective hydroxides. The hdroxides cake is dissolved in acid and thorium is separated firstly by pH regulation, then peroxide precipitation is applied for the final purification of thorium.

Creating a multi-national development platform: Thorium energy and rare earth value chain

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Rare earths and thorium are linked at the mineralogical level. Changes in thorium regulations and liabilities resulted in the development of excessive market concentrations in the rare earth value chain. High value monazite rare earth resources, a by-product of heavy mineral sands mining, constituted a significant portion of global rare earth supply (and nearly 100% of heavy rare earths) until legislative changes, interpretation and enforcement regarding "source materials" in the early 1980s eliminated these materials from the supply chain.

Thorium bearing rare earth by-products from existing non-rare earth mining operations outside of China could potentially meet or exceed global rare earth demand if the existing 'thorium problem' is resolved.

A recently introduced bill in the United States Congress resolves the 'thorium problem' and is structured to create a fully integrated rare earth value chain structured as a multi-national rare earth cooperative.

The presentation will outline the structure and objectives of the legislation that are intended to:

1. utilizing better utilize existing and available rare earth resources;
2. create a Federally Chartered Rare Earth Cooperative (and Thorium Corporation);
3. establish a full value chain for rare earth metals, alloys, magnets and components; and
4. outline that this can/will be funded and owned by multi-national corporations, defense contractors, allied nation agencies, and organizations

More importantly, the bill also creates a federally chartered Thorium Energy and Industrial Products Corporation that will take and hold all thorium and related actinide liabilities from the Rare Earth Cooperative, its owners and its suppliers.

The Thorium Corporation will be given Congressional authority to establish a multi-national corporate platform:

1. to develop industrial uses and markets for thorium (including decay products) that include
    a. alloys
    b. catalysts
    c. medical isotopes
2. for the commercial development of thorium energy systems, that include

a. solid fuels from thorium
b. solid fuel reactor technology
c. liquid fuel reactors technology, including
    i. electric power
    ii. thermal energy
    iii. liquid fuel production
    iv. desalination
    v. nuclear waste reduction (actinide burners)
    vi. hardened and deployable energy systems.

Uranium mining and processing

Building a uranium heap leach project

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Heap leach looks easy, seems inexpensive and easy to design and operate. Is that really how this works? What are the issues to consider using heap leach for a uranium project?

Heap leach or dump leach has been practiced for the recovery of uranium and other metals for many decades, but the technology has advanced and now there are several new important projects underway in uranium mining.

This presentation will look at the steps and important issues required to successfully consider using heap leach for uranium production.

Heap leaching technology is moving the frontier for the treatment

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Dump leaching was used in the past for uranium recovery from low grade uranium ores, mainly in the USA and in Canada. AREVA had in the 1980s some installations in France and Niger.

The renewal of uranium market by the end of 2005 and the advances in the heap leaching technology commonly applied in copper and gold mining industry renewed the interest for considering heap leaching as a promising alternative for the treatment of low grade uranium ores.

Three projects have been launched by AREVA since then. One is the SOMAIR LIXI Project, operated in Niger since 2010 with a production of 800 to1000 tU/year. Another operation was built in Namibia to treat 100,000 t/d of ore from the very low grade Trekkopje orebody to produce about 3000 t U/year. The start up of this operation was delayed due to the current Uranium market conditions and now is in stand-by and maintenance. Finally, the Imouraren Project in Niger, for a nominal production of 5000 tU/year which is now under construction.

A description of these three heap leaching projects including a discussion of the main process development features is presented in this paper.

Implementation of a new milling process at Caetité-Brazil uranium site

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The Caetité-Brazil uranium facility produces about 400 t/yr of U_3O_8 [~340 tU/yr] from an ore averaging 0.29% U_3O_8 [~0.25% U]. The steps of the process consist in: ore crushing, heap leaching with sulfuric acid, uranium separation and purification by solvent extraction with a tertiary amine followed by stripping with a sodium chloride solution and precipitation as ammonium uranate and then dried. A change in the milling process is in course in order to increase the production as well as uranium recovery. Heap leaching will be replaced by conventional tank agitated leaching of the <0.59 mm ground ore slurry in a sulfuric acid medium. Uranium stripping will be carried out with strong sulfuric acid solution in order to increase the efficiency of the operation. After pre-neutralization of the pregnant stripping solution uranium will be precipitated with hydrogen peroxide to have a product of better quality and environmentally friendly.

Ablation - breakthrough technology to reduce uranium mining cost and increase resources

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Ablation Technologies, LLC has developed and patented a revolutionary mining technology termed “ablation”. Ablation is a process using only mechanical forces to upgrade sandstone uranium ores. Uranium bearing sandstone orebodies are formed from a uranium enriched solution flowing through an aquifer until it reached some type of a “red/ox” zone forcing the uranium and other heavy metals to come out of solution. The precipitate forms a thin coating on the sand grains and fills the interstitial space between the sand grains but does no penetrate the sand grains. The ablation process knocks the precipitate off the sand grains using the forces of abrasion, elastic compression and rebounding, much like a mud coated tennis ball will sheds the mud when bounced off the ground, and to some extent, sonic waves. This produces a product which collectively is exactly the same as the ore going in but with all the individual components separated. This allows for disgressionary separation, the most important of which is screening. The uranium and heavy metals report to the finer fractions of the material, typically less than 250 mesh. The larger fractions contain less than five percent of the uranium but 90 to 95 percent of the mass.

The advantages of making an enriched ore are numerous:

• Reduce haulage costs from 90 to 95 percent.

• Reduce milling costs by reducing material handling costs, acid consumption and tailings disposal costs.

• In addition to reducing overall mining and milling costs, the overall recovery of the recourse is increased because the ablation process is so inexpensive, if the material has to be mined it will be ablated and screened. This basically means ore control is significantly reduced, cutoff grade goes to practically zero and overall resource recovery is significantly increased.

• Environmentally, the two major advantages are reduced tailings requirements at the mill site and cleaner waste dumps at the mine site.

This paper will show test results from sandstone uranium ores from all over the world, all getting ninety plus percent recovery in a matter of minutes plus economic comparisons with what has heretofore been referred to as conventional mining practices.

Metallurgical testwork to support development of the Kintyre Project

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The Kintyre uranium deposit is located in the Pilbara region of Western Australia and is jointly owned by Cameco and Mitsubishi. The current indicated resource estimate is approximately 55 million pounds of U_3O_8 equivalent [~21,000 t U] at an average grade of 0.58% [0.49% U]. Due to the high levels of carbonate minerals in the deposit, alkaline leaching was strongly considered as an option to the usually preferred acid route. Following a detailed assessment, the acid option was chosen, with the preferred flowsheet involving an acid leach, followed by solvent extraction and precipitation.

As part of the Kintyre metallurgical investigations, ANSTO Minerals performed an extensive work program, examining numerous aspects of the proposed flowsheet. This included a leach optimisation program, followed by a study determining the effects of sample variability in leaching. Settling, filtration and rheology work on slurries and tailings was performed, as well as testwork to determine the effect of neutralisation conditions on metal precipitation and radionuclide deportment.

In addition, an extensive laboratory and solvent extraction mixer-settler mini-pilot plan campaign was performed to compare the performance of conventional ammonia/ammonium sulphate strip and the non-conventional strong acid strip (400 g/L H_2SO_4) using leach liquor generated from Kintyre ore. The pilot plant involved two campaigns of three days continuous operation using each stripping system, with >99.5% uranium recovery achieved in each campaign.

This paper will present an overview of the key results from the Kintyre leaching and neutralisation testwork undertaken at ANSTO Minerals, and will also outline the performance of the solvent extraction mini pilot plant.

Reguibat calcrete uranium project, Mauritania: Beneficiation upgrades and rapid leaching

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The Reguibat Project is a major greenfields calcrete uranium discovery in Mauritania with 49 Mlbs U_3O_8 [~18,800 t U] in current resources. The mineralisation is amenable to exceptional levels of pre-concentration, and will require relatively small leaching capability. Leach grades will be in the 0.2-0.5% U_3O_8 [~0.17 - ~0.42% U] range.

The area of the deposit is flat lying, and is largely devoid of vegetation. The only people in the region are a small number of nomadic herdsmen.

Resources

The initial JORC compliant resource has been estimated at 49 Mlbs U_3O_8 [~18,800 t U] at average grade of 334 ppm [~283 ppm U].

Subsequent to the resource estimation Aura has completed a successful drilling programme in 2012, but these results are not yet in the current resource. Aura also anticipates additional resources in open extensions to the existing resources, and permits that have yet to be drilled.

Mining

Mining at Reguibat will be straightforward. In the case of the Reguibat Project most of the mineralisation occurs in a single sheet within four metres of the surface. The material is soft and can be readily dug by scrapers. The project will have a strip ratio of less than 0.5.

Beneficiation

Aura's beneficiation upgrade test results for its Reguibat Project have provided exceptional results. 89% of the mass can be rejected while retaining 86% of the uranium. The average concentration of the fine-grained product was 2476 ppm U_3O_8. [~2100 ppm U]. This represents an upgrade factor of 7, achievable using simple beneficiation processes. The high product grade compares with the resource grade of 334 ppm U_3O_8 [~283 ppm U].

Test work completed to date has given concentrate grades of up to 0.34% U_3O_8 [~0.29 % U].

The presence of the uranium mineral, carnotite, in the fine fractions, and the difference in grain size between carnotite and the host rock minerals, explains the positive results to date. There is also potential that this difference may result in even higher grade products by refinement of the size fractioning, and dry cycloning separation may be feasible.

Uranium extraction

The beneficiated Reguibat material was leached independently at ANSTO Minerals using atmospheric alkaline leaching typical of industry conditions. The first leach tests provided excellent results, with 94% uranium extraction within 4 hours, and moderate reagent consumption given high feed grade of material.

The generation of finer size fractions may see a further improvement of the leach results. Typically calcrete uranium projects require 24-36 hours for >90% uranium extraction.

Implications of beneficiation results on a future mining project.

The generation of this high grade product, and the rapid and effective leaching of the uranium from concentrate, now opens up substantial opportunities for a small footprint mining project. The Project flow sheet requires conventional and simple technologies, and it is anticipated that the reduced plant size would have a significant impact on project economics. Both conventional beneficiation procedures and rapid leaching infer a relatively small leaching capacity requirement, and consequently lower capital and operating costs.

Development of the Falea polymetallic uranium project

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The Falea uranium, silver, copper deposit is located in south western Mali, West Africa and is owned by Denison Mines Corp. The current resource estimate is approximately 45 million pounds of U_3O_8 [~17,300 t U] at an average grade of ~ 0.07% U_3O_8. [~0.06% U].The deposit also contains ~37 million Oz Ag and ~70,000 t Cu. The dominant uranium mineral is uraninite, copper is present mainly as chalcopyrite and silver mainly as argentite, and in its native form. Only 5% of the property has been explored to date, and all zones remain open. This paper reports the results of several stages of metallurgical investigations to support ongoing economic studies for the project.

The polymetallic nature of the Falea deposit dictates that there are a range of flowsheet options. The ore contains both carbonate and sulphide mineralisations, which have potential impacts on acid and alkaline leaching, respectively. There is also the need to recover both silver and copper. Two primary flowsheet options were considered:

1) Acid leach of ore to recover uranium / flotation of leach residue to recover sulphide concentrate, treatment of concentrate for Cu and Ag recovery

2) Flotation of ore / alkaline leaching of flotation tails to recover uranium and treatment of flotation concentrate for Cu and Ag recovery.

A number of sub-options were considered for each flowsheet. Test work showed that high recoveries of copper and silver to flotation concentrate were obtained for both flotation of ore or acid leach residue. Uranium extraction was also > 90% for both acid and alkaline leaching. The preferred flowsheet was selected after trade-off studies by DRA.

This paper presents an overview of the various flowsheet options considered, an outline of the preferred flowsheet, and the results and conclusions of on-going engineering and laboratory/pilot studies to refine the preferred flowsheet.

Improvement of the technology of treatment of uranium ores from the Streltsovsky group of deposits

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Production of uranium ores has been carried out in the Russian Federation from the Streltsovsly group of deposits by the Priargunsky Mining and Chemical plant OJSC since 1970. During the exploitation period, the ore bodies most rich with uranium were mined-out. At the present time, the uranium content is about 2 times lower compared to that of the ores produced in 1970–2000. Deterioration of the produced ores quality caused change of the approaches to selection of the treatment method.

A specific stage in the scheme of the uranium ores leaching in pachucas was development of the method that included separation of the initial ore pulp into two streams; treatment of the heading stream, that amounted to 35–70% of the total volume, by sulphuric acid solutions with pH 2 to 4.2 with transformation of the iron, contained in the ore, to the liquid phase; mixture of that stream with the remaining part of the initial ore pulp; oxidation of the dissolved iron to the trivalent form by atmospheric oxygen, which is transferred to the leaching pachucas for concitation; admission of sulphuric acid and manganese dioxide to the joined pulp, and uranium leaching under the pH values in the leached pulp equal to 1.5–2.5 and the redox potential ≥ 450 mV. The developed method enabled decreasing consumption of sulphuric acid and oxidant.

The technical solutions providing significant decrease of expenses for ore treatment were the methods of parcelwise sorting and heap leaching of low-grade uranium ores. All the low-grade ore obtained for treatment passes the screen sizing operation, where it is divided into three streams: slurries with coarseness -5 mm (uranium-enriched) are transferred to the main hydrometallurgic process of reach ores treatment; ore with coarseness -40+5 mm (with uranium content close to the one in the initial low-grade ore) is transmitted to the unit for heap leaching of low-grade ores; and the machine-class ores 200+80 mm and –80+40 mm runs to the separators. The enrichment products are the tailings having uranium content 0 ≤ 0.013% that are removed from the treatment, and the concentrate that is transferred to the hydrometallurgic process of reach ores treatment.

At various times in our enterprise were conducted the pilot works for the block-based in situ underground leaching of uranium ores. The pilot works were carried out within several specially prepared blocks with varying mine technical and mine geological conditions, and they have shown the principal possibility and practicability of the block-based underground leaching for some areas, mainly for re-exploitation of residual reserves after excavation of the principal volumes of the Uranium ores by traditional methods.

This way, the separately developed and implemented technical improvements formed a complex mining and chemical technology providing optimal composition of the classical methods of hydrometallurgy, heap leaching, underground leaching, and roentgen-radiometric enrichment that gives the possibility to reduce the cost of the uanium peroxide-oxide produced.

Solvent extraction of uranium: Towards good practice in design, operation and management

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Uranium solvent extraction, USX has been applied commercially for recovery and concentration for over 60 years. Uranium in acidic liquor, which is prepared following ore leaching, solid/liquid separation and clarification, can be treated through a sequence of operations; extraction-scrubbing-stripping, to obtain purified liquor, and hence precipitation of marketable products.

USX has dominated the primary uranium industry as the preferred technological route for recovery of uranium into converter grade yellowcake or Uranium Ore Concentrate.

The practices of design and operation of USX facilities has found renewed interest as new mines are developed following decades of industry dormancy. Development of the Olympic Dam and Honeymoon operations in Australia has lead to innovative design and operation of pulsed columns technology in applications of solvent extraction.

This article seeks to outline principles of design and operation from the practitioner's perspective. The discussion also reviews historical developments of USX applications and highlights recent innovations. This review is hoped to provide guidance for technical personnel who wish to learn more about good practices that leads to reliable USX performance.

Advances in exploration and uranium mineral potential modelling - 2

Forecasting sandstone uranium deposits in oil-and-gas bearing basins

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The interrelation between oxidation and reduction processes in the carbonaceous strata of Paleogene age was first studied in the 1950s in deposit of the Fergana depression. The presence of pre-ore and post-ore epigenesis of petroleum series was established. Part of uranium mineralization was found to be covered with fluid oil. In the middle of the 1960s in the Sabirsay deposit (Uzbekistan) in primary red-coloured continental sediment of Cretaceous age were studied pre-ore reduction changes, which caused economic uranium mineralization in contrasting geochemical barrier. Further research showed that multidirectional epigenetic processes had changed repeatedly. Later, in the 1970s, American geologists studying uranium deposits in the oil-and-gas bearing Texas Plain reached similar conclusions. From their point of view, in the Benevides deposit the main zones of mineralization tend to be located near the boundary where the zones of oxidation in the strata wedge in, developing in epigenetically reduced formations. A second post-mineral reduction was registered in a number of rock bodies.

The complexity of the processes is determined by the double role of hydrocarbon fluids and the products of their dissolution. On the one hand, bituminization of permeable strata as well as pyritization, chloritization, dolomitization and other alterations associated with it create favourable geochemical conditions of a reducing character for a subsequent concentration of ore and nonmetal raw materials. On the other hand, intrusion of bitumen and its dissolution in the aeration zone leads to the burial of the mineralization which formed earlier and disappearance of all traces of its formation (epigenetic oxidation zoning). Thus forecasting and subsequent prospecting become impeded.

The established sequence of epigenetic alterations allows us to carry out specialized mapping in productive regions, uncovering hidden parts of epigenetic oxidation zoning and “buried” mineralization. Such work was carried out within the limits of the Ordos oil and gas basin and adjacent structures, where a set of paleontological maps and cross-sections was created. They reflect the relationship between hydrogenic redox processes over long periods in the geological history of the region.

Comparative analysis of the sequence of multidirectional epigenetic alterations in sedimentary basins in Central Asia and adjacent territories was instrumental in forming the overall picture of uranium ore genesis complicated by the intrusion of various reducing agents. The methods used in the study of epigenetic alterations in the formations of oil and gas sedimentary basins were developed on uranium rock bodies in Central Asia. These methods were successfully applied during forecasting on the fringes of oil-and-gas basins across the whole of the Asian continent. They made it possible to carry out metallogenic zoning of a large territory in terms of uranium and at the same time to estimate the role of hydrocarbons. The interrelation of epigenetic processes determines the distinctive characteristics of ore genesis in different parts of oil and gas basins. Their detection by means of mapping creates the necessary conditions for determining the prospects for both local regions of subsoil assets and large geological structures.

Uranium exploration in Mongolia: A major discovery in the Gobi Desert

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Uranium exploration in Mongolia started with Russian and Mongolian endeavours from 1950s, searching for volcano-sedimentary Strelsovska type deposits as well as sandstone hosted type within proximal sedimentary cretaceous basins. During the 1970s to the 1990s, systematic geological surveys allowed to target attractive areas with about 100 significant uranium occurrences of various mineralization types.

In 1997, AREVA with its COGEGOBI subsidiary started uranium exploration in Mongolia. It was the first company to believe in the potential of the wide distal Cretaceous sedimentary basins of south-eastern Gobi Desert. Over the past 12 years, work has been focused on the Dornogobi Province, approximately 550km southeast of Ulaanbaatar, in the Uneget and Zuunbayaan sub-basins, in which two deposits have been discovered in the Sainshand Formation (Upper Cretaceous). The first one is the Dulaan Uul deposit in the Uneget basin, a typical roll-front type deposit with 6500 t of uranium resources at 150 ppm U average grade, officially reported in 2011. The second one, located about 20 km east, is Zoovch Ovoo deposit with 56,500 t of uranium resources at 223 ppm U, reported in 2013 (both based on a 75 ppm U cut-off).

The Zoovch Ovoo deposit is likely to be the only world size deposit discovered during the last decade. Story began in 2008 within Zoovch Ovoo exploration license covering part of the Tsagaan Els endorheic depression, which roughly coincides with Zuunbayaan sub-basin, limited to the north by the NE-SW left strike slip Zuunbayaan regional fault. First reconnaissance works highlighted prospective sand reservoirs constituted by cycles of unconsolidated lacustrine and alluvial sediments with redox contrast. In 2009, the first mineralized impacts were discovered, and 30 km of oxidization fronts were delineated. Between 2010 and 2012, an extensive development campaign was performed on the whole mineralized bodies covered by a 200×200m up to 100×100 m drilling grid. This extensive development work confirmed the high potential of the deposit

Zoovch Ovoo deposit is a major high tonnage low grade sedimentary-hosted roll front type deposit. It consists of a complex system of partly over-imposed elementary sub-rolls of irregular shapes that built a quite atypical sub-massive tabular looking ore body. The recognized mineralization, comprising three main enriched blocks (SE, N and W), covers a WNW-trending area of approximately 7km × 3.5 km, and ranges up to 40 m thick, with an average thickness of about 15 m. It occurs at depths ranging from 100 m to 230 m below the surface. The mineralization commonly consists in poorly expressed uranium oxide generally associated with pyritized organic matter fragments, coffinite, phosphocoffinite and uranothorite at the redox interface. The deposit is affected by a network of N60 to N70 striking minor normal faults (only few meters of vertical slip) suspected to constrain the circulation of oxidizing fluid flows coming from the South. However, these faults seem not to significantly affect or control the geometry of the ore bodies. In 2014, the project enters into a prefeasibility study phase for an in-situ recovery (ISR) exploitation method.

Drill site selection process using geophysical (seismic, EM, magnetic) surveys and regional geochemical uranium deposit vectors within the Keefe Lake Uranium Property and its vicinity – Athabasca Basin, Saskatchewan, Canada

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This study was initiated at the request of Athabasca Uranium Inc. of Vancouver, Canada. The area of investigation is around 4000 km^2 and includes the Keefe Lake (KL) property of the Company, located at the southeastern flank of the Athabasca Basin in Northern Saskatchewan. The intention of the program was multi-fold: to establish trends of regional uranium mineralization vectors, and incorporate these findings into the multidimensional integrated analysis of the currently available KL data set with an aim of providing an advanced priority ranking of drill hole selection process for the upcoming drilling programs. The information adapted for this investigation includes data from 450 boreholes, as well as drilling results of a recent KL prospect; data obtained from 114 Assessment Reports of the Saskatchewan Mineral Assessment Data Base (SMAD), and the analyses of 4 high-resolution 2D seismic profiles within the claims of Athabasca Uranium Inc. To establish more effective spatial perspectives, the results of the regional lithology study (investigating alteration, graphitic, structural, pelitic, and pegmatitic features) were displayed along with the EM conductors, whereas basement lithology and faults were obtained from the Geological Atlas of Saskatchewan (southeastern segment of the Athabasca Basin). The regional investigation also included a study of the depth variations of the unconformity (UC), spatial vectors in geochemistry of the indicative path finder elements (U, Co, Cu, Ni, Pb, Zn, As, and B), and also the clay mineralization (illite and kaolinite) indicative of uranium mineralization related to alteration zones. Local area investigations consisted of integrating the AEROTEM (2009) and VTEM (2013) airborne EM data, the associated magnetic observations, and computation of relevant attributes.

The comprehensive synthesis of the above geophysical information incorporated all the available and derived geological perspectives. The high-resolution 2D seismic data defined several highly favorable structural features in the basement; with some extending into the overlying sandstones. Close correlation between features of potential field data anomalies and the seismic signatures, together with the geochemical uranium deposit vectors, established the north-western corner of the property as a significant site for drilling.

The successful application of modern exploration techniques to previously explored areas in the Athabasca Basin, Canada

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Several project areas within the Athabasca Basin of northern Saskatchewan, Canada, which were explored in the 1970s and 1980s have had recent discoveries due to the application of modern exploration techniques and the evolution in the understanding of unconformity uranium deposit models. The Otis, Barney and Opie showings of the Maurice Bay area and the Patterson Lake deposits on the west side of the basin, and the Roughrider, Midwest A and Phoenix deposits on the east side of the basin are all recent discoveries in areas that were explored in the past.

New showings in the Maurice Bay area on the northwest shore of Lake Athabasca were discovered mainly by the application of the Millennium basement-hosted unconformity model in conjunction with a refined ground gravity survey which easily delineated areas of less dense hydrothermal alteration within Proterozoic lithologies. Previous exploration methods relied heavily on surface prospecting of glaciated terrain and tracing uraniferous boulders back to their source, or EM surveys which delineated graphitic conductors.

The Patterson Lake South (PLS) deposits were found by a combination of the age-old technique of following a train of uraniferous boulders to its source along an EM conductor and by a refined radon sampling system which led to the quick discovery of a series of mineralized pods under Patterson Lake (the zone may be continuous but this has yet to be proven). The new radon surveys have a quick turnaround time (1 day), are easy to collect and are reproducible. This survey appears to work better in lakes when samples are collected from under the ice in winter. Previous exploration in this area was concentrated to the north within the Athabasca Basin.

The Midwest A deposit was found along the NNE extension of the Midwest trend within a grid of previous drill holes completed in the early 1980s. A mixture of lithogeochemistry and a ground resistivity survey provided the target for the drill program. This deposit was found at the intersection of the N030E Midwest structure and a cross-cutting N070E structure and is located at the unconformity.

The Roughrider deposit was also found along the NNE extension of the Midwest structure using lithogeochemistry from historic drill holes, and is also located at the intersection with a cross-cutting N070E structure. The illitic alteration halo in the overlying sandstone in the historic drill hole was similar to that found above the Millennium deposit.

The Phoenix deposit was discovered on the southeast side of the Athabasca Basin on a project previously worked since the 1970s. Several sub-economic zones were discovered on the project by previous explorers, but the use of a detailed resistivity survey along a prospective trend based on the McArthur River deposit model (footwall of a quartzite ridge) provided three well-defined drill targets that led to the discovery.

Comprehensive geophysical survey technique in exploration for deep-buried hydrothermal type uranium deposits in Xiangshan volcanic basin, China

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According to recent drilling results, uranium mineralization has been found underground more than 1000 m deep in the Xiangshan volcanic basin, in where uranium exploration has been carried out for over 50 years. This paper presents a comprehensive geophysical survey technique, including audio magnetotelluric method (AMT), high resolution ground magnetic and radon survey, which aim to prospect deep-buried and concealed uranium deposits in Xiangshan volcanic basin. Based on research and application, a comprehensive geophysical technique consisting of data acquisition, processing and interpretation has been established. Concealed rock and ore-controlling structure buried deeper than 1000 m can be detected by using this technique. Moreover, one kind of anti-interference technique of AMT survey is presented, which can eliminate the interference induced by the high-voltage power lines. Result of AMT in Xiangshan volcanic basin is demonstrated as high-low-high mode, which indicates there are three layers in geology. The upper layer with high resistivity is mainly the react of porphyroclastic lava. The middle layer with low resistivity is metamorphic schists or dellenite whereas the lower layer with high resistivity is inferred as granite. The interface between middle and lower layer is recognized as the potential zone for occurrence of uranium deposits. According to the corresponding relation of the resistivity and magnetic anomaly with uranium ore bodies, the tracing model of faults and interfaces between the different rocks, and the forecasting model of advantageous area for uranium deposits have been established. In terms of the forecasting model, some significant sections for uranium deposits were delineated in the west of the Xiangshan volcanic basin. As a result, some achievements on uranium prospecting have been acquired. High grade economic uranium ore bodies have been found in several boreholes, which are located in the forecasted zones.

Mining of low grade ore in carbonate rock

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Uranium mining has commenced in the carbonate hosted Tummalapalle Uranium Project, Andhra Pradesh. Uranium mineralization is hosted in carbonate rock. The underground mine is to be accessed by three declines along the apparent dip of the ore body. The central decline will be equipped with a conveyor for ore transport and the other two declines are to be used as service paths. The ore is treated in a pressurised alkali leaching plant close to the mine. The mine processes 2 000 t ore/day and expansion of the mine and processing plant has been planned to augment uranium production. This paper will discuss experience in the mining of low grade ore in carbonate rock in India.

Application of resin in pulp technique for ion exchange separation of uranium from alkaline leachate

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The hydrometallurgical process for the recovery of uranium from different ores uses ion exchange (IX) technique for the separation of dissolved uranium values. Conventionally, the IX process is carried out on leach solution obtained after the filtration or counter-current decantation of the leach slurries. Amongst the two types of leach pulps generated in uranium ore processing, viz acidic and alkaline, the latter one consists of predominantly fine-size pulps of higher viscosity, thus making the solid-liquid separation an arduous task. Sustained research for improvising the efficiency of various unit operations in the uranium process flowsheet have resulted in advent of new generation resins which are mechanically re-silent, posses higher exchange capacity thereby enabling separation of dissolved uranium ions from the leach pulps directly.

Some of the prominent low-grade uranium ore deposits in India are hosted in acid consuming gangue matrix. These ore deposits necessitate fine grinding as well as application of alkaline leaching for the dissolution of uranium values. The leach pulps analyse 500 – 600 mg/l of U3O8 and contain total dissolved solutes (TDS) to the extent of about 50 g/l. Analysis of the characteristics of the leach pulp indicated suitability of resin-in-pulp technique for the separation of uranyl carbonate anions from the leachate. This paper describes the results of the RIP test work on alkaline leach slurry using various commercially available strong base anionic exchange resins. Parametric variation studies were conducted to establish the adsorption isotherm and sorption kinetics followed by elution of loaded uranium. Based on these results semi-continuous experiments on "carousel" mode were carried out. The results indicate superiority of gel type polystyrene based resins grafted with quaternary ammonium ion in comparison to the macro-porous resins. Semi-continuous counter-current extraction and elution tests indicated that about 98% of the dissolved uranium values can be recovered during the loading process and practically the entire loaded uranium can be eluted using NaCl eluant. Integration of the RIP followed by precipitation of dissolved uranium as uranium peroxide helps in overcoming processing difficulties associated with slimy diuranate precipitates.

Uranium from unconventional resources

Uranium extraction from phosphates: Background, opportunities, process overview and way forward for commercialisation

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Socio-economic up-gradation for major part of global population, particularly in developing countries will call for large growth of electricity demand. The fact that 2 billion of world's 7 billion population do not have access to electricity justifies this growth projection. Environmental concern along with increasing demand for other essential ingredients for improved standard of living like affordable food, water, healthcare etc. will encourage large growth in nuclear technology utilisation.

