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OPENING SESSION

Monday AM, May 11, 2009

Nuclear Fuel Cycle vs. the Carbon Cycle: Uranium/Plutonium vs. Carbon

Rodney C. Ewing: University of Michigan

Nuclear power provides approximately 17% of the world's electricity, which is equivalent to a reduction in carbon emissions of ~ 0.5 Gt of C/y. This is a modest contribution to the reduction of global carbon emissions, ~ 8 Gt C/y. Most analyses suggest that in order to have a significant and timely impact on carbon emissions, carbon-free sources, such as nuclear power, would have to expand total energy production by factors of three to ten by 2050. Thus, one can expect considerable demands on proven inferred and undiscovered resources for uranium, which total some 16 to 23 million tons (depending on price). Based on present consumption rates for the present fleet of nuclear reactors, uranium resources are sufficient for the next 100 years, but this time would shorten with a major expansion of nuclear power. In addition, an increase on this scale has important implications for the production of nuclear waste and the potential for the diversion of fissile material. A three-fold increase in nuclear power capacity would result in a projected reduction in carbon emissions of 1 to 2 Gt C/y, depending on the type of carbon-based energy source that is displaced. A three-fold increase in nuclear power capacity utilizing present technologies would result in 30,000 metric tonnes (mt) of spent nuclear fuel (SNF) per year, containing approximately 250 mt of plutonium. This is compared to a present global inventory of approximately 280,000 mt of SNF and >1,800 mt of Pu. A nuclear weapon can be fashioned from as little as 5 kg of Pu. However, there is considerable technological flexibility in the nuclear fuel cycle. There are three types of nuclear fuel cycles that might be utilized for the increased production of energy: open, closed, or a symbiotic combination of different reactor types (such as, thermal and fast neutron reactors). The neutron energy spectrum has a significant effect on the fission product yield, and the consumption of long-lived actinides by fission, is best achieved by fast neutrons. Of course, breeder reactors can extend the uranium resource by the conversion of ^{238}U to fissile ^{239}Pu. Within each cycle, the volume and composition of the nuclear waste and fissile material depend on the type of nuclear fuel, the amount of burn-up, the extent of radionuclide separation during reprocessing, and the types of materials used to immobilize different radionuclides. During the past decade there has been considerable progress in developing materials for the immobilization of radionuclides. A variety of actinide-bearing phases (e.g., zircon, monazite, apatite, zirconolite, pyrochlore and muratiate) may be used to immobilize the Pu. Some of these materials are remarkably radiation "resistant" nuclear waste forms.

Federal and State Law Preemption Issues as it Impacts the Uranium Mining Industry

Dick Kaufman: McKenna Long & Aldridge, LLP

My proposal focuses on the preemption of state or local regulation of uranium mining processes by federal or state law. With both presidential candidates expressing their support for a renewed emphasis on nuclear generated power, the importance of this subject will remain important for the foreseeable future. In brief, which level of government has the authority to regulate uranium mining processes? It has already been the subject of legislation and a pending appellate case here in Colorado. During the past session of the Colorado General Assembly the legislature adopted legislation restricting the use of in situ mining processes in uranium mining in Colorado. In addition, a case is pending before the Colorado Supreme Court which focuses on the issue of local government restrictions on gold mining processes imposed through local county zoning ordinances. The legislation and pending appeal raise the specter of preemption issues.

My paper and presentation will focus on the general parameters of preemption law at the federal and state levels in the United States and in particular those States where uranium mining is a significant part of the economy. The paper will cover federal and state case law, statutory law and most importantly suggested strategies for handling these issues in the future so uranium mining can proceed in an effective and profitable manner.

The Global Uranium Market – Continuing to Evolve

Dustin J. Garrow: Paladin Energy, Ltd.

A global "Nuclear Renaissance" is upon us. After decades of neglect and virtual decay, nuclear power now has begun to assume its rightful place as a premier technology providing a broad spectrum of economic and climate change benefits. While the science of "global warming" can be debated, it is no mistaking that national governments are seeing nuclear power as a vital component of future electricity generation.

The international uranium market continues to evolve as both demand and supply factors place competing pressures on pricing. The existing commercial "fleet" of nuclear power stations is growing at an accelerating rate. Ever-increasing forecasts of planned and potential nuclear reactors clearly demonstrate massive electrification imperatives.

In addition to anticipated robust growth in uranium requirements, trade patterns are shifting as countries such as China and Russia are no longer net exporters of uranium but are now becoming net importers while India, a long-standing pariah in the international nuclear fuel marketplace, has been accepted into the Western nuclear fuel markets.

Extensive uranium inventories which resulted from over-production in the 1950-1980's and, during the 1990's, had helped to force the uranium price down to levels insufficient to support global requirements and led to minimal exploration and development expenditures are depleting. That "already-mined" uranium precipitated the drastic decline in the uranium production sector which continues to struggle to effectively respond to historic price signals including spot prices exceeding US$135/pound U3O8. Recent price volatility has only added to future uranium supply uncertainties.

A New Activity at the IAEA to Support Training and Education in the Uranium Production Cycle

Jan Slezak: IAEA

Doubling uranium production within 10 years, between 2005 and 2015, especially after a 25-year-long depression, raises many questions. One of the most important, but still underestimated, is education and training of a new generation of uranium industry workers. Many newly designed operations will cover the production and each of them will need a certain number of professionals, who cannot cover more than one site. There are many limitations in their proper development, such as limited number of those who can teach, train and consult, because they are already busy with their work. Another one is a myth we can simply "buy" them from other mining industries (oil and gas, coal, gold, copper, zinc etc.). All these industries are also developing quickly and are facing similar problems. Creation of an international network for training and education in uranium production cycle activities would be one step forward in resolving their problem.

The availability of sufficient numbers of properly educated, trained and experienced personnel should limit the creation of "new" legacies following uranium production. This is important in the current situation as not all existing legacy issues have been satisfactorily resolved.

Environment, Health and Safety

Session A – Monday PM, May 11, 2009

Bridging the Gap: Overcoming the Lack of Information in the UIC Class III Permit Application Process

Kaci Walker & J. Erich Rauber: R Squared, Inc.

As in-situ recovery (ISR) of uranium continues to develop, so does the demand for Underground Injection Control (UIC) Class III well permits. While many states have primacy over their UIC programs, the Environmental Protection Agency (EPA) has final approval of all state regulation regardless of primacy. Due to the fairly complex state and federal regulatory structures of the UIC program and the relative newness of ISR uranium mining in many states, the information available concerning the application process is spotty at best. A UIC Class III permit applicant must patch together the sparse guidance and policy from EPA headquarters and regional offices in order to submit a completed application. The purpose of this paper is to compare and contrast Class III permit application information from its various sources and hopefully provide applicants with a better understanding of the application process and its requirements. With a clear understanding of available guidance (as well as its gaps), a UIC Class III applicant can hopefully navigate the application process more efficiently.

Applying the Concepts of Sustainability to Uranium Mining

Caitlin Rood: Tetra Tech, Inc.

One of the greatest challenges brought on by the uranium mining renaissance is a widespread lack of knowledge by the public of the impacts associated with uranium mining and today's regulatory structure. When most Americans think of uranium mining, they think of uranium mine and tailings legacy sites, Three Mile Island, and Chernobyl. Uranium mining companies in the United States are paying for the public perception in lawsuits, delayed permit approvals, and costly environmental evaluations demanded by the public that may go far beyond the level of necessary study warranted for the work being done. For example, tribal or public demand for exhaustive environmental baseline studies and National Environmental Policy Act (NEPA) Environmental Impact Statements (EIS's) is becoming increasingly common in the earliest exploration drilling phases of uranium projects, even though neither federal nor state statute nor the respective agency guidance require this level of analysis for stand-alone drilling programs.

The existing standards of practice from the last (1970's) uranium boom, for most agencies charged with making NEPA environmental evaluations as part of the decision process for uranium exploration drilling permits, has been to limit the environmental evaluation to a categorical exclusion, or at most, an environmental assessment (EA). This approach, consistent with NEPA statute and various federal agency policies and guidance, was applied regularly from the 1970's to the early 2000's to the decision process for exploration drilling permits. However, in more recent cases in which agencies have attempted to follow the existing policies, the public reaction has been rejection of the agency decision and a backlash of lawsuits, protests, and impediments to the projects. In each recent case considered in this paper, potentially-affected nearby landowners, residents, or tribal representatives used the agency's public involvement process, or the courts, to demand an EIS level of analysis and/or impede the project, with differing results. In each case, the public demand for an EIS was coupled with stakeholder claims that, in their perception, the agency's selection of a lesser evaluation was tantamount to gross oversight or neglect. This paper begins by comparing several of these exploration situations and the effect of the public demands and resolution process on the project schedules and progress.

Whether the alarmed public reaction to uranium exploration drilling, and the increasing demand for exhaustive up front studies, actually results from true concerns about exploration impacts, or reflects an attempt at preventing later mining and milling by early intervention (forestalling exploration) likely varies from project site to project site. The balance of this paper explores the use of the concepts of sustainability to help overcome some of the negative public perception with respect to the uranium mining industry in the United States. Generally, sustainability involves taking into consideration economic, societal, and environmental factors as an approach to the business of uranium mining. Applying the concepts of sustainability to uranium mining requires a shift in thinking for most uranium mining companies. Rather than only involving the public in legally mandated public comment periods, the sustainability approach involves working with local community members as a part of the project team at the very earliest stages of the project and throughout the life of the project. Following a sustainable model for uranium mining means to understand that incorporating its common principles (transparency, valuation, integration, community, conservation, equity, global integration, best practices, human and natural capital, continual improvement, and governance) will lead to less contentious path to the end goal (pounds in the can) and will ultimately save the mining companies' money.

The Uranium Recovery Industry and the Current Nuclear Renaissance – A Health Physicist's Perspective

Steven H. Brown: SENES

Concurrent with the recognition that nuclear generated electricity must play an increasing role in worldwide energy supply and in consideration of the new nuclear power plants ordered or planned, the demand for uranium needed to fuel these reactors has already outpaced supplies. Accordingly, the price of uranium (typically expressed as $ per pound U3O8 equivalent) has increased significantly over the last two years. As a result, numerous new and reconstituted uranium recovery projects are being developed in the United States and in other countries that possess considerable uranium ore reserves (e.g., Canada, Australia, Kazakhstan, Mongolia, Namibia, and others).