While conventional uranium resources will continue to be the major source for meeting the resultant surge in uranium demand, there is a need to look forward beyond this. Inherent advantage of uranium extraction from phosphate (UxP) is that it is the by-product of phosphate fertilizer industry. There is no need for separate mine development, ore processing or tailing disposal. Feed phosphoric acid is available from phosphate industry in ready to use condition. UxP thus enables recovery of energy resource otherwise lost for ever besides making the fertiliser cleaner. UxP has also potential to make phosphate industry economically more viable and socially more acceptable. Phosphate industry also benefits from cleaner return acid making operation of downstream plant simpler and cleaner besides possible value addition of the product basket

Due to low uranium concentration in source material, normally in the range of 80 – 150 ppm, and several process and engineering issues inherent to this relatively difficult separation process, large scale commercial deployment will depend on development of commercially viable technology. Though the process has been utilised for production of uranium in the past, before setting up a new commercial facility, it is imperative that its techno-economic feasibility be established considering all related aspects of the proposed facility. This will address the difficulties encountered in earlier plants, problems related to wide variation in physical and chemical characteristics of phosphate ore / phosphoric acid and ensure cost effectiveness by fine tuning the process integration, equipment selection and optimisation of process parameters. To improve success rate of programme implementation, this is best done by using a proven tool for managing life-cycle of 'technology development to commercialisation' and by following a systematic approach towards feasibility study.

Proven approach is to develop competencies in all related field of chemistry, process, technology and commercialisation by successively engaging in research, development, demonstration and deployment. Engaging concerned professionals in these activities and systematic transition from one activity to the next enables all stakeholders to get familiarised with related challenges and ways to overcome them. The generated institutional knowledgebase helps in timely project completion as well as achieving desired performance from the installed facility. During plant operational phase, this institutional knowledgebase helps in improvement of several performance parameters like energy efficiency, resource consumption, capacity utilisation and thus overall economy of operation.

Uranium and REE recovery from Florida phosphates – Looking back and going forward

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Uranium recovered during the production of phosphoric acid represents a significant source of nuclear fuel as the gap between uranium supply and demand is expected to grow. The phosphate industry in Florida supplied uranium to both the defense and energy sectors in the past, but market conditions ended the recovery process. Currently, the uranium is retained in the phosphoric acid and the granulated fertilizer products, diammonium and monoammonium phosphate, and dispersed on farm fields as a trace element in blended fertilizers. This represents a loss to the nuclear fuel cycle that will never be recovered. In an era of heightened awareness of sustainability and increasing pressure to reduce greenhouse gas emissions, market conditions and social factors may converge to create favorable conditions for uranium recovery to resume. However, the future may not resemble the past as uranium concentrations are lower in the newer mining areas and ion exchange challenges solvent extraction for the extraction technology of choice.

New factors will also influence both the economic decision to resume recovery operations, as well as the recovery technology. Rare earth elements (REE) are also present in the processing streams at recoverable levels, and can be co-extracted with uranium using the proven solvent extraction method. REE are vital to the phosphor industry, green energy development, and technology advances in many fields. However, the world has limited REE resources, and the recovery of REE from many of these resources is both economically challenging and environmentally troublesome. Phosphate as a secondary REE resource has a great potential to fill this gap. World annual phosphate rock production has surpassed 200 million tons, representing 60,000 tons of unrecovered REE assuming an average concentration of 300 ppm. In the case of Florida, REE in the phosphate ore reports to four mining and processing streams, with approximately 10% to flotation tailings, 30-40% to waste clay, 35-40% to phosphogypsum (PG), and 15-20% to phosphoric acid. Due to the concern about disposal of thorium-containing wastes, the Florida phosphate industry stepped back from their effort to recover REE from flotation tailings in the past. Now there is even greater concern about potential disruption of the REE supply, such that the government, industry, and academia are partnering to develop economical extraction technologies. At the same time, we must develop recovery flowsheets that adhere to the regulatory framework of the US EPA for phosphogypsum management due to its radium content, and the US Nuclear Regulatory Commission for uranium as U_3O_8 prior to enrichment, and thorium that could approach or exceed the concentrations meeting the “source material” definition.

Development of a new process for the selective extraction of uranium from phosphate rocks

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Commercially available phosphoric acid, obtained by action of sulphuric acid on calcium phosphate rocks (wet process phosphoric acid pathway – WPA), contains low concentration of uranium (30 to 300 ppm of U_3O_8) [~25 to ~250 ppm U] with high concentrations of iron (several g/L). Because of the high toxicity of uranium, the matter of removal uranium from WPA in terms of health safety has been considered at different times. In addition the worldwide uranium resources associated with phosphorite deposits are estimated at approximately 9 Mt which is an important secondary source of uranium for nuclear applications.

Liquid-liquid extraction processes have been developed during the seventies in order to recover uranium as a by-product of industrial phosphoric acid. The production ceased in the late 1990s due to the decline in the price of uranium. Further studies are in progress at CEA with AREVA since 2009 to propose a new extracting molecule improving extraction performances of uranium and greater selectivity for uranium compared to other cationic impurities such as iron, the main impurity.

Parametric experiments in batch conditions led to select and optimize a new design of bitopic extracting molecule which shows a high extraction of uranium (VI) with a very high selectivity versus iron(III) from 5M H_3PO_4. Extraction isotherms were acquired and helped to determine the stoichiometry of the complexes formed in organic phase. Kinetic studies were also conducted in a turbulent thermostatic cell in order to verify that the chosen molecule is compatible with an industrial process. These acquisitions enabled the development of an extraction model for uranium and iron, taking into account the deviations from ideality of the aqueous phase. This model was implemented in the PAREX simulation code, developed by CEA to simulate the operations of solvent extraction in continuous laboratory contactors. A process flowsheet was proposed for the selective extraction of uranium from phosphoric acid solution and successfully implemented, on the laboratory platform PROUST at CEA Marcoule, using a synthetic solution first and then a solution of a genuine industrial phosphoric acid.

Uranium in phosphate rocks and future nuclear power fleets

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According to almost all forward-looking studies, the world's energy consumption will increase in the future decades, mostly because of the growing world population and the long-term development of emerging countries. The effort to contain global warming makes it hard to exclude nuclear energy from the global energy mix.

Current light water reactors (LWR) burn fissile uranium (a natural, finite resource), whereas some future Generation IV reactors, as Sodium fast reactors (SFR), starting with an initial fissile load, will be capable of recycling their own plutonium and already-extracted depleted uranium. This makes them a feasible solution for the sustainable development of nuclear energy. Nonetheless, a sufficient quantity of plutonium is needed to start up an SFR, with the plutonium already being produced in LWR. The availability of natural uranium therefore has a direct impact on the capacity of the reactors (both LWR and SFR) that we can build.

This paper discusses the correspondence between the resources and the nuclear power demand as estimated by various international organisations.

Uranium is currently produced from conventional sources. The estimated quantities of uranium evolve over time in relation to their rate of extraction and the discovery of new deposits. Contrary to conventional resources, unconventional resources – because they are hardly used – also exist. These resources are more uncertain both in terms of their quantities and the feasibility of recovering them. Recovering uranium from seawater would guarantee a virtually infinite resource of nuclear fuel, but its technical and economic feasibility has yet to be demonstrated, and huge advances need to be achieved in this direction. According to different publications on phosphate reserves, the potential amount of uranium recoverable from phosphates can be estimated at around 4 MtU. Furthermore, the production of uranium as a by-product of phosphate is determined by the world production of phosphoric acid. Uranium recovery as a by-product of phosphate rocks could be competitive for the moment, but limited at the most to 10 kt U per year, i.e. less than 20% of current world demand. The only way to lift the constraint of capacity production is to produce uranium as a primary product of phosphates. Unfortunately, this solution is very unlikely due to its high unit cost.

In line with these considerations, the correspondence between the estimated resources and the forecast energy scenarios is examined, first with the current type of light water reactors which burn uranium, and secondly with a mixed fleet with both light water reactors and fast reactors which use plutonium.

The giant Alum Shale polymetallic deposits of Jämtland, Sweden – a major potential low cost supplier of uranium for the future

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Jämtland County in Sweden contains approximately 11% of global uranium resources which are compliant with either the Toronto or Australian Stock Exchange codes. A widespread unit through northern Europe, the Alum Shale host rock has been a historic source of alum, oil and uranium. Exploration for uranium in the 1970s located several tens of square kilometres with the development of relatively thick Alum Shale in Jämtland.

The Alum Shale in Jämtland is a fine-grained, carbonaceous schist. The groundmass comprises quartz, feldspar, white micas and carbon. The uranium, molybdenum and vanadium have been shown to be concentrated in the organic/mica matrix. Nickel and zinc are preferentially concentrated within the pyrite grains.

Total mineral resources in the district are approximately 5 billion tonnes, at a grade of approximately 136 ppm U (160 ppm U_3O_8). Aura Energy Ltd, one of the holders of permits in the district, has 2.35 BT @ 131 ppm U (155 ppm U_3O_8). The average grades of other metals present in the resource are: molybdenum 207ppm, vanadium 1,519ppm, nickel 316ppm, and zinc 431ppm.

These polymetallic resources are exceptionally large, and Aura's uranium resource constitutes the second largest undeveloped resource anywhere in the world. Black schists are typically considered to be challenging metallurgically. Hence the Alum Shale has been previously considered a potential high cost source of uranium. The primary issue has been the high cost associated with acid reagent to extract the uranium. Recently the pyrite has been recognised as a possible source of acid within the ore itself. Bacterial leaching to catalyse the oxidation of pyrite was demonstrated to be the most effective process for generating this acid.

The Jämtland Alum Shales appear ideally suited to bioleaching because of the level of pyrite present, and the lower proportion of acid consuming minerals such as carbonates. Aura Energy has established leach extractions of up to 85% of the uranium, and 66% of the nickel indicate the suitability of the Shale to this technology.

These extractions can be obtained at coarse crush sizes up to 25 mm. This result demonstrated the potential to utilise a coarse-crushed low-cost bacterial heap leach operation for the Häggån material. Bacterial heap leaching is widely applied in the copper industry, particularly in Chile.

A scoping study completed by Aura Energy has suggested that a notional 30 Mtpa operation would produce approximately 3077 tU (8 Mlbs of U_3O_8) per annum, plus other metals. Such a project has a Net Present Value of $1.85 billion, and a rate of return of 49%.

Operating costs estimated by the Scoping Study, after co-product credits, are within the lower quartile of the WNA uranium producers cost curve. Aura Energy has estimated operating costs at smaller throughputs between 3.5 and 7.5 Mtpa, and these remain below $25.00/lb.

Uranium from coal ash: resource assessment and outlook on production capacities

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Sixty years after first investigations on producing uranium from coal ash, this uranium source of supply has regained a strong interest. While the world consumption of coal keeps rising, several papers tackle radiological health issues. They actually point out big uranium-rich coal-ash disposals that coal-fired power plants generate. These disposals could be washed of their radiological hazards as they suggest. Besides, uranium-bearing coal deposits are also viewed as a potentially economic source of supply for the nuclear fuel cycle. Uranium as a by-product of coal used to remain sub-commercial but recent news releases mention the promising pre-feasibility achievements of Sparton Resources. This Canadian company should soon operate the first ash leaching plant in over 40 years. Furthermore, it has shown significant production capacities.

While uranium production from coal ash has remained sub-economic for decades, the emergence of new projects is refreshing the question of resource assessment: how much coal ash do we have? Are they all rich in uranium? Can we produce it all? Sparton has announced that the Yunnan region (China) could produce 145 tU a year from 3 coal-fired power plants. Although these three coal power plants could almost be enough to supply a nuclear one, it is hard to tell how many of the 2300 world power stations could provide uranium. The present study proposes to estimate both the world resources and the production capacities of uranium as a co-product or a by-product of coal.

Based on the distinction between uranium-rich and uranium-bearing coal deposits, a review of some potentially promising ore deposits is covered. A parametric study stresses the main uncertainties in the resource assessment, sometimes outlining what could be the bottlenecks of developing projects. Finally, our technical and economic conclusion is thus established, drawing an outlook on how the reserves of uranium from coal ash could vary.

Overview of the nuclear fuel resources – seawater uranium recovery program sponsored by the U.S. Department of Energy

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For nuclear energy to remain a sustainable energy source, there must be assurance that an economically viable supply of nuclear fuel is available. One major goal of the Fuel Cycle Technology Research and Development (R&D) Program in the United States Department of Energy (DOE), Office of Nuclear Energy (NE) is to develop sustainable fuel cycles options. The development of technology to recover uranium from seawater has the potential to fulfill this program goal. Seawater uranium recovery technology is identified in the U.S. DOE NE Roadmap as an area most appropriate for federal involvement to support long-term, "game-changing" approach.

Seawater contains more than 4 billion metric tons of dissolved uranium. This unconventional uranium resource, combined with a suitable extraction cost, can potentially meet the uranium demands for centuries to come. The challenge, however, is the low concentration of uranium in seawater – approximately 3.3 ppb. A multidisciplinary team from the U.S. national laboratories, universities, and research institutes has been assembled to address this challenge.

Polymeric adsorbents materials containing amidoxime ligands, developed at the Oak Ridge National Laboratory (ORNL), have demonstrated great promise for the extraction of uranium from seawater. These ORNL adsorbents showed adsorption capacities for the extraction of uranium from seawater that exceed 3 mg U/g adsorbent in testing at the Pacific Northwest National Laboratory Marine Sciences Laboratory. A key component of this novel technology lies in the unique high surface-area polyethylene fibers that considerably increase the surface area and thus the grafting yield of functional groups without compromising its mechanical properties. In addition, high surface area nanomaterial adsorbents are under development at ORNL with the goal of increasing uranium adsorption capacity by taking advantage of the high surface areas and tunable porosity of carbon-based nanomaterials.

Structure-based computational design methods are being used to identify more selective and stable ligands. The most promising candidates are being synthesized, tested and evaluated for incorporation onto a support matrix. Fundamental thermodynamic and kinetic studies are being carried out to improve the adsorption efficiency, the selectivity of uranium over other elements, and the durability of the adsorbents. Understanding the rate-limiting step of uranium uptake from seawater is essential in designing an effective uranium recovery system.

Economic analyses have been used to guide the technology development and highlight what parameters, such as capacity, recyclability, and stability, have the largest impact on the cost of extraction of uranium from seawater. Initially, cost estimates by Japanese researchers for extraction of uranium from seawater with braided polymeric fibers functionalized with amidoxime ligands were evaluated and updated. The economic analyses were subsequently updated to reflect the results of the U.S. program while providing insight for cost reductions in the adsorbent development through "cradle-to-grave" case studies for the extraction process.

Cost analysis of seawater uranium recovered by a polymeric adsorbent system

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In tandem with its adsorbent development and marine testing efforts, the United States Department of Energy, Office of Nuclear Energy, routinely updates and expands its cost analysis of technologies for extracting uranium from seawater. If informed by repeatable data from field tests, a rigorous cost analysis can convincingly establish seawater uranium as a “backstop” to conventional uranium resources. A backstop provides an essentially unlimited supply of an otherwise exhaustible resource. Its role is to remove the uncertainty around the long-term sustainability of the resource. The cost analysis ultimately aims to demonstrate a uranium production cost that is sustainable for the nuclear power industry, with no insurmountable technical or environmental roadblocks. It is also a tool for guiding further R&D, identifying inputs and performance factors where further development would offer the greatest reduction in costs and/or uncertainties.

A life cycle discounted cash flow methodology is used to calculate the uranium production cost and its uncertainty from the costs of fundamental inputs including chemicals and materials, labor, equipment, energy carriers and facilities. The inputs themselves are defined by process flow models of the adsorbent fabrication and grafting, mooring at sea, recovery, and elution and purification steps in the seawater uranium recovery process.

Pacific Northwest National Laboratory (PNNL) has carried out marine tests of the Oak Ridge National Laboratory amidoxime grafted polymer adsorbent in natural seawater. Multiple test campaigns demonstrated that after 60 days of immersion the uranium uptake averaged 3090 ± 310 µg U/g of adsorbent. Past ocean experiments on similar material by the Japan Atomic Energy Agency (JAEA) demonstrated that the adsorbent may be used in the sea six times before being replaced, with 5% uptake degradation per reuse. The mooring and recovery system envisioned for the adsorbent is similar to one proposed by JAEA for its braided polymers, but with costs reduced by eluting the uranium offshore and adopting a lighter weight mooring system. Both measures reduce the number, cargo capacity and energy use of the ships required to service an offshore field.

Given these parameters, the cost of producing uranium from an offshore adsorbent field with a capacity of 1200 tonnes U per year is $640/kg U. When uncertainties in input costs and adsorbent performance are considered, the 95% confidence interval is $470 to $860/kg U. Costs associated with adsorbent production, primarily for purchasing or fabricating chemicals, account for 56% of the $640/kg U total. Mooring and deployment costs contribute 37% and are dominated by anchoring system and work boat purchase and operations. Uranium uptake is the key cost driver: if 60-day uptake reached 4890 µg U/g of adsorbent, the ORNL adsorbent saturation capacity found in the PNNL experiments, the uranium production cost would drop by 30% to $445/kg U. If the durability of the adsorbent could be improved, so that capacity loss was limited to 3% per reuse over 12 uses, the cost would drop by a further 18% to $360/kg U. This corresponds to the peak uranium spot price reached during the 2007 boom.

Closing keynote papers

A market in transition

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In March 2011, the uranium market was hit hard by the Fukushima disaster, which stalled the growth in nuclear reactor requirements and is still having a profound effect today with zero Japanese nuclear reactors in operation. To make matters worse, the evolving shale gas revolution has made it difficult for many U.S. merchant nuclear plants to compete with gas-fired plants, leading some of these plants to shut down early.

As Japanese nuclear plants remain offline, uranium inventories have been building, with the market currently sitting on excess supply of about 14 million pounds U_3O_8 [~5,400 t U] for 2014. Due to the current oversupply situation, uranium prices have moved below where the true equilibrium likely should be, especially given that 50% of current uranium production is at a full cost above the current spot price of $35 per pound [91 USD/kg U].

Although new uranium projects are planned over the next few years, they are not assured of coming online unless market conditions improve. And with more production cutbacks eminent due to the unfavorable economics for some operating and planned uranium mines, the market could find itself in a volatile situation in only a few years with Chinese nuclear generation expected to grow rapidly, and new countries such as the U.A.E. and Saudi Arabia advancing their nuclear power programs. In fact, the pullback in both the spot and long-term uranium prices over the past three years could again create a problem for the market over the next few years since there is currently less impetus to expand uranium production or engage in exploration.

With global nuclear reactor requirements still increasing significantly in the medium- to long-term, more requisite new production will have to be brought online, especially with the U.S.-Russia HEU deal having ended last year, which contributed to up to 24 million pounds of U_3O_8 [~9,200 tU] feed annually. In addition to transitioning from an inventory-driven market to a production-driven one, a significant component of uranium production is linked to regions of the world with higher than average geopolitical risk, which could make the market more vulnerable to potential future supply disruptions.

Theory to practice: The scope, purpose and practice of prefeasibility studies for critical resources in the era of sustainable development

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While the fundamental goal of a Pre-Feasibility Study, (PFS) to justify the technical, financial, social and environmental case for a given mining and/or processing project, remains unchanged, the way this goal is met in the era of sustainable development must change to meet a wide range of new appraisal criteria against which "feasibility" can be determined. This paper addresses what a new look PFS might need to contain. The change drivers for sustainability include:

- Whole Basin Resource Management - new upstream approaches to estimating and managing resources across whole basins, such as sedimentary basins containing oil, gas, coal, phosphate, uranium on Rare Earth Elements

- Comprehensive Extraction - new comprehensive extraction technologies based on integrated flow-sheets designed to extract all resources of interest from a single ore body in the best economic, social and environmental manner, as for example, extraction of P, U, Th, REE, etc. from a P ore body

- Life-cycle Resource Management (Primary, Secondary, Circular) – based on models of criticality and substitutability, life-cycle resource management requires the approach to all resource management to be similar to that required for non-substitutable resources such as phosphates – even when substitutes are available

- Waste Hierarchy – progressive / step-wise transformation of waste to resource, with a hierarchy of waste itself premised as i. prevention (or transformation to resource), ii. minimisation, iii. reuse; iv, recycling, v. disposal.

- Stakeholder Engagement and Social Licensing – a project can no longer be regarded as either safe or sustainable if it does not earn and retain a social licence to operate, based on stakeholder communications and engagement. Key determinants of success will be the aggregate beneficial or detrimental impact on Food, Energy and Water (FEW) security.

The operational fulcrum of these changes, and hence the core of the new look PFS, is that the driver of sustainability is the resource set itself, such that once ground is broken or holes are drilled, the return from that activity is optimised across all resources, not just a single target. In short, the process is resource driven, and hence the key determinant in the PFS is to work out the best strategic solution to managing such resources rather than taking the project-based tactical solution of selecting single targets. This change of approach in one key way facilitates the PFS task, because the other key resources required to succeed, human and financial, become alternate facets of the same project, and feasibility is demonstrated when they come into congruence. Hence in a People, Process, Purpose

approach, Human Resources must be suitably capitalised, as must Process Solutions (whether for mining or processing) to meet Triple Bottom Line Purposes – economic, social and environmental.

Positioning for a positive future: Cigar Lake starts production

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Closing industry keynote paper from Tim Gitzel, CEO, Cameco Corporation.

Posters

Regulatory preparations towards commencement of uranium mining and processing of radioactive ores in Tanzania

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The regulatory preparatory work undertaken by the government of the United Republic of Tanzania through the Tanzania Atomic Energy Commission (TAEC) following the Mkuyu River Uranium Project definitive feasibility study is discussed. The project, which has been taken over by ARMZ Uranium One, acquired a construction permit in April 2013, where by 345 km^2 of land inside the 50,000 km^2 world heritage Selous Game Reserve was allocated for the purpose.

The project has been realized through the government effort to strengthen the regulatory framework via the revised Atomic Energy Act No.7 of 2003, preparations of Radiation Safety in Mining and Radioactive Ores Regulations of 2011, and the human resource capacity development in areas related to inspection and licensing. Sample collection in Bahi and Manyoni areas in the central part of the country to investigate uranium uptake from the plants and radioactivity from water and plant samples is ongoing. The regulatory preparatory work will provide an opportunity to the public to comprehend the measures undertaken by TAEC to protect human health and the environment.

The last twenty years of the iaea technical cooperation on the uranium producyion cycle in Argentina

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Since 1993, the National Atomic Energy Commission (Argentina) has been involved in several IAEA Technical Cooperation Projects at interregional, regional and national levels, covering different aspects of the uranium production cycle. The TC referred projects can be listed as follows:

- INT 2/015 “Supporting Uranium Exploration Resource Augmentation and Production Using Advanced Techniques” (2012 – Present).

- RLA 3/006 - 010 “Upgrading of Uranium Exploration, Exploitation and Yellowcake Production Techniques taking Environmental Problems into Account” (2007 - Present).

- ARG 2/014 “Development and Strengthening of the Uranium Mining Cycle Human Resources” (2012 – Present).

- ARG 3/012 - 014 "Geology favourability, production feasibility and environmental impact assessment of uranium deposits exploitable by the in situ leaching technology (ISL)" (2007 - Present).

- ARG 3/009 “Development and use of biological techniques for uranium production (ARG 3/009)” (2003 - 2006).

- ARG 3/008 “Prospection of uranium and other elements using gamma-ray spectrometry surveys” (2001 – 2005).

- ARG 3/007 “Uranium Favorability and Exploration in Argentina” (1993 - 1997).

It can be considered that the role of the technological transfer by the IAEA has been highly relevant for increasing the capability of strategically plan and more efficiently carry out the uranium production cycle projects in Argentina.

Uranium deposit types and resources of Argentina

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The uranium-related activities in Argentina begun in the 1950s and, as a result of the systematic exploration, several types of deposits have been discovered since then: volcanic and caldera-related, sandstone-hosted, vein spatially related to granite (intragranitic and perigranitic) and surficial.

The deposits that have been the focus of the most important uranium exploitations are the ones that belong to the volcaniclastic type. These are localized in Permian formations associated with synsedimentary acid volcanism in the Sierra Pintada district (Mendoza province). The volcanic and caldera related type is also present in the Laguna Colorada deposit (Chubut province) located in the San Jorge basin (Cretaceous).

Several important uranium mineralisations have been identified in Cretaceous fluvial sandstones and conglomerates, among which the most relevant is the Cerro Solo deposit (Chubut province) that corresponds to the paleochannel structure subtype.

Other subtypes of sandstone model have been studied. For instance, the Don Otto deposit (Salta province), located in the Salta Group Basin (Cretaceous - Tertiary), belongs to the tabular U-V subtype. The roll front subtype can be also found in the Los Mogotes Colorados deposit (La Rioja province) which is hosted by Carboniferous continental sandstones.

The uranium mineralisations in veins and disseminated episyenites within peraluminous leucogranites of the Sierras Pampeanas (Cordoba and San Luis provinces) represent other types of existing deposits. These granites are Devonian – Carboniferous and the related deposits are comparable to those from the Middle European Variscan.

There are also other vein-type uranium deposits located in metamorphic basement in the periphery of high potassium calcalkaline granites (Sierras Pampeanas of Catamarca and La Rioja provinces), where the mineralisation control is mainly structural.

The current uranium identified resources of the country are approximately 24,000 tU in the production cost category < USD 130/Kg and belong to volcanic and caldera-related and sandstone-hosted models.

Uranium refining by solvent extraction

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The solvent extraction process to produce higher purity uranium from yellowcake was studied in laboratory scale. Yellowcake, which the uranium purity is around 70% and the main impurity is thorium, was obtained from monazite processing pilot plant of Rare Earth Research and Development Center in Thailand. For uranium re-extraction process, the extractant chosen was Tributylphosphate (TBP) in kerosene. It was found that the optimum concentration of TBP was 10% in kerosene and the optimum nitric acid concentration in uranyl nitrate feed solution was 4 N. An increase in concentrations of uranium and thorium in feed solution resulted in a decrease in the distribution of both components in the extractant. However, the distribution of uranium into the extractant was found to be more than that of thorium. The equilibration study of the extraction system, $UO_2(NO_3)$/4N HNO_3 – 10%TBP/Kerosene, was also investigated. Two extraction stages were calculated graphically from 100,000 ppm uranium concentration in feed solution input with 90% extraction efficiency and the flow ratio of aqueous phase to organic phase was adjusted to 1.0. For thorium impurity scrubbing process, 10% TBP in kerosene was loaded with uranium and minor thorium from uranyl nitrate solution prepared from yellowcake and was scrubbed with different low concentration nitric acid. The results showed that at nitric acid normality was lower than 1 N, uranium distributed well to aqueous phase. As conclusion, optimum nitric acid concentration for scrubbing process should not less than 1 N and diluted nitric acid or de-ionized water should be applied to strip uranium from organic phase in the final refining process.

Safe management of uranium milling waste

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The mining of uranium ores by underground and by surface methods produces large and small amounts of bulk waste material such as excavated top soil, overburden that contains only traces of ore, weakly uranium-enriched waste rock, subgrade ores and evaporation pond sludges and scales. These materials typically contain radionuclides of radium, uranium, and thorium. TENORM (Technologically Enhanced Naturally Occurring Radioactive Material) may be present in mining wastes. These wastes, most significantly from uranium mining, may be generated in large volumes. Because the waste rock and soil have little or no practical use, they are generally stored on land near the mine site. Some countries have begun conducting studies to assess the risk to human health and the environment from industrial releases of materials that are now categorized as TENORM.

Geochemical dispersion associated with uranium deposits in sandstone roll front type and its relationship to the Orinoco Oil Belt, Venezuela

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In Venezuela, there is a potential for the formation of uranium deposits in areas such as the Guiana Shield, the south of the Eastern Basin, the Andes and the massif of Baúl, among other areas. Especially great interest is the exploration of uranium redox interface type (roll front), in areas such as the southern part of the Orinoco Oil Belt, north and northwest of the Guiana Shield, where groundwater uranium collecting the weathering shield flowing northward in the sandstones and mudstones of the Cretaceous to Quaternary formations, which constitute the southern boundary of the Eastern basin Venezuela. The presence of gas, extra-heavy crude oil, bitumen and lignite of the Orinoco Oil Belt can be an effective barrier for uranium in solution, which may have precipitated at the redox interface of this groundwater. This process certainly was more effective before the Orinoco river take its course to the east and the waters of small rivers and large draining shield contributed to uranium aquifers became more deep north.

This work was based on a qualitative model describing geochemical dispersion associated with uranium deposits in sandstone, roll front type, which indicates that the daughter isotopes ^{238}U, which can migrate extensively are: ^{222}Rn, ^{4}He, and in a smaller proportion: ^{226}Ra and ^{222}Rn daughters (^{214}Bi, ^{210}Pb). The main exploration methods were established, which can be applied in areas of the Orinoco Oil Belt, north of the Guiana Shield, and areas west of this, among the most important are: soil measurements of radon and helium near faults, sampling soils with gamma spectrometry analysis, log interpretation of oil wells in the area of interest to establish gamma – lithological anomalies, ground water analysis of uranium, radon, radium, helium, vanadium, selenium, molybdenum, analysis of samples oil drilling cores to locate anomalous stratigraphic levels.

This research will provide the basis to establish methodologies for uraniferous exploration in the region of the Orinoco Oil Belt in the Eastern Basin of Venezuela, which is an area with potential for formation of uranium deposits in sandstone, similar to Powder River basin in Wyoming, deposits in South Texas, United States, the Chu-Saryisu deposit in Kazakhstan and deposits in the San Jorge basin, Argentina, which can be considered energy basins.

Environmental radioactivity and mitigation of radiological impact at legacy uranium sites in Portugal

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Uranium legacy sites in the country contain large amounts of milling tailings, mining waste, old infrastructures and acid mine drainage with high radioactivity concentrations. Radioactivity surveillance of these sites has been maintained for many years and institutional control kept beyond cessation of Portuguese uranium mining in 2001. A research programme (2003-2006) requested by the government to assess environmental contamination and public health risks in these regions advised implementing environmental remediation measures. A national programme was approved for remediation of abandoned mine sites, including radioactive and non-radioactive mines, that started in 2005 and since has completed significant remediation works in several old uranium mines. One amongst these sites, the Urgeiriça mine and milling site, was re-engineered, tailings were covered, the mine was closed, the area of mine and milling facilities cleaned, and an automated contaminated water treatment plant installed. Environmental radioactivity surveys carried out in this region showed reduced ambient radiation doses, lower radon concentrations in surface air, return to background radioactivity in surface air aerosols, and decrease of radionuclide concentrations in the river receiving water discharges from the mine site, resulting in a reduced radiation exposure to members of the public. Other legacy uranium mines without milling tailings, were mainly remediated for landscape engineering and the adopted solutions included, for example, preservation of non-contaminated ponds for public leisure. Although not completed yet in many sites, the remediation works implemented contributed already to a significant abatement of radiation exposure allowing for safer implementation of activities, such as agriculture and cattle grazing, in the surroundings of legacy sites. Environmental remediation and abatement of radiation exposure contributed to revitalize socio-economic activities of the region and rebuild confidence in mining activities.

Ensuring safe use of water in a river basin with uranium drainage

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A regular radioactivity monitoring programme ensures radioactivity surveillance in a river system with multiple and intensive uses of water. In the catchment of River Mondego, centre of Portugal, there is a uranium mining and milling legacy which encompasses about 12 old uranium mine sites and 3 uranium milling sites. This river basin is an important agriculture and cattle growing region with forest areas for paper pulp production. In the catchment of this river there are four dams for electricity production and two main artificial lakes which are water reservoirs to supply drinking water to more than 3 million people, and irrigation water for agriculture including maize and rice production. In the river basin, environmental remediation works were recently implemented especially at the milling tailings and at the major mine sites, which reduced radioactive drainage into the Mondego tributaries and thus into the Mondego river. Mine drainage and seepage from tailings are recuperated and treated in mine water treatment stations. Although, for example, in drainage from milling tailings at Urgeiriça, water may contain high concentrations of dissolved uranium (^{238}U), radium (^{22}6Ra) and polonium (^{210}Po) at 35,700±1100, 1084±30, and 700±40 mBq/L, respectively, in the stream receiving discharges of treated water today radionuclide concentrations are orders of magnitude lower. The tributary streams that in the past received untreated mine discharges are today recovering and concentrations decreased to near natural levels. In the artificial lake of Aguieira dam, built on the Mondego River downstream all uranium sites, and where the main capture of water for human consumption is located, radionuclide concentrations were of 9.2±0.3 mBq/L, 17.7±1.9 mBq/L, and 5.3±0.2 mBq/L for uranium (^{238}U), radium (^{226}Ra) and polonium (^{210}Po), respectively. This water has been over the last years consistently in compliance with the EU drinking water quality standards, and radioactivity levels are comparable to natural levels of other rivers with no uranium mines. Furthermore, water quality allows for use of these lakes as fishing and swimming grounds.

Radiological legacy of uranium mining – the case study of Caldas, Minas Gerais, Brazil

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The Brazilian uranium mine of Caldas, Minas Gerais, has produced 1,030 tons of uranium, during twenty years of operation, from 1977 to 1997. Actually, the mine and the mill are deactivated and the decommissioning process is in course. The total mass of ore tailings produced is equal to 108,164,248 tons and the mass of milling solid waste is equal to 2,395,821 tons. The ore tailings are distributed through several piles placed near the mine pit and the milling wastes are deposited in the waste dam. The mine pit and two of the tailing piles generate acid water which requires treatment before the environmental standards are achieved and the water is liberated to the environment. The waste dam also liberates treated water to the environment.

This work presents data, discussions and main conclusions of radiological monitoring of the water liberated by Caldas uranium mine to the environment during the 2013. The complete annual environmental monitoring program requires 1,689 surface water samples; 39 underground water samples; 17 sediment samples; 5 soil samples; 7 farm products and fish samples; and 1,728 direct measurements of pH, temperature, dissolved oxygen, turbidity and salinity. The chemical parameters determined in water samples are: Mg^{2+}, Ca^{2+}, Cr^{n+}, Cu^{n+}, Ni^{2+}, Zn^{2+}, Ba^{2+}, Mn^{n+}, Fe^{n+}, Al^{3+}, SiO_2, SO_4^{2-}, F-, Na^+, K^+, P, Cl^-, NO_3^{2-}, and N. The radionuclides determined in all samples are: U-238, Th-230, Ra-226, Pb-210, Th-232 and Ra-228. All of the Caldas uranium mine environmental monitoring results will be presented in the INB annual report of the year 2013.

The maximum permissible concentrations of radionuclides in the liquid effluents were determined considering the maximum annual dose constraint of the optimization process for members of the public, which is equal to 0.3 mSv per year. According to the monitoring results of year 2013, the increase in the annual dose of the individual of the critical group is approximately equal to 0.3 mSv per year, which means that it is below the annual public dose limit equal to 1 mSv per year. The higher monitoring results are due to the leakage directly into the environment of untreated acid water from one of the tailing piles, the tailing pile number 4. Corrective measures are been taken in order to mitigate the environmental impacts of Caldas uranium mine.

A pathway to supplier status: The case of Greenland and Denmark

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On 24 October 2013, the Greenland parliament, Inatsisartut, lifted a decades-long moratorium on mining radioactive elements. For a Kingdom that has otherwise foregone the nuclear fuel cycle (except for medical purposes), the abolishment of the so-called ‘zero tolerance’ policy has the potential to catapult the Kingdom of Denmark (or 'Rigsfælleskabet') into one of the world’s top suppliers of natural uranium. Greenland’s status as a country within a state is accompanied by a complicated legal system within the Rigsfælleskabet, where Greenland has authority over its natural resources and Copenhagen is constitutionally responsible for the Kingdom’s foreign, defence and security policies. This system is further complicated by Denmark’s membership (and Greenland’s non-membership) in the EU. Consequently, the process ahead for Greenland and Denmark in jointly developing a regulatory system to govern uranium will be complex, and one based on a steep learning curve. This paper will look at the process of how Greenland and Denmark are approaching the development of a governance system, not only for uranium production as a primary product but also as a byproduct of other resources, particularly REE (as is the case with the Kvanefjeld deposit in southern Greenland).

On-line XRF analysis of uranium materials in the mining and processing industry

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The introduction of on-line X-ray fluorescence (XRF) analysis in the mining and processing industry of uranium (U) can improve the representativeness and speed of analysis and lower costs. Potential applicability of the industrial XRF analyzer CON-X series is demonstrated for continuous measurement of uranium content in various materials (rutile and zircon sands, phosphate rock and fertilizers, U ore residues after leaching, monazite ore etc.) and at wide ranges of U concentrations (from 100 ppm up to tens %). In addition to the physical components required to perform on-line XRF measurements, analyzer design and analytical method can be customized to the requirements of specific field or process.

The dynamic laboratory simulation of on-line measurement of uranium in ground N-P-K fertilizers indicates statistically acceptable correlation with routine analysis. Estimated detection limit obtained with replicate measurements is 25-50 ppm depending on the type of phosphate material.

On-site test of the CON-X analyzer for continuous analysis of uranium in ore residues after heap-leaching showed that the difference between on-line and laboratory results was within 10% relative at the level of 100 ppm U. Uranium detection limit is estimated at 30-50 ppm in 5 minute measurements depending on interfering element.

Advantages and limitations of CON-X analyzer for on-line analysis of uranium solid materials transported by the conveyor are also discussed.

Quantitative analysis of thorium-containing materials using an Industrial XRF analyzer

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Thorium (Th) as nuclear fuel is clean and safe and offers significant advantages over uranium. The technology for several types of thorium reactors is proven but still must be developed on a commercial scale. In the case of commercialization of thorium nuclear reactor thorium raw materials will be on demand. With this, mining and processing companies producing Th and rare earth elements will require prompt and reliable methods and instrumentation for Th quantitative on-line analysis.

Potential applicability of X-ray fluorescence conveyor analyzer CON-X series is discussed for Th quantitative or semi-quantitative on-line measurement in several types of Th-bearing materials. Laboratory study of several minerals (zircon sands and limestone as unconventional Th resources; monazite concentrate as Th associated resources and uranium ore residues after extraction as a waste product) was performed and analyzer was tested for on-line quantitative measurements of Th contents along with other major and minor components.

Th concentration range in zircon sand is 50-350 ppm; its detection limit at this level is estimated at 25-50 ppm in 5 minute measurements depending on the type of material. On-site test of the CON-X analyzer for continuous analysis of thorium traces along with other elements in zircon sand showed that accuracy of Th measurements is within 20% relative. When Th content is higher than 1% as in the concentrate of monazite ore (5-8% ThO_2) accuracy of Th determination is within 1% relative.

Although preliminary on-site test is recommended in order to address system feasibility at a large scale, provided results show that industrial conveyor XRF analyzer CON-X series can be effectively used for analytical control of mining and processing streams of Th-bearing materials.

Uranium and REE recovery from acid mine drainage treatment waste – the Caldas Brazil case

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The Caldas uranium mine and mill was the first uranium producer site in Brazil. It has ceased its operations since 1995 and is now under it's decommissioning process. One of the main issues to be dealt with is the acid water produced in some of the waste rock deposits due to the nature of the rock and ore.

As it is very well known, the presence of sulfide containing minerals in the ore may promote the occurring of acid mine drainage (AMD), one of the main problems regarding environmental impacts of mining activities. To prevent contamination of the local watersheds, it is usual to treat the acid water produced with lime, to precipitate the soluble metals, and then store the solid produced in a safe way.

This work aims to assess the uranium and rare earths recovery in the solid material produced at the Caldas site. It contains about 0,25% U_3O_8 and 2,5% RE_2O_3. The hydrometallurgical process being developed comprises leaching, solvent extraction and precipitation steps. Preliminary results of the acid leaching tests point to 96% and 90% recovery of U_3O_8 and RE_2O_3, respectively. The isotherm for uranium extraction shows a recovery of 99.7% of this element.

Brazilian uranium production and demand: Scenarios for the near future

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The Brazilian government announced some years ago its plans to reactivate the nuclear program. As a result of this decision, a new nuclear power plant is already being built and there are studies dealing with, among other activities, the building of 5 to 9 new ones until the end of 2030. Such increase of the country's uranium demand affects ina effective way the Brazilian state companies that are in charge of the nuclear fuel cycle.

This paper describes scenarios predicted to impact the Brazilian nuclear industry for the next years and the related intitutions (nuclear fuel cycle companies and the nuclear authority) plans to meet the country's needs in terms of uranium exploration and production.

International overview of ISL uranium mining operations

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In situ leach (ISL; also called in situ leaching or in situ recovery, ISR) mining has become one of the standard uranium production methods, following early experimentation and production in the 1960s. Its application to amenable uranium deposits (in certain sedimentary formations) has been growing in view of its competitive production costs and low surface impacts. In 1997 the ISL share in total uranium production was 13%; by 2009 it had grown to over 30%, reaching 46% in 2011. In the past, ISL technology was applied mainly in Ukraine, the Czech Republic, Uzbekistan, Kazakhstan, Bulgaria and the United States of America (USA). Recently it has been used in Kazakhstan, Uzbekistan, the USA, Australia, China and the Russian Federation, with small operations or experiments elsewhere. ISL mining is gaining widespread acceptance.

The IAEA is preparing an overview document to show how ISL experience around the world can be used to direct the development of technical activities, taking into account environmental considerations and an emphasis on the economics of the process, including responsible mine closure. With this document Member States and interested parties will have more information to design and efficiently and safely regulate current and future projects, with a view to maximize economic performance and minimize negative environmental impact. Highlights of the report's findings will be provided here with a summary of the IAEA's involvement in ISL over recent decades. Many reference links are provided to allow access to voluminous additional information.

Uranium mining and extraction industries: Environmental impacts and mitigation techniques

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In the nuclear fuel cycle, the initial stages or processes; mining and milling of uranium ores produce huge volumes of residual materials are created contaminated with certain levels of radioactivity. Other stages of the nuclear fuel cycle produce different quantities of radioactive waste vary in volume and activity level according the type of the process and the adopted strategy of the nuclear fuel cycle. In this context, the present paper is concerning with the safety aspects of nuclear fuel cycle facilities with emphasis to uranium mining and extraction processes. Uranium resources and mining capabilities in Egypt have been reviewed and discussed in the light of the governments of Egypt planning and R efforts from the beginning of the 1980s, to implement a nuclear power program for electric power generation. The environmental radiological impacts, siting issues and potential health hazards of uranium mining and extraction processes have been reviewed, discussed and evaluated. The paper outlines and discusses different aspects of the environmental hazards of uranium ores waste rocks as well as mill tailings produced during uranium extraction processes. Within the framework of an intensive program for nuclear safety and radiation control in Egypt, airborne radioactivity measurements and radiological dose assessment were conducted in some phosphate and uranium mines. In Abu-Tartur mine, is one of the biggest underground phosphate mines in Egypt. Airborne radioactivity, radon (^{222}Rn) and its short-lived decay products (progenies) and thoron (^{220}Rn), were measured in selected locations along the mine. The environmental gamma and workers dose equivalent rate were measured inside and outside the mine using thermo-luminescence dosimeters. The results indicated that, the annual effective dose due to airborne radioactivity occupational exposure for mine workers, are exceeding the maximum recommended level by ICRP-60 inside the mine tunnels. Useful recommendations are suggested to control the occupational exposures, and various techniques adopted worldwide either to confine or to mitigate these hazards are reviewed, discussed and evaluated.

Modelling of radon control and air cleaning requirements in underground uranium mines

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As a part of a comprehensive study concerned with control workplace short-lived radon daughter concentration in underground uranium mines to safe levels, a computer program has been developed and verified, to calculate ventilation parameters e.g. local pressures, flow rates and radon daughter concentration levels. The computer program is composed of two parts, one part for mine ventilation and the other part for radon daughter levels calculations. This program has been validated in an actual case study to calculate radon concentration levels, pressure and flow rates required to maintain acceptable levels of radon concentrations in each point of the mine. The required fan static pressure and the approximate energy consumption were also estimated. The results of the calculations have been evaluated and compared with similar investigation. It was found that the calculated values are in good agreement with the corresponding values obtained using "REDES" standard ventilation modelling software. The developed computer model can be used as an available tool to help in the evaluation of ventilation systems proposed by mining authority, to assist the uranium mining industry in maintaining the health and safety of the workers underground while efficiently achieving economic production targets. It could be used also for regulatory inspection and radiation protection assessments of workers in the underground mining. Also with using this model, one can effectively design, assess and manage underground mine ventilation systems. Values of radon decay products concentration in units of working level, pressures drop and flow rates required to reach the acceptable radon concentration relative to the recommended levels, at different extraction points in the mine and fan static pressure could be estimated which are not available using other software.

World uranium exploration, resources, production and related activities

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A Nuclear Energy Series publication entitled "World Uranium Exploration, Resources, Production and Related Activities" (WUERPRA) will soon be published by the IAEA. The objective of the publication is to provide a comprehensive compilation of historic uranium exploration, resources, production and related activities based primarily on information from the 1966 to 2009 editions of the publication "Uranium Resources, Production and Demand", a joint publication of the International Atomic Energy Agency and the Nuclear Energy Agency/Organization for Economic Cooperation and Development commonly known as the 'Red Book'. This has been supplemented by historic information from other reliable sources. The publications also include, where enough information was available, descriptions of the relative potential for discovery of new uranium resources on a per country basis.

To recover complete historic information it is frequently necessary to refer to earlier editions of the Red Book, many of which may not be readily available. This publication aims to provide one comprehensive source for much of this type of information which will reduce the effort required to prepare future editions of the Red Book, as well as make the historic Red Book information, together with select related information from other sources, more readily available to all users with an interest in uranium.

WUERPRA comprises 6 volumes containing 164 country reports, each organized by region; Volume 1: Africa (53 countries); Volume 2: Central, Eastern and Southeastern Europe (25 countries); Volume 3: Southeastern Asia, Pacific, East Asia (18 countries); Volume 4: Western Europe (22 countries); Volume 5: Middle East, Central and Southern Asia (19 countries), and; Volume 6: North America, Central America and South America (27 countries). The report also contains information on countries that have not reported to the Red Book.

The poster will summarize select major highlights from each volume.

Brecciation and Ca-Na alteration at the Salaki uranium prospect, Northern Cameroon

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Breccias are amongst the most common fault rocks closely associated with hydrothermal vein-type deposits. The Salaki U-occurrence is geologically situated within the early Neoproterozoic back-arc basin regionally termed the Poli Group. The lithology of this area comprises a diversity of rocks including on one hand metamorphic formations (chloritoschists, amphibolites, metatrachytes and epidotite) and igneous rocks (quartz-monzonite, syenite and granodiorite) on the other hand. The Salaki U-prospect is traversed by three fault sets trending NW-SE (N320E), N-S (N350-N10E) and E-W (N80-N95E). Subsidiary to faults are fractures/joints that extend from the faults into the surrounding rocks. The fault and fracture geometry likely formed in response to the NW-SE direction of shortening over the region. As such, this area is probably part of the Riedel faults/fractures system in the region involving the nearby "Vallée des Rhoniers" and Demsa dextral SZ. Mapping of the study perimeter has demonstrated that breccias are widespread in the area and are typically tectonic and fluid-assisted breccias. Tectonic breccias are characterized by intense fracturing along closely spaced brittle micro-shear planes that give the rock a stockwork appearance. In fluid-assisted breccias, fragments are angular in shape and exhibit mosaic and jigsaw textures. The rock fragments are commonly extensively broken and each clast is characterized by frequently branching or arborescent fissures. These fragments are held together by cement precipitated from hydrothermal fluids. Breccias are associated to veins, and all these structures were favored by the reactivation of this dilation zone and acted as channel-ways for hydrothermal fluids bearing uranium. Uranium mineralization was accompanied by an intense Ca-Na metasomatism that pervasively altered the lithologies of the prospect, and these alterations were initiated by veining and brecciation. Apart from Na and Ca alteration, the hydrothermal facies also experienced hematitization and quartz dissolution. Petrographic surveys have revealed that albite, aegirine and riebeckite developed in response to Na alteration while the Ca episode was mostly characterized by the development of calcite and carbonate.

Geochemical study revealed that breccias from Salaki region generally contain low to very low K_2O contents and a comparatively high Na_2O contents and the high Na_2O contents are always associated with high CaO contents. These Ca-Na metasomatic breccias have U contents varying from 1.33 to 2453 ppm. Thorium is constantly low and thus the radioactivity in the prospect is due to uranium.

Uranium from phosphates to rabbit bones: Predicting dietary contribution to uranium deposition in animal bones

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Uranium is a hazardous element, both for radioactivity and metallotoxicity. Health implications of human overexposure to uranium are well documented: from reproduction impairment, liver and kidney diseases to some types of cancer.

There are limited data in the modern literature concerning the levels of uranium in animal tissues and foods, as well the dietary daily intake of uranium is not fully known both for man and livestock.

On the other hand, practically every phosphate and its products contain uranium in its structure. The average U content in agricultural phosphate may vary from 10 up to 390 ppm.

In this particular feature, uranium can reach animal and man food chain by ingestion of feed and food grade phosphate containing U.

Uranium content in mineral products and animal tissues can be precisely determined by mass spectrometry and nuclear methods including: Delayed Neutrons and by Instrumental Neutron Activation Analysis. Both nuclear methods are instrumental, precise, short turn-around, sensitive and non-destructive methods.

In this study, Delayed Neutrons Technique was applied at the IPR-R1 TRIGA Mark I Reactor at the CDTN/CNEN, studying eight different phosphorus sources produced in Brazil, (results as U level in parts per million): Calcined Bone Meal (6), Dicalcium Phosphate (190), Super Triple Phosphate (56), Super Simple Phosphate (108), Monoammonium Phosphate (58), Sulphur Ammonium Phosphate (42), Ammoniated Calcium Polyphosphate (67) and a Bovine Mineral Supplement (47).

Additionally, an experiment with 30-days young New Zealand rabbits (48 males, 48 females) was conducted in order to determine the deposition of uranium from phosphate up to the shinbone through ingestion of phosphate-U-containing diets.

Young rabbits were taken in randomized blocks with 12 repetitions. Treatments were consisted on 98% of a basic diet plus 2% of each U source (listed above). Rabbits were fed ad-libitum from 30 to 72 days. At the end of experiment, all animals were slaughtered and their shinbones were extracted and separated from added tissues. All samples were freeze-dried and milled. Individual aliquots of 1.000 g were weighted and conditioned in irradiation vessels.

Experimental data of U content in shinbone of each of eight groups were statistically analyzed according to Newman-Keuls' test ($p \leq 0.05$). Group means vary from 3.4 to 5.2 ppm of uranium in shinbones. Comparing means (n=12) from the eight groups, it is not possible to identify any significantly difference for uranium content in shinbone of rabbits from the eight treatments of the experiment. Hence, an amount up to 6 ppm of uranium in the diet appears to have little or no influence on uranium bone levels in the rabbit shinbones.

In conclusion, the present study showed that uranium does not biomagnify in rabbit shinbone due to a 42 days period of feed consumption, respecting the experimental limits: up to 6 ppm of U in feed from phosphates containing U up to 190 ppm.

The role of naturally occurring biofilm in the treatment of mine water in abandoned uranium mine

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The uranium mine in Kowary (SW Poland) was active from 1948 to 1967. After exploitation ceased the mine was abandoned and from the beginning of 21^{st} century it is a touristic attraction of this region of Poland. The largest uranium mining fields, Kowary and Kowary-Podgorze, were located in southern part of the metamorphic cover of the Karkonosze Granite. In the mine dumps at Kowary-Podgorze ore fragments containing up to 0.15% of uranium can still be found. Several dumps have been left in the Kowary Podgorze vicinity as the post mining uranium waste. The dump of adits Nos. 19 and 19a at Kowary Podgorze is located in the Jedlica River valley. Water from adit No. 19a is still discharged by the pipe directly to the Jedlica River. In the end of this pipe a small dam was built to regulate the level of water in adit and small reservoir of mine water was created in this place. The level of uranium observed in water before dam is between 10 $\mu g/dm^3$ and 670 $\mu g/dm^3$. The bottom of reservoir is covered by strongly mineralized biofilm containing up to 60 mg U/kg (dry weight), 1 500 mg As/kg, 10 000 mg Al/kg and about 1700 mg Mn/kg. Water in Jedlica River contains 6-7 μg U/dm^3, 16 μg As/dm^3 and about 10 μg Mn/dm^3 and these values are within the limits for non-contaminated surface water. The water from the reservoir together with the biofilm is discharged minimum twice a year immediately to Jedlica River causing a temporary increase of contaminants (beyond the limits) and dispersion of uranium and arsenic up to 20 km from the main source of pollution. It seems that biofilm from reservoir acts as an active filter that removes main contaminants from mine water mainly through biosorption. Laboratory studies show that sorption complexes are relatively stable. Maximum 10% of absorbed uranium was eluted by EDTA buffer or acetic acid (soluble and carbonate fraction). Arsenic was eluted in 25% by phosphate buffer (ion exchange) and almost all iron and cadmium (occurring in trace amount in biofilm and in mine water) was removed from sorption complexes by EDTA buffer. Sorption capacity of biofilm dry mass was estimated for As, Co, Mn, Cu and Cd at 5g/kg, 12 g/kg, 5 g/kg, 1 g/kg and 28 g/kg respectively. Presented results clearly show that mats from adit No.19 in uranium mine in Kowary-Podgorze have large capacity for biosorption of metals and metalloids and for this reason, special attention should be paid to discharging them immediately to Jedlica River. On the other hand, further studies are needed to develop method of culturing the specific biofilm for water filtration under controlled conditions.

Uranium nanoparticle synthesis from leaching solution

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The removal of uranium from leaching and bioleaching solutions is of great significance for an environment protection. In comparison with conventional separation techniques, synthesis of uranium nanoparticles has a number of benefits. It has been demonstrated that the uranium nanoparticles show high catalytic activity. In the present studies a variety of synthesis systems have been used for reduction of uranium from bioleaching solution. Among various catalytical templates the hematite Fe_2O_3 nanoparticles are most interest It was presented the report on development of synthesis method to produce nanostructured Fe_2O_3 particles. The efficiency of hematite nanoparticles for adsorption of uranium ions from bioleaching solutions was investigated. Bacterial leaching is alternate technique used to extract uranium from mining wastes. The bioleaching process is environment friendly and gives the extraction yield of over 90%. The bioleaching solutions were obtained from bioleaching experiments using waste materials from different places at Lower Silesia (Kowary, Grzmiaca, Kopaniec, Radoniow). Chemoautotrophic bacteria were used for bioleaching tests.

The significant adsorption capacity of U(VI) onto iron oxide and hydroxides (goethite, hematite, and magnetite) was observed. The sorption of U(VI) onto the hematite surface was connected with the chemical reduction of U(VI) to U(IV) by Fe^{2+} ions. The initial reaction system contained excess of Fe^{2+} ions which were used to reduce of U(VI). The reduction of U(VI) occurred at pH at the vicinity of pH=2.4. The colloid particles of hematite with UO_2 nanoparticles were obtained.

The results of zeta potential measurements of hematite nanoparticles showed that at the ionic strength equals 10^{-3}M NaCl, the average zeta potential was +32.4±3.5 mV at pH = 2.6. The interaction of hematite nanoparticles with the bioleaching solutions led to decrease of positive zeta potential to the value of 6.4± 2.7 mV.

The simulation experiment study on humic acid in the ore-forming process of sandstone-hosted uranium deposits in Northwest China

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Sandstone-hosted roll-front uranium deposits were recently discovered in Yili Basin, Tuha Basin and Ordos Basin, north-west China. Uranium minerals in sandstone-hosted uranium deposits have frequently been reported to coexist with carbonaceous materials and sulfides. Thus precipitation of U(IV) was generally thought to form from U(VI) reduced by either sulfides or organic matters. There are many organic matters in uranium-bearing sandstone, including humic acid (HA) which is closely related to uranium precipitation and enrichment. It is found through the experiments which separated and extracted humic acid from rocks in different interlayered oxidation zones in uranium deposits in north-west China that, the HF-HCl mixed acid can not only remove the silicate impurity from the humic acid, but also decrease the ash of the samples, thus better purifing the samples. The composition of humic acid in this area has been analyzed. The contents of C, O and H are high, and small amounts of N and S are also contained. Studied by infrared spectroscopy, the humic acid has a high aromatic degree, a big molecular weight and a low degree of humification. There are many acidic function groups in the humic acid, such as carboxyl, hydroxyl, phenolic hydroxyl, carbonyl and so on. Laboratory experiment studies have shown that acidic function groups help ranium precipitate and become enriched through reduction, complexation and adsorption.

Uranium development in Nigeria

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Nigeria uranium exploration started in 1973. Uranium was found in seven states of the country; Cross River, Adamawa, Taraba, Plateau, Bauchi, Kogi and Kano.

Three government agencies were involved. At the end of the various exploration campaigns in 2001, the uranium reserve was estimated at about 200 t U. The Grade ranges from 0.63% - 0-9% at a vertical depth between 130 – 200 m.

Currently, the Nigeria Atomic Energy Commission activated in 2006 is charged with the responsibility among others to prospect for and mine radioactive minerals.

The main aim of this poster presentation is to review the development of uranium in Nigeria with a view to encourage local and international investors to develop and exploit these deposits. Nigeria is located on latitude 100 N and longitude 80 E surrounded in the north by Niger and Chad, in the east by Cameroun and in the west by the Benin Republic. Available data indicated the viability of mineral investment in the Nigerian uranium resources. With the current economic reforms and investment incentives in Nigeria, interested investors are highly welcome to take advantage of developing these mineral resources.

Decommissioning of uranium pilot plants at IPEN-CNEN/SP: Facilities dismantling, decontamination and reuse as new laboratories for strategic programs

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Radical changes of the Brazilian nuclear policy, in the beginning of 1990s, determined the interruption of most nuclear fuel cycle activities and the facilities shutdown at IPEN. Those facilities had already played their roles of technological development and personnel's training, with transfer of the technology for institutions entrusted of the “scale up" of the units. Most of the pilot plants interrupted the activities more than ten years ago, due to the lack of resources for the continuity of the research. The appropriate facilities maintenance had been also harmed by the lack of resources, with evident signs of deterioration in structures and equipment. The existence of those facilities also implicated in the need of constant surveillance, representing additional obligations, costs and problems. It should be emphasized that one of the most concerning aspects, with relationship to the future of the facilities and the postponement of the dismantling, was the loss of the experience accumulated by the personnel that set up and operated the referred units. Besides the mentioned aspects, other reasons to promote the dismantling of the IPEN´s Nuclear Fuel Cycle Pilot Plants elapsed mainly from the need of physical space for new activities, since the R in the nuclear fuel cycle area were interrupted. In the last decade IPEN has changed its “nuclear profile” to a “comprehensive and multidisciplinary profile”. During this period, IPEN has been restructured in 13 Research Centers. With the end of most nuclear fuel cycle activities, the former facilities were distributed in four different centers: Environmental and Chemical Technology Center; Fuel Cell Center; Materials Science and Engineering Center; Nuclear Fuel Center. Each center has adopted a different strategy and priority to face the R problem and to reintegrate the areas. The resources available depend on the specific program developed in each area (resources available from other sources, not only CNEN). One of those new activities is the IPEN´s Environmental Program. In the building where there was the Uranium Dissolution and Purification Pilot Plant, already dismantled, it was decided to settle the Laboratory of Chemical and Environmental Analyses, being necessary its total liberation from the point of view of radioactive contamination. This paper describes the procedures, problems faced and results related to the reintegration of the former pilot plant areas as new laboratories of the Chemical and Environmental Technology Center – CQMA – of the IPEN.