It should be noted that in the United States, the current reactor fleet of 104 operating units, which generate 20 percent of the US's base-load electricity, requires approximately 55 million pounds of U3O8 per year, but only about 4-5 million pounds per year is produced domestically. That is, over 90 percent of current demand, ignoring anticipated increase in requirements in the near future as new plants come online must come from foreign sources. Domestic uranium production over the last 10 years reached a low of about two million pounds in 2003 and has been increasing steadily since then.

Uranium recovery as defined in this paper encompasses conventional uranium mining and milling as well as in situ recovery techniques and the recovery of uranium as a byproduct from other processes, such as phosphoric acid production. Following a brief history of uranium recovery in the US, the paper describes the basic methods and technologies associated with conventional uranium mining, conventional uranium milling and In Situ Recovery (ISR). The "health physicist's perspective" is introduced into these discussions by providing summaries of the various radiological environmental monitoring and operational health physics programs that are required for these recovery techniques based on specific design and operational aspects of each. Applicable regulatory guidance and associated "best health physics practices" developed at these facilities are described. Human resource needs and opportunities for radiological scientists in the Uranium recovery industry are presented.

Uranium Mining and Milling Regulation in Saskatchewan, Canada

Tim Moulding: Saskatchewan Ministry of Environment

Uranium has been mined in the Athabasca Basin region of Saskatchewan since the 1940's and during this time the regulation of mining and milling operations has evolved substantially. This evolution has progressed from a time where decommissioning was not an operational consideration to a regime where decommissioning and reclamation are key considerations early in the assessment of any projects contemplated.

This presentation describes the present regulatory framework of the Saskatchewan Ministry of Environment for uranium mining and milling operations focusing on the life cycle phases of exploration, assessment, construction, operation, decommissioning, and release. Applicable legislation and guidelines are described in the context of the life cycle phases with focus on the key regulatory requirements for each phase. Information on interaction with other provincial and federal regulatory agencies is included. Other information includes monitoring requirements related to baseline information gathering, operation, and post decommissioning with emphasis on the intent of monitoring for each applicable phase and a brief description of uranium mining developments in the Athabasca Basin.

Development of a Health, Safety Environmental, and Community (HSEC) Management System and How It's Implementation Can Benefit the Uranium Mining and Milling Industry

Paul Nazaryk, M.A, J.D[1] & Andres Meglioli, Ph.D., MBA[2]: [1]BHP Billiton & [2]ERM

The environmental and socioeconomic aspects of a large uranium mining or milling project can be profound. Such a project can present both opportunities and problems for surrounding local communities. Despite the improved local employment opportunities and increased tax base, communities and local stakeholders have become wary of the traditional mining "boom and bust" cycles, fear the influx of newcomers to the area, and are concerned about the associated environmental and socioeconomic impacts.

Minimal compliance with government standards was once the goal of many companies. Now many major international corporations, including mining and energy companies, have developed their own internal standards and principles for managing environmental, health, and safety aspects, and they have instituted sophisticated programs for implementing these standards. These standards often move beyond the traditional environmental, health, and safety arenas and establish guiding principles for social responsibility as well as for managing their impact on local communities and indigenous peoples. Many of these same corporations are developing standards for mine closure and plans for future land use.

Many of these same corporations have learned that a poorly-planned or ill-managed project or operation can give their company a "black eye". As a result, many large mining and energy companies are conducting environmental, socioeconomic and health impact assessments to identify and mitigate such concerns during the planning and development phase, even when such an assessment is not required under local law. Likewise, they are requiring implementation of management systems based upon ISO 14001 and OHSAS 18001 standards at the facility level. Such investments and approaches can be of great benefit to any company developing new large projects, including uranium mining and milling operations.

This paper will review current international developments and expectations, including the International Finance Corporation (IFC) Equator Principles, the International Council on Mining & Metals (ICMM) Global Mining Initiative, ISO 14001, and OHSAS 18001, and how these expectations may impact the burgeoning uranium mining and milling industry.

House Bill 1161 and the Environmental Movement

J. Fognani: Fognani & Faught

The aim of this paper is to illustrate how House Bill 1161 and similar legislative efforts are inconsistent with the purported purposes behind the environmental movement and the quest for sustainable development with respect to the mining industry. This paper will highlight the concept of sustainable development and how the implementation of in-situ recovery mining supports sustainable development by encompassing economic, environmental and social considerations through the utilization of the best available technology in an environmentally safe and sound process. This paper will provide a detailed analysis regarding how House Bill 1161 and similar legislative efforts neglect to follow the sustainable development model, which has become the operating paradigm for the mining industry, by unrealistically prioritizing environmental sustainability. It is concluded that House Bill 1161 defeats the purpose behind the environmental movement and quest for sustainable development by providing a context in which to improve overall environmental sustainability where cutting edge green development is unattainable, ultimately preventing all in-situ leach mining in Colorado.

Uranium General Interest

Session B - Monday PM, May 11, 2009

Some Aspects of Disequilibrium

Robert D. Maxwell: Mineral Property Evaluation LLC

Uranium in shallow deposits in sandstones in the western United States may be dispersed by the action of modern oxygenated ground water. This activity moves uranium away from the original site and distances it from daughter products that were produced by the radioactive decay of uranium. In the past, several mine operators recognized the phenomenon and adjusted extraction practices. Others did not recognize the condition which led to dilution, loss of uranium, and/or expensive pit slope revisions.

Deposits or portions of deposits out of equilibrium will exhibit zones of favorable disequilibrium balanced by zones of unfavorable disequilibrium. Identification of these zones is crucial to resource estimation, mine planning, and grade control for conventional as well as for in-situ recovery operations.

Another aspect of the effect of modern (or post uranium deposition) oxidizing ground conditions is that early exploration programs may have mistakenly mapped the current state of oxidation of iron as an indicator of the position of a roll-front deposit. A result of this approach may be that several mineralized fronts in south Texas may have been passed over.

Developing a Comprehensive Relational Database from Historical Exploration Data with Seamless Bridges to Analysis Tools

Phil Cavendor[1], Cary Leppert[2], Amanda Huffer[1], & Dana Spanjer[1]: [1] AATA International, Inc. & [2] Leppert Associates

Given the current energy situation within the United States, it is appropriate to examine the economic viability of developing uranium resources that have been previously explored but not recovered. During past surges in uranium exploration large numbers of borings were drilled in targeted environments throughout the Rocky Mountain West. Since the last surge in uranium exploration occurred in the 1970's, data collected during these exploration efforts were recorded on hardcopy. These historic exploration boring data require translation into an organized, digital format to be incorporated into state-of-the-science uranium resource economic viability analyses. Our team has developed a

rigorous and regimented methodology for translating historic exploration boring data from a hardcopy format into a comprehensive relational database.

An application of this methodology is demonstrated using historic uranium exploration boring data collected in southeast Montana from the period spanning 1968 through 1981. Data from over 1,000 exploration bore holes were compiled into the relational database. A wide variety of data were incorporated into the database including; multiple types of geophysical logs, geologic logs with lithologic cuttings, and geologic logs of cores. All area geophysical logs, geologic data including lithologic descriptions, maps and reports, were digitally scanned and processed as PDF files and TIFF files for entry into the database.

The first step in the methodology implemented was the development of a well mapped, intuitive, and documented exploration boring relational database to store the historic data. This stand alone fully functional, robust site-wide relational database was created using the Microsoft Access data format with a diverse structure to cover the needs of its many users. The amount of data and its varying forms required an efficient procedure to accomplish this task with as few user errors as possible. Tools were created to automate the transfer of data to the database. Simple graphical user interfaces (GUI's) were built to scribe digital and non-digital data to the site wide relational database with automated data quality assurance/quality control abilities to eliminate the user entry errors. Data flow bridges were constructed to seamlessly connect to analysis tools in a way that the integrity and stability of the site-wide relational database remained independent and non-corruptible but the data needs of these various analysis tools were achieved with ease and efficiency. A centralized hub location stored the database and was connected through local networks and the World Wide Web. The database data were then available for use between multiple users including geologists, project managers, data managers and consultants in a timely and efficient manner.

Computer Aided Interpretation of Geophysical Logs: Development of a 3-D Lithologic Model for a Uranium Roll-Front Deposits

Shawn Leppert[1], Mike Hawks[2], Mike Williams[1] & Robert Clark[3]: [1]Leppert and Associates, [2]WildHorse Energy & [3]AATA International

The economic viability for In-Situ Recovery (ISR) of uranium mineralization mapped in shallow alluvial deposits located in central Wyoming is dependent on our understanding of the nature and distribution of permeable sandy lenses present in the shallow subsurface. In the site project area, the shallow subsurface is dominated by lacustrine and fluvial derived mudstones inter-bedded with silty sandstone lenses. These lenses facilitate lateral groundwater flow within the mudstone matrix. The targeted uranium mineralization occurs in a particular silty sandstone horizon. The orientation of this horizon in 3-dimensional space is complex and can be difficult to trace.

Fortunately, the shallow geologic setting in the project area has been explored in detail as part of previous investigations. During the 1960s and 1970s, hundreds of exploration borings were advanced into the potential uranium-bearing zones. Geophysical logging was performed within the vast majority of these borings. For the most part, two geophysical techniques were used to describe the porous media encountered. The Gamma Ray Log was used to locate the uranium mineralization by measuring the natural gamma radiation. A Single-Point Resistance Log generally accompanied the Gamma Ray Log. The Single-Point Resistance Log is an analog recording of a geologic material's ability to impede the flow of electricity. This analog recording represents the logging tool's signal which communicates the relative down-boring porous media electrical resistance. Resistance Logs can be interpreted to provide insight about the lithology encountered within a boring.

We developed a mathematically-based computer algorithm to efficiently interpret the large number of digital Single Point Resistance Logs available for the project area (over 500 separate digital logs). This algorithm makes use of simple signal analysis techniques to identify significant changes in the recorded geophysical signal which designate changes in the lithology encountered within a boring. For this application, we targeted the electrical resistance change that occurs when a silty sandstone was encountered within the mudstone matrix. To demarcate the digital signal change, this tool delineates the occurrence of all signal peaks and troughs using a five-point derivative scheme. The magnitude of change between peaks and troughs was used to estimate what lithologic type was encountered. The thickness of a particular lithologic lens was estimated through the use of inflection points delineated by the second derivative of the electrical resistance. This tool was calibrated by comparing lithologic interpretations made by an experienced geologist for a subset of the project area logs to the lithologic interpretation made by the computer algorithm.

Results from lithologic interpretation of the geophysical logs were interpolated onto a finely discretized, digital 3-dimensional lithologic model of the project area. A detailed evaluation of the model was performed to verify that the distribution of lithologies produced by the computer tool were consistent with the conceptual model developed by site geologists. The digital lithologic model was integrated with the digital hydrologic model to create a groundwater flow and geochemical analysis tool for the project area. This analysis tool will assist in the design of an ISR operation that has an optimally placed injection/recovery well network enabling the efficient and cost effective in-situ recovery of the targeted uranium mineralization.

Modeling and Analysis if Realistic Uncertainty in ISL Hydrologic Systems

Robert Will, PhD, PG, PGP: Schlumberger Water Services

The In-Situ Leaching (ISL) process for mining of uranium ore holds many economic and environmental advantages over methods. The ISL technique requires relatively low capital investment, typically provides high recovery rates, and minimizes surface impacts such as excavations and dust. However, due to the nature of the ISL technique, understanding and minimizing the impact of mining operations on

groundwater quality is a high priority for regulators and operators.

Commercial grade uranium deposits of the type conductive to ISL are typically found in sandstones in which uranium change in redox conditions have caused precipitation of uranium minerals from pregnant groundwater. Typical depositional environments are sheet sands to paleo-channels. Both the operational efficiency of the ISL project and the management of groundwater quality are intimately related through the subsurface geological setting. Improvements in subsurface characterization, therefore, provide not only potential direct gains in operational efficiency, but facilitate efforts to mitigate undesirable groundwater impacts and assist in post-operational remediation efforts.

Although the depositional environments may be fairly homogenous on a large scale, localized heterogeneities may have profound impact on the characteristics of the roll front and on sweep efficiency. Further, even best practices in exploration methodology leave significant uncertainty in subsurface characteristics. These technical uncertainties translate to significant economic and environmental uncertainties.

Field design and key operational factors in in-situ leaching operations are very similar to those encountered in development of shallow petroleum deposits. As such, many of the tools designed for modeling and evaluation of petroleum reserves map directly into evaluation of ISL systems. This presentation discusses the important role of state-of-theart tools and techniques for geoscience data integration and subsurface modeling developed for the petroleum industry. In particular, Schlumberger's PETREL and Eclipse modeling and simulation software provide powerful tools for geological and geophysical driven subsurface characterization of ore deposits and evaluation of the flow systems controlling ISL efficiency. Streamlined workflows are shown which result in highly representative models of important depositional systems. These workflows incorporate stochastic uncertainty analysis to develop realistic probability based estimates of key operational performance metrics. These uncertainty analysis methods are applied to a typical ISL system.

AML Funded Uranium Reclamation Projects in Wyoming

Brenda K. Schladweiler, Ph.D: BKS Environmental Associates, Inc.

The Abandoned Mine Lands (AML) program is funded by the federal coal severance tax and is administered by the Wyoming Department of Environmental Quality (DEQ) working in conjunction with the Office of Surface Mining Reclamation and Enforcement (OSMRE). Such funds are distributed for non-coal projects that are deemed to be safety risks to the citizens of Wyoming.

Historical uranium exploration and mining activity began in Wyoming in 1953 in three primary districts, i.e., Gas Hills, Shirley Basin and the southern end of the Powder River Basin. The Wyoming AML program has addressed pre-law (1973) impacts from this historical activity and has spent millions of dollars reclaiming abandoned uranium mines and exploration drill holes throughout Wyoming. AML program objectives include the repair of environmental damage and elimination of safety hazards influenced by past uranium mining and exploration activities. In addition, AML monies provide funding for various research projects throughout the state and administered by the University of Wyoming Research Office. Some of these research projects were directly related to uranium reclamation.

The primary focus of uranium mine reclamation is shaft, adit or large open pit closure or reduction in highwalls and topographic stabilization. Since AML sites are pre-law, little or no topsoil or suitable plant growth medium was salvaged prior to disturbance. In addition, many of the uranium districts in Wyoming are characterized by short growing seasons, low precipitation and high winds. Such harsh environmental conditions provide challenges for revegetation of these sites.

Examples of uranium reclamation on AML funded projects will be discussed in addition to any research directly associated with these projects.

Evaluation of Geosynthetic Clay Liners for the Piñon Ridge Uranium Mill Tailings Disposal Cell

Chris Athanassopoulos[1], Kimberly Finke Morrison, P.E., R.G.[2], & John Allen[3]: [1]P.E., CETCO, [2]Golder Associates, & [3]TRI Environmental

Uranium mill tailings are a finely-ground waste product of uranium rock ore processing operations. The tailings are typically deposited in lined disposal cells as a slurry, which contains some residual uranium, dissolved metals, and chemical reagents added during the milling process (often a low-pH sulfuric acid leaching solution). As part of the tailings disposal cell design for the Piñon Ridge Uranium Mill in Western Montrose County, Colorado, Golder Associates performed a feasibility study of two liner system alternatives. The first alternative, prescribed by the Nuclear Regulatory Commission (NRC), consists of the following components (from top to bottom):

- 60 mil HDPE geomembrane;
- Drainage geocomposite, with minimum transmissivity = 3×10^{-4} m^2/sec;
- 60 mil HDPE geomembrane; and
- 3-foot thick compacted clay layer with a maximum hydraulic conductivity of 1×10^{-7} cm/sec.

The second alternative is very similar to the prescriptive remedy, except the compacted clay liner is replaced by a geosynthetic clay liner (GCL). GCLs are sodium bentonite-based hydraulic barriers commonly used in place of compacted clay liners in waste and liquid containment applications. GCLs have a certified laboratory hydraulic conductivity of 5×10^{-9} cm/sec with deionized water. This presentation will evaluate both compacted clay liners and GCLs as potential alternatives for uranium mill tailings disposal applications. The

evaluation will include chemical compatibility, performance at low pH, and performance under high confining pressures. Results of ongoing long-term laboratory compatibility tests of various GCLs in contact with synthetic mill tailings solutions will also be presented.

Uranium Deposit Genesis and the Geological Cycle

Session A - Tuesday AM, May 12, 2009

Early Fractionation Processes of the Uranium Cycle and the Origin of Large Uranium Provinces

Michel Cuney: Nancy University

The first uranium-rich granites able to crystallize uraninite appeared on the Earth at about 3.1 Ga. Several younger generations were emplaced at about 2.9 and 2.6 Ga. The earliest granites correspond to the most fractionated members of high-K calcalkaline suites. They result from crystal fractionation of magmas derived from melting of mantle wedges enriched in K, U, Th and other large ion lithophile elements. These enriched mantle wedges formed by the injection of uppercrustal material into subduction zones. Such granites attest to the extensive development of plate tectonic by that time. Also, highly fractionated peraluminous leucogranites, sufficiently enriched in uranium to crystallize uraninite, appeared at about 2.6 Ga. Erosion of these two granite types led to the detrital accumulation of Th-rich uraninite that formed the first uranium deposits on Earth: the Quartz Pebble Conglomerates. Mechanical transport of uraninite was only possible before about 2.3 Ga because of low oxygen levels in the atmosphere prior to that time. From 2.3 Ga onwards, increasing oxygen availability led to the oxidation of U(IV) to U(VI), uranium transport in solution, and exuberant development of marine algae with formation of algal coal (shungite) in epicontinental platform sediments. From 2.3 to 1.8 Ga large amounts of U, previously accumulated as U(IV) minerals, were dissolved and trapped preferentially in passive margin settings, in organic-rich sediments,: specifically shales, marls and arkoses. This succession of U fractionation steps led to the formation of the world's largest Paleoproterozoic U provinces, such as the Wollaston belt in Canada and the Cahill Formation in Northern Australia. During and after the worldwide 2.1-1.75 Ga orogenic events, which were responsible for the formation of the Nuna, the first real supercontinent, U trapped in these formations became the source for several deposit types: (i) metamorphosed uranium-mineralized graphitic schists, calcsilicates and metaarkoses, (ii) diagenetic-hydrothermal remobilization with the formation of the first economic deposits related to redox processes at 2.0 Ga: Oklo area deposits, (iii) disseminated uraninite in pegmatoids resulting from partial melting of U-rich metsediments, as Charlebois (Canada), (iv) remobilization in hydrothermal veins as at Beaverlodge, Canada at about 1.75 Ga, and (v) disseminated U mineralization in albitites as at Lagoa Real, Brazil or in the Central Ukrainian district ... Other generations of high-K granites, enriched in U, were also emplaced during these orogenic events. After 1.75 Ga, a long period of tectonic quiescence occurred on the Earth, and large intracontinental basins filled at their base with oxidized siliciclastic sediments in many parts of the Nuna. In the Athabasca (Canada) and Kombolgie (Australia) basins, thick series of perquartzose sediments represented huge aquitards for sodic brines derived from overlying evaporitic sequences. These brines became calcic when infiltrating into the basement. They leached U from the Paleoproterozoic epicontinental sediments, their anatectic derivatives, high-K-U granites and some pre- and late-Hudsonian U mineralization to form the unconformity related U deposits.

The Fraser Lakes Uranium Showings, Northern Saskatchewan: Geological, Geochemical, and Geophysical Relationships of Granitic Pegmatites/Leucogranites Hosting Low- to Medium-Grade Uranium Mineralization

Annesley, I.R., Kusmirskik, R.T., Billard, D., & Wayliuk, K.: JNR Resources Inc.

The Way Lake uranium project of JNR Resources Inc. is located 55 kilometres east of the Key Lake uranium mine in the Athabasca Basin of northern Saskatchewan. The property is underlain by a steeply-dipping, northeast-trending, highly folded sequence of intercalated Paleoproterozoic Wollaston Group metasediments and underlying Archean orthogneisses. In 2006, high-grade uranium mineralization was obtained from a previously identified massive pitchblende vein, now called the Hook Lake showing, where two grab samples yielded 40.1% and 48% U3O8 with significant lead, REE, and thorium enrichment, and anomalous boron, cobalt, and vanadium.