Environmental monitoring data review of a uranium ore processing facility in Argentina

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An uranium ore processing facility in the province of Mendoza (Argentina) that has produced uranium concentrate from 1954 to 1986 is currently undergoing the last steps of environmental restoration. The operator has been performing post-closure environmental monitoring since 1986, while the Nuclear Regulatory Authority (ARN) has been carrying out its own independent radiological environmental monitoring for verification purposes since its creation, in 1995. A detailed revision of ARN´s monitoring plan for uranium mining and milling facilities has been undergoing since 2013, starting with this particular site. Results obtained from long-time sampling locations (some of them currently unused) have been analyzed and potentially new sampling points have been studied and proposed. In this paper, some statistical analysis and comparison of sampling-points' datasets are presented (specifically uranium and radium concentration in groundwater, surface water and sediments) with conclusions pertaining to their keeping or discarding as sampling points in future monitoring plans.

Characterisation and dissolution studies on the uranium pyrochlore mineral betafite $(Ca,U)_2(Nb,Ti,Ta)_2O_7$

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The pyrochlore group mineral, betafite (nominally $(Ca,U)_2(Nb,Ti,Ta)_2O_7$); is a refractory uranium mineral found in many ore deposits, including the currently mined deposit at Rössing, Namibia and the currently unmined deposit at Saima Massif, China. The decreasing abundance of "easy to leach" uranium minerals (i.e. uraninite), has led to interest in the extraction of uranium from refractory uranium minerals such as betafite. In the current study, three naturally occurring betafite mineral samples (obtained from Ambatofotsky and Miarinarivo, Madagascar (BAM and BMM respectively) and Silver Crater Mine, Canada (BSC)) were characterised using ex-situ high temperature X-Ray Diffraction (XRD), multi acid digestion / ICP-MS analysis (composition) and X-Ray Photoelectron Spectroscopy (XPS). Dissolution of the three samples was also investigated under conditions similar to those used in commercial tank based uranium leaching processes.

XRD analysis showed that all three samples were highly metamict. Samples BMM and BSC showed no assignable diffraction lines before heat treating, whereas the XRD pattern obtained for sample BAM contained diffraction lines that confirmed the presence of crystalline anatase (TiO_2). Heat treatment studies on the samples showed that the betafite in the samples was converted into a crystalline form at 700°C in all 3 samples. Gangue minerals, rutile, Nb-rutile, $UTiNb_2O_{10}$, and studitite were also found to be present in the heat treated samples. Multi acid digestion ICP-MS analysis showed the natural samples contained between 16 and 26% w/w uranium as well as all the major elements present typically in betafite. XPS analysis was conducted on the unheated betafite samples. XPS analysis showed that the uranium in the samples was predominately in U^{5+} oxidation state. Some U^{6+} was also identified though this was most likely restricted to the outer surface of the samples.

Dissolution studies (batch mode) were conducted under the following conditions: $[H_2SO_4]$ between 0 and 100 g/L, $[Fe_{TOT}]$ between 0 and 12 g/L, Redox potential (Fe^{3+}:Fe^{2+} Ratio), between 1:0 to 0:1, Temperature (35-95°C) and crystallinity (pre heat treated and heat treated). The results of the dissolution studies showed similar trends between the 3 samples studied. Increasing the temperature had the most significant effect on dissolution. Similar trends between the samples were seen with the effect of $[Fe_{TOT}]$ and Redox potential. All studies completed looking at these two parameters showed very minor changes in dissolution concentration as these parameters were changed. The maximum uranium dissolution for BAM, BMM and BSC was 70, 34 and 45% respectively. This was achieved with; 3g/L Iron (100% as Fe^{3+}); 50g/L H_2SO_4; 95°C temperature after 24 hrs.

Recovery of uranium and REEs from phosphate rocks: The GCT experience

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Interest in nuclear power has increased substantially over the past decade worldwide leading to increased attention being paid to supply of uranium from conventional sources. With a possible forecast of mismatch in uranium demand and production in the near future, uranium recovery from unconventional sources is seen is a viable alternative to narrow down the supply gap. Phosphoric acid is an important source not only of uranium but also for rare earth elements (REEs) as well. Rare earth elements are critical materials for advanced Technology and green- energy applications, which give them an undeniable strategic aspect.

In this context, a study was recently carried out in Tunisia under an IAEA technology Cooperation project TUN/2/006 on extraction of uranium from industrial phosphoric acid. Studies were carried out to evaluate with more accuracy the content of U and REEs in the three main phosphates deposits in general, and that of the Gafsa mining basin in particular. The results obtained show that uranium in phosphate rock samples vary between 20 to 120 ppm depending on the deposit location. REEs were mostly light REEs belonging to the cerium series, in the order of 300 to 1500 ppm.

The distribution of these elements, between phosphoric acid and phosphogypsum products were also investigated. In particular the distribution coefficients particularly of U, La, Ce, Nd and Th, were determined. For this purpose, phosphoric acid production tests were carried on certain grades of selected phosphates, according to an experimental protocol developed for this purpose. The results show that, in the case of U and Th, partitioning rates recorded in product acid were higher than 75%, whereas for Ce, Nd and La, maximum values of 20% were obtained. These results were in good agreement with the data available for other similar studies in the literature.

The investigations carried out under TUN/2/006 project looked into the recovery of uranium and REEs from phosphoric acid by the improved Octyl Phenyl Acid Phosphate OPAP process at a pilot plant scale. The main objective was to come up with a more cost effective route by selecting the right combination of the P_2O_5 concentration of the phosphoric acid, the appropriate solvent and the optimization of the different operational parameters.

New exploration results of the Elkon uranium district deposits and prospects for their development

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The Elkon Uranium District (EUD) is located in the Republic of Sakha (Yakutia) and is of strategic importance for the Russian uranium industry. It comprises more than 40% of the entire Russian uranium mineral resource and 4% of the world's uranium resources.

Drilling and underground mining completed in 1961-1986 amounted to over 600,000 m and 52,500 m, respectively. The performed activities resulted in the discovery of the Yuzhnaya Zone and the Severnoe deposits. The Yuzhnaya Zone uranium resources (Measured + Indicated + Inferred) amounted to 257.8 kt (grade 0.146%). Uranium mineralisation contains 141 t of gold, 1784 t of silver and 41,5 kt of molybdenum. The Severnoe Inferred resources have been estimated at 58.6 kt (grade 0.149%).

During the period of 2007-2011 over 100,000 m of drilling and associated activities was completed within the Yuzhnaya Zone and Severnoe deposits along with optimisation of ore mining and processing methods, and geological and economic revaluation of the deposits.

The key results of the exploration activities are as follows:

- an increase in Mesured uranium resources by more than 50 kt;
- new data in the geological structure, material composition and technological properties of ore, hydrogeological and geotechnical conditions of mining;
- the mineralised bodies received estimates of gold, silver and molybdenum resources; Inferred vanadium resource estimate produced for the first time (113 kt, 0.05% grade);
- there are areas revealed in the Severnoe oxidation zone suitable for gold open pit mining and heap leaching. Gold and silver Inferred resources have been estimated at 19 t (grade 1.09 g/t) and 125 t (grade 7.08 g/t). Detailed exploration activities and geological and economic evaluation resulted in definition of the principal directions for improving economic efficiency of development:
- increase in the mineral resource of the projected mine through detailed exploration of the Severnoe flanks;
- high-priority involvement of relatively high grade uranium mineralisation; open mining of gold from oxidised ore, which will make it possible to reduce the time required for the mine to achieve maximum production rate and reduce the specific costs for the mine construction;
- increase in production rate due to the application of advanced mining methods;
- mineralogical and metallurgical mapping to define oxidised ore which can be processed by atmospheric leaching;
- application of X-ray radiometric separation;
- increase in the associated components recovery degree.

The prospects for the application of the new generation neutron logging system developed by Rusburmash Inc (Russian Federation) for handling geotechnical issues at sandstone-hosted uranium deposits

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In 2011-2013 Rusburmash Inc was developing AINK-49 new generation hardware system for fission neutron logging. The work was completed using the financing provided by and upon the technical assignment from Atomredmetzoloto JSC as part of their Research and Development Plan. The system was developed with the involvement of the Russian leading scientific and manufacturing companies in this field.

The relevance of the system is based on the fact that Rusburmash Inc is one of the leading Russian companies involved in the exploration and preparation of sandstone-hosted uranium deposits for ISR mining.

The peculiarity of these deposits consists in the complex radiological environment which is additionally subjected to complex and uncontrolled production-induced changes in the process of leaching. In such conditions the application of prompt fission neutron (PFN) logging has a promising outlook that has no alternative for operation in the conditions of altered ore as a result of production. This method is designed for the direct determination of uranium mass fraction within the drill hole environment. It is based on creating a neutron flux using an impulse neutron generator and recording of secondary neutrons produced in the natural environment under the influence from the generated neutrons.

In addition to PFN logging the developed system features impulse neutron-neutron logging technique using thermal neutrons. This allows determination of ore in-situ moisture content and considerably increases the reliability of uranium mass fraction determination owing to the precise account of the moisture content. Availability of a pulsed neutron-neutron logging channel makes it possible to assess the coefficient of ore clay content, to reliably and reasonably define sub-economic ore types by permeability.

The system has a range of advantages compared to similar tools. Application of new neutron generators increased the output of the neutron flux, increased the life of the generator up to 250 hours and reduced the downhole tool diameter to 49 mm. This significantly broadens the scope of the equipment application due to the possibility of using it in small diameter holes (60 mm) and cased holes. Logging speed can be increased to 60 m/hour (instead of 30-45 m/hour) as well as significantly reduce operational costs.

The hardware complex provides reliable results in a complex radiological environment including the areas subject to alteration due to ISR operations. Therefore, in addition to handling exploration issues, the complex can become widely used in the operational and mined-out ISR sites to monitor the leaching process, to provide on-going control of the applied ISR process flowsheet performance, to assess uranium in-situ recovery performance and recovery level from the production-induced areas of uranium redeposition.

Prospects for increasing uranium resources in the Khiagda ore field (Russian Federation)

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The Khiagda ore field uranium deposits are located in the Republic of Buryatia, on the Amalat Plateau formed by the Neogene basalts.

The position of the ore field is defined by a large tectonic structure having a north-eastern strike the Baisykhan Uplift. The slopes of the Baisykhan dividing uplift are incised by short (4 to 16 km) lateral tributaries of the Amalat and Atalanga paleorivers. The paleovalley network is filled with terrigenous-volcanogenic units of the Miocene Dzhilinda Formation (N1dz) buried under a thick cover of plateau basalts.

The upheaval of the Baisykhan Uplift in the Neogene caused the penetration of the hydrodynamic flow of oxygenous uranium-bearing water into the sedimentary rock mass and formation of the subsoil/tabular oxidation zone (STOZ) on the boundary of which there formed uranium mineralisation.

The new data obtained from geological exploration activities and mining of the ore field deposits allow for the following confident statements:

- the current position of the Khiagda field uranium mineralization is controlled by the STOZ pinching-out boundary;
- the STOZ underwent partial gley reduction which is accompanied by the removal of soluble iron;
- the development of the STOZ within the Khiagda ore field takes place from the Baisykhan Uplift in the sides of the Atalanga and Amalat paleovalleys. In plan view it has a continuous complex bay-like morphology of the pinch-out;
- the oxidation zone and uranium mineralisation is developing in all permeable assemblages of rocks:
    - in the weathering crust of granites and in the disintegrated fractured portion of granites of the Paleozoic basement;
    - in the sedimentary, volcanogenic-sedimentary and volcanogenic deposits of the Neogene Dzhilinda Formation.

The STOZ pinching-out within the Khiagda ore field and associated uranium mineralisation have currently been studied in detail only in the basal portions of the sedimentary deposits of the Lower and Upper Members of the Lower Dzhilinda Formation. This has been done in the upper reaches of the revealed principal paleotributaries of the Atalanga and Amalat stem paleovalleys, within the areas of the STOZ pinching-out near the thalwegs of the paleotributaries. No detail study of the pinching-out of the oxidation zone that retreats to the sides in the lower reaches of the paleotributaries and the sides of the stem paleovalleys or in the upper layers of sedimentary deposits has been performed.

A detailed study of these areas will allow a significant increase in uranium resources in the deposits most proximate to those explored and mined.

The pinching-out of the STOZ and associated mineralisation occurring in the volcanic-sedimentary deposits of the Dzhilinda Formation within the Khiagda ore field has been intersected by single lines of holes drilled in some of the deposits. A focused study of this ore-bearing level within the area of the entire ore field will reveal multi-layer mineralisation associated with the pinching-out of the STOZ not only in the upper reaches of the paleotributaries but also in the sides of the Amalat, Atalanga stem paleovalleys.

Using high temperature gas-cooled reactors for energy neutral mineral development processes – a proposed IAEA Coordinated Research Project

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Today, uranium mined from various regions is the predominant reactor fuel of the present generation of nuclear power plants. The anticipated growth in nuclear energy may require introducing uranium/thorium from unconventional resources (e.g. phosphates, coal ash or sea water) as a future nuclear reactor fuel. The demand for mineral commodities is growing exponentially and high-grade, easily-extractable resources are being depleted rapidly. This shifts the global production to low-grade, or in certain cases unconventional mineral resources, the production of which is constrained by the availability of large amounts of energy.

Numerous mining processes can benefit from the use of so-called “thermal processing”. This is in particular beneficial for (1) low grade deposits that cannot be treated using the presently dominant chemical processing techniques; (2) the extraction of high purity end products; and (3) the separation of high value or unwanted impurities (e.g. uranium, thorium, rare earths, etc.) that could be used/sold, when extracted, which will result in cleaner final products. The considerably lower waste products also make it attractive compared to chemical processing. In the future, we may need to extract nuclear fuel and minerals from the same unconventional resources to make nuclear fuel- and low grade ore processing feasible and cost-effective. These processes could be sustainable only if low-cost, carbon free, reliable energy is available for comprehensive extraction of all valuable commodities, for the entire life of the project. Nuclear power plants and specifically High Temperature Gas-cooled Reactors (HTGRs) can produce this energy and heat in a sustainable way, especially if enough uranium/thorium can be extracted to fuel these reactors.

The proposed Coordinated Research Project (CRP) will thus conduct research and techno-economic feasibility studies on the combination of the following aspects: (1) the use of unconventional uranium (and thorium) resources as future nuclear reactor fuel; (2) the use of thermal processing to extract minerals and by-products in mining and mineral development processes and (3) the study of the sustainability of these two processes, individually or combined with the utilization of HTGRs as the electricity/heat source. The CRP further intends to generate basic data on the availability and characteristics of such low grade mineral resources and their impurities. Finally, the possibility of "energy neutral" value addition in mineral development projects by using the recovered uranium/thorium as reactor fuel for the HTGR deployed to power the process will be evaluated.

Although the need to utilize unconventional uranium (and thorium) resources may still be far into the future, the legal requirements for beneficiation of minerals (such as the recently implemented law in Indonesia) and new cleaner regulations of end products (e.g. cleaner fertilizers, reduced impurities in end products) create an urgency to investigate the feasibility of thermal processing of minerals and removal of impurities such as uranium and thorium that are disadvantageous in the final product but beneficial if used otherwise or sold.

Dadag uranium deposit in Central Anatolia, Turkey

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Consumption of electricity increases very rapidly in Turkey. Production of energy is largely provided with natural gas and coal thermal power plants. There is no sufficient domestic reserve to supply all fuel needs for power plants. Because of this, Turkey has to import natural gas and coal to produce electricity. This situation results for the foreign trade deficit. In addition, the cost of imported fuels increases day by day. The government prefers to use domestic resources which are uranium, thorium and low grade lignite to supply fuels for power plants. Nuclear energy is the best choice to close gap of energy and the foreign trade deficit of Turkey. Therefore, the first Nuclear Power Plant (NPP) construction has been continued in Mersin. The other NPPs are going to be constructed to close energy gap.

The exploration of radioactive elements in Turkey has been continued for forty years. Almost all of the uranium and thorium reserves were found by General Directorate of Mineral Research and Exploration. Geoscientists explored approximately 9000 tons U_3O_8 reserves [~7600 t U] in Turkey. In the past, pilot yellow cake production was successfully completed but there is no former stage products for nuclear energy which are uranium pellets and fuel bars.

Exploration of radioactive elements is more important than past nowadays. As a result, General Directorate of Mineral Research and Exploration prepared a new exploration program in Central Anatolia. After the geological, geophysical and geochemical applications, Dadag deposit was found in 2012. In the project, approximately 6000 m diamond core drilling, hundreds of surface rock sampling and thousands of surface geophysical anomaly points were completed in 2013. According to geochemistry results of rock samples from cores and trenches, the grade changes between 100 – 900 ppm. Core samples were taken with the help of down hole geophysical methods which were gamma ray log and natural gamma ray spectrometry method. Anomalous curves are observed in Early Eocene aged Kubaca unit which consists of limestone, sandstone and bituminous shale. Reserve calculation has been continued for this uranium reserve. Exploration facilities which are 10,000 m diamond core drilling, detailed geological mapping 3-D modeling and geophysical investigations are going to continue in 2014.

Research on uranium and thorium elements exploration through the study of petrography, petrology and geophysical method in the Saghand Area (Central Iran) Islamic Republic of Iran

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This study is a research on uranium and thorium exploration by use of the petrography, petrology and radiometric data in the Saghand area, Central Iran plateau. The lithologies of this area comprise of granite and metasomatized granite. As a result of metasomatic process, uranium and thorium bearing minerals such as davidite and alanite were formed. Sericitization and albitization are the main alterations detected in the study area and thorium mineralization is more common in albitization. By investigation of the chemical classification, non-radioactive specimens, rock types include: diorite and granodiorite, while radioactive specimens consist of gabbroic rocks (basalt). According to the magma source graphs, these rocks formed by calc-alkaline series magma. A scintillometer and spectrometer (MGS-150) were used for radiometric data acquisition. 1001 data points have been obtained from 11 profiles and total counts for, K, U, Th were measured. After primary data processing, data logarithms were calculated for normalizing, and the radiometric data show that uranium and thorium enrichment is more than potassium, while thorium and uranium enrichment are approximately equal. After data integration, two probable anomalies were determined in northwest and northeast parts of the study area.

Uranium legacy of Soviet Union in Tajikistan: problems and ways forward

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Currently, the serious radiological and ecological problems in Tajikistan are overcoming consequences of uranium mining and milling activities which were intensively developed during the Soviet period. After the collapse of USSR, uranium ore extraction in Tajikistan stopped due to the completion or deposits within the territory of the Republic. Remediation of mining and milling activities sites became the most urgent once all mines were closed.

The uranium legacy of Soviet Union in Tajikistan started in 1944, when the uranium concentrate production was initiated in pilot plant of the city of Gafurov. Six small plants on uranium oxide production were constructed in the north of the Republic in 1945, of which only one big plant operated at the end of 1960s in the city of Chkalovsk. After reconstruction in 1980s this plant reprocessed up to 1 million tons of ore per year and produced a sulfuric solution containing uranium up to 200 g/L. The plant produced approximately 2000 tons of uranium oxide per year. During the second half of 20th century Tajikistan was one of the uranium raw materials suppliers in USSR: more than 20% of produced uranium in USSR was delivered from Tajikistan.

Remediation activities were carried out only in small parts of sites which were located in places which were close to residential areas. Thus, uranium ore processing dumps were covered by solid layer of soil of a thickness of 1 m in the densely-populated district of the city of Gafurov, which considerably reduced radon exhalation and gamma-emission dose rates on the surface of the dump. Nevertheless, dumps there continue to remain a risk factor since they are located sometimes only 50 m distant from neighboring residential houses. For example, Degmay tailing dump, which is located in 2 km distance from the nearest residential settlement, is not covered at all and there is a free access to public and cattle pasture on the surface of the tailing dump, where vegetation has been grown up.

Another essential limitation for carrying out the remediation measures is lack of relevant infrastructure. In this regard the regulatory authority of Tajikistan should solve many problems including:

-Assessment of radiological consequences on uranium industry sites;
-Assessment of remediation measures conditions;
-Analysis of compliances with international standards and recommendations;
-Action plan development on minimization of uranium industry site impact on public and environment;
-Purchase of analytical equipment for monitoring.

It is evident that solution of problem on remediation of former uranium industries in Tajikistan is of great importance since significant number of sites and uranium ores reprocessing are located in the basin of Syrdarya River which flows through densely-populated Fergana valley with population more than 20 million people.

In conclusion it is necessary to mention that implementation of international projects with IAEA active participation facilitated to expanding cooperation and mutual understanding among Central Asian countries in issues of environmental protection. The re-establishment of radiation control system on former sites of the uranium industry of the Republic of Tajikistan is the first step to their full remediation.

Physico-chemical basics for production of uranium concentrate from wastes of hydrometallurgical plants and technical waters

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Physico-chemical and technological basics for reprocessing of uranium industry wastes of Northern Tajikistan shows that the most perspective site for reprocessing is Chkalovkst tailings wastes.

The engineering and geological conditions and content of radionuclides in wastes were investigated. It was determined that considered by radioactivity the wastes are low activity and they can be reprocessed for the purpose of U_3O_8 production.

Characteristics of mine and technical waters of uranium industry wastes were studied. Characteristics of mine and technical waters of Kiik-Tal and Istiklol city (former Taboshar) showed the expediency of uranium oxide extraction from them.

The reasons for non-additional recovery extraction from dumps of SE “Vostokredmet” by classical methods of uranium leaching are studied. The kinetics of sulfuric leaching of residues from anthropogenic deposit of Map 1-9 (Chkalovsk City) were also investigated. Further investigations are to reveal the flow mechanism process of sulfuric leaching of residues and to enable the selection of a radiation regime for U_3O_8 production.

The kinetics of sorption process of uranium extraction from mine and technical waters of uranium industry wastes were studied. High sorption properties of apricot shell compared to other sorbents were revealed.

A basic process flow diagram for reprocessing of uranium tailing wastes was developed as well as diagrams for uranium extraction from mine and technical waters from uranium industry wastes. The process consists of the following stages: acidification, sorption, burning, leaching, sedimentation, filtration and drying.

The possibility of uranium extraction from natural uranic waters of a complicated salt composition was considered. Investigations revealed that uranium extraction from brines containing chloride ion is possible. A developed uranium extraction scheme from Sasik-Kul lake’s brine consists of the following main stages: evaporation, leaching, chloride deletion, sorption, desorption, sedimentation, drying and tempering.

Thus, the technological basics of uranium industry wastes reprocessing in Tajikistan are presented. Information about the tailings of former uranium industry in the north of Tajikistan in provided. Issues of waste safe management of mining and reprocessing, uranium ores are considered. Types of uranium revealing in wastes and drainage waters are described.

Further, the possibility of local material use – apricot’s shell – as an sorbent for uranium extraction from run-off mine and technical waters of mining and milling enterprises is shown.

Petrography, metasomatism and mineralization of uranium and other radioactive minerals in the Narigan Area (Central Iran) Islamic Republic of Iran

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The Narigan Zone is a portion of Yazd Province based on geopolitical division. In the Narigan Valley, rocks of zone have experienced a lot of fracturing and faulting events that are caused by different compressional and tensional tectonic processes. Tensional forces by producing fractures and faults have created an appropriate place for migration of magmatic hydrothermal solutions. The assemblage rock of these study area includes of various mineralogical types such as: acidic rocks, basic rocks, sedimentary rocks, rhyolite and rhyodacite, andesite, limestone layers, quartz-porphyry, metasomatic granites and diabasic dikes. On the basis of petrographical and mineralogical studies, various alterations were observed in the Narigan area, such as: gumbeite or potassic alteration, bresite or phyllic alteration, argillic or clay alteration, propylitic alteration, hornfelsic alteration and hydromica, chlorite, carbonate, magnetite and pyritic alteration. Elevated radiometric counts usually occur in phlogopite-magnetite alteration zone that in this complex usually consists of minerals like biotite, phlogopite, hydromica, magnetite, carbonate, pyrite, chlorite and less commonly apatite. The greatest increase in U content is accompanied by phlogopite-magnetite alteration, sometimes this increase is also observed in the propylitic zone. Respectively, the greatest increases in Th contents were observed by phlogopitic-magnetitic, gumbeitey, bresitic-propylitic intermediate zone and the bresitic and propylitic alteration zones. Increasing amounts of Cu is accompanied by phlogopitic-magnetitic, phyllic, phyllic-propylitic intermediate zone, hornfelsic and propylitic alteration zones. The greatest increase in Mo contents is respectively accompanied by phlogopitic-magnetitic, hornfelsic, bresitic-propylitic intermediate zone, bresitic, propylitic and gumbeitic alteration zones. Respectively, the most increase in amount of Co is associated with phlogopite-magnetite, hornfelsic, phyllic and propylitic alteration zones. Ni shows an adaptable increase in phlogopite-magnetite zone and hornfelsic, propylitic alterations. Uranium mineralization in this study area, is comparable with two uranium ore types: plutogenic and volcanogenic. These matters were indicated by various alteration types that observed in Narigan area.

In plutonic-type uranium mineralization, uranium is present in sulphide-uraninite and arsenide-uraninite types. In the Narigan Zone, the presence of sulphide is seen in minerals like pyrite, calcopyrite, and sphalerite. Existence of arsenide is indicated by a few minerals such as: arsenopyrite and glokodot and also relative enrichment of elements like Ag, Bi, Co, Ni and U in some veins. These are signatures for sulphide-uraninite and arsinide-uraninite mineralizing type. Presence of brannerite (davidite-branerite paragenesis) in thin sections is an index signature for volcanogenic uranium-titanium mineralizing type. The secondary titanium-bearing minerals are made by ilmenite and sphene alterations. Relative enrichment of elements like Cu, Mo, Ni, Pb and Zn is made by the effect of high temperature potassic phase on the Narigan volcanogenic rocks. With the consideration of sub-volcanic nature of Narigan zone, metasomatic processes and related hydrothermal phases have been active in shallow environment. On the basis of Bardina and Popov classification the different metasomatic processes at Narigan area have happened in basic to acidic circumstance, with pH 3-9 under temperature range of 150-600ºC.

Environmental geological studies of thorium and other radioactive elements in the Narigan Area (Central Iran) Islamic Republic of Iran

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The study area is located in the Yazd Province, the Bafg-Saqand metallogenic zone in Central Iran structural zone. Lithologically, the stratigraphic units of the Narigan area include the Rizzo limestone formations, Narigan granite, quartz-porphyry and metasomatic granites. The study area has higher concentrations of radioactive elements and some elements of exceeding health standards. These elements are potentially mobile and may migrate from the soil into plant tissues via root absorption and thence to animals. The emitted radiation can also put animals at risk. Environmental studies were undertaken in this research area in order to determine the biodiversity of plants and animals in the Narigan area. Soil and plant root samples were also taken. The amounts of radioactive elements were analyzed by gamma-ray spectrometry with hyper-purity germanium detectors (HPGe). Data obtained from analysis of these plants shows that most samples had elevated concentrations of the radioactive elements ^{226}Ra, ^{137}Cs, ^{40}K, ^{238}U and ^{232}Th, and can be considered as an environmental risk. The radionuclide study of plant and laboratory XRF studies of soil samples show that the roots of the plant *Astragalus* can be a geobotanical reference material for the two elements U and Th in the Narigan region.

Measurement of ^{226}Ra and ^{228}Ra in Brazilian and Israeli Phosphates

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Since the 1970s, the IAEA recognizes that phosphoric acid presents an alternate source of uranium, but given the status of both phosphate and uranium markets the potential of recovering uranium from phosphoric acid still marginal. New technologies for the recovery of uranium from phosphoric acid, national and global interests and environment barriers could shape this market in the medium and long-term scenarios.

On the other hand, the use of phosphates is the major source of phosphorus in agriculture and livestock. Beyond phosphorus and calcium, phosphate is also source of some hazardous elements, such: arsenic, cadmium, thorium and uranium, including a variety of radioisotopes as well. This radioactivity is sure to be released in the environment, contributing to the background. The risk is not recognized for some of the players in this market, mainly workers who apply phosphate fertilizers in the farmland, in some cases manipulating phosphates with their bare hands, and without any respiratory protection equipment (RPE) as well.

This paper deals with the radioactivity from ^{226}Ra and ^{228}Ra in four phosphates often used in Brazilian agriculture. Three Brazilian and an Israeli phosphate were analysed and compared with international criteria. The specific activities of ^{226}Ra (from the uranium decay series) and ^{228}Ra (from the thorium decay series) were taken into consideration to ensure an adequate risk assessment.

Specific activities were determined by high-resolution gamma spectroscopy with germanium detector and Genie® software from Canberra in the Centre of Nuclear Technology Development (CDTN/CNEN). The concentration of ^{226}Ra was measured using the 186.2 keV energy peak, the concentration of ^{228}Ra through ^{228}Ac. The system was calibrated using a set of standard materials from IAEA. The measured samples were crushed and sieved to a grain (98% at least) size as small as 75 µm. Stable mass was achieved grinding, drying at 105°C and mixing each material.

For exposure arising from work involving NORM, consensus seems to be emerging around activity concentrations of 1 Bq/g for uranium and thorium series radionuclides as criteria for determining whether exposure to NORM should be excluded from regulatory consideration. For materials with activity concentrations above these levels, such as the Israeli phosphate studied, the regulatory body needs to decide on a case-by-case basis if it should be included in the system of control.

Hence, people working at factories that mine and process phosphate or handling phosphate fertilizers in farmland activities, are expect to be exposed to higher doses of gamma radiation than rest of the population.

Uranium exploration in Egypt past, current and future activities

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The Egyptian Nuclear Materials Authority (NMA), is the government body responsible for exploration of the nuclear raw materials in the country. The early NMA U-exploration activities has included training of exploration teams, conduction of airborne, ground follow up and preliminary geological mapping as well as execution of limited exploration drilling. A number of TC projects and expert missions were mainly executed in collaboration with the IAEA for this purpose. These efforts have resulted in the discovery of seven U-potential prospects. NMA has also exercised limited heap leaching on experimental scale and obtained small amounts of U-concentrates, utilized for R & D purposes. However, the exploration activities remained in the preliminary phases and did not succeed to reach either reliable evaluation of the discovered uranium resources or running productive U-exploitation.

By the end of the last decade, Egypt has declared the intention to adopt a peaceful program for electric power generation; this implied NMA to implement a twofold plan as described hereafter.

Regarding the conventional U-resources, occurring in the Eastern Desert, NMA focus the exploration activities on the younger granites of Pan African type, and the associated inter-mountain basins. The activities will be restricted to the evaluation of U-reserves in at least three of the most promising uranium prospects that still require extensive exploration drilling programs. NMA is now implementing an international bid announcement seeking for partnership of an experienced international firm, to assess the uranium resources in these sites, in addition to receiving relevant IAEA/TC programs.

Regarding non-conventional resources, the black sand project is mainly a resource of a titanium and zirconium minerals; however, NMA is now trying to process monazite to obtain mainly Th and minor U by-products. NMA has successfully completed an exploration study and. the Government of Egypt has recently advertized an international bid to invest in a mining project in El Burullus mineral sand deposit on the Mediterranean coast. NMA is also planning to support the current purification of phosphoric acid, employing a semi- pilot plant supposed to be operated also for yellow cake extraction as bi-product. The uranium extraction cycle faced difficulties aroused since testing of this unit in 1997. The current NMA efforts, supported by receiving IAEA/TC, aiming to avoid the serious failures in the extraction cycle of uranium in this unit.

New method for development of stagnant zones and man-made mineral formations for in-situ leaching

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Drilling of ISL ore bodies (mineralization) that is more than 8-10 m thick and imbedded in lithologically heterogeneous section creates some problems with full extraction of uranium from the subsoil. The maximum possible flow rate of production wells does not provide for the entire operating block thickness to be treated with process solutions, and different degree of permeability of ore-bearing deposits prevents from the uniform mining of the ore bodies. The final stage of such ore mining usually drags on and leads to further expansion of mining infrastructure (extra load on sorption) and increase of operating costs. On the other hand, construction of additional wells (2nd level) on such ore significantly increases the unit cost of drilling (per kgU), as well as consumption of chemicals and electricity.

The method developed by the company for the final mining stage of the block constructed on such ore suggests the following:

- The block is completely removed from operation. At this time, the process solutions get mixed and flow down by gravity towards the lower confining layer, and diffusion leaching processes become active.

- By using the artesian flow effect the injection wells are converted into production mode. Solutions produced from injection wells are collected into the movable tank with sulphuric acid being added to them and then these solutions are injected into all production wells during 30-35 days. It, therefore, creates a closed cycle of solution collection from injection wells and their feed into production wells. The reverse process results in acid solution penetration into the stagnant zones and involvement of previously unaffected mineralisation in mining.

- The block is then put into operation with the uranium concentration in pregnantsolutions increasing 2.5 - 4 times compared to the previous operation stage.

The use of such scheme made it possible to significantly shorten the final mining stage of four operating blocks, reduce operating costs and avoid additional costs on the well field reconstruction.

Development of Budenovskoye Deposit in South Kazakhstan

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Budenovskoye deposit was discovered in 1979 in permeable alluvial deposits of the Upper Cretaceous and is the world largest sandstone type deposit. The prospecting and exploration works were started there in 1987 with inferred resources of the southern flank only estimated at about 200,000 tU.

Key geology features of the deposit are:

- The deposit is located in the maximum submerged part of the depression formed in the Upper Cretaceous period by channel facies; a very complex morphology of mineralisation in plan, large vertical area, multilayer structure, relatively high productivity of the deposits.
- High-pressure nature of groundwaters with positive occurrence of piezometric level, very high water conductivity, permeability of horizons and their water abundance, lack of consistent confining layers, and location of the deposit in the artesian basin at the junction with hydrogeological massif of B Karatau Range.
- Relatively low concentration of main syngenetic genesis reducing agents in ore-bearing rocks in combination with other factors causes the insufficiently contrastive reducing barrier and extraordinary stretched profile of epigenetic zonation with fuzzy boundaries between separate zones and subzones.

These and other factors were considered for successful operation of Karatau:

- During exploration, the “stretched” profile of epigenetic zonation was first of all evaluated in the central and “bag” parts; the flanks of this site will be drilled during operational exploration. This allowed reducing the time and cost of exploration, as well as the transition to production. About 100 tonnes of explored uranium reserves were accounted for in 1 exploration hole.
- A profound differential algorithm is used to interpret gamma-ray logging and assess stem reserves of uranium taking into account both the position of well in epigenetic zonation and the average concentration of radium in the section.
- Drilling of multi-layered deposits is performed step-by-step, from a simple and large ore body, to complex ones, with consequent more precise determination of ore boundaries. Several such ore bodies projected together to the daylight surface are mined successively, when possible, using the same piping of technological blocks at different times.
- The experimental block piping is used at positive piezometric level: production wells are constructed as injection wells (without submersible pumps); the system is equipped with additional 1- 5 small pumping wells equipped with powerful pumps arranged in the wells below the dynamic level. The wells are all connected by pipes to get a system of communicating vessels that does not require placing the pump in a certain point or having the infrastructure for it; the required movement vector of reservoir water at such point is created remotely with the use of pumping wells. This tremendously optimizes the operation

and allows any combination of production and injection pumps at any time reducing the production costs.

- The minimum difference between drilled, acidified and prepared reserves (“K” of prepared reserves is ≤ 1.5) is mainly defined by hydrogeological characteristics of the site what also reduces the well field development costs.
- About 6,000 tU is produced per one worker with the record low cost figures

A newly developed accelerator to convert thorium to uranium-233

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For constructing a sustainable society, low-carbon energy sources and low-carbon automobiles are required. In addition to the use of nuclear power, renewable energy such as wind-mills and solar power are used as low-carbon energy sources. Electric vehicle (EV) and hybrid vehicle (HV) are expected to be used as low-carbon automobiles. Essential raw material in order to fabricate these machineries is rare-earth elements (REE). In these few years, rare-earth supply has been unstable due to China's monopoly in its production. China's monopoly of rare-earth production was caused by loss of market competitiveness of other countries that needed to spend cost for taking care of "thorium" which occurred as by-product of rare-earth refining. Thorium can be used as nuclear fuel but thorium is merely fertile. Therefore, additional supply of fissile material is necessary to use thorium. As a result, there are no countries that separate and store thorium as valuable except India.

The authors have studied (1) molten-salt reactor (MSR) as a utilizing technology of thorium, (2) implementation capacity of thorium MSR supported by a supply of plutonium from spent uranium fuel and (3) international framework to protect environment from thorium which occurs as by-product of rare-earth refining. Available implementation capacity of thorium MSR by using all plutonium based on the prediction of IEA's uranium fuel cycle is only 392 GW at 2050. This capacity of thorium MSR requires 76 thousand tonnes of thorium but total amount of thorium occurring as by-product of rare-earth reaches to 444 thousand tonnes. If there is no use of thorium, it could be abandoned to environment illegally.

The authors are considering a new framework to protect environment by giving an incentive of storing thorium by adding value to these excess thorium. A newly developed accelerator neutron source is a method to add value to thorium. Spallation reaction has been known as neutron source which uses high-energy acceleration. The authors adopts low-energy and high-intensity accelerator to use D-Be reaction. This is named as "TRANS (Tandem Repeat Accelerator Neutron Source)". TRANS can operate multiple accelerator-tubes in parallel to increase neutron yield. The maximum neutron yield of TRANS-2012 (acceleration energy 2 MeV) is 5×10^{14} n/s.

In this paper, concept of TRANS is described and its applications such as thorium-fuel production, accelerator driven sub-critical system (ADS) will be introduced.

Prospects of block underground leaching application on Streltsovskoe field deposits

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The Streltsovskoe uranium ore field belongs to the category of a unique deposit and is represented by 26 deposits which lie on a large area. The original average uranium grade was 0.212% in reserves approved by State Committee for Mineral Reserves. The main volumes of uranium ores are mined via descending horizontal slicing with hardened backfilling, which accounts for more than 90% of the uranium mined. The uranium grade in run-of-mine ore decreased by 2013 to a half of earlier values because the richest ore reserves were mined over the more than forty years work of the enterprise. The uranium grade reduction has led to a decline the technical and economic performance of the enterprise, a sharp cost rise of mining and hydrometallurgical processing, fall-off of the running mines' final product output. Uranium production growth is not possible by increasing the volume of mined ore due to the high-cost current mining system and technical condition of existing equipment.

Nevertheless, the proven ore reserves remaining at the depths are enough for 50 years of operation.

The development of new deposits could be delayed due to a hard geographical and mining operation conditions. The proposed, complicated approach for the remaining ore reserves recovery including descending horizontal slicing for the high grade ore mining and block underground leaching of low-grade ore will ensure the profitable operation of the enterprise. From 1986 to 2006 block underground leaching commercial tests were carried out under mining of ore bodies with various configurations, angle of dip, thickness and different host rock at the Priargunskiy enterprise.

The long-term scientific research results and commercial tests, as well as technical and economic calculations show that the most promising way to improve the mining operation is the use of physical and chemical geotechnology by means of direct underground uranium ore leaching into a production solution from the most part of the broken and size-reduced ore inside an operational ore block, avoiding thus ore hoisting and hydrometallurgical processing. However, the large-scale block underground leaching application was not implemented under mining of Streltsovskoe ore field reserves due to an unstable (from 34% to 88%) uranium rate extraction from broken ore within testing blocks. The main reasons of the low uranium recovery in a some blocks were improper testing block development, broken ore mass repacking, flowing channels appearance within the blasted ore mass, blockages and failure to comply the schedule of tests. Overall, it was due to lack of properly scientific study of technological schemes, operation conditions and parameters of leaching. At present the JSC "Priargunsky Industrial Mining and Chemical Union" (JSC "PIMCU") together with the Leading Research and Development Institute for Industrial Technologies (OJSC "VNIPIpromtekhnologii") and the Trans-Baikal State University make a complex scientific researches on the block underground uranium leaching technology. Now the pilot tests of uranium leaching from run-of-mine ore size in percolation columns are completed at the Central Research Laboratory of JSC "PIMCU".

Unconventional isotope systems applied to enhancing the petrogenesis of uranium deposits

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Among the new techniques applied to the petrogenesis and evolution of uranium deposits from their formation to later alteration is isotope tracing. The isotope systems being used include Li, C, N, Fe, Mo, Tl, Pb and U, all of which reflect different, but overlapping, processes. Although Pb isotopes have been used to understand the temporal evolution and migration of radiogenic Pb from the deposits, Li, C, N, Mo, Tl and U isotope systems are new ways to analyze deposits and barren areas and to reveal their precise redox mechanisms. Geochemical technologies for exploration include $^{238}U/^{235}U$ ratios of uranium minerals, which vary as a function of the type of uranium deposit and the efficiency of the redox processes. Lithium isotope ratios in muscovite and chlorite associated with mineralizing events are distinct from background ratios, with the lowest values reflecting the beginning of hydrothermal alteration systems and the highest values indicative of the terminal flow of hydrothermal fluids. Carbon and N reflect the influence of biospheric processes on the deposits and dispersion of elements that can be used for exploration. Iron, Mo and Tl are common elements in many uranium deposits and are among the most redox active elements. Their isotopes separate among phases having different oxidation potentials. They reflect the efficiency of the redox systems associated with fixing the uranium and the subsequent processes involved in mobilizing elements from the deposits. Isotopes add benefits to refining genetic models for uranium deposits, thereby enhancing our exploration models as well. An additional goal of applying isotope geochemistry to uranium deposits is to be able to use them to reflect a definitive process that occurs in the deposit and not in barren systems, and then to relate these to something that is easier to measure, namely elemental concentrations.

Current state of uranium exploration in central Colombia: Regional perspective and selected case studies

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The Colombian Geological Survey has been working in a regional exploration program focus on the ancients massifs of the Eastern Cordillera. The general geology distribution in these massifs (Santander and Quetame) includes a core of meta sedimentary to medium grade metamorphic rocks of pellitic origin presumed to be of Cambro – Ordovician age, intruded by Ordovician age plutons that grade from granodiorite to quartz diorite. This igneous – metamorphic core is unconformable overlain by a Devonian age sedimentary cover that includes conglomerates of continental origin, black mudstone of marine origin and red sandstones of deltaic enviroments with some calcareous intervals. In the Santander Massif a sequence of continental red beds of Jurasic age is present and in the Zapatoca (Santander) area contains uranium. In the Santander Massif, mineral exploration in an area on 1300 km^2 with 1235 sample locations, gives average uranium values of 5.44 ppm, an a maximum of 20 ppm, located in Ordovician plutonic rocks. In the Quetame Massif, mineral exploration in an area on 1000 km^2 with 1274 samples locations, gives average uranium values of 6.13 ppm, and a maximum of 2763 ppm, located in Devonian to Carboniferous sedimentary rocks.

In the Paipa area, 140 kilometers from Bogota, the Colombian Geological Survey has undertaken exploratory drilling. As a result there is an anomalous area of 500 m^2 with values of 2000 ppm uranium and rare earth associations has been identified. The volcanic system has been studied by several authors and is important for its location and extention.

In recent years, exploration by private companies was reactivated. In early 2000 several junior companies such as KPS/Energentia Resources Inc., Mega Uranium, U3O8 Corp, Energentia Resources Inc., Blue Sky Uranium Corp, Sprott Resource Corp. and UrAmericaLtd and began exploratory work in Colombia. The Berlin project, located in the central mountain range, is perhaps the most developed in the exploratory stage. The Berlin project was reported by the company MINATOME (now Areva) in the 1980s and is found in sedimentary rocks with an area of 10.5 km^2 in a synclinal structure and of Cretaceous age. The Canadian company U3O8 Corp subsidiary GaiaEnergy develops the Berlin project today. To the south of the project (3 km) an 1.5 indicated Mlb, 20 Mlb Inferred [~580 tU and ~7700 tU respectively] has been reported.,The rocks have a 12% recovery of uranium and 97% of the mineral. Over 22,000 m have been drill and a part of the project is under a prefeasibility study.

Challenges of development of regulatory control infrastructure for uranium mining in developing countries (Tanzania) to achieve regulatory compliance

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Managing radiation and waste in uranium mining is of paramount importance for the protection of occupational workers, the public and the environment. Responsibilities of the parties which are involved in the part of the Nuclear Fuel Cycle are outlined in the legistlations and regulations governing uranium prospecting, mining and processing. The Tanzania Atomic Energy Commission, as the regulator for radiation and atomic energy, has developed regulations for exploration, construction, mining, milling, packaging, transport of yellow cake and decommissioning of uranium mine site in Tanzania. This paper outlines the development of these regulations and compares with the international standards. The paper also reviews and analyses gaps and shortcomings for safe uranium mining in United Republic of Tanzania.

Extraction of uranium from low-grade uranium ores in Poland

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In January 2014 Polish Government adopted the Program of Polish Nuclear Energy. One of the objectives of this Program is the assessment of domestic uranium deposits as a potential source of uranium for Polish nuclear reactors. Presently, mining of Polish low-grade uranium ores is unprofitable. However, studies on the prospects of recovery of uranium from domestic resources are in progress, keeping in mind the inevitable growing uranium demand and perspectives of the global uranium market.

The most perspective deposits are in the Lower Ordovician Dictyonema Shale of the Podlasie Depression (north-east Poland) with uranium concentration of 75-250 ppm and the Lower and Middle Triassic rocks of the central parts of Peribaltic Syneclise, where concentrations reach 1.5% U (recent analysis of archive samples).

Uranium usually is accompanied by other rare metals e.g. V, Mo, Ln, Ag or Co that can be recovered in technological process to improve the profitability of the whole venture.

The characteristics of the material originating from uranium ores vary significantly from deposit to deposit. The effect of ore mineralogy and mineral liberation on the leaching behaviour of uranium is not well defined. The procedure of uranium extraction must be designed to fit specific characteristics of the ore; however the general scheme of the process is similar for most of the ore materials.

The main objectives of this research were: to assess the possibility of exploitation of uranium resources in Poland, and to work out methods of uranium extraction from the ores to produce yellow cake – U_3O_8.

In the present work at the beginning of the extraction process, uranium was leached from the ground ore by using sulphuric acid or carbonate (CO_3^{2-}) solutions. In comparison with acid processing, alkaline leaching had the advantage of being selective for uranium. The post-leaching solutions were concentrated and purified using solvent extraction or ion exchange chromatography. Novel systems for solvent extraction were tested and the use of new extracting agents were considered. The precipitation of ammonium diuranate or uranium peroxide forms was the most crucial step in the production of uranium oxide. This is followed by calcination step forming U_3O_8. The preliminary economic assessment of the technology employing several stages of processing, carried out in the pilot-scale installation was done on the basis of the data collected in laboratory-scale experiments.

Recovery of uranium and accompanying metals from various types of industrial wastes

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On Janury 28th 2014 the Program of Polish Nuclear Energy was signed by Polish Government. According to this program Poland has to secure a constant supply of uranium for Polish NPPs in the future. Uranium in Poland occurs in Vistula Spit area in sandstone rocks and Podlasie Depression area in black dictyonema shales, which are low grade ores. Scarce uranium resources stimulate interest in its recovery from secondary resources as potential raw materials. Industrial wastes and by-products were considered as a source of uranium in this studies. Apart from uranium other valuable metals (e.g. vanadium, molybdenum or lanthanides) were recovered to improve the economy of the process. Three types of industrial wastes were examined: flotation tailings from the copper industry, phosphoric acid from the fertilizer industry and fracturing fluid from shale gas exploitation.

Metals from flotation tailings were separated in two steps: 1) acidic leaching of the flotation waste using sulfuric acid solution and 2) separation of metals by ion-exchange chromatography. All the liquid samples were analyzed by ICP-MS method to determine the separation efficiency of the process.

Uranium was recovered from phosphoric acid by high-pressure membrane filtration or by extraction/stripping integrated processes applying membrane modules Liquid-Cel® Extra-Flow (Celgard).

Aqueous solutions after hydraulic fracturing are very diverse in terms of chemical composition, depending on borehole and fracturing technology applied. The content of various substances in backflow fluid depends on mechanical behavior and chemical composition of shale. Organic matter content in this type of waste did not exceed 1% usually, but the salinity is high. Initially, organic pollutants were removed and next the fluid was purified by combined various ion-exchangers. Individual metals were selectively eluted from ion-exchanger by combination of different eluents. The content of metals in samples was analyzed by ICP-OES. Organic matter was analyzed by TOC method.

Development of the heap leaching of low-grade uranium ores for conditions of OJSC Priargunsky Mining and Chemical plant (PPGKhO)

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The treatment of low-grade commercial uranium ores by heap leaching has been carried out at the enterprise since 1996.

During the initial stage of development, the ore piles were formed of the raw ore having the run-of-mine coarseness with uranium content around 0.08%. Under such conditions, recovery of the metal to the solution is 60-65% in case of a pile treatment lasting 2 years.

To intensify the process and to provide a stable concentration of uranium in the productive solutions transferred to sorption, the enterprise developed and implemented a method of percolation leaching of low-grade ores with re-circulation of productive solutions through the re-treated ore bulk (RF patent No. 2226564). The main peculiarity of such leaching is simultaneous moistening of the ore by productive solutions and by barren solutions that are sharpened with sulphuric acid; that gives the possibility to wet far bigger areas of piles under constant volume of productive solutions outputting to the sorption treatment. Such scheme enables to treat successively first the piles at the “re-treatment” (where the metal is mainly extracted), and then the piles at the “active leaching” stage (where the metal is mainly inside the ore bulk).

The technical and economic indexes of the heap leaching of low-grade uranium ores were significantly increased in 2006, when the X-ray-radiometric treatment plant was commissioned. The technological scheme of ore treatment at the processing plant includes mould and grating of the raw material with delivery of undersized products enriched with uranium: -5 mm are transferred to the pulp process; fractions (-200+40) mm to the X-ray-radiometric separation; the material of size (-40+5) mm, washed-out from clayey and fine particles, are sent to the uranium heap leaching in piles.

Delivery of the ore material having size (-40+5) mm to treatment by the acid leaching method excluded colmatage and creation of zones impermeable for water, and in combination with re-circulation of productive leaching solutions it enables to intensify the process and to increase the recovery of uranium to the solution up to 75%, with the time of an ore pile treatment equal to 1.2 to 1.5 years.

The next stage of the uranium heap leaching process intensification shall be implementation of the scheme of fractioning of the ore at the X-ray-radiometric treatment plant before creation of piles from the material having size below 15 mm. Use of such method will give the possibility to increase the recovery of uranium of to 85% in case of the ore with the initial uranium content ~ 0.06-0.07% and the leaching period having duration of less than one year.

Uranium in the north of Côte d'Ivoire: the case of Odienné

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This work is a contribution to a better knowledge of Precambrian formations of Odienne region (Côte d'Ivoire), through their petrography and geochemistry.

Those formations may be divided into two main groups:

- first the metamorphic rocks constituted of Liberian rock relics, volcanic and volcano-sedimentary complex of Birimian age, ortho-gneiss and amphibolites considered either as Ante-Eburnean or early from the Eburnean cycle;

- second, the plutonic rocks which are mainly made of granitoids.

The discovery of aluminous gneiss of granulite facies within the Liberian formations, petrographically and chemically similar to those described in the Man region, and the presence of magnetite containing quartzites, are evidences of the existence of Liberian basement in the Odienne region.

All the features of the Odienne Eburnean volcanism, as shown by the study made on the volcanic and volcano-sedimentary complex, allow us to connect it to the calco-alkaline series. In the present case, a formation model related to the big cutting accidents seems to fit best.

As for the granitoids, they show:

• a cataclais characterized by mineral torsions or breakages, a frequent mineral lineation, and an ondulating extinction; these are evidences of a syncinematic set-up;

• a high content of Na_2O that seems to be expressed by a very important plagioclasic charge;

• an evolution wholly silico-potassic in nature; all the samples studied vary from a quartzic-diorite pole to a granitic pole, with the majority of the compositions found in the granodiorite and adamellite domains ; the magma which generated those granitoids is of the calco-alkaline type;

• relatively low average uranium and thorium contents; most of the radioactivity of those rocks is concentrated in the biotite or in the accessory minerals (generally in the form of inclusions in the biotite).

Geochemical model on uranium mineralizations in the rhyolite-granite complex in the Jabal Eghei area, Libya

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The history of geological investigations of the Tibesti Massif and its surroundings is dating from the mid-1860s. After almost half a century of inactivity, the first sketches and rough topographic maps of Tibesti were done in the early 1900s. Significant changes in the approach to geological investigations began when the Industrial Research Center of Libya, founded in 1970, commissioned the production of detailed geologic maps and geological investigations of rhyolite-granitoide rocks in the Jabal Eghei area in order to investigate the mining potential of this region.

The radiological survey of the terrain, followed by laboratory analysis of geological samples by gamma-spectrometry and ICP-MS techniques, resulted with discovery of two significant uranium mineralizations in rhyolite-granite rocks located in the central part of the investigated region, covering an area of about 60 square kilometres. The concentrations of uranium in these mineralizations were found to range from approx. 50 mg/kg to more than 600 mg/kg, the latter being about 240 times above the Earth's average. Additional geochemical analysis had shown that these mineralizations are accompanied by increased contents of silver (up to 17 times), arsenic (up to 8 times), molybdenum (up to 50 times), mercury (up to 9 times), and lead (up to 14 times), with regards to the Clark values.

A simple generic model for uranium mineralization in the Jabal Eghei region is proposed. The main primary sources of uranium mineralization are granitoides and uranium was mobilized from them mostly through cold solutions and deposited in contact zones with rhyolites, fault structures filled with clay, ferrous oxides etc. Uranium mineralization is spatially and genetically related to the volcanic complexes (rhyolites) and the spatial position of the postorogen magmatism, which is the lithologic control factor of the mineralization position. The forms of the ore bodies depend on the structural and lithologic control factor and are probably in the form of a pillar (column). The main ore material was pitchblende, although the presence of uranitite, coffinite and uranium titanite could not be excluded. A full explanation of the genesis of these uranium mineralizations could be obtained from detailed geological investigations.

Regarding the genesis of the ore deposits and the possibilities of the formation of economically interesting uranium concentrations, which are spatially and genetically related to acidic and intermediate magmatic complexes, the leaching of uranium is of particular interest.

These results warrant a continued investigation of this region because of potential interest in the discovery of nuclear mineral raw materials.

Thermodynamic and kinetic study of uranium peroxide precipitation

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In the processing of uranium ores, uranium is recovered from mill leach solutions and is transported to a processing plant. This step allows obtaining an uranium concentrate by precipitation. After drying, a solid uranium concentrate is produced (called "yellow cake" due to its color and its doughy texture at the end of the procedure), containing around 75% uranium. The "yellow cake" is packaged and put into barrels, then sent to conversion facilities for further chemical processing.

Among the different existing precipitation devices, the continuous precipitation with hydrogen peroxide in a fluidized bed reactor leads to high-quality solid particles. The precipitation is achieved at pH ~ 3 by mixing hydrogen peroxide and uranyl sulfate solutions, according to the following equation:

$$UO_2SO_4 + H_2O_2 + 4H_2O \leftrightarrow UO_4 \cdot 4H_2O + H_2SO_4$$

Solid particles must fulfill specific requirements, in particular concerning the size. Thus, the control of the crystal growth becomes a key parameter during the uranium peroxide precipitation. Moreover, the solubility product, K_s, is required to calculate the driving force on which the kinetic law depends. For the uranium peroxide precipitation, the supersaturation ratio, S, is linked to the activities of the uranyl and peroxide ion as:

$$S = \sqrt{\frac{a(UO_2^{2+})\, a(O_2^{2-})}{K_s}}$$

with:

$$K_s = a(UO_2^{2+})_{eq}\, a(O_2^{2-})_{eq}$$

where $a(UO_2^{2+})_{eq}$ and $a(O_2^{2-})_{eq}$ are the uranyl ion activity and the peroxide ion activity at equilibrium.

The uranyl ion activity is obtain as the product of the uranyl activity coefficient and the uranyl free concentration, which are calculated from the Specific Interaction Theory and total concentration balance, respectively. Considering the experimental data of the dissociation constants of hydrogen peroxide and knowing that it is not very dissociated in solution, the expression of the supersaturation ratio becomes:

$$S = \sqrt{\frac{\gamma_{UO_2^{2+}}[UO_2^{2+}][H_2O_2]}{a(H^+)^2} \frac{K_{A3}K_{A4}}{K_s}}$$

where K_{A3} and K_{A4} are the dissociation constants of hydrogen peroxide and $a(H^+) = 10^{-pH}$.

In order to calculate the supersaturation ratio, the ratio $\frac{K_{A3}K_{A4}}{K_s}$ is determined from the speciation study by a regression technique.

Once the thermodynamic law is established, the determination of the crystal growth rate expression for modelling the precipitation processes is performed. The experimental study is carried out in a glass baffled batch reactor equipped with a marine propeller and a wide range of experimental conditions.

Particle size distributions are measured before and after the growth tests; the results show that the distribution remains practically unchanged. Consequently, the two distributions confirm the absence of agglomeration, breakage and nucleation. In addition, processing experimental data, it is found that the crystal growth is linearly dependent on the supersaturation. Furthermore, the mechanism which governs the uranium peroxide growth is the dislocation mechanism. Finally, crystal growth kinetics is independent from the impeller speed.

Delivering competence based training and capacity building to support sustainable uranium mining in less prepared areas

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The IAEA project “Supporting sustainable uranium mining in less prepared areas” consists of a 3-year catalytic training and capacity building of a range of work packages/tasks targeted on technical, operational, regulatory, environmental, stakeholders and governance needs in uranium mining of African francophone uranium producer or potential producer countries. The project is externally funded by a contribution from the USA. The scope is defined by the identification and the delivery of training and further capacity-building measures to enhance national and regional preparedness in these francophone Member States for the conduct of sustainable uranium mining and production, with particular reference to environmental, social, economic issues and good governance within the context of fostering good, safe practices in the comprehensive extraction of all possible economic resources from the mining process.

The participating countries are: new countries considering exploration and/or mining for the first time, but with no current commitment to the activity (Burkina Faso, Ivory Coast and Mauritius); restarting countries initiating or reinvigorating uranium mining, with known exploitable reserves (Algeria, Cameroon, Central African Republic, Chad, Democratic Republic of Congo, Mauritania, Morocco, Senegal and Tunisia) and the active countries with a long history of uranium mining and milling wishing to enhance their existing capacity (Gabon and Niger).