Within the Walker Lake area (southwestern part of the property), two major uranium showings (now called Fraser Lakes Zones A and B) were identified by airborne geophysics and ground prospecting. Fraser Lakes Zone A occurs within a reactivated NE-plunging synformal fold nose, associated with Wollaston Group graphitic pelitic gneisses. A major prospecting campaign during the summer of 2008 identified uranium mineralization in several outcrop showings coincident with this conductive EM trend. The Fraser Lakes Zone B showing is the most significant, which occurs over a 1.5-kilometre long by 0.5-kilometre wide area within an antiformal fold nose cut by an E-W dextral ductile-brittle cross-structure. Outcrop grab samples returned from 0.038 to 0.453% U_3O_8 and drill core samples returned mineralized sections with values from 0.012 to 0.552% U_3O_8.

Significant uranium, thorium, and REE mineralization occur in outcrops of granitic pegmatites and leucogranites. These outcrops are estimated to be ~200-250 meters below a glacially eroded Athabasca/basement unconformity. The radioactive granitic pegmatites and leucogranites occur within a highly tectonized contact zone between Archean granitoids and basal Wollaston Group metasediments. This crustal melt shear zone (decollement) is folded around Archean granitic domes and is thickest within NE-plunging fold noses. These fold noses are dilation zones with potential for brittle reactivation and associated fluid flow. The radioactive quartz-feldspar-biotite granitic pegmatites and leucogranites contain minor to trace amounts of uraninite, U-Th-REE-rich monazite, molybdenite, chalcopyrite, pyrite, and ilmenite. Locally, dark smoky quartz segregations and veins are present.

Six drill holes from Zones A and B have intersected radioactive granitic pegmatites/leucogranites, and down-hole radiometric logging reveals U and Th mineralization over significant widths. Preliminary geochemical results have confirmed intersects of weak to moderate U308 mineralization, suggesting the potential depth and volume of these bodies.

Outcrop radiometrics of the granitic pegmatites/leucogranites correlate well with a high-resolution magnetic/radiometric survey over the Fraser Lakes and surrounding area. The large aerial extent of the airborne anomalies and the presence of uranium in outcrop and within several boreholes clearly show that the Fraser Lakes area has a very high potential and likelihood of further uranium discoveries, including high-grade root zones to unconformity-type mineralization, with similarities to nearby basement-hosted uranium deposits, such as Eagle Point and Millennium.

The Labrador Central Mineral Belt: An Established Uranium District With Growing Resources and Diverse Metallogeny

Greg Sparkes & Andrew Kerr: Geological Survey of Newfoundland and Labrador

The Central Mineral Belt (CMB) of Labrador was first defined as a uranium province 50 years ago, and is now second only to the Athabasca Basin as an exploration target area in Canada. Resources at previously-known deposits have been expanded significantly, and new styles of mineralization have been discovered. Uranium mineralization in the CMB is extraordinarily diverse, but the known deposits fall broadly into three classes considered to have developed in broadly magmatic, metamorphic-metasomatic and sedimentary environments, respectively.

Syngenetic magmatic mineralization is represented by uraniferous pegmatites and aplites, and by some locally stratiform mineralization in felsic volcanic rocks. Magmatic-hydrothermal mineralization of epigenetic affinity is represented by unusual breccia-hosted mineralization associated with iron metasomatism, and V, Cu and Ag enrichment. This style is compared by some to so-called iron oxide-copper-gold (IOCG) environments, although copper and gold are largely absent. The most important deposits are those considered to be of metamorphic and/or metasomatic origins, hosted by strongly deformed felsic metavolcanic rocks, pelitic metasedimentary rocks and possibly granitic metaplutonic rocks. The Michelin deposit (~100 million lbs of U_3O_8) remains the largest example, although the Jacques Lake deposit (currently ~17 million lbs) continues to grow. These deposits exhibit pre- or syndeformational timing, are located in regional shear zones, and are associated with soda metasomatism. They were originally considered to be deformed synvolcanic deposits, although a general affinity to so-called "metasomatite" or "albitite" deposits is perhaps more likely. Predictably, IOCG-type models have also been invoked, but are hard to reconcile with a general absence of iron-oxide, copper or gold enrichment; to a large extent, these are uranium-only deposits. Hydrothermal transport and deposition of uranium during regional deformation and metamorphism are likely important processes, but genetic details remain unclear. Mineralization in sedimentary rocks in Labrador is associated mostly with terrestrial facies, within which uranium concentration is linked to localized reduction of oxidized sequences, but there is no clear association with regional unconformities. The links between such mineralization and that of magmatic or metamorphic origins remain unclear, but at least some of the sandstone-hosted mineralization must be significantly younger in age. On a wider scale, preliminary geochronological data from the CMB suggest that it records several discrete metallogenic events. The most significant deposits appear to be of Paleoproterozoic age (~1.9 to 1.8 Ma) but were not necessarily formed as part of a single event.

Almost without exception, uranium deposits in the CMB district enjoy surface expression in the form of outcrop or boulder trains, and there are no truly "blind" discoveries. The great challenge for the systematic research programs now underway is to develop predictive deposit models that will facilitate exploration for deeper-level, unexposed, uranium deposits. Logic dictates that such resources *must* exist in this diverse and prolific uranium district.

Genesis of Uranium-Rich, Base-Metal Bearing, Solution-Collapse Breccia Pipes, Northern Arizona

Karen J. Wenrich[1] & Spencer R. Titley[2]: [1]Wenrich Consulting 4 U & University of Arizona

Solution-collapse breccia pipes in northwestern Arizona are sites of high-grade uranium deposits, the highest grade in the U.S. U-Pb ages by Ludwig and Simmons on uraninite of 200 and 260Ma link the mineralization with Pangean time, events, and mid-continent MVT ores; chemistry and fluid inclusion temperatures on sphalerite and dolomite of 80°-173° link them with MVT deposits, particularly those in the Viburnum Trend. Fluid mixing of oxidizing groundwaters from overlying sandstones, with reducing brines that had entered the pipes due to dewatering of the Mississippian limestones created the uranium deposits

The uraninite ages span the range of times from the beginning to the end of stability in Pangea, a time that allowed many MVT deposits to form throughout the world. If intrinsic heat from the earth found no mechanical outlet during the time of continental stasis (Pangea) it may have driven the basinal brines from the Redwall Limestone strata deep in the basin, up dip to the platform strata of northwestern Arizona (basin dewatering). During the period of crustal stasis it is quite likely that the water table fluctuated during the many cycles of climate change, reactivating the Mississippian karst of the Redwall Limestone, where the breccia pipes are rooted.

We propose that the Cordilleran Miogeocline, proximal to the west, is a significant geological component of the origin of the pipe complex, and that basin dewatering was a principal source of reactive waters and metals. There are significant occurrences of Pb-Zn (Ag) ores in adjacent western Nevada (Goodsprings District) and Pioche, Nevada, where MVT origins have been proposed for the deeper strata. At the same time that the mega Cordilleran basin had formed to the west, to the east, northeast, and southeast of the Grand Canyon region the Emery

positive area, Kaibab Arch, Defiance Zuni positive area, and the Sedona Arch had formed. These uplifts would have created large hydraulic heads in the Grand Canyon region aquifers. The uranium pipes occur within the platform strata of this Paleozoic miogeocline. Once the pipes had formed by the close of the Permian Kaibab deposition due to the fluctuating water table, they had the potential for trapping and mixing basin dewatered fluids. Not only could the breccia pipes trap upwelling waters and metals of deeper derivation from the reduced strata of the miogeoclinal shelf, but essentially provided conduits for artesian movement of these brines as the pipes cut through sandstone aquifers and shale aquitards of the Grand Canyon region. Within the pipes the brines would have readily mixed with oxidizing waters from redbed sandstones, such as the Pennsylvania-Permian Supai Group, which contain small stratiform uranium occurrences elsewhere on the Plateau, such as at Promontory Butte. The hydraulic head dictated the extent of upward fluid movement in the pipe and the stratigraphic location of the ore mineralization.

With the placement of these pipes into the tectonic cycle of worldwide MVT deposits, a fresh exploration approach to these breccia pipes might be to follow our suggestion of increased probability for such MVT deposits along margins of cratonic basins.

Sedimentologic and Paleoclimatic Controls on the Distribution of Uranium Deposits in the Upper Triassic Chinle Formation, Colorado Plateau, USA

Russell F. Dubiel: U.S. Geological Survey

Continental strata of the Upper Triassic Chinle Formation contain uranium deposits over much of the Colorado Plateau. Three units are the primary hosts for uranium. In ascending order, these are the Shinarump, Monitor Butte, and Moss Back Members. The Shinarump is coarse-grained to conglomeratic gray sandstone; the Monitor Butte is green sandstone to black mudstone; and the Moss Back is medium-grained brown sandstone. Whichever of these members is in contact with the underlying Lower Triassic Moenkopi Formation is the ore host. A combination of factors, including depositional environment, paleoclimate with seasonal rainfall, and burial history, all controlled the distribution of uranium deposits. The lower Chinle was deposited within extensive paleovalleys eroded into the top of the fine-grained Moenkopi, which later acted as an aquitard below Chinle strata. The upper Chinle was deposited in meandering stream, lacustrine, and eolian systems. Paleosols are abundant throughout the section.

Shinarump sandstones were deposited within trunk rivers and tributary streams that flowed northwest from the continental interior and local highlands. Meanderings and avulsions of the trunk rivers blocked drainage of tributary streams and formed dendritic lakes with extensive marginal marshes. Lacustrine deltas and levees gradually prograded and filled the lakes with siliciclastic sediment and ash from volcanic eruptions. The lacustrine deltas contained abundant plant material both as whole fossil specimens and abundant comminuted fragments. Marshes developed at the margins of the deltaic systems and locally deposited black organic-rich mudstones. Rapid deposition and detrital organic matter in the marshes produced reducing conditions responsible for the characteristically green and gray beds of Monitor Butte strata.