The training courses will be adapted to the local conditions: needs of the aforementioned countries and of the different stakeholders: professional beneficiaries (governments, industries and academia) [modules covering the U life cycle with associated materials such as checklists, scorecards and SOPs addressing topics as: technical and scientific; regulatory; governance and good management; safety, security and safeguards] and affected local communities (engagement and outreach planning, communities and consultation process, social returns and social licensing).

The methodology is based on the competency based training in a safe and sustainable conduct of U production life cycle. The training is considered as a mix of tactic/strategic means, delivering pilot courses in year 1, and then improving continually the model; deliver a capacity building programme of training for the sustainable resources management; amplify the results by the train the trainer’s activities. The availability of a SharePoint and supported on-demand web resources is considered as a good and necessary exit strategy of the project.

The approach is based on the competency matrix by type of job description; training courses overall normalised adaptable to targets and local conditions; Personal Development Professional Plan; regular feedbacks, monitoring and evaluation allowing adjustments and readjustments of the training courses and the activity programme with a follow up of the relevant normative and summative indicators selected for ongoing monitoring and review, with a focus on normative indicators as guides to qualitative improvements in line with sustainability goals; control and assurance quality (“PDCA”).

The proposed outcomes are to enhance preparedness leading to improved national capability for uranium production delivering sustainable socio-economic returns and ability to comply with international standards and good practices based on a “pathway to preparedness”.

Critical dependencies for achieving these outcomes will be a sustainable, probably virtual, competency centre tasked with supporting the professional community and critical mass in that community.

Developments in the modelling approach for radiological safety assessment of ^{238}U-series radionuclides in waste disposal

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Human and environmental radiation exposures from sites or areas contaminated with radioactive substances need to be quantified as part of the risk assessment process and for developing long-term remediation strategies. In most radiological assessment models, simplistic, empirical ratios are used to simulate contaminant transfers between environmental compartments. These are favoured because they facilitate modelling. Their use, however, significantly increases the uncertainty of model predictions, because they do not account for the underlying processes that govern spatial and temporal variations in radionuclide concentrations. In relation to more explicit, process-based modelling, representation of the migration of radionuclides in the ^{238}U decay series in soils and their uptake by plants is of interest in various contexts, including the disposal of radioactive wastes and the remediation of former sites of uranium mining and milling.

The structures of models used to assess doses in the biosphere for long-term waste disposal assessments have not changed significantly in the last few years. Several aspects of the model representations of the biosphere are currently being debated in international forums, and these aspects would benefit from further investigation. The potential topics of interest include biogeochemical zonation of radionuclides in the sub-surface, caused by changes in the redox characteristics in response to a variable water table. It has been proposed that traditional model structures are not able to represent this aspect of the system adequately.

Major improvements are needed to make models more process-based and capable of simulating the kinetics of contaminant transfers. A major challenge is to identify where the greatest advantages can be gained in reducing model uncertainty and understanding variability, developing criteria to identify if further research is required for parameterizing dynamic-mechanistic models, and identifying the level of model complexity needed for specific exposure scenarios.

This paper reviews the processes that need to be represented in order to simulate the behavior of ^{238}U-series radionuclides in long-term assessment models for radioactive waste disposal, and proposes a model structure and associated mathematical model that can be used to investigate the potential impacts of seasonally variable conditions on the calculated radionuclide concentrations in soils and plants. This work looks also at the potential for the inclusion of spatio-temporal variability in models for long-term dose assessments.

Steady-state fluid flow as a complementary driver of mineralization and redistribution processes at unconformity-type uranium deposits in the Athabasca Basin, Canada

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Numerical modeling shows that faulting in a dilational regime may have driven oxidized uraniferous basinal fluids into reducing basement environment. In a compressional setting, basement fluids would have been injected into Athabasca Group rocks thereby precipitating uranium out of oxidizing basinal fluids.

The complementary fluid flow model based on steady-state conditions presented here rests on the following premises:

1. Convection is the predominant driving force in the Athabasca Group during seismically quiet times.

2. Each faulting episode disturbs the convection flow, which recovers within a certain time span.

3. The length of time between faulting events is long enough to re-establish steady-state conditions.

4. Rapid recovery of fluid pressure in dilation spaces prevents complete sealing of the fault.

Steady-state groundwater flow was investigated using a generic 3D finite-difference flow model of a typical unconformity-related uranium deposit in the Athabasca Basin. The parametrization of an assemblage of basement rocks overlain by sedimentary rocks of the Athabasca Group and intersected by a strike-slip or reverse fault was based on literature values. A regional gradient was selected that, at given hydraulic conductivities, produced flow velocities as modeled previously for thermal convection. The gradient was oriented at an oblique angle to the structure. No initial vertical gradients were applied. Mixing zones were defined by parallel orientation of basin and basement derived streamlines suggesting potential interaction to be expected under turbulent flow conditions.

Solute transport was simulated as advection modified by dispersion in order to circumscribe the extent of a hydrogeochemical plume in groundwater stemming from mobilized ore and alteration products.

The following streamline patterns are observed:

1. A structure with elevated hydraulic conductivity focuses the flow of fluids from a large volume of both basement and sandstone rocks.

2. Basinal and basement fluids cross the unconformity near the structure thus giving rise to chemical interaction with rocks and existing mineralization.

3. Mixing zones for fluids of varying provenience form in the immediate vicinity of the structure and within the structure above, at and below the unconformity.

4. The contrast of hydraulic conductivity of the structure and that of the wall rocks determines the vertical position of a mixing zone relative to the unconformity.

5. Solute transport circumscribes large potential geochemical halos in the Athabasca Group rocks and dispersion of limited size in the basement.

6. Vertical flow exists without the contribution of initial vertical gradients caused by thermal effects.

Fluid flow patterns under steady-state flow conditions localize mixing zones that coincide with observed distribution of mineralization and alteration in the basement, at the unconformity and in the Athabasca Group. Pre-Athabasca U-sources in the basement could be located within the range of scavenging basinal fluids crossing the unconformity in the upstream area. Basinal fluids entering mineralized structures may have caused the corrosion of existing U-mineralization and in reaction with basement fluids, the re-precipitation along the structure.

Comparing recent uranium supply scenarios

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For more than one decade – even after the Fukushima accidents - an increase in global nuclear energy generation capacity is widely expected. At the same time a variety of uranium supply scenarios were published by industry, academics or international organizations, drawing different pictures of future uranium supply. They were created with the background of a uranium market facing several challenges. First an excursion in the uranium market price, in 2007, then reduced nuclear growth expectations after 2011, at least in non-Asian countries, also implying considerable changes to the supply side.

For this publication a meta-study was carried out identifying, evaluating and comparing different recent scenarios on the availability of uranium. While there are some differences in the frame conditions (e.g. the expected uranium demand, the time fame, the considered mining projects,..), there are also notable similarities in these scenarios. This concerns long lead times for mine openings as well as the dependence on large mining projects (e.g. Olympic Dam, Cigar Lake). Generally, a decline in production in about 10 years is assumed, and thus the necessity of the timely development of mining projects is pointed out. In addition the omission of uranium from Russian nuclear weapons and the chances of keeping the changes in secondary supplies in balance with primary production have been widely discussed. Here, the production growth in Kazakhstan but also the role of the current market situation are central aspects. As another aspect the possible contribution from unconventional resources is of interest, particularly against the background of rising production costs for conventional resources.

Finally, it shall be reflected how well older scenarios were able to map the reality and which trends could or could not be anticipated. It is relevant to identify which aspects in the development of mining capacities are essential for security of supply, and can therefore be regarded as critical or less critical, and especially which impacts can be expected from the delay of projects.

Overall, it has to be noted that the availability of uranium will have a significant impact on growth prospects of nuclear energy, probably much more than publically discussed.

Fluid flow and reactive mass transport modeling of reducing mechanisms in the formation of unconformity-related uranium deposits

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Unconformity-related uranium deposits in sedimentary basins represent the most important and profitable deposits among other types of uranium deposits, however their origin is still not fully understood. To better understand their formation, and in particular to address possible reducing mechanisms in the precipitation of uraninite, we develop a highly conceptualized 2-D model that fully couples fluid flow and heat transfer with reactive mass transport. We consider a series of numerical scenarios and examine the effect of graphite zone and Fe-rich silicates as the carbon-based and the inorganic-based reducing agents on the ore genesis. Our numerical results reveal that both the reducing mechanisms can lead to the precipitation of uraninite below the unconformity interface away from the faulted zone. Physiochemical parameters such as oxygen fugacity and temperature play a significant role in localization of the uraninite. Localization of these deposits is in relation to the decrease of oxygen fugacity, generally resulting from the interaction of oxidized uranium-bearing fluids with the reductants. Uraninites precipitate simultaneously with hematite in the areas experiencing reduction of oxygen fugacity and having a temperature of 180-200°C and a pH of 2.5-4.5. Wide-spread alteration halos in the basement and around the uranium deposit include hematite, Mg-chlorite, and muscovite associated with minor amounts of pyrite and K-feldspar alteration. These results have important geological and exploration implications.

Problems of developing remedial strategy for the uranium ore processing legacy site Pridneprovsky Chemical Plant site (Dneprodzerginsk, Ukraine)

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In this paper we present results of works and studies carried out in the frame of ongoing national and international projects aimed at developing the remedial strategy for the Soviet era legacy uranium production site Pridneprovsky Chemical Plant, Dneprodzerginsk, Ukraine. The site includes several uranium mill tailings, contaminated buildings, ore storage grounds and other contaminated facilities.

Taking into account the necessity to implement provisions of the new IAEA standards (Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, No. GSR Part 3 (Interim) and others) as well as the provisions of the ICRP 103 publication, the State Nuclear Regulatory Inspectorate Ukraine developed the draft of the new licensing requirements for activities of uranium ores processing.

These requirements include provisions for radiation safety for decommissioning of uranium facilities (including legacy sites).

These new requirements take into account achievements of best practices, include: requirements to provide comprehensive safety analysis for designing, realization of rehabilitation measures, as well as requirement to produce the complete and adequate assessment of the risks for humans and the environment after completion of rehabilitation works.

The is considered a possibility of Central Asian countries using these licensing requirements for support of rehabilitation of the legacy uranium sites.

One other subject is characterization of contamination of environment by radionuclides and toxic substances at the legacy cite. For this purpose the waste material, soil, groundwater and surface water samples were collected and systematically analyzed for radionuclides of U-238 decay series, toxic metals and major ions in 2012-13. An important focus of the study was chemo-toxic substances and their potential impact on population and environment. Special attention was paid to QA/QC issues.

Monitoring data show that the most mobile radioactive contaminant in groundwater is uranium. Uranium mobility in groundwater is supposedly promoted by oxidizing conditions and complexation with hydrocarbonate. The key toxic contaminants of concern for groundwater and surface water are Mn, Pb, Ni, Cd, Co and As. In addition, groundwater has elevated concentrations of ammonia, potassium, sodium, sulphate, chlorine and other ions. The radionuclide and chemical pollution is related to technological process (uranium ore leaching by nitric and sulphuric acid, neutralization by lime and ammonia, radiochemical effluents, etc.) and to composition of uranium ore rock minerals.

The problem is complicated by the fact that apart from the uranium mill tailings, there are multiple industrial sources of atmospheric pollution and wastewater releases (metallurgical, chemical industry) in the vicinity of the study site.

Our results indicate that comprehensive risk assessment of the uranium legacy site with respect to both radionuclides and toxic chemicals is needed to develop the remedial strategy. Cross-influences from industrial sources and background chemical pollution in the study region also need to be taken into account for developing rational remedial objectives and clean-up criteria for the legacy site.

The reported results are obtained in the frame of international project ENSURE-Academic funded by Swedish SIDA.

A new edition global map - uranium deposits of the world

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In 1995 The International Atomic Energy Agency published a hard copy map entitled "World Distribution of Uranium Deposits" at a scale of 1:30 000 000. The map displayed data from agency information that was to become UDEPO database of uranium deposits, overlaid on a generalised geological map supplied by the Geological Survey of Canada. At that time, the database contained 582 deposits with a cut-off of 500 t U at an average grade of 0.03% U, and was generated over a period of half a decade by small group external experts. The experts developed a revised deposit classification scheme displayed on the map and in the accompanying guidebook in 1996. A revised and expanded UDEPO database was made widely available on the internet from 2004, and contained additional deposit information and a constantly increasing number of deposits (874 by the end of 2008 coinciding with a new UDEPO guidebook in 2009). Enhanced efforts by the IAEA and consultants of the UDEPO Working Group have now generated a database that has 1526 deposits with a more detailed classification subdivision utilised in a forthcoming IAEA UDEPO publication. The establishment of this classification scheme and the completion of a major phase of updating UDEPO has created an opportunity for creating a completely new edition of the Uranium Deposits Of The World Map using modern GIS techniques.

Cartographic tools within GIS software have become very sophisticated, allowing better display of variably dense data through real-time manipulation of layers and symbology with the GIS dataset. Moreover, some of the results of this functionality can then be transferred to the data display aspects the online version of UDEPO as well as distributed as scale-independent digital version of the map.

In parallel, a planned IAEA publication regarding global uranium provinces allows a more rigorous clustering of deposits for the purposes of showing particular metallogenic aspects in more detail. This also has an important secondary purpose of spatially defining population subsets in the UDEPO database for subsequent province or country uranium endowments. The aspatial deposit-type attributes permit further refining of the spatial analysis. In this way powerful GIS querying capabilities can extract greater "derived" information from the UNDEPO data, such as deposit density relationship with other geological features, more meaningful province-specific spatial information and global mineral potential information. The latter will prove a useful complementary tool to provide insight into relatively unexplored parts of a known province, or extrapolation to completely greenfield (but similar) areas.

Sub level open stoping mining method for the Remaja type deposits, Kalan, West Kalimantan, Indonesia

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According to historic drilling, probing and trenching, geologists previously assumed that the Eko Remaja type deposits belonged to the vein type family. To test this assumption, it was decided to drive a tunnel into Eko Remaja hill, in which eighteen mineralized intersections were discovered. A small mining test has been carried out in the area where the potentially mineable veins are concentrated. The idea was to check the continuity of the mineralization and assist in considering possible mining methods. Two methods were considered: the traditional and well known cut and fill method, or the long parallel holes method. This second method has not been used a lot up to now so was dropped. Regarding cut and fill testing, it was decided to test vein 179 from the tunnel level at 450-460 m above sea level. As a vein continuity check a ramp was driven in vein 169 and a drift in vein 169 at both levels 169 and 179. Vein 179 vein seemed rather regular at 450 level, but was quite different in the ramp in 169 vein and in the 179 drift at level 460. No continuity at all existed between the two levels or at level 460. Although good quality ore was found, it was considered that it could not be mined by the cut and fill method due to a lack of continuity.

Hence the regular vein type concept was abandoned for the Eko Remaja type deposits, which looked more like some kind of "stockwork", although not very complicated, because there are at the maximum three general directions of the mineralization. Fortunately, the major part of the reserves are concentrated in the four veins 157,169,179 and 184 which are rather close to each other. Although the quantity of waste will be important, diluted ore could still be extracted. Fortunately ore and the waste are quite distinctive in aspect, colour, shape, specific gravity and radioactivity. Therefore sorting is included in the present study, considering low capital and operating costs means and equipment. Two methods have been studied and compared respectively as part of Vertical Crater Retreat and Sub Level Stoping mining methods. Actually the latter method is not strictly Sub Level Stoping, because in order to minimize the risk of collapse of the hanging wall, which dips at 65°, the major part of the depleted stope is back filled with the waste and could be called Sub Level Open Stoping. This method has been considered as the more convenient but might be do more for the feasibility study, and slightly modified it in order to make the loading of the broken ore at the bottom of the stope easier and allow earlier back filling in order to increase the hanging wall stability.

Philippines targeting unconventional sources for uranium

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The quest for uranium in the Philippines dates back in the mid–1950s and to date about 70% of the country has been systematically explored, from reconnaissance to some detailed level using the combined radiometric and geochemical survey methods. However, no major uranium deposit has been discovered so far, only some minor mineralization. Also, there is a general view that the geological environment of the Philippines is unfavourable for uranium based on the lack of similarity between the geological features of known uranium–producing districts around the world and that of the country. It is in this light that the search for uranium in the country shifted to unconventional sources.

The first unconventional source of uranium (U) that is being looked into is from rare earth elements (REE)–thorium (Th) minerals. Radiometric measurements along the beaches in northern Palawan identified major REE–Th and minor U potential areas. Heavy beach and stream panned concentrate gave high values of REE and Th, including U within the Ombo and Erawan coastal areas. Preliminary evaluation conducted in these two prospective areas indicated; 1) in the Ombo area, an estimated reserve of 750 t of Th, 30,450 t of REE and 80 t of U contained in about 540,000 t of beach sand with a respective average grade of 0.14% Th, 5.64% REE and 0.015% U, and 2) in the Erawan area, an estimated total reserve of 2,200 t of Th, 113,430 t of REE and 150 t U contained in 2,450,00 t of beach sand with an average grade of 0.09% Th, 4.63% REE and 0.006% U, respectively. Major allanite and minor monazite are the minerals identified and the source of these heavy minerals is the Tertiary Kapoas granitic intrusive rocks.

Another unconventional source is a base metal zone with numerous occurrences containing complex assemblages of Cu–Mo–U within the Larap–Paracale mineralized district in Camarines Norte province, in which uranium may be produced as a by–product. A private mining company conducted drilling operations within their 333–hectare block exploration area in this mineralized district for iron, copper, gold, molybdenum and uranium deposits. This company entered into a Memorandum of Agreement with the Philippine Nuclear Research Institute (PNRI) to assess their eight initial exploratory drill holes for abnormal radioactivity and possibly uranium potential. A total of 530 m of core samples were scanned with the use of SPP–2NF scintillometer and those exhibiting greater than 40 counts per second (cps) were measured for uranium with the use of GR256 gamma ray spectrometer. Significant radioactive sections were detected in the core samples of 3 drill holes: 1). 884 – 1450 cps equivalent to 93.8 – 224.8 ppm U at 82.75 – 88.50 m, 2). 900 – 1200 cps equivalent to 94.8 – 144.2 ppm U at 97.15 – 102.05 m, and 3). 1250 – 2500 cps = 149.1 – 220.8 ppm U at 86.2 – 91.7 m.

Regulatory issues for safety and environmental regarding uranium mining and milling in Romania

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The safe deployment of nuclear activities in Romania is provided by Law 111/1996, republished and completed by Law 193/2003 and Law 378/2013.

The competent national authority in the nuclear field, which has responsibilities of regulation, authorization and control as stipulated in this Law, is the National Commission for Nuclear Activities Control (CNCAN). According art. 2b) provisions of the nuclear Law shall apply to design, possession, siting, construction-assembly, commissioning, operation, conservation and decommissioning of the mining and milling facilities for uranium and thorium ores and of the waste management facilities of the waste resulted from the mining and milling of uranium and thorium ores.

With regards to uranium mining and milling, the Romanian legislation takes into account three objectives:

- to ensure that the workers, the public and the environment are protected against the radiological hazard resulting from the exploitation of the uranium mining and milling industries;
- to provide protection during the period of exploitation and after the closure of uranium mines or milling facilities;
- to ensure that wastes (dumps) resulting from the operating of uranium mines and tailing ponds resulting of uranium ore milling are treated as radioactive waste.

Based on the provisions of Law 111/1996 CNCAN has issued a series of Radiological Safety Norms and Guidelines for Uranium and Thorium Ores. The provisions of this norms provide elementary safety standards for the health protection of both workers and the general public against the dangers arising from ionizing radiation. In the same vein the specific regulations and guidelines contain detailed provisions on: the content of radiation protection program, conditions for release in the environment of liquid and gaseous effluents, monitoring and surveillance programs of the radioactivity of the environment factors, long term stability of damps and tailing ponds, decommissioning of uranium production facilities, and so on.

World Nuclear University School of Uranium Production: Eight years' experience

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The World Nuclear University School of Uranium Production was established by DIAMO, state enterprise in 2006 year under the auspices of the World Nuclear University in London in partnership with international nuclear organizations – OECD/NEA and IAEA. Using the expertise and infrastructure of DIAMO State Enterprise, in conjuction with national and international universities, scientific institutions, regulatory authorities and other individual experts, the "school" covers its mission with the aim to provide world-class training on all aspects of uranium production cycle to equip operators, regulators and executives with the knowledge and expertise needed to provide expanded, environmentally-sound uranium mining throughout the world.

- to educate students on all aspects of uranium production cycle including exploration, planning, development, operation, remediation and closure of uranium production facilities

- to improve the state of the art of uranium exploration, mining and mine remediation through research and development

- to provide a forum for the exchange of information on the latest uranium mining technologies and experiences – best practices.

All "school" activities are opened to all organizations and individuals interested in the tasks of the uranium mining life cycle. On principle there are two main accesses for application:

- Direct commercial contract

- Fellowship or scientific visit based on TC Project between IAEA and counterpart countries or regions

Beside these two basic approaches any other cooperation can be implemented based on national or multinational activities, workshops or technical meetings.

Seventy-nine participants within the framework of the IAEA technical cooperation projects and 153 participants on commercial contracts, from a total from 18 countries, successfully passed 27 different training programmes of all uranium mining life cycle aspects up until January 2014.

Further new activities at uranium deposit Rozna, Czech Republic

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Mining of uranium ore has been running at Rozna deposit for 56 years, since 1957.

Extraction of uranium ore is currently performed in the mining field of blind shaft R7S. Top slicing and caving under the artificial roof method is used for the extraction.

Uranium ore mined in the Rozna deposit is treated at a chemical treatment plant (a mill) situated in the close vicinity of the Rozna mine. In the mill, uranium is extracted from the crushed and ground ore by alkaline leaching. The uranium is then removed from the solution by sorption on resin; the next steps are precipitation and drying. Alkaline leaching is applied at the atmospheric pressure and the temperature of 80 °C. The final product of the milling is ammonium diuranate $(NH_4)_2U_2O_7$, which is further treated into a fuel for nuclear power plants in conversion facilities abroad.

The milling is carried on under the condition of the closed cycle of technology water. Due to the positive annual precipitation balance, the over balance of mill water in tailings pond has to be purified before discharging into a river. Forced evaporation and membrane processes (electrodialysis and reverse osmosis) are used to purify the water.

New activities are searched and carried out with consequence of gradual decreasing of the uranium production. The main target and also benefit of this is the using of skilled human resources in the mine Rozna I and entry able underground spaces.

Geological exploration works for a construction of the underground gas storage were started on 21st level of shaft R7S three years ago. New horizontal galleries with profile 9 m^2 were driven during geological exploration works. Exploratory holes with length 100m were drilled. Sampling of rocks for geochemical, geomechanical and petrographic tests were carried out. So far 1264.9 m of exploration galleries and 1130 m exploration drill holes have been made.

Geological exploration works for construction of underground research workplace on 12th level started in 2013 near the shaft Bukov1. 140 m of horizontal exploration galleries with profile of 9 m^2 have been driven so far.

Geological modelling and resource estimation of Lemajung, Kalan, West Kalimantan, Indonesia

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Lemajung is a uranium potential sector in Kalan Basin, West Kalimantan, Indonesia which contains at least 48 mineralized zones hosted in metasiltstone. Three style of mineralization are consist, vertical west-east lens associated with tourmaline, west-east open fracture filling dipping 70° to N which parallel with the foliation, and N100°E – N130°E open fracture filling dipping 60° to NE. Previous resource estimation in Lemajung done in 1995, resulted 680 t of U_3O_8 [~576 t U] on indicated resource category, averaged 0.056% [~0.047% U]. No geological modeling works conducted prior to resource estimation due to limited computer code available in that time. The estimation applied the 2D krigging statistical approach with 25 × 25 m block model size and 50 m searching radius.

On the current research, uranium resource evaluation based on existing 38 rock core drilling and 7 open holes drilling. Geological modeling and resource estimation performed under Surpac v.6.3 computer program. First step, database composed for collar, survey, geology, and assay. Topography digital terrain model made based on topography map with the scale of 1:2000. Sections are created for manual ore body correlation with the result of 51 ore mineralization plane which is parallel to foliation. Due to complex and irregular dimension of mineralization, the two other type of mineralization cannot be modeled and ignored. Maximum thickness of ore is 8.58 m, directed N250E to N270E, and dipping 60° to sub-vertical. Inverse distance estimation (IDE) statistical approach then applied for resource estimation. The IDE using specific ellipsoid shape for analysis of each mineralization plane. The bearing of ellipsoid range from 55.09 to 90.00°, dipping from –30 to –40°, and plunge from 0 to –40.27°. For top cut the outliers, a confidence interval is applied. The size of the block model on the estimation is 4 × 4 × 2 m, with sub-blocks of 0.50 × 0.50 × 0.25 m. The searching radius for measured and indicated resource is 25 m and 50 m respectively and the cut-off grade 0.01%. The result for uranium resources is 169 t U_3O_8 [~143 t U] for measured resource category and 39.5 t U_3O_8 [~33.5 t U] for indicated resource category.

The characteristics of uranium oxide sintered pellets from phosphate fertilizer waste as a potential resource of uranium

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Indonesia's energy demand is increasing rapidly. In order to meet the needs of electrical energy in Indonesia, the government increases the use of potential energy sources, both fossil and non-fossil energy in synergy (energy mix). Fossil energy sources come from petroleum, coal and natural gas. The non-fossil energy sources derived from hydroelectric, geothermal, biofuel, micro hydro, biomass, solar, wind and nuclear power. According to the National Energy Management Blueprint 2005-2025, the role of nuclear energy is planned to be about 2% of the total national electrical energy. Efforts were made to support the program. Some of the efforts are strengthening the domestication option of nuclear fuel industry and enhancing the sustainability of the nuclear fuel supply. Therefore, the availability of uranium resources becomes important. Indonesia has many considerable potential sources of uranium. Uranium ores are widely available in the Kalan area, West Kalimantan. Another potential source of uranium comes from phosphate fertilizer waste of Petrokimia Gresik Company. Results of previous study indicate that the uranium content in phosphate fertilizer waste of Petrokimia Gresik Company ranged from 70-100 ppm in a solution of phosphoric acid. The yellow cake which can be obtained from fertilizer waste is as much as 55.5 tonnes per year. Yellowcake powder derived from phosphate fertilizer waste has been successfully converted into nuclear grade UO_2 powder. This study reveals that UO_2 powder from phosphate fertilizer waste of Petrokimia Gresik Company could be used to make UO_2 sintered pellets which meet the specifications of nuclear fuel. The use of UO_2 powder from phosphate fertilizer waste would not only ensure the availability of uranium in Indonesia but also address the environmental issue.

Evaluation and design of the uranium project "Tigre I – La Terraza", Sierra Pintada, Mendoza, Argentina

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The Sierra Pintada uranium district in Mendoza Province, Argentina, was discovered by airborne survey. This deposit is associated with a volcanic caldera and occurs in the Lower Permian volcaniclastic sediments of the Cochico Group, in which aeolian and fluvial sandstones, inter-bedded with ignimbrites, were reworked by pyroclastic flows. The origin of the mineralization is interpreted as a product of the leaching of the inter-bedded rhyolitic tuff.

The mineralization is lenticular and nearly concordant with the bedding. The deposit has been affected by a complex fault system, which is responsible for mineralization and disposition via spatial displacement. The primary uranium minerals are uraninite, brannerite and coffinite. Uranophane and low liebigite uranium are the products of the oxidative alteration of primary minerals.

This study involves the technical and economical evaluation of the open pit uranium mining project Tigre I – La Terraza in Mendoza, Argentina, at prefeasibility level. Its development includes geological modeling through economic evaluation, and the incorporation of different mining-specific software.

For the development of the project, priority was given to the utilization of mineral resources, despite the fact that this resulted in reduced economic benefits.

Evaluation began with analysis of the available drill-hole information and bibliographic material essential for modeling of the deposit. The result was a suitable database for resource modeling.

With this information and with the support of basic engineering, the deposit was modeled (Model I: Ore wireframes) and represented as a block model (Model II: Empty ore block model).

In order to estimate the resources in situ, a geostatistical analysis was performed, which resulted in the interpolation of uranium grades into the block model by the ordinary kriging method (Model III: Ore block model estimated by ordinary kriging).

The surrounding waste blocks were then added to the model (Model IV: Union of the waste block model with Model III), as required to perform pit optimization with the specific software (Model V: Software optimization). It was also necessary to obtain the costs and other geotechnical and metallurgical data from project parameters and the existing mine plan. This optimization was achieved by systematically integrating the mine plan design, derived from the history of mine operation, in conjunction with technical calculations.

After pit optimization, a pit design was completed and, consequently, blocks that can be extracted from the interpolated block model were selected. Selections were made taking the pit design into consideration (Model VI: Model IV limited by the designed pit).

Subsequently, a schedule optimization was completed to obtain the optimal extraction sequence of the final model (Model VII: Final software optimization).

Finally, an economic evaluation of the project was performed to provide the estimated cash flows, payback, net present value and internal rate of return, with the corresponding sensitivity analysis.

Uranium exploration status in Bangladesh: Conceptual feasibility studies

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Bangladesh has a nuclear power program of its own and has been trying to setup a nuclear power reactor. For this reason the Bangladesh Atomic Energy Commission (BAEC) is very much interested to get uranium from indigenous sources. Considering the basic need of nuclear minerals and favourable geological setup for nuclear mineral exploration in Bangladesh, BAEC has been operating nuclear mineral exploration program by its limited resource. As Bangladesh is geologically made of solely sedimentary rocks, it is only possibility to mineralize sedimentary types of uranium deposits under favourable reducing environment, which tends to be deposited as commercial uranium ore. Considering the favourable criteria for uranium formation Bangladesh has been divided into 4 zones as the (1) Eastern Mobile Belt (EMB), (2) Stable Platform (SP), (3) Dauki Fault Belt (DFB) and (4) Dinajpur Slope (DS).