The formation of uranium ore bodies in the basal sandstones of the Chinle required a specific set of sedimentologic and post-depositional geochemical conditions to mobilize, localize, and precipitate uranium and related elements. Uranium-bearing fluvial sandstones at the base of the Chinle thus occur only within paleovalley systems that subsequently contained lacustrine deltas and adjacent organic-rich marshes. These deposits established reducing geochemical conditions that resulted from the degradation of organic plant material below the water table or the sediment-water interface. Fluvial channel systems that lack associated overlying lacustrine deltaic and marsh systems contain no uranium ore bodies. Uranium was most likely released from the volcanic ash-rich sediment under oxidizing conditions that existed in subaerial floodplain paleosols and in deltaic strata deposited in oxygenated lake water. As soluble uranium entered the ground-water system, it flowed through the paleoaquifers formed by the underlying Shinarump channels. Further downward flow was retarded by the fine-grained clay-rich character of the underlying Moenkopi. Uranium precipitated to form ore bodies in pore spaces within these coarse-grained sandstones, a process initiated by the mixing of oxygenated uranium-bearing ground waters with reducing, downward-migrating organic acid-rich fluids generated within and expelled from the lacustrine marshes. These interpretations of the paleo-geography, paleoclimate, and geochemical conditions allow for the reconstruction of depositional systems that contain lakes and marshes and thus belts of channel sandstones likely to contain ore bodies, as well as unfavorable fluvial channel systems that contain no ore bodies.

Sandstone-Hosted Uranium Deposits of the Huemul District, Neuquen Basin, Argentina as a New Uranium Deposit Model for the Western United States

Jon P. Thorson[1] & Guillermo P. Pensado[2]: [1]Consulting Geologist, Parker, CO, [2]Calypso Uranium Corp.

The Neuquen Basin of Argentina and its sandstone-hosted uranium deposits resemble the uranium basins of the western United States in several ways. The basin is largely filled with continental fluvial and red beds sediments, and the uranium deposits are hosted in porous and permeable sandstone or conglomerate bodies where the uranium and associated metals have been deposited through reduction by carbonaceous material.

In Argentine deposits, three uranium source models may be inferred based on metals, trace elements and REE present with the mineralization. The first model is generated by meteoric waters descending trough uraniferous sediments, which release uranium when oxidized. Uranium is deposited downward or laterally where waters find a reductant agent such us organic material. The deposits that fit this model are characteristically uranium-only occurrences.

A second type may be related to oil generation, where source rock black shales release metals such as copper, cobalt, nickel, silver, vanadium and uranium from sandstone or shale during maturation of organic matter. Diagenetic chlorine-rich solutions migrate laterally and upwards through high permeability rocks following faults and paleo-channels that are altered and bleached. Uranium precipitates at redox fronts containing organic or hydrocarbon material. This paragenesis is more complex and may result in uranium-vanadium (±copper, silver) deposits or copper (±uranium, vanadium, silver, cobalt, nickel) deposits.

The third model applies to basins that have developed an anomalously high geothermal gradient where intra-basin fluids were heated over 200ºC. Rare earth-bearing minerals like monazite, $(Ce,La,Nd,Th)PO_4$ are leached of metals and REE at elevated temperatures and contribute a unique geochemical signature to the basinal fluids. The movements of REE- and multimetal-rich solutions are similar to the model presented above, upward and laterally, until they find a redox barrier. The mineral paragenesis and REE content of uranium deposits in the Huemul district indicate an origin from these deep basinal fluids. The host rocks, however, are bitumen impregnated sandstone and conglomerate in breached petroleum reservoirs.

The association of petroleum related fluids with uranium deposits in the western US has been described in south Texas and Gas Hills, Wyoming. On the San Rafael Swell, Utah, uranium deposits are commonly associated with bitumen at Temple Mountain and other mines. A drill intercept of uranium with bitumen in the dune sand facies of the Permian Cutler Fm at Lisbon Valley, Utah suggests that uranium replacing bitumen reductant may be more common than previously described and may be a new model to be considered in the western US.

The Grants Uranium District: Source and Deposition

Virginia T. McLemore: New Mexico Bureau of Geology and Mineral Resources- New Mexico Institute of Mining and Technology

More than 340 million lbs of U_3O_8 have been produced from the Grants deposits 1948-2002 and it is estimated that at least 560 million pounds of uranium remain in the ground as resources. Thus, the Grants district contained more than 900 million pounds of uranium, making it one of the largest uranium provinces in the world. The Grants district is one large district in the San Juan Basin, extending from east of Laguna to west of Gallup and consists of eight subdistricts. Although, several studies have examined the source of this uranium, most geologists are concerned with locating additional deposits. The source of uranium is important in understanding how the Grants deposits formed and locating additional uranium provinces elsewhere in the world. A granitic highland, enriched in uranium lies south of the district. The Zuni Mountains area is known for high heat flow (2-2.5 HFU; Reiter et al., 1975) and Precambrian granites in the Zuni Mountains contain as much as 11 ppm (Brookins, 1978), thereby suggesting that the Precambrian granites in the vicinity of the Zuni Mountains could have been a local source. Other researchers have suggested that Jurassic arc volcanism southwest of the San Juan Basin was the source the Grants uranium. It is likely that uranium was leached from both the Jurassic arc volcanic terrain and the Precambrian granites and these waters migrated into the San Juan Basin. These waters likely could have mixed with uranium being leached from the volcanic ash that covered much of the San Juan Basin during Brushy Basin times, as suggested by Turner-Peterson (1986; Turner-Peterson and Fishman, 1986). The uraniferous ground water migrated into the Westwater Canyon sandstones and precipitated in the vicinity of humate and locally other organic material to form the primary-uranium deposits. Subsequent oxidation and re-mobilization during the late Cretaceous or mid-Tertiary formed the redistributed-deposits (roll-front, stack ore). Uranium from different sources actually will help in understanding the complexity and local differences within the primary-uranium deposits in the district, which then had a major impact on the remobilization and redistribution of uranium to form the redistributed deposits.

Tectonics, Basin Development and Uranium Episodes: Similarities and Differences Among Four Canadian Proterozoic Settings

Jefferson, C.W., Davis, W., Ramaekers, P., Rainbird, R., Bosman, S., Chamberlain, K, Peterson, T. & Bleeker, W.: Natural Resources

Prospective intracontinental basins developed 100 to >400 million years before local tectonic adjustments mobilized and precipitated uranium during the Proterozoic. Low-temperature hydrothermal alteration pervaded these basins, and regional layer-parallel flow has been modeled between hypothetical diagenetic aquitards, supported by some diagenetic features. Nevertheless, deposit-specific alteration is most obviously associated with fault systems that were active before, during and after deposition of multiple, unconformity-bound, fluvial sequences. Reactivated steep faults, lateral thickness and facies changes, and basement uplifts clearly enhanced the vertical components of fluid flow, redox and alteration. Telltale uraniferous phosphate cements formed at a range of sites just before uraninite deposition was focused where certain reactivated structures intersected geochemically favourable basement rocks, mafic dykes with contact metasomatic effects in sandstone, or stratigraphic facies changes. Such structural and temporal coincidences provide unique vectors and events for exploring each basin.

The largest highest grade deposits and potential are unchallenged in the Athabasca Basin, but at least three other basins offer viable potential. The **Athabasca Basin** was initiated ~1750 Ma with its fourth sequence still accumulating after 1541 +/- 13 Ma (Re-Os isochron on oil shale)., Local tectonic rejuvenation generated a regional angular unconformity between sequences 2 and 3 that is constrained by basin-transecting uranium-bearing fluorapatite cement (U-Pb ~1640 to 1610 Ma), and felsic tuff above (U-Pb 1644 +/- 13 Ma) that unconformity. Pre-ore hydrothermal minerals near the basal unconformity were formed ~1670-1620 Ma. The principal uraninite ore deposits have so far yielded U-Pb ages as old as 1600-1500 Ma. Newly dated uraniferous fluorapatite in **Thelon Basin** (U-Pb 1667 ± 6 Ma) formed about 80 million years after basin initiation (<1750 Ma) and prior to similar Athabasca cements. Thelon apatite has yet to be linked temporally to

regional unconformities or uraninite, but is found in at least the lower two sequences, predates the Kuungmi shoshonite flows (U-Pb 1540 ± 30 Ma), and occupies a range of sites including altered basement, basal silicified breccia and higher soft-sediment faults. Brittle fault arrays are associated with basin margins, and with unconformity uranium deposits hosted by Archean or Paleoproterozoic strata and/or 1750 Ma granitic complexes. In **Otish Basin** >440 million years separated basin initiation (U-Pb >2170 Ma,) from alteration (K-Ar and Sm-Nd 1730 Ma) associated with uranium deposits along fault offsets of the basal unconformity and northerly trending mafic dykes. In **"Hornby Bay Basin"** more than 450 million years, dramatic basin reorganization and volcanism at 1667 ± 8 Ma separated initiation of detrital sedimentation (<1750 Ma) from deposition of the uranium host sandstone that contains local xenotime cement (U-Pb 1284 ± 11 Ma) in corrosive contact with detrital quartz and early quartz cement. Fluorapatite then cemented lower strata (U-Pb 1160 ± 80 Ma), not long before uraninite was disseminated in sandstone (U-Pb 1050 ± 50 Ma). Here the ore trap was an overlying carbonaceous unit within a graben superimposed on an older horst. In summary, each basin has its own structural, lithologic and temporal coincidences to better quantify for exploration.

Cenozoic Uraniferous Geothermal Systems and Biogenic Uraninite from the Sierra Peña Blanca, Mexico

Samuel Angiboust[1,2], Mostafa Fayek[2], Alfredo Camacho[2], George Calas[3] : [1]Laboratoire de Tectonique, Université Pierre et Marie Curie, [2]Department of Geological Sciences, University of Manitoba, & [3]Institut de Minéralogie et de Physique des Milieux Condensés, Université Pierre et Marie Curie

The U.S. Department of Energy (DOE) has incorporated the study of natural analogues into the Yucca Mountain Project (YMP) to provide additional ways of testing process models that support the Yucca Mountain total system performance assessment (TSPA). The Peña Blanca uranium district is located approximately 50 km north of the city of Chihuahua, Mexico and within a similar climate and geologic environment that hosts the Yucca Mountain site. Therefore, many researchers recognized the similarities between the Peña Blanca uranium district in particular the Nopal I uranium deposit and Yucca Mountain more than a decade ago.

There are numerous uranium occurrences and 105 airborne anomalies within the Peña Blanca uranium district. For over thirty years (1960 to 1990's) the Instituto Nacional de Energia Nuclear (INEN) and Uranio Mexicano (URAMEX) explored and exploited the Sierra Peña Blanca district. Many studies over the past 30 years have focused on the chronology of the host volcanic rocks, genetic and tectonic models, and radionuclide transport in the unsaturated zone (UZ). Despite these numerous studies of the Nopal I uranium deposit and the Peña Blanca uranium district, the genesis of the uranium mineralization and its association with the tectonic and geologic history of the Peña Blanca district remains poorly constrained and controversial. The fluid evolution of these deposits is complex and several models for the formation of these deposits have been proposed. In particular, it has been difficult to constrain the timing of interaction between U-rich minerals and post-depositional fluids because the uranium minerals associated with these deposits, in particular uraninite, are fine grained (~1-100 □m). These problems are further magnified by the susceptibility of uraninite to alteration and radiation damage and by the tendency for the effects from these processes to be manifested at the micrometer scale. To effectively use the uranium deposits of the Peña Blanca district as natural analogues to test process models that support the Yucca Mountain total system performance assessment (TSPA), a unifying genetic and post-depositional model that includes the tectonic activity is required.

Here we present a new genetic model that incorporates both geochemical characteristics as well as structural and tectonic features of the deposits, the region, and one of the few documented cases of a geochemical signature of biogenic uranium mineralization. Four major tectono-magmatic fault and fracture systems were identified. Uranium occurrences and deposits are associated with breccia zones at the intersection of two or more fault systems. Periodic reactivation of these structures associated with Basin and Range and Rio Grande tectonic events resulted in the mobilization of U and other elements by fluids associated with geothermal activity. Focussed along breccia zones, these fluids precipitated several generations of pyrite and uraninite together with kaolinite. Very low $\delta^{34}S$ values (~ -24.5 ‰) of pyrites intimately associated with uraninite suggest that both minerals were biogenically precipitated. These data show that tectonism and microbial activity can play a major role in the formation and remobilization of uranium in near surface environments.

Uranium General Interest

Session B – Tuesday AM, May 12, 2009

More than Just Compliance Using NI 43-101-Compliant Feasibility Studies as Strategic Management Tools

D.H. Graves, P.E. & M.J. Yovich, P.E.: TREC, Inc.

Preliminary Assessments (PA), Pre-Feasibility Studies (PFS) and/or Feasibility Studies (FS) are required by National Instrument 43-101 in conjunction with public disclosure of the efficacy or statement of reserve quantities for uranium development projects. Additionally, and possibly as important, the PA, PFS or FS can be very useful tools for mine company managers to evaluate and monitor strategic planning and performance of a mine project from relatively early stages of development through production.

NI-43-101-compliance requires detailed evaluation of both the technical and financial feasibility of a mine project. This requires development and detailed evaluation of the project including "pounds in the ground," amenability to proposed mining methods, permitting

potential, schedules, preliminary facility design and cost, restoration requirements, labor requirements, royalty and tax consequences, capital investment requirements and other relevant specifics. These same evaluations can be invaluable to mining companies for planning and tracking individual mine projects.

This presentation will discuss the practical application of PAs, PFSs and FSs for, not only the benefits that can be realized from positive public disclosure, but the internal project management benefits for strategic planning, resource allocation, critical path scheduling and procurement, establishing baseline project performance criteria, key performance indicators, project budget development or budget confirmation. The presentation will also provide a brief overview of the content and sensitivities of the analyses.

Applying International Environmental Standards for Uranium Projects, such as ISO 14001 and Environmental Management Systems

Ronda L. Sandquist, Esq. & Kristi J. Livedalen, Esq.: Jackson Kelly PLLC

Uranium projects attract scrutiny internationally for environmental compliance. First, there is a need to address site-specific environmental matters such as water quality, waste management, and air quality. Second, uranium projects are frequently owned and/or operated by multi-national companies which must satisfy the environmental requirements of customers and shareholders from different countries. ISO 14001 sets forth various environmental protocols for companies and environmental management systems outline an adaptive process for industry – specific environmental management. This presentation will address how ISO 14001 can be used to structure an environmental compliance program for uranium operators, and the benefits (and pitfalls) of ISO 14001. We will also discuss whether an environmental management system may be necessary, in conjunction with ISO 14001 and guidelines for uranium/environmental management systems. Approaching the environmental issues for uranium projects from an international perspective will provide consistent approaches to similar issues notwithstanding the situs of the project, and facilitate improved corporate oversight.

Some Other Things to Think About – Part Two

Lawrence R. Jacobi, Jr., P.E., J.D.: Jacobi Consulting

This is an update on a paper, "Some Other Things to Think About," that was presented at the U2007 Global Uranium Symposium in Corpus Christi, Texas in May 2007 and the Canadian Uranium Symposium in Vancouver BC in April 2008. The paper discusses a simple method for developing a media plan that considers the message, the messenger, the audience, and methods for gauging success of the plan. The importance of a concise campaign statement and public opinion polling are explored. Practical considerations such as resources and budgeting for a media plan are discussed.

This revised presentation is a primer for engineers, scientists, geologists and miners that extends the discussion of media planning to incorporate such things as social networking, blogging, tweeting, file and video sharing, text messaging, wikis and podcasting. In an age where traditional print and electronic media are fast losing ground to Internet-based and interactive communications, a working knowledge of web- and mobile-based communications is essential. The paper discusses in a very broad way the new avenues for getting your message out to a wider audience.

As public opinion on uranium mining and milling becomes more important to the eventual success of a mining project, communicating with stakeholders, including the media, becomes more critical. This presentation is intended to give the audience "some other things to think about."

Colorado Water Rights for the Uranium Industry-Options, Challenges, and Solutions

Robinson, G.M.L. & Frank Hagar: R^2 Incorporated

Demand for water in Colorado is dramatically increasing with the nation's desire to become energy independent. For example, in Colorado, the call for water has been raised to support uranium mine and oil shale development, nuclear power plants, coal-to-liquids facilities, and biofuels. Not assessing or acquiring water during the mine engineering feasibility assessment can be—and, in some instances, is—a project "fatal flaw." The State of Colorado administers the appropriation doctrine, "First in time, first in right," wherein prior water uses have seniority to new demands. New demands on existing supplies require the mine operator to acquire or supply a water source through a plan of augmentation. This allows junior water rights to divert water out of priority, as long as new water is added to the system in sufficient quantities at the proper time and place, to prevent material damage to senior water rights.

The development of a sustainable water supply requires a comprehensive understanding of depletion factors (evaporation, consumption, sanitation, land application, deep well disposal, and processing) and the available sources (tributary, non-tributary, direct surface flows, reservoirs and transbasin, augmentation wells, and recharge wells and basins). Utilizing a proactive approach and sound engineering, an economically desirable and reliable water resource augmentation plan can be approved to support project requirements.

In-Situ Uranium Mining Well Field Design Considerations

S.C. Way, Ph.D., P.E.: In-Situ, Inc.

Production from uranium mines supplies 64 percent of the current nuclear power utility requirements (World Nuclear Association, July 2008). To sustain current and future uranium demands, world mine production must expand. While increasing mine production will feed the requirements of civil and industrial sectors, the potential for contaminating groundwater supplies and local ecosystems must be addressed.

In 1990, 55 percent of world's uranium production came from conventional mining operations, but by 1999 the volume had decreased significantly to 33 percent (WNA, July 2008). Conventional mining methods produce tailings, run-off, and significant land disturbance—all requiring significant rehabilitation. With in-situ leach mining methods, disturbance is reduced because only multiple boreholes are drilled for recovery. Rehabilitation is much simpler, resulting in the steady increase of in-situ uranium mining operations.

Other than a site's uranium reserves, hydrologic characterization of the formation is probably the most important consideration in studying the economic feasibility of an in-situ uranium mining operation. Once characterization is complete, engineers need to address three major aspects in order to increase the economic feasibility of the operation and to minimize the associated environmental effects. These key steps include recovery process design, well field design, and monitoring program. The recovery process design influences how efficiently the minerals can be recovered and minimizes the time and cost to complete the recovery. A proper well field pattern with the optimum areal sweep efficiency reduces costs and duration of the operation, provides better control of lixiviant flow, and minimizes the area of potential leakage. Lastly, a groundwater monitoring program provides baseline data and detects potential leakage from the site. This paper will discuss these topics in detail.

Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain

Susan M. Hall: U.S. Geological Survey

The Texas Commission on Environmental Quality (TCEQ) has permitted 38 in-situ recovery (ISR) uranium mines, of which four are currently active and two are proposed. The remaining mines have been or are being restored using techniques such as ground-water sweeping and reinjection of reverse osmosis treated water. Restoration standards for ground-water chemistry from 80 production authorization areas (PAAs) representing 26 mines were compiled by TCEQ as part of their efforts to track groundwater restoration at these mines. These data are being analyzed by the U.S. Geological Survey as part of a nationwide study focused on characterizing groundwater in uranium ISR operations.

The U.S. Geological Survey compared baseline and post-restoration groundwater target restoration values set by the TCEQ to primary drinking water maximum contaminant levels (MCLs) set by both the U.S. Environmental Protection Agency (USEPA) and TCEQ and secondary drinking water standards. Primary MCLs are based on adverse health impacts to humans and are legally enforceable. Secondary standards are non-enforceable guidelines and regulate contaminants that affect aesthetic water quality or cause cosmetic effects such as skin or tooth discoloration.

All primary MCLs are exceeded in baseline water samples in some PAAs and radium is exceeded in all PAAs, precluding groundwater in these areas from use as untreated drinking water. Amended restoration tables are available for 26 PAA's, and of these final sample values are available for 13 PAA's. Post-restoration amended targets for arsenic, mercury, selenium and uranium exceed MCLs in more fields after mining, and fewer fields exceeded cadmium, lead and nitrate MCLs. Secondary standards sulfate, total dissolved solids, iron and manganese increased in post-mining amended targets, whereas sulfate standards were exceeded in fewer instances. When compared with baseline water chemistry, amended restoration targets indicate higher concentrations of calcium, manganese, sodium, potassium, bicarbonate, silica, conductivity, alkalinity, molybdenum, and ammonia. Post-restoration final sample values for 13 PAA's show a pattern of increasing uranium, molybdenum, ammonia, alkalinity, sulfate, magnesium and calcium in post-restoration groundwater, and declines in other elements although results varied with individual mines. Overall, post-restoration groundwater quality in Texas ISR facilities declined as compared with pre-mining baseline.