The occurrence of uranium in Harargaj anticline is the most suitable indication of uranium potentiality in the EMB. The SP is characterized by the occurrences of Gondwana basins in the subsurface. These basins are quite similar to those exist in uranium bearing Gondwana basins of India, South Africa, Brazil, Argentina, Niger, Australia and Madagascar. The DFB is situated close to the Mahadek uranium belt in the southern fringe of Shillong plateau. Recent investigations has shown that number of anomalous radioactive sites have been detected in Jaintiapur, Sreepur and Jadukata river valley of DFB. These results indicate that uranium bearing solution is still flowing in this zone. So, it can be assumed that the solution has been flowing for very long geologic time and ore might have been formed in and around the DFB. The Dinajpur Slope is characterized by Siwalik sediments, which is capable of hosting uranium as found in India and Pakistan. Besides, the gravels beds of alluvial fans have originated from Darjeeling and Sikkim belts, that are two reportedly uranium potential zones of uranium. As Bangladesh is drained by the Padma-Meghna-Jamuna systems, there are numerous sand bars in those river channels. These sand bars are the prospective locations for uranium bearing minerals. In Bangladesh a regional reconnaissance survey was carried out in more than 2000 sq. km areas of greater Chittagong and Chittagong Hill Tracts and Sylhet districts that has resulted in the identification of more than 150 surface radiometric anomalies. Most of the samples collected from anomalous beds contain uranium ranging from 10 - 300 ppm. The highest radiometric counts occurred in Phooltala Reserve Forest within the Harargaj anticline of Moulavi bazar district, which was about 6000 cps (60 times the background counts). Chemical analysis of this sample has indicated the presence of 1020 ppm total uranium and two uranium bearing minerals namely uranothorite and thorianite have been discovered in the rock samples. Besides, anomalous reading of 25 times higher than the background was observed in the crystalline basement rocks at Mitapukur in Rangpur district. Moreover, in recent studies conducted by the Geological Survey of Bangladesh (GSB), higher radiometric counts have been observed in sand bar deposits of the Brahmaputra River.

Networking as a tool to improve education and training in environmental remediation of uranium mining and processing sites – the role of the ENVIRONET/CONNECT

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The operation of uranium mining and processing facilities in the past gave rise, in several cases, to sites that now are in need of extensive environmental remediation. They were originated because these operations were not developed under appropriate regulatory control. Some countries have been successful in achieving good progress and results with the remediation of these sites. In some other countries however, remediation works move at a slow pace or are virtually stagnant. The IAEA has a vision that its Member States (MS) will eventually have in place a proper infrastructure and technologies for managing these and other legacies and resolve all related issues in a timely, safe and cost-effective manner. Experience has shown that with appropriate planning and assistance (including financial support) remedial actions are more likely to be implemented. As such the interaction of inexperienced with experienced countries facilitated by the IAEA may lead to better conditions for real implementation of projects and sharing of lessons learned. Countries may be inspired to reproduce (after necessary adaptation to local conditions and constraints) the experience gained by others.

Therefore, in addition to the traditional mechanisms of assistance that the IAEA offers its MS the concept of networking has been adopted in an attempt to improve even more the technical support offered by the Agency. One of the created networks is the ENVIRONET – Network of Environmental Management and Remediation - that was established with the objectives of making available the relevant skills, knowledge, managerial approaches and expertise, related to environmental management and remediation. It is also aimed at offering a broad and diversified range of training and demonstration activities with a regional or thematic focus while providing hands-on, user-oriented experience and disseminating proven technologies. Facilitating the sharing and exchange of knowledge and experience among organizations with advanced environmental management and remediation programme in pursuit of good practices, is also in the scope of the network's objectives. Finally, it is also intended to sustain a forum in which advice and technical guidance may be provided. The scope of activities of the ENVIRONET is not restricted to deal with past-operations. The network fosters the adoption of the life-cycle thinking to the planning and implementation of new operations in so that remediation is considered from the very beginning in a way to avoid the generation of future legacy sites and/or the need for implementation of extensive remediation projects.

The outreach of the IAEA networks, ENVIRONET included, will be enhanced with the full operation of CONNECT; an online collaboration platform hosted by the IAEA on behalf of its MS that provides a gateway for interconnecting existing and planned IAEA Networks, increasing the participation of individuals and organizations involved in them, and making available additional sources of information that complement existing training workshops and meetings. With the full use of the IAEA CONNECT platform's opportunities e-learning materials and educational videos will be made available. A Wiki database has been recently created allowing for ENVIRONET members to create and edit content in a very simple way. As a user one will be able to browse content (e.g. compare technologies, case studies, find relevant IAEA guidance), create pages/articles (e.g. for new case studies, new technologies, innovative methodologies), change content (e.g. add additional information, files, pictures and videos to an existing topic) and discuss solutions and approaches on discussion pages. It is recognized that the success of ENVIRONET and CONNECT will depend, to a very large extent, on the support given by individuals and organisations willing to participate in this project. Therefore, participants of URAM are invited to get in touch with these tools and contribute with their experience to expedite the remediation of existing legacy sites and disseminate the so called good practices to avoid the generation of new contaminated sites.

Study of geological details towards feasibility of uranium project: Indian case studies

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Appropriate technical evaluation of geological details at early stage of exploration is the key to minimising the lead-time between discovery and production. This has a major influence on economic viability of the deposits. Indian uranium deposits are of medium-tonnage and low-grade occurring in dissimilar geological provinces. Detailed studies of geological characteristics of these deposits are very vital to the proper selection of technology and subsequent successful operation. The method of mining (underground/open pit/in-situ recovery) is influenced by the ore body depth, size, grade, configuration, hostrock and adjoining strata characteristics, hydrological condition etc. The ore processing technology is also subjective to mineralogical characteristics of the ore. In order to draw the flowsheet, determine process parameters and selection of reagents, a comprehensive study on identification of minerals and their probable metallurgical characteristics, general physical relationship between various minerals, mineral liberation size etc is of great significance. The technology for disposal of tailings is also influenced by geological/geo-hydrological characteristics.

The key to successful operation of Indian uranium deposits lies in outlining a pre-development strategy as the exploration advances to different stages. This phase called "exploratory mining" - which starts with detailed exploration and ends with approval of the project is very critical for early commissioning of the project. The activities during this period include collection of representative drill core samples during exploration, laboratory studies, geo-technical studies and determination of geo-mechanical properties of ore and waste rock etc. Later, the ore lenses are accessed through limited entry(ies). Developments along the ore body helps in better understanding of the configuration of the lenses. Studies for strata control in case of underground mining are carried out towards deciding the mining (e.g. stoping) method. Large ore samples generated during the process helps in detailed pilot plant studies and operation of the plant on continuous mode while fine-tuning all process related steps. The period of exploratory mining is further utilised in locating and planning infrastructure needs, preparation of different reports for regulatory clearances and generating public opinion in favour of uranium mining.

All Indian uranium deposits have gone through glorious phase of exploratory mining generating large volume of data which are of immense value to the operators during the life of the mines and plants.

Uranium exploration in albitised rocks of North Delhi Fold Belt in Rajasthan and Haryana, India

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Uranium deposits in Na-metasomatised granites and metasediments are reported from several places in the world. In India, uranium mineralization associated with soda metasomatic activity has been recognized at a number of places in North Delhi Fold Belt (NDFB) in Rajasthan and adjoining Haryana. Exploration activities for uranium in Khetri Sub Basin (KSB) of North Delhi Fold Belt (NDFB) in last six decades have resulted in locating number of uranium occurrences in the albitites and albitised metasediments at Sior, Siswali, Maonda, Hurra ki Dhani, Diara, Saladipura, Khandela, Rohil, Ghateshwar, Bichun, Sakhun, Ladera and Chota Udaipur in parts of Rajasthan and Dhancholi, Raghunathpura, Rambas and Gorir, in parts of Haryana. Incidentally, the occurrences fall along a NNE-SSW trending "Albitite line", which comprises a 170 km long, structurally weak zone/lineament and axial trace of major folds in the KSB extending from Raghunathpura in Mahendragarh district of southern Haryana to Ladera-Sakun-Bichun in Rajasthan.

Lithounits of KSB comprise lower Alwar Group consisting quartzite, amphibole quartzite, subordinate phyllite and schist and upper Ajabgarh Group consisting schist, phyllite, marble, quartzite and carbon phyllite. The post-Delhi magmatic activity in NDFB is represented by alkali granites, pegmatites, aplites and albitites. The rocks of Delhi supergroup have undergone low to medium grade metamorphism (amphibolite facies) and polyphase deformation. First two deformations with N-S to NNE-SSW axial plane are coaxial while the third phase have E-W axial plane. Prominent shear zones are developed along the N-S to NNE-SSW axial planes, characterized by intense silicification, brecciation and ferruginisation. The NE-SW trending disposition of albitised granites indicate that the metasomatic fluids originated during reactivation of the NE-SW trending Khetri lineament, caused pervasive albitisation of the preexisting rocks, the deformed lithounits providing conduits for the migration of large volumes of albitising fluids.

Sustained exploration efforts along the albitised zone have led to establishing a polymetallic (U± Cu, Mo, Ni, Co) type uranium deposit at Rohil within the albitised metasediments of Ajabgarh Group.

Ore genesis of Gogi uranium deposit in Bhima Basin, Yadgir District, Karnataka, India

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The Gogi Uranium Deposit in Karnataka, India, is located in the 40 km long E-W trending Kurlagere - Gundahalli (KG) fault in the southern margin of the Neoproterozoic Bhima Basin. The uranium mineralisation is hosted by brecciated limestone and basement granite, in tectonised zone along the reverse KG fault. The basement granite has been thrusted over the Bhima sediment along KG fault forming nose-like structure, resulting in intense brecciation and fracturing in limestone.

Uranium mineralisation in Gogi occurs as veins, veinlets and fracture fillings. The mineralisation is intimately associated with sulphides and low rank bituminous organic matter of migratory type. The discrete uranium phases in both the host rocks are mainly coffinite and pitchblende, with minor amounts of U-Ti complex in granite. Two generations of pitchblende are identified, viz. the early phase, which is partially replaced by coffinite, and the later phase replacing coffinite. The silica content in pitchblende has wide range from 1.7 to 10.2% due to varying degree of coffinitisation. The UO_2 content in pitchblende ranges between 74.56 and 87.22%, whereas the same in coffinite is in the range 64.18-84.65%. Both these minerals are characterised by negligible thorium (av. 0.04% and 0.02% respectively) and low REO content (average 0.66% and 0.29% respectively), indicating low temperature (80 to 200° C) of formation.

Pyrite is the main sulphide mineral observed in the mineralised samples, with minor chalcopyrite, marcasite, arsenopyrite and galena. Pyrite occurs in various modes viz., coarse euhedral grains, reticulate network, oolitic, colloform/botryoidal, zoned and framboidal grains. The coarse cubic pyrite is brecciated with its microfractures filled with secondary calcite and limonite, whereas framboidal pyrite has overgrowths indicating solution activity.

The fertile basement granite in the area has anomalous uranium content in labile state, ranging from 10 to 110 ppm. Higher uranium values, upto 308 ppb, are also observed in the ground water from the granitic terrain. It is envisaged that the uranium from fertile granite was remobilised during deformation and transported as soluble carbonate complexes in the hydrothermal fluid. The spatial and textural relationship of sulphides and organic matter with uranium phases suggest that they have formed earlier and provided a strong reducing environment for the precipitation of uranium from hydrothermal fluids. Sulphur isotope study of pyrite revealed large variation in $\delta^{34}S$ from -13.9 to +25.3‰, indicating both biogenic as well as hydrothermal sources of sulphur. The mineral assemblage of pyrite, coffinite, pitchblende and calcite indicates that the mineralisation has taken place at Eh of -0.2 to -0.3 V and pH of 7 to 8.

The mineralogy of uranium minerals indicate a paragenetic sequence of pitchblende (early phase), followed by coffinite, later phase of pitchblende and U-Ti complex. The mode of occurrence, mineral assemblage, textural relationship, paragenetic sequence coupled with compositional characteristics suggest that the uranium deposit at Gogi is a fracture- controlled polyphase, epithermal vein type uranium mineralisation.

Exploration and uranium mining in Niger

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Niger is a Sahelian country bordered by Algeria and Libya to the north, Mali and Burkina Faso to the west, Benin and Nigeria to the south and Chad to the east. Niger has approximately 17 million habitants in the last census (2013) and covers an area of 1.27 million km^2. Niger’s climate is very hot and dry (45-50°C in the hot season, 30°C in the winter), daily ranges of temperature vary from 20 to 30°C. There is a rainy season with light rain fall (40 mm) extending from June to September.

Niger’s economy is centered on subsistence agriculture, animal husbandry and uranium production. Uranium exports accounted for 70% of the national export economy during the 1970s, but falling prices have caused the contribution from uranium to shrink substantially in recent years.

Uranium ore deposits in the Niger Republic are located in the western part of the country, west of the Aïr Mountains. The Arlit site is located 250 km north of Agadez, and 1200 km north-west of Niamey, the capital of Niger.

After the discovery of the first uranium occurrences in 1956, systematic exploration programmes were conducted between 1960 and 1968 along the western sedimentary margin of Aïr Mountains, in North Central Niger by French company CEA. These programmes led to the discovery of several uranium deposits including the Arlit and Akouta deposits which are presently being mined respectively by SOMAIR and Cominak. Further works by CEA and its 100% subsidiary COGEMA and other companies consisted basically in follow up of the different targets outlined by the above programmes.

The rocks hosting the uranium mineralisation are commonly arenites of the Carboniferous age Guezouman and Tarat Formations. Some beds within the Tchirozerine Formation of Jurassic age and the Irhazer Formation of Cretaceous age also contain uranium. The depositional environment of these formations was fluvial to deltaic. Apparently uranium was leached from the basement. Tectonic, lithological and geochemical features are important in trapping the mineralisation which is often of roll front type, either reduced consisting in pitchblende and coffinite (Akouta, Arlit, Afasto, Madaouela) or oxidized (Imouraren).

The main exploration companies of Uranium in the basin of Tim Mersoï (Northern Iullemenden) are:

- AREVA-Niger for the uranium-bearing prospecting permits of Imouraren, Afouday, Agebout;
- Cominak for the uranium-bearing prospecting permit Western Afasto;
- NorthWestern Mineral Ventures Inc for the uranium-bearing prospecting permits Irhazer and Ingal;
- North Atlantic Resources Ltd. for the uranium-bearing prospecting permit Abélajouad;
- CNUC for the uranium-bearing permit of Tiguida
- Goviex for uranium permit of Madaouéla;
- International Uranium Ltd for the uranium-bearing prospecting permits of Agelal I, II, III, IV and Aserka I, II, III, IV;
- Total Uranium Corporation for the licences of Chock Negouran I, II, III and IV;
- Trend Field Holding SA for the uranium-bearing prospecting permits Tagaza II and IV.

Development of polymeric adsorbents for recovery of uranium from seawater

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Extraction of uranium from unconventional resources, where uranium is in low concentrations as in seawater, can be orders of magnitude higher in cost than extraction from conventional sources. As a part of the Fuel Cycle Technology Research and Development Program in the United States Department of Energy, Office of Nuclear Energy, Oak Ridge National Laboratory (ORNL) is developing new adsorbents with higher capacities, selectivities, and durability for the cost effective extraction of uranium from seawater, the most challenging but highest-payoff unconventional resource. The ultimate goal is to develop a selective, high capacity, durable adsorbent that can economically extract uranium from seawater.

Over the last three years, the key focus of the ORNL R&D efforts has been on increasing the adsorption capacity of amidoxime-based polymeric adsorbents by the radiation-induced graft polymerization on high surface-area polyethylene fiberous trunk materials. These trunk materials have been fabricated through an “islands-in-the-sea” fiber-spinning method, which can considerably enhance the surface area of the high-density polyethylene fibers without compromising its mechanical properties. Acrylonitrile and methacrylic acid can be effectively grafted onto these high surface-area fibers followed by conversion of the nitrile groups to amidoxime groups. Marine testing of these poly(acryamidoxime-co-methacrylic acid) adsorbents at the Pacific Northwest National Laboratory Marine Sciences Laboratory showed uranium adsorption capacities, for the extraction of uranium from seawater, that were more than three-times higher than that previously reported. We are continuing to work to increase the adsorbent capacities of the amidoxime-based adsorbents through optimization of the polymerization conditions and investigation of new grafting methods without the use of ionizing radiation such as Atom-Transfer Radical Polymerization. We have also successfully manufactured several braided fiber adsorbents that are potentially suitable for marine deployment.

In addition to these studies, we have also explored methodologies to develop novel adsorbents that contain chelating sites with higher uranium binding affinity and selectivity than current adsorbents. Using a combined theoretical and experimental approach, it was discovered that amidoximate anion binds uranyl ion in the η^2 binding motif. Thus, de novo structure-based design methods were used to design bis(amidoxime) ligands in which the ligands can engage the uranyl ion in the most stable binding motif. The best bis ligands were synthesized and experimentally found to exhibit a log K for uranyl complexation that were at least 4 to 8 orders of magnitude stronger than the amidoxime ligand. Moreover, these bis ligands were significantly more stable to acid stripping of the adsorbed metals. Methods, such as click chemistry, are now being investigated to attach these ligands onto polymeric and ultrahigh surface-area nanoporous trunk materials. This presentation will highlight some of the recent advances in synthesis of high capacity amidoxime-based polymeric adsorbents and in the understanding of how amidoxime ligands binds uranium, the thermodynamics of binding, and the design, synthesis and testing of new chelating ligands with higher binding affinity for uranium.

Characterization and testing of adsorbent materials to extract uranium from natural seawater

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A marine testing and characterization program was initiated at the Marine Sciences Laboratory (MSL), a part of the Pacific Northwest National Laboratory (PNNL) with the objective to evaluate advanced absorbent materials for the extraction of uranium using natural seawater. The uranium from seawater program is being conducted by the United States Department of Energy, Office of Nuclear Energy, Fuel Resources Program, in coordination with Oak Ridge National Laboratory (ORNL) for adsorbent synthesis and characterization, and Lawrence Berkeley National Laboratory for characterization of the thermodynamics and kinetics of adsorption. The MSL has a specialized ambient seawater delivery system for material testing and specialized analytical capabilities for determination of trace elements in natural seawater at part per trillion levels.

Marine testing of adsorbent fibers is being conducted in packed columns using flow-through filtered natural seawater in which temperature and flow-rate (linear velocity) are controlled at realistic marine conditions. Measurements of the adsorption of uranium and other elements from seawater as a function of time onto the adsorbent materials are used to determine the adsorbent capacity and adsorption rate (kinetics) of uranium and other elements. An adsorption capacity of 3240 µgU/g adsorbent (normalized to a salinity of 35 psu) was observed with multiple time series experiments using the ORNL amidoxime-based polymeric adsorbent after 8 weeks of exposure in natural filtered seawater. Applying a one-site ligand saturation model predicts a saturation adsorption capacity of 4890 ± 830 µgU/g of adsorbent material (normalized to a salinity of 35 psu) and a half-saturation time of 28 ± 10 days. The amidoxime-based adsorbent material developed by the Japan Atomic Energy Agency was used a reference material in conducting these investigations. Additional adsorbent characterization studies have been initiated with high surface area nanomaterial adsorbents and to investigate the effects of flow-rate (linear velocity) and temperature on adsorption capacity and adsorption rate. Assessing the durability of adsorbent materials to marine conditions has focused on developing optimal chemical extraction pathways for removal of uranium from adsorbent material and understanding the impact of biological fouling on adsorbent capacity and kinetics for re-use.

Mining the sea for uranium at viable scales will require deployment of expansive “farms” of adsorbent material that must be shown not to harm marine biota and the marine ecosystem. This program has been investigating two issues: toxicity of adsorbent material and reduction in ocean currents from deployment of a farm of “kelp-like” adsorbent material. Toxicity testing is being conducted with the “Microtox®” aquatic toxicity test on solid adsorbents and column effluents containing adsorbent. Concern about reduction in coastal currents is being addressed by assessing the form drag from a braid adsorbent farm using hydrodynamic modelling. Applying the model to an 670 km2 adsorbent farm with a spacing density of 0.00178 moorings/m^2 results in the reduction in ambient currents of 4-10%. This reduction is fairly minor compared to the reduction in currents through a kelp forest (up to 50%) and is not anticipated to have significant impact in the open ocean.

Estimation of uranium concentration in building stones used in Jordanian buildings

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Materials derived from rock and soil such as building stones contain mainly natural various quantities of uranium (U) that cause a biological risk on the human beings.

The aim of this work was to determine the concentrations and isotopic compositions of uranium in Jordanian natural building stones samples for safeguards purposes. The collected building stone samples, include five types used mainly in the Jordanian buildings, were analyzed using inductively coupled plasma-mass spectrometry ICP-MS in addition to gamma spectrometry. The main advantage of using ICP-MS technique is that it allows a direct determination of the U concentration, while requiring little sample preparation. Also, gamma spectrometry was used to obtain the relative concentrations ratios of $^{235}U/^{238}U$. The measured U concentrations ranged from (0.477±0.057) ppm to (4.092±0.413) ppm, and the obtained $^{235}U/^{238}U$ ratios from gamma spectrometry did not exceed 0.15.

Uranium potential of the Central African Republic

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Several factors determine the long-term sustainability of nuclear power. The terms of reference of the URAM-2014 already give very valuable insights on the future of nuclear energy. The combination of all these factors plus the new ores discoveries generated by ongoing exploration efforts can satisfy nuclear power by long and sunny days. Member countries of the IAEA, such as the Central African Republic (CAR), are each called in what concerns him to invest in shares arising on these factors.

The mineral potential of the CAR which is pretty well supplied with at least 470 mineral occurrences, but few are mined other than some gold and diamond enterprises that are operated by craftsmen. The weakness of its economy does not allow the CAR to undertake by itself work to highlight possible extensions of these occurrences in depth and that might constitute possible mineable deposits. Note the presence occurrences of rare earths elements among these occurrences.

The uranium exploration which started since 1947 in the CAR has not yet been able to progress to allow the country to join the list of producer countries. The door for a new producer is unfortunately very narrow. Its unique sedimentary Bakouma site of uranium mineralization is known. However, the Areva Company, for internal reasons, suspended the completion of research there. Expectations are that this uranium deposit may see its beginning of extraction in the future, but it is also expected that exploration will continue in granite, pegmatite and metamorphic rocks using new exploration technologies in the framework of public-private partnership.

Estimation of uranium mining peak

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1. In this work the dynamics of uranium mining is shown for five countries – leaders in terms of uranium mining and uranium resources – Canada, Australia, Kazakhstan, Russia, the USA, and the world (as a whole). Forecasts are constructed on the basis of our ‘relaxation balance model’. Time dependence of annual uranium mining is described by a symmetric bell-shaped curve (similar to Gauss's distribution) and normalized on the mass of uranium extracted. The model allows determining the correlation between the maximum of annual mining (mining peak) and the time of mining peak whereas the volume of metal ores resources and the rate of resource development are known values.

2. Using the formulas it is convenient to run annual monitoring of the forecast and its correction taking into account a new data of input parameters.

3. Calculations of the world’s uranium mining dynamics and in particular countries show that long before the end of the current century the resources of natural uranium at the prime cost of mining less than 130 USD/kg will be almost exhausted. The peak of uranium mining in these countries for various scenarios is reached in 2020-2050. During the second half of the 21st century uranium mining in the world will be essentially reduced whereas existing fields and mining technologies remain unchanged.

4. The forecasts of complete exhaustion of natural uranium resources by the middle of our century show that fast neutrons breeders may increase the resource base of nuclear power by 140-300 times due to inclusion in a fuel cycle of isotopes uranium-238 and thorium-232 could become a basis of long-term development of nuclear power. Commercially acceptable and safe reactors on fast neutrons should be widely used in power engineering no later than the middle of the century, while natural uranium resources are sufficient for their running. As, moreover, as M. King Habbert noted uranium in the closed fuel cycle is similar to a renewable resource.

Challenges in authorization of exploration and exploitation of radioactive minerals in Slovakia

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Slovakia has a long tradition in the peaceful use of nuclear energy which dates back to the 1950s of last century. In parallel with the development of nuclear power uranium exploitation has started. Whereas the development of nuclear power has continued without interruption the uranium exploitation has been suspended during the political and economic restructuralization until 2005. There is also a difference in the acceptance of nuclear power by the local authorities in comparison with uranium exploration and exploitation.

Permitting process of exploration activities in the Slovak Republic is regulated by geological law and falls within the competence of the Ministry of Environment. Radioactive minerals are considered as exclusive minerals and their survey is allowed to the applicant only in exploration territory. The exploration area is determined for four years and then extended for additional periods. The opinions of the affected municipalities and self governing regions (which reflect the compliance of the geological project with the objectives and priorities of the economic and social development programs and with the land-use planning documentation) have to be submitted with the application. Meanwhile, the affected municipality and the self governing region are the parties of administrative procedure of designation, change or cancellation of exploration area for radioactive minerals and they have a right of veto. In case, that affected municipality or autonomous region disagree with proposal, the Ministry of the Environment recommends a modification of proposed exploration area.

Extraction of minerals is regulated by the mining act that falls under the competency of the Ministry of Economy. The right to mine exclusive deposits has the organization which has got mining license and which a mining area has been determined to. Preferential right for mining area determination has the company, that exploration area was determined and the research was carried out at their own expense. Opening, preparation, mining, processing, refining of minerals and liquidation of tailings have to be based on a technology that is in accordance with the principle of sustainable development, with requirements for protection of the environment and the best available technologies. The proposed technologies have to be agreed by the Ministry of Environment. However, a license application could be refused, if the applicant does not submit a favourable opinion of the municipality, favourable opinions of the neighbouring villages and a favourable opinion of the self governing region. These provisions were introduced by the representatives of non-profit organizations and at present they represent a challenge for the authorities and exploration and exploitation activities of radioactive minerals as well.

Actual uranium mining and exploration in Niger

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The search for uranium in Niger began in the 1960s and its mining in the 1970s. As given the drop in uranium prices in the 80s, these activities decreased significantly. The exploration activities took place in 2006 when many mining companies were very interested in the research of this radioactive metal (uranium). In 2007, Niger had more than 150 exploration licenses (all minerals included) whose more than 100 uranium exploration permits. It had two (2) uranium operating mining companies (COMINAK and SOMAIR) till 2008 and it passed to four (4) mining companies in 2009. At the end of 2011, Niger got a third operating mining company (SOMINIA). In 2013, 88 exploration licenses (all minerals) are valid whose 59 for uranium exploration, one mining company in development (IMOURAREN) and one exploration company (GOVIEX) is advanced in exploration activities which can be the mining companies in 2 or 3 years.

Mineralogical and geochemical characterization of Lower Cretaceous Sandstones at Gabel El Ghurfa, Eastern Desert, Egypt

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Gabel El Ghurfa area is situated at the eastern part of Natash volcanics, south Eastern Desert, Egypt. Gabel El Ghurfa forms a ring dyke (2 km^2) with a diameter of 1.2 km and mainly composed of normal and alkaline trachyte at the outer zone with high relief (49 Ma, by $^{40}Ar/^{39}Ar$ method). The inner zone of the ring (600 m in diameter) is mainly represented by Cretaceous Lower Nubia Sandstones (LNSS) that extruded by minor trachyte plug. They are mainly composed of quartz arenite (at the base), greywacke, calcareous sandstone and conglomerate (at the top). The Lower Cretaceous sandstones are bearing radioactive minerals (metaheinrichite, autunite, uranophane and uranothorite), niobate-tantalite (yttrocolumbite and yttrotantalite), base metals (gold, brass alloy and zincite), sulfides (argentite, pyrite, galena and hauerits), and accessories (zircon, monazite, fluorite, taenite, rutile and allanite). The occurrence of native gold (1.5-8 g/ton) and uranium minerals in LNSS (75-195 ppm) is considering a first record in Egypt.

The geochemical data of the bulk LNSS samples reflects the enrichment of SiO_2, CaO, U, Au, Zr, Ba, Sr, Ti, Cr and Ni. The LNSS deposited in semi-arid to semi-humid climatic conditions. Their total REEs contents vary between 50 and 295 ppm and characterized by (1) enrichment in light rare earth element (LREE), (2) depletion in heavy rare earth element (HREE) and (3) negative Eu- anomaly.

Preliminary evaluation of uranium resources in Productora's Prospect, Chile

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This paper presents information obtained on Productora's prospect that allows a preliminary evaluation of uranium resources of Sub – Productora´s prospect 1 which contains the largest amount of resources from the prospect. The Productora's prospect is an area of hydrothermal alteration of elongated shape 3 km long and 0.5 - 0.8 km wide and oriented N 10° W with an incipient internal zonation of quartz-sericite, silica, chlorite, epidote . This is located in an area of 192 km^2 called Sector Estación Romero, near the city of Vallenar, III Region of Chile.

This primary uraniferous mineralization is scarce and finely disseminated, it is consist by davidita (Fe(II), Re, U, Ca, Zn, Th)$_6$ (Ti, Fe(III), U, Cr)$_5$ (O, OH)$_{36}$; probably submicroscopic uraninite (U(IV)$_{1-x}$, U(VI)$_x$ O$_{2+}$x that occurs in contact zones of rhyolite intrusive bodies and related metasomatic processes and superimposition of hydrothermal alteration, with introduction of free silica and feldspar pertita.