Groundwater Restoration Practices and Requirements for Uranium In-Situ Recovery Projects in the United States

Wayne W. Heili: Ur-Energy

U.S. based in-situ uranium recovery operations are well-positioned to generate an increasing share of the global uranium production. While the mining technique is commonly regarded as one of the most environmentally benign methods of producing uranium, the industry is under increasing public and regulatory scrutiny for its potential impacts to the local groundwater quality during and after recovery operations. This paper reviews the various state and federal groundwater restoration requirements while reviewing past-practices, results and best practicable technologies.

Coles Hill Uranium Deposit, Pittsylvania County, Virginia

Aylor, Joseph G. Jr.[1], Reynolds, Norm[1], Beard, James S[2], Bodnar, Robert J[3], Henika, William S[3]: [1]Virginia Uranium, Inc, [2]Virginia Museum of Natural History, & [3]Department of Geosciences, Virginia Tech

The Coles Hill uranium deposit (CHUP) in Pittsylvania County, Virginia, represents one of the largest undeveloped uranium occurrences in the United States. An estimated resource of 119 million pounds of U_3O_8 is in place with a cutoff of 0.025 wt% and an average grade of 0.06 wt%, which contains a high grade resource of 30 million pounds of U_3O_8 at an average grade of 0.22 wt%. The epigenetic deposit lies within the Paleozoic Smith River Allochthon Synclinorium of the western Piedmont Province and is hosted by the Ordovician Leatherwood Granite (440 Ma). Mineralization is younger than the granite and is localized within a strongly deformed zone proximal and bounded to the southeast by a normal fault contact (Chatham Fault). The Chatham Fault separates the granite from the sedimentary rocks of the Triassic Danville Basin. Deformation in and along the eastern margin of the host granite is complex and likely records the reactivation of a Paleozoic thrust/transpressional fault during Mesozoic normal faulting. An early ductile deformation in the granite is represented by overturned isoclinal folds, with an axial planar foliation striking N30E, dipping 45SE. These structures are overprinted by mylonites and brittle fractures, both of uncertain age. The host rocks are highly fractured at all scales, often associated with hematite and mineralization occurs along microfractures and as disseminations in the host rock. The age of the mineralization is not known.

The host rocks for the CHUP have experienced intense hydrothermal alteration. The rocks show silica depletion and strong sodium metasomatism that is characterized by early pervasive albitization and later albitization along fractures, joints and cleavages. Secondary apatite is common and much of the uranium mineralization occurs as uranium oxide (uraninite, pitchblende) or complex U, Th, Zr silicate minerals (coffinite) either included within or rimming apatite. Uranium is also found in association with Fe, Mg chlorites that are later than apatite and occur along joints and fissures that parallel the main foliation. Often chlorite + uranium joints are stylolitic and are associated with mylonitization. When found in association with chlorite, uranium minerals often rim or are included within titanium oxides. Uranium also occurs in association with carbonaceous material and barium minerals in small vugs and veinlets and also associated with epidote.

Uranium mineralization at CHUP is clearly epigenetic, but the source of the uranium is at present unknown. Possible sources include Leatherwood magmas, buried granitic plutons, and the adjacent Triassic Basin. Research currently in progress addresses the age and source(s) of the uranium at Coles Hill.

Beaverlodge Uranium District, Northern Saskatchewan, Canada – A New Look at an Old Camp by Red Rock Energy Inc.

R.A. Olson, S.L. Loutitt, B. Wing, S. Botterill, A. Melnik & J. Sciarra: Red Rock Energy Inc.

Beaverlodge Uranium District is in northern Saskatchewan near the northern shore of Lake Athabasca, centered on 59°34'N latitude, 108°37W longitude, about 720 km northeast of Edmonton, Alberta. From the 1950's to the 1970's the Uranium City area had a total population of a few thousand people. In 1982 the main mine closed and the population dwindled to about 100 permanent residents. Nonetheless, local infrastructure, including power, water and sewage is available, including many houses suitable for occupancy. The Beaverlodge Uranium District was visited by Alcock of the Geological Survey of Canada in 1936 who reported two pitchblende showings. The Canadian Crown Corporation Eldorado Nuclear sent two prospectors, Phil St. Louis and Einar Larum, to the area in 1946. During the course of their fieldwork they found a 3 m long radioactive fracture zone that subsequently resulted in the discovery of the important uranium orebodies of the Ace-Fay-Verna mine. Between the early 1950s and 1982, about 77.7 million pounds of uranium was produced from some 16 former mines which operated in the district, with the bulk of these pounds having been produced from the former Ace-Fay-Verna mine that occurs proximal to the St. Louis Fault.

The Beaverlodge District lies along a major northeasterly trending crustal suture between the predominantly Archean Rae province to the east and the Paleoproterozoic Taltson Orogen to the west. In general, the local geology comprises (a) emplacement of Archean granitoid basement rocks, (b) deposition of the Neoarchean or early Paleoproterozoic Murmac Bay Group, (c) at least two major thermotectonic events to upper amphibolites facies, coupled with emplacement of early to late Paleoproterozoic granitoid intrusions, (d) a late Paleoproterozoic brittle to brittle-ductile tectonic event that transposed all earlier structures into a predominantly northeasterly-trend and which included in part retrograde chlorite-zone metamorphism, (e) deposition of the ca. 1.80 Ga Martin Group red-bed sequence with subordinate basaltic volcanic rocks, (f) deformation of the Martin Group, but with little metamorphic overprinting, and finally (g) deposition of the ca. 1.75 Ga relatively flat-lying Athabasca Group which now exists to the south.

In the past the Beaverlodge District uranium deposits were postulated to be classic hydrothermal vein systems, related to late brittle structures and possibly to granitoid intrusions. However, the majority of the uranium in the Beaverlodge District, based on limited and now somewhat old age dating, was deposited about 1.78±0.2 Ga; that is, at or shortly after deposition of the Martin Group. As a result of these dates and the recognition of the unconformity style uranium deposits associated with the Athabasca Basin in Saskatchewan and in Kombolgie Sandstone in

northern Australia, the genetic uranium deposit model has changed. That is, it has been suggested the uranium deposits in the Beaverlodge District are both spatially and perhaps genetically associated with the basal unconformity beneath the Martin Group.

Red Rock Energy's properties at the Crackingstone Peninsula encompass five small former producing underground or open pit mines, some of which closed with reported in-ground reserves or resources. Red Rock's focus is to give a 'new look' to this old historic camp and thus to build uranium resources to revitalize this historically important uranium district.

Exploration and Discovery of Blind Breccia Pipes and the Potential Significance to the Uranium Endowment of the Arizona Strip District, Northern Arizona

Eugene D. Spiering, Patrick D. Hillard, & Joseph R. Inman: Quaterra Resources Inc.

In April 2008, Quaterra Resources announced the discovery of uranium mineralization in a blind breccia pipe on the A-1 geophysical target. Hole A-01-31 intercepted a thickness of 57 feet averaging 0.33% U_3O_8 in a mineralized collapse structure at a depth of 1,034 feet. The A-1 pipe structure has no vertical collapse evident within 400 feet of the surface. The discovery resulted from holes testing the first of more than 200 anomalies identified by an airborne time domain electro-magnetic (VTEM) geophysical survey. Two months later, the first hole targeting A-20, the second VTEM anomaly to be tested, discovered another mineralized breccia pipe. The A-1 discovery and the geophysical technology used to identify it could have a significant impact on the production potential of the district.

Most breccia pipes with structures visible at the surface in northern Arizona have been found by past exploration. The total amount of mineable uranium discovered to date is estimated to be in the range of 40 million pounds eU_3O_8. Approximately one sixth of this total (7 million pounds) was mined from Hack 2; a single blind pipe discovered by tracing alteration in the Coconino Sandstone near the Hermit Shale contact along the walls of Hack Canyon by Western Nuclear in 1979.

Hack 2 represented the only blind pipe ever found in the Arizona Strip until Quaterra's discovery of the A-1 pipe. However, blind pipes may be the most numerous type of mineralized structures in the district. The USGS Open File Report (OFR-89-550) shows the mapped locations of 1,296 pipes in northwestern Arizona. Carboniferous strata exposed in the deeper canyons of the region have the highest density of pipes with approximately 3 pipes per 10 square miles. The number of outcropping pipes decreases dramatically below the cover of successive layers of Permian sediments until fewer than 2 pipes are evident over an area of 500 square miles in the lower Triassic section. The upper level of stoping by collapse varies and many pipes occur at depth with no surface evidence of a pipe throat. If these structures penetrate the Coconino Sandstone in a favorable area of the district, a blind orebody can exist with no pipe structure at the surface. The number of pipes identified to date could represent only a small fraction of the total number of mineralized blind pipes that lie waiting to be discovered at depth.

A 1987 USGS study (Circular 1051) calculated a mean endowment of 112.4 tons eU3O8 per square mile for the Arizona Strip district. The 1,670 square miles of public lands remaining open to uranium exploration in the district has an estimated total mean endowment of 187,690 tons (375 million pounds) eU3O8 representing a potential energy equivalence of 13 billion barrels of oil. With modern airborne and down-hole time domain EM geophysical surveys applied to the search for blind breccia pipe orebodies, the Arizona Strip may one day become one of the most important uranium and energy producing districts in the US.

Uranium Exploration Targets in the Overlooked and Under-Explored Nebraska Panhandle

Steven S. Sibray: Nebraska Geological Survey, University of Nebraska

The discovery of the Crow Butte uranium deposit [$U_3O_8 \geq 25$ million pounds, ≥ 0.25 percent] was announced January 13, 1981. The additional exploration activity sparked by this discovery was short-lived due to the continuing decline in the price of uranium. Despite the continuous ISL mining of uranium at Crow Butte since 1991, only one company, Cameco, is exploring for uranium in Nebraska. The Nebraska Panhandle is arguably one of the most overlooked and under-explored uranium provinces in the US.

The stratigraphy of the White River Group (WRG) in Nebraska and South Dakota has been recently revised based on new studies of lithostratigraphic units and sequence bounding paleosols. The new stratigraphic model can be used to reconstruct the paleohydrogeology of the WRG and aid in the exploration for uranium. Uranium at the Crow Butte deposit occurs in the basal sandstone of the Chamberlain Pass Formation (CPF).