The secondary mineralization consists of torbernite ($Cu(UO_2)_2$ $(PO_4)_4$•8-12H_2O), autunite ($Ca(UO_2)_2$ $(PO_4)_2$•10-12H_2O), uranotile ($Ca(UO_2)_2Si_2O_7$•5-6H_2O), uranotile α ($Ca(H_2O)_2(UO_2)$ $(SiO4)_2$•3H_2O, fosfouranilite ($Ca(UO_2)_4$ $(PO_4)_2$ $(OH)_4$•8H_2O), cuprosklodowskita ($Cu(UO_2)_2(SiO_3)_2(OH)_2$•5$H_2O$) and renardite $Pb(UO_2)_4(PO_4)_2(OH)_4$•7H_2O), this is located in the contact zone of rhyolite and diorite dikes permeating both rocks.

During exploration geochemistry studies of residual soil magnetometry and spectroscopy were performed. In the eight selected subsectors detailed radiometric and mineral exploration work was carried out.

In anomalous sectors detailed radiometric measurements were performed on a grid of 5×5 m, covering 38 hectares. Based on these results was scheduled and dug trenches totaling 1031.9 m with varying depths and a total of 16 sampling depths between 2.0 and 15.0 m. In this work 576 samples were taken at constant length of 0.15 m, which were analyzed for U, Cu and Mo, where mobile uranium content was between 7.0 and 1820 ppm.

The surface geological data, from surveys conducted (trenches, shafts and tastings), and subsurface information (drilling), together with the analytical and radiometric data allowed to define the existence in the prospectus of 18 veins. These veins have run under 50 m and varying thicknesses from 0.1 to 3.5 m and lenticular form.

Using a cut-off grade of 295 ppm U_3O_8 [~250 ppm U] the thicknesses of the ore bodies were determined considering the direction and dip of the mineralized structures and the direction and inclination of the drilling and/or recognition. Considering a density of 2.2, it was calculated for the sub- Productora´s prospect 1, by the method of horizontal plants and cross sections, the following resources: Measured 21.1 t U_3O_8 [~17.9 tU], Indicated 9.1 t U_3O_8 [~7.7 t U] and Inferred 1.4 t U_3O_8 [~1.2 t U].

REE in Brazil – condition of formation and types of deposits

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The REE pertains to two series (Lantanides, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu) according to increasing number and atomic masses and Actinides corresponding to U, Th, Pa and decay products, which are still not economically important for private activities. Brazil possesses larges reserves of REE concentrated in several geological environments and conditions. Some of these deposits correspond to the Nb-rich and phosphate-rich Araxá Carbonatite Complex, exploited for four decades. The other deposits are represented by the monazite-rich placers with zirconite as the main products, ilmenite, rutile and secondarily siliceous sands and garnet. Investments in Brazil are poorly developed because of lack of technology and wrong governmental policies. Coastal placer deposits are monazite-rich containing most of above listed REE constituents, consequently forming one of the important Brazilian sources, explored since the beginning of last century. The circular structure of Monte Alegre at Pará state is structured in Paleozoic shales and contains values in U_3O_8 (300-1800 ppm) [~250-1500 ppm U], ThO_2 (850-1800 ppm) and La_2O_3 (0.1-0.7 ppm important contents of REE (CeO_2=0.3-1.0 ppm and 0.1-0.0.7 ppm) and is deeply weathered. The quartzites of Serra de Itiuba (Bahia) revealed important concentrations of cheralite, monazite and Fe-autunite with significant grades of REE. Cryolite deposits of Pitinga (Amazon), exploited for Sn and Nb since the beginning of 1970, contain 0.03%Y_2O_3 and 0.036%HREE, mostly in the mine tailings. Pirochlore itself consists of 0.25%Y_2O_3 and in the metallurgical product, remaining in the storage sites several tons of material reach 2-3%REE exist. Euxenite and samarskite from pegmatites of Serra do Pangarito (Minas Gerais) are rich in REE (13%Y_2O_3 from the total of REE=37%). In pegmatites from Sabinópolis, Divino do Ubá and Generosa the grades of Y_2O_3 (12.1-28.6%), Ce_2O_3 (0.81-8.62%) attain in samarskite, but significant values are obtained in the pegmatites from Rio Pomba (Minas Gerais) in the range 7-29% REE-oxides. In the pegmatites from the Serra da Mesa (Goias) the grades in REE varies from 0.03-4.76% Y_2O_3 and 0.04-4.35%Yb_2O_3 in ixiolite and Ti-ixiolite. Another impostant area with pegmatites and alluvial deposits is the Rio Tajaui (Amapá) in uranothorianite (0.2-0.5% La_2O_3 and 0.4-0.6% Nd_2O_3) in an unexplored region. The albitites of Espinharas (Paraiba state) contains high grades of La (2.7-195 ppm), Ce (3.2-220 ppm), Pr (0.33-29.9 ppm), Nd (1.1-88.5 ppm), Sm (0.5-37.9 ppm), Eu (0.05-7.11 ppm), Gd (0.63-51.7 ppm), Tb (0.09-12.9 ppm), Dy (0.55-12.5 ppm), Ho (0.09-34.1 ppm) Er (0.25-12.9 ppm), Tm (0.05-15.8 ppm) and Yb (0.3-88.7 ppm) indicating high potential for REE. Some outstanding deposits of pyrochlore of Araxá (Zero Area) are famous for the REE contents (3.2%Ce_2O_3, 2%La_2O_3, 1%Y_2O_3, 0.2% Sm_2O_3, 0.7% Nd_2O_3, and 0.4% Pr_6O_{11} occurring as fine-grained phosphate minerals in the weathered carbonatite. The spectacular intrusive alkaline dome of Seis Lagos (Amazon) found through airborne gamma-spectrometric survey is Nb-rich where the values of total REE reached 20% in the lateritic cover. In conclusion the potential for exploration of REE in Brazil are vast and promising.

Topological relations in the U-Si-O-H system derived by weathering at Lagoa Real Province, Bahia, Brazil

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The Lagoa Real Uranium Province besides the economic uraninite deposits holds thermodynamically interesting association of secondary and weathering-derived hydrated silicates and oxides minerals. These minerals can be arranged in isobaric, isothermal, qualitative, chemical potential diagrams (μSiO_2 - μH_2O) and showing the equilibrium and stability condition of the existent minerals found by us and by the several investigators in the past. The alteration U-minerals can be grouped into two main series: orthorhombic and monoclinic and also some triclinic minerals distributed in both series. X-ray powder data to recognize the minerals have been done in UFRJ and CBPF diffractometers. It is interesting to notice that minerals from the orthorhombic series are reddish orange and the ones from the monoclinic series are yellow. On the other hand in a triangular U-Si-O diagram it could be discriminated two series of uranium minerals: orthorhombic series (mostly oxides) and monoclinic series (mostly hydrated silicates). The orthorhombic consists of curite, fourmarierite, billietite, ianthinite, becquerelite, vandendrisscheite, schoepite, agrienierite, wolsendorfite, compreignacite, soddyite and the monoclinic consisting of masuyite, studtite, swamboite, weeksite boltwoodite, sklodowskite, haweeite, uranophane, kasolite, gastunite, sayrite, uranosphaerite, protasite, rameauite. Some triclinic minerals also plot close to the orthorhombic field such as the richetite, clarkeite, bauranoite, vandenbrandeite.

The μSiO_2 - μH_2O diagram show the coexistence between uraninite or pitchblende at the lower μH_2O field being transformed into soddyite, uranophane and boltwoodite under moderate increase of μH_2O and into haiweeite under higher μSiO_2 situation and into becquerelite under low μSiO_2 condition. Increasing both μSiO_2 - μH_2O, kasolite, schoepite and sklodowskite would be stable. In conclusion the weathering-derived U-minerals, mostly from Cachoeira Mine may be grouped into two series and the ones more abundantly occurring in the area could be arranged in a μSiO_2 - μH_2O diagram in order to understand the alteration pattern and equilibrium conditions. The reactions interesting the chemical potential diagram are described in the paper.

Processing uranium ores of Central Jordan

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A process conceptual design is proposed based on the results of a sequential metallurgical testing campaign. During which, both random and designed samples collected from uranium ore deposits of central Jordan have been subjected to dynamic and static leaching testing. The ore amenability to leaching under alkaline and acidic conditions was studied using finely ground, P80 < 64 µm, arbitrarily picked samples. Findings indicated obvious leaching amenabilities in both media, however acid leaching track was not pursued further due to the high consumption rates of reagent. Alkaline dynamic leaching rates were relatively slower and demonstrated a nonlinear tendency.

Deportment analysis and dynamic testing on coarsely crushed bulk samples, planned and collected by JFUMC, supported the choice for heap leach as one promising option to process the aforementioned ore. A set of six columns were used to imitate, on a semi-pilot scale, the flow behavior inside a heap pad. Steadiness of liquid flow inside the bed was observed under a testing range 1 – 5 $L/h/m^2$; however, slumping behavior of around 7% was detected. Uranium recoveries matched well the findings of rotating bottle investigations and were attained in less than two weeks for fluxes larger than 4.5 $L/h/m^2$.

Approaches to mastering the uranium potential of Cameroon

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Uranium deposits are spread over the five continents. According to the lnternational Atomic Energy Agency (IAEA) estimation in 2009, the global reserves of economically recoverable uranium are estimated at 4.5 million tonnes.

ln 2012, the world production of uranium was about 54,610 tonnes and the main producers were Kazakhstan (36%), Canada (15%) and Australia (12%). Brazil, Russia, China, lndia productions accounted for 9.4% of the overall world production. Significant deposits also exist in Africa including Cameroon; those currently in mining stage are in Namibia, Malawi, and Niger.

Cameroon has significant mineral deposits such as gold, alluvial diamonds, iron, bauxite and uranium. All of them are still in the exploration stage.

Although Cameroon has not launched a nuclear power programme, the mining of its uranium resources is considered as an important component of the national economy.

Many uranium occurrences have so far been discovered in Cameroon. They include Kitongo, Salaki, Mayo Nielse and Teubang in the Northern region and Ngombas near Lolodorf in the Southern region.

The Cameroon Government is engaged in (i) the assessment of the U-ore resource through drilling, and (ii) the airborne geophysical survey of mining potentials areas.

The result of these studies may lead to a better estimation of the national uranium potential.

This paper aims at pointing out constraints to assess the uranium potential of Cameroon and proposes measures that could improve on the leveraging of exploitation of this mineral.

Cachoeira Uranium Deposit, Lagoa Real, Bahia, Brazil – kinematic, compositional and fluid evolution

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The Cachoeira uranium albitite-type deposit occurs in a steep dip shear zone aligned with several other similar uranium deposits in the Lagoa Real Province. Uranium resources are estimated as about 90,000 t U_3O_8 [~76,000 t U] grading 2500 ppm U_3O_8 [~2100 ppm U]. Uraniferous albitite occupies a 15 m-thick strongly mylonitized shear zone structurally enclosed within “zebra” biotite gneiss. Uranium albitite mineralization forms cigar-shaped (prolate) and secondarily pancake-shaped (oblate) bodies composed of albite-hornblende-garnet-uraninite-magnetite ore grading to quartz-free skarn-type rock with fluorite-kyanite-calcite-quartz concordant veins and pockets formed by late hydrothermal process. Brown chalcedony was the latest mineral to form. Fine-grained, disseminated uraninite is distributed and concentrated in the mafic portions of the gneiss consisting of hornblende-andradite-sphene-apatite-epidote forming 30% and albite portions consisting of 70% of the albitite, which allows its gravitational treatment, thus decreasing acid leaching. While the host rock was severely affected by K-metasomatism the uraninite zone was deposited together with hornblende by Na- and Ca-metasomatism.

Another reaction involves garnet crystallization exclusively together with uraninite, which liberates sílica and oxygen, differently from previous reaction which consumes silica and oxygen. Both reactions involve magnetite. The destabilization of biotite at the ore zone implies in the formation of GSPO-biotite overgrowing the LPO-biotite previously formed at host rock, due to the excess of K in the system. Magnetite is absent. The reaction represents the K-metasomatism at the host zebra gneiss: biotite + plagioclase + pyroxene + UO_2Cl^+ + Ca^{2+} = hornblende + uraninite + kyanite + quartz. The excess of Ca is allocated in the sphene, apatite and epidote structures. Consumption of Ca results in rutile deposition. As fluid composition was complex F and CO_2 were enriched in the system, after main metamorphism/metasomatism occurred. Consequently hydrothermal process dominated the system, resulting in the formation of fluorite, calcite and an excess of silica as brown chalcedony. Uranium minerals also formed, as secondary phosphate, hydro-silicates, hydrated oxides and pechblende, under lower temperature conditions. In a still Ca-rich system sphene and brannerite, together with late calcite could form: $FeOTiO_2 + Ca + UO_2 + SiO_2 = CaTiSiO_5 + (Ca,U)(Ti,Fe)_2O_6$ (brannerite), marking destabilization of primary ilmenite and uraninite formed in metasomatic stage. Formation of fluorite and calcite corresponds to the next hydrothermal episode: $UF_6 + CaTiSiO_5 = CaF_2 + TiO_2 + SiO_2$ + pitchblende. Brannerite is also destabilized in favor of calcite, rutile, pitchblende and hematite under higher oxygen fugacity condition: $(Ca,U)(Ti,Fe)_2O_2 + CO_2 + O_2 = CaCO_3 + TiO_2 + Fe_2O_3$ + pitchblende, the excess of silica forming chalcedony.

Geology of uranium in the Republic of Madagascar

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Madagascar has a high potential of uranium in terms of mineral resources on the island. Two thirds are distributed of these potential mining resources are distributed in crystalline basement and the third in a sedimentary formation. The Government of the Republic of Madagascar has been promoting a comprehensive national policy, aiming at the major goal of poverty reduction through economic growth. In order to realize this policy, it was recognized that the promotion of mining activities is crucially important, focusing on the large-scale mining development by introducing foreign capital investment. The obvious effort shown by the Government of Madagascar for this national policy has been highly evaluated by the international community. The CAE, PNUD, IAEA have supported this nation since 2009.

The first discovery of uranium in Madagascar is located in the lacustrine basin of Antsirabe located in the central part of Madagascar. Generally, the uranium found within five types of formation and different ores: the first proceed from the pegmatite (central part of Madagascar; Itasy, Antsirabe, Mandoto regions), locally called uranium pegmatite; the second from the pyroxenite; third from urano-thorianite (Fort-Dauphin area, south east); fourth from uraninite-bearing granites (Ankazobe); and finally from the neogene lacustrine basin of Antsirabe, with autunite (central part) and from the Isalo formation of Mahajanga and Moramanga basin, locally called uranium sandstones (containing carnotite).

Uranium resources potential of Thailand and the Lao PDR

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There are a number of uranium deposits in Thailand. In the past, when tin mining was once the major mining activity in Thailand, uranium deposits had been found along with tin exploration in granite terrain. Department of Mineral Resources (DMR) together with help from national and international organizations started uranium exploration since 1960. In 1977, IAEA's International Uranium Resources Evaluation Project (IUREP) had suggested some areas in the northern and eastern parts of Thailand to have significant uranium potential. The speculative resource estimate in the report was in the range of 1500 to 38,500 tU.

However, not until 1976 was systematic exploration for uranium ore carried out nationwide, with some airborne geophysical survey as well as drilling programs. Airborne geophysical survey over the whole country was completed by 1987. The results demonstrated that there are a few uranium deposits located in the north and northeastern region of Thailand.

This paper will summarize past exploration results. Those information from uranium exploration will be re-evaluated and modelled by using a sophisticated mining software since at that time DMR used only an old method. Some pictures will be redrawn with an aid of GIS system. The purpose of this work is not only to verify past projects but also to delineate new target area for future exploration. In addition, the possibility for sustainable recovery of uranium as a by-product from unconventional sources such as tin ores and heavy mineral sands holds a good prospect for Thailand. Those unconventional sources will be illustrated as well. Finally, the summary will be provided for the IAEA's UDEPO database.

Right next to Thailand, there are some potential areas for uranium exploration in the Lao People's Democratic Republic (Lao PDR or Laos). Some of the geological units of Thailand extended into Lao PDR. Thailand and the Lao PDR, being close and having shared language and culture, are increasing collaboration, in geological and mineral exploration activities. The Lao PDR, joining IAEA since 2011 as one of the newest Member States, has opened new opportunities for closer collaboration between the two countries in uranium exploration and resource assessment. In the Lao PDR, the population is much smaller than in Thailand. In addition, the government of the Lao PDR strongly encourages both local and foreign investment in mineral exploration and mining activities. In 1977, the IUREP study, based on sparse data, assessed that uranium potential exists in some parts of the country, especially associated with Precambrian metamorphic rocks. The Lao RDR is known to have tin deposits, and the possibility of uranium associated with tin mineralization is another potential to be investigated. Various models of uranium deposits will be compared with the Lao PDR's geology and a uranium potential map will be presented.

Focus on uranium research in Senegal

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Two periods stand out in the history of mining exploration for uranium in Senegal:

- 1957 - 1965 in the context of a general inventory of the uranium potential of Africa, which is also the time that the large deposits of Niger and Gabon were discovered;
- 1973 to the present, is characterized by surveys more focused on specific topics such as Birrimian Superior Precambrian Sedimentary, Secondary and Tertiary Phosphates.

The collapse of uranium price that began since 1980 calls into question the validity of these surveys on areas away from the coast that lack infrastructure and forces the elimination of targets where there is little hope of finding high enough concentrations of uranium for possible mining.

The first work undertaken by the Office of Senegal the French Atomic Energy Commission from 1957 to 1961, was part of a systematic aerial survey of West Africa covering Senegal, Mali, Upper Volta and Niger. During these flights the aerial radiometric anomaly Saraya was found near Kédougou (South East Senegal). Gamma meters surveys, 14 trenches and geochemical samples were undertaken and two types of anomalies highlighted:

- One in a fracture N130 with yellow products (1700 c/s);
- Another in a white syenite calcite (8000 c/s).

At the same time, ground controlling of other airborne anomalies was undertaken, in particular through geochemical sampling and small wells research. Some geochemical anomalies were detected (Dalafinn site for example), usually associated with lateritic material. However, in 1961 the decision was taken to suspend the study of anomalies near Kédougou, until some more work from 1974.

In 1966, as part of a joint study Mauritania, Senegal teams also undertook systematic radiometric study of continental sedimentary basin of the Ferlo (Northern Senegal) and the bank of the Senegal River; however, this work furnished no interesting result.

On 1974, the Minister of Development of the Republic of Senegal contacted to the Administrator General of the CEA in a letter requesting the consideration of the resumption of uranium research. On an affirmative response, a research permit in East Senegal of 38,600 km² was awarded and further uranium research was conducted. These studies were devoted there the study of Precambrian and Cambrian age rocks.

The General Atomic Company Materials (COGEMA) extensively explored for uranium in eastern Senegal in the period 1975-1985. However, the drastic drop in the price of uranium in the context of rather mixed results (resources of the order of 2000 t of uranium) lead to the discontinuation of the exploration program.

Uranium exploration revived in 2007, thanks to the soaring price of uranium. The license of the junior South African Uranium, for Saraya East, was purchased the same year by AREVA.

Using pattern classification and nuclear forensic signatures to link UOC to source rocks and purification processes

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Nuclear forensics is a scientific discipline interfacing law enforcement, nuclear science and non-proliferation. Information on the history and on the potential origin of unknown nuclear material can be obtained through nuclear forensic analysis. Using commonly available techniques of mass spectrometry, microscopy and x-ray diffraction, we have gained insight into the processing and origin of a suite of uranium ore concentrate (UOC) samples. We have applied chemometric techniques to investigate the relationships between uranium ore deposits and UOC samples in order to identify chemical and isotopic signatures of nuclear forensic importance. We developed multivariate signatures based on elemental concentrations and isotope ratios using a database of characteristics of UOC originating throughout the world. By introducing detailed and specific information about the source rock geology for each sample, we improved our understanding of the preservation of forensic signatures in UOC. Improved characterization of sample processing and provenance allows us to begin to assess the statistical significance of different groupings of samples and identify underlying patterns. Initial results indicate the concentration of uranium in the ore body, the geochemical conditions associated with uranium emplacement, and host rock petrogenesis exert controlling influences on the impurities preserved in UOC. Specific ore processing techniques, particularly those related to In-Situ Recovery, are also reflected in UOC impurity signatures. Stable and radiogenic isotope geochemistry can be used in conjunction with rare earth element patterns and other characteristics to link UOCs to specific geologic deposits of origin. We will present a number of case studies illustrating the ways in which nuclear forensic analysis can provide insight into the ore geology and production and purification processes used to produce UOC.

Uranium resources and potential of the Republic of Niger

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Following the discovery of the first occurrences of Uranium in Niger in 1958, the French undertook a systematic and detailed exploration programme from 1959 to 1980 in the north part of the Iullemmeden basin (114,000 km^2). This led to the discovery of other occurrences and worldwide uranium deposits. Two Palaeozoic basins (Djado and Emi Lulu) have shown also good uranium potential. In 1971, the Company of the Mines of Aïr (SOMAIR) and later in 1978 the Company of the Mines of Akouta (COMINAK) has begun the production of uranium with a cumulative production of 125,000 tU.

From 1973 to 1980 and following the spectacular increase of the uranium price and the growing of the demand, many oil and mining companies have been granted a uranium exploration tenement (permit). Many occurrences have been listed, explored and evaluated. The following deposits have shown an economic interest: Arlette, Ariège, Taza, Tamou, Takriza, Artois, Tabellé, Imouraren, Irhawenzegirhan, Azelik, Madaouela, Ebene, Akouta, Akola, Ebba.

Later and following the spectacular increase of the uranium price and the growth of the demand, exploration work, interrupted for a decade, restarted in 2002: 120 exploration permits have been granted to more than forty mining companies in Niger.

• Geological background: all mineralization economically viable is localized in clastic sedimentary formations (conglomerates, sandstone and siltstone) rich in organic matter and sulfides, formed during the carboniferous age to the cretaceous age. The redox and tectonic evolution phenomena in the northern region of Niger have played a decisive role in the formation of the different deposits along with the sedimentological and stratigraphic control.

• Mineralization: In the Tim Mersoi Basin, the uranium is mainly present under its own mineralogical forms, of which the mainly identified minerals are pitchblende - uraninite and coffinite. Its presence in the crystal lattice of clay or other minerals is rarely observed. However, the secondary minerals yellow products (gummite, uranotile, tyuyamunite, autunite) exist in particular at the Azelik and Imouraren deposits. The average ore grade of the deposits from Niger varies from 0.08 %U and 0.6%U.

• Resources: despite the fact that 125,000 tU have been removed over the past 40 years, there are still significant global resources in Niger, estimated at around 515,000 tU, of which 315,000 tU being proved as economically recoverable reserves, and 200,000 tU as probable and inferred resources.

• Prospects: the exploitation of Imouraren (230,000 tU recoverable) and Azelik (13,700 tU) deposits is underway near the lineament of Arlit and its satellites. A detailed exploration with new effective methods will allow the discovery of other deposits around many existing occurrences within the following licenses: Madaouela, Adrar Imoles, Afasto, Toulouk, Terzemazour, Tagait, Asamaka, Agelal, Zéline.

Conclusion: Niger is on the way to become the world's third-ranked country with regard to available uranium resources and production, and could keep this position for several decades.

Bottle roll leach test for Temrezli uranium ore

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The bottle roll leach test is one of the dynamic leaching procedure which can meet in-situ mining needs for determining suitable working conditions and helps to simulate one of the important parameter; injection well design. In this test, the most important parameters are pulp density, acidic or basic concentration of leach solution, time and temperature. In recent years, bottle roll test is used not only for uranium but also gold, silver, copper and nickel metals where in situ leach (ISL) mining is going to be applied. For this purpose for gold and silver metal cyanide bottle roll tests and for uranium metal; acidic and basic bottle roll tests could be applied. The new leach test procedure which is held in General Directorate of Mineral Research and Exploration (MTA) of Turkey is mostly suitable for determining metal extraction conditions and recovery values in uranium containing ore bodies.

The tests were conducted with samples taken from Temrezli Uranium Ore located in approximately 200 km east of Turkey's capital, Ankara. Mining rights of Temrezli Ore is controlled 100% by Anatolia Energy Ltd. The resource estimate includes an indicated mineral resource of 10.827 Mlbs U_3O_8 [~4160 t U] at an average grade of 1426 ppm [~1210 ppm U] and an additional inferred resource of 6.587 Mlbs of U_3O_8 [~2530 t U] at an average grade of 904 ppm [~767 ppm U]. In accordance with the demand from Anatolia Energy bottle roll leach tests have been initiated in MTA laboratories to investigate the recovery values of low-grade uranium ore under in-situ leach conditions. Bottle roll leaching tests are performed on pulverized samples with representative lixiviant solution at ambient pressure and provide an initial evaluation of ore leachability with a rough estimate of recovery value. At the end of the tests by using 2 g/L $NaHCO_3$ and 0.2 g/L H_2O_2 more than 90% of uranium can pass into leach solution in 12 days.

The development condition of longitudinal channels of a Lower Cretaceous formation and its perspective for sandstone type uranium deposits in the Erlian basin, northern China

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The palaeochannel, which is classified as basal and interformational types on the basis of geological setting, is an important host for the sandstone type uranium deposit. Diversities exist in development conditions and uranium minerogenetic potential of the two types of palaeochanneles. The Erlian basin, about 105 km^2 and adjacent to channel-type uranium deposit provinces in Russia and Mongolia, is one of main uraniferous basins in the north of China. It is significant to research into development conditions of palaeochannels for uranium mineral exploration in the Erlian basin.

1. Geological background

The Erlian basin consists of five depressions which divide the basin and form alternations with uplifts and depressions. Sedimentary capping strata of the basin mainly is the Lower Cretaceous Bayanhua group (K1b) which consists of the Aershan group (K1ba), Tenger group (K1bt) and Saihan group (K1bs) from bottom to top. The Saihan group, which is the product in the phase of depression, is the most important uranous strata in the Erlian basin.

2. Development characteristic and condition of the longitudinal palaeochannel of the Saihan formation

Large-scale longitudinal multi-palaeochannels are identified in the center and northeast of the basin, such as the QiHaRiGeTu-SaiHanGaoBi palaeochannel (CH01), BaYanWuLa palaeochannel (CH02) and GaoLiHan palaeochanne l(CH03), et al., which character the length from several 10s of km to 100 km, width of several 10s of km and thickness of sand bodies from 20 m to 130 m, more or less. Palaeochannels of the Saihan formation are interformational type because the underlay is argillite at the top of the Tenggeer formation.

Restrictive geological environments and conditions are necessary to form longitudinal channels and mainly are as follows: (1) the basin in the sustained step of depression; (2) sharp gradient (>5°?) in parts of sub-depressions and sufficient sedimentary supply from the upstream; (3) elongate erosional lowlands or normal faults along the macroaxis inside of the depression.

3. Minerogenetic perspective

Sandstone type uranium deposits detected, which are middle scale or larger, mainly locate in longitudinal palaeochannels in the Erlian basin. Longitudinal palaeochannels are rich sandstone bodies which character well continuation, rich organic clastic debris, well aquifer region and favorableness of adequate hydro-litho reciprocal action, and therefore are the most favourable sedimentary facie for mineralizing of sandstone type uranium deposits in the Erlian basin which possesses a high mineralization and exploration perspective.

Uranium in South Africa: Exploration, mining and production

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There are eight known uranium deposits in South Africa, which are: quartz-pebble conglomerate-hosted deposit in the Witwatersrand Basin, sandstone-hosted deposit in the Karoo Uranium Province, carbonaceous shale- and coal-hosted deposit in the Springbok Flats Basin, surficial deposit in the Namaqualand region, intrusive-hosted deposit in the Palaborwa, granite-related deposit in the Namaqualand region, and phosphorite deposits within the marine areas. However, the major uranium deposits, which contribute to the nation's uranium identified resource inventory, are quartz-pebble conglomerate, sandstone, coal, carbonaceous shale, and surficial deposits.

Between 1967 and 1976, uranium deposits were discovered in the Karoo Uranium Province (sandstone-hosted deposits), Namaqualand region (surficial deposits), and Springbok Flats Basin (carbonaceous shale and coal-hosted deposits). Recent exploration has increased the resource potential in these deposits, with the exploration activities focused on drilling to delineate resources at high levels of confidence. The Council for Geoscience is currently conducting high resolution magnetic and radiometric surveys and geochemical sampling in the Namaqualand region beyond the known uranium mineralization. The uranium in the Springbok Flats Basin is difficult to delineate from aerial radiometric data due to its deep depths of occurrence. However, the extent of the basin is clearly shown on the regional total counts image with contrast from the Bushveld granite which is believed to be the source of uranium mineralization in the Springbok Flats Basin. Gravity, magnetic and down hole surveys are planned to develop a three-dimensional structural understanding of the basin. In addition, a selected few drill holes have been drilled and completed in the beginning of 2014, by the Council for Geoscience, in the Springbok Flats Basin to ascertain the uranium mineralization extents in the basin. The results will be made available as soon as analysis and interpretations are completed.

Witwatersrand Basin is the only deposit where uranium mining is, at present, active in South Africa, from both the underground operations and the associated tailing dam facilities. The primary commodity in the basin is gold, with uranium recovered as by-product. Uranium is currently produced from Vaal River operations by processing the reef material from Moab Khotsong, Great Noligwa and Kopanang in the Noligwa gold plant/South Uranium plant circuit by reverse leach process.

Uranium production in South Africa begun in 1952, and reached peak production in the early 1980s in which production was over 6000 t of uranium per year. Uranium production has since declined to below 500 t of uranium per year by 2013. However, with production expected from Karoo Uranium Province and Namaqualand region in the near future, uranium production is expected to increase significantly by 2020.

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