The CPF consists of a basal white to greenish white sandstone composed of coarse grains of quartz, quartzite, and chert. Extensive chemical weathering including the removal iron and kaolinization give the sandstone a "bleached" appearance. The sandstone thickness varies from 0 to 350 feet and unconformably overlies the Cretaceous Pierre Shale or the Yellow Mounds Paleosol. The uppermost part of the CPF is bright red Interior Paleosol Series and the laterally equivalent light green Weta Paleosol Series. Unconformably overlying the CPF is the Chadron Formation which consists of bluish green mudstones, thin, interbedded lacustrine limestone beds and localized channel sandstone deposits. The Chadron Formation sandstones are arkosic, contain granitic rock fragments and more weatherable minerals than the CPF. Differentiation of the two sandstones is likely a critical factor in exploring for uranium.

There are a number of potential exploration plays outside of the known mineralized area of the Crawford Basin. The tuffaceous WRG rocks

have long been considered the source of uranium in the Tertiary basins of Wyoming. The initial uranium mineralization probably occurred during the development of the Interior-Weta Paleosol Series at the CPF-Chadron Formation unconformity. Although the overlaying Chadron Formation bentonitic mudstones might be considered a source of uranium, evidence from paleohydrogeology [tufas, lacustrine limestone, reducing paleosols] suggests that groundwater table was high and groundwater discharge was largely local. In contrast, groundwater during the development of the Interior-Weta Paleosol Series was largely oxidizing and groundwater flow was downward into the underlying aquifers [CPF and older units]. Exploration efforts in Nebraska should be the directed to permeable formations underlying the Interior-Weta Paleosol Series. There are a number of areas in the Nebraska Panhandle where permeable Cretaceous rocks are directly overlain by the WRG. Outside of the Crawford Basin, the CPF is present in several paleovalleys that have seen only little or no exploration activity.

Black Shale Source for Uranium in the Paradox Basin

C.A. Wallace[1] & J.P. Thorson[2]: [1]Wallace Consulting International, Inc. & [2]Consulting Geologist, Parker, CO

During the 1950's, a vigorous dialogue began about the source and deposition of uranium minerals as new deposits were discovered on the Colorado Plateau. Central to the debate was whether the fluid that transported uranium was reduced or oxidized.

Uranium occurs in the uranyl (+6) valence state (oxidized) or the uranous (+4) state (reduced) and can be transported in brine by forming coordination compounds. Uranium that occurs in reduced, oil-generating source rocks (commonly black shale) is in the uranous state. Carboxylic acids can form soluble uranous dicarboxylate and tricarboxylate as stable coordination compounds in a reduced medium. Some other organic compounds that bond with uranous atoms are asphaltenes and naphthenic acids because both contain carboxyl groups. Porphyrins begin to form at about 25°C in nonconsolidated sediment and incomplete porphyrin structures form strong bonds between nitrogen groups and uranous ions.

Fundamental to transport of uranium in reduced, warm, saline, formation fluids expelled from black shale in subsiding sedimentary basins are the following observations:

1. U^{+4} (uranous) and U^{+6} (uranyl) valence states are soluble in aqueous solutions, whereas U^{+3} and U^{+5} are slightly soluble. U^{+5} decomposes in aqueous media into compounds that contain U^{+4} and U^{+6}.
2. U^{+4} forms SO_4 coordination compounds $U(SO_4)_4^{-4}$ and $U(SO_4)_3^{-2}$ in high concentrations of SO_4^{-2}.
3. U^{+4} forms Cl^- and Br^- coordination compounds. UCl^{+3} and UBr^{+3} form weaker coordination compounds than $U(SO_4)_4^{-4}$ and $U(SO_4)_3^{-2}$.
4. U^{+4} forms much stronger coordination compounds than U^{+6} as UO_2^{+2}.
5. Organic molecules form coordination compounds of uranium.
6. The uranyl state can be reduced to the uranous state in a brine: $UO_2^{+2} + [H] \rightarrow U^{+4} + Cl^- \rightarrow UCl^{+3}$ (soluble in warm brine).
7. Alternatively, the uranous state can be oxidized to the uranyl state: $2U^{+4} + 2H_2O + O_2 \rightarrow 2UO_2^{+2} + 4H^{+1}$. This reaction is slow at 60-100ºC, but the rate of oxidation is increased by presence of small amounts of Cu^{+2} or Fe^{+3}.
8. Uraninite is composed of 80% U_3O_8 ($[2UO_3][UO_2]$). Uraninite contains uranous and uranyl atoms in a range of ratios of U^{+4}:U^{+6} between 1:1.22 and 1:2.58. Frondel (1958) attributed the presence of the uranyl atom in uraninite to "secondary" oxidation of original uranous atoms. Alternatively, one uranyl atom can be reduced to one uranous atom in the presence of approximately two uranyl atoms to precipitate uraninite.

In the Paradox Basin, reduced shale in the Paradox Formation contains gamma-ray spikes that commonly range between 200 and 600 API units (about 33 to 100 ppm uranium). These concentrations represent uranium that was <u>not</u> flushed from shale into low temperature, reduced brine. Uranium atoms and coordination compounds have large radii, and they were flushed from black shale when permeability was high during the petroleum and brine generation event. Reduced brine that contained uranium coordination compounds migrated through aquifers with hydrocarbons, and the brine was expelled upward into an oxidizing environment where redox reactions precipitated uraninite. The reduced brine model for uranium transport opens new terrain for uranium exploration in oil-producing basins.

Mineralogy and Leaching Behaviour of Selected ISR Ores

G.W. Heinrich, R.J. De Klerk, L. Reimann & Ed Lam: Cameco

The evaluation of ore from in situ recovery operations (ISR)at Cameco involves detailed qualitative and quantitative mineralogical characterization as well as laboratory based experimentation to establish leaching behaviour via pressurized bottle roll and column leach tests. The characterization techniques employed include elemental analysis, porosity measurements, optical and scanning electron microscopy and quantitative X-ray diffractometry for mineralogical characterization. As follow-up on bottle roll testing, column leach tests were carried out with solution recirculation via ion exchange columns to provide a complete simulation of an ISR process. Based on evaluation of selected examples, variations in mineralogical and ISR characteristics between and within individual deposits have been observed. The ores discussed consisted of arkosic sandstones and siltstones with variable contents of clay and carbonaceous matter and contained uranium in the range of 700 to 2,600 ppm. The most common uranium mineral encountered was a phosphorous bearing calcium-uranium silicate, interpreted as uranophane, although uraninite, coffinite and autunite were also present in various amounts. It was found that the ore characteristics could change as much within a deposit as it did between individual deposits for both, mineralogy and leaching behaviour. The final uranium recoveries obtained varied between 70% and over 90%. Data on the leaching of impurities and of the effects of mineralogical characteristics are discussed.

Role of Geochemistry in the Search for Uranium

Samuel B. Romberger: Colorado School of Mines

The understanding of the geochemistry of uranium in natural aqueous systems is paramount in the design of exploration models for economically recoverable deposits. This understanding should consider: 1) the mechanisms of uranium transport and deposition, and thus the petrogenesis of the deposits; 2) alteration assemblages typical of various types of deposits and important in field recognition of mineralization; and 3) the hydromorphic dispersion of uranium and associated elements during secondary processes, the interpretation of which is the focus of geochemical exploration. Characteristics that complicate the interpretation of geochemical and radiometric data for uranium deposits include: 1) variable oxidation state of uranium; 2) the variety of aqueous species possible; 3) the tendency for soluble uranium to adsorb onto various oxides and clays; and 4) the contrasting behavior of uranium and decay products in the secondary environment. Therefore, Eh, pH and fluid composition are important parameters in geochemical exploration programs. Additionally, the type of deposit targeted will also be important in the interpretation of geochemical data.

Depending on type, uranium deposits exhibit characteristic primary alteration and trace element zoning patterns, the latter commonly including, but are not limited, to elements exhibiting changes in oxidation state, such as vanadium, selenium, molybdenum, arsenic, cobalt, and nickel. Analytical data including anomalous amounts of more than one of these elements showing consistent spatial patterns may be useful in determining the type of deposit and the nature of dispersion. Alteration assemblages may include primary chlorite, illite, and/or kaolinite, and various primary and secondary iron oxides, carbonates, and sulfides, and clays of contrasting origin. Lithologic geochemical surveys rely on an understanding of these patterns to vector towards uranium deposits. The interpretation of hydromorphic geochemical surveys, including lake and stream sediment, and soil, depends on the mobility of uranium and associated elements in the surface and near surface environment. The interpretation of radiometric surveys is affected by the degree of disequilibrium between uranium and decay products, which, in turn, depends on the relative mobility of parent and daughter nuclides and their half lives, such as radium, radon, bismuth and lead. Therefore, relying on total gamma eU determinations for estimation of uranium concentrations may be suspect.

The design of a viable geochemical exploration program must include local background and threshold studies, particularly in areas where known uranium geochemical provinces occur. Geochemical surveys should not be used alone, but in conjunction with detailed geology, including primary lithology, alteration zoning and structure, both pre- and post-mineralization. In hydrologic systems fluid flow is important and structures commonly define pathways that control element distribution during both primary mineralization and secondary dispersion. Pathfinder elements may be useful if their distribution is more widespread than uranium, particularly in hydrothermal deposits. However, because of its high mobility in the oxidizing environment, uranium may exhibit a wider secondary dispersion than associated trace elements, and therefore it may be best to analyze for uranium directly.

Processing

Session B – Tuesday PM, May 12, 2009

Making Yellowcake "Green": Improving Uranium to Improve Conversion

Jim Graham: ConverDyn

The Nuclear Renaissance is real and vital to its success are the processes associated with the front end of the nuclear fuel cycle: mining, conversion, enrichment and fabrication. Specifically, building new facilities or expanding existing facilities to support the expected growth. However, responsibility must be taken to assure the expansions are "green" to meet global environmental objectives. The conversion industry is well aware of the challenges associated with such an endeavor, but are committed to using past experiences to accomplish said goals. In this paper, we will examine the processes currently being utilized in the industry. Discussions will focus on the current transport, ore quality and process requirements within the nuclear industry and the need for "green" processes when considering new builds or expanding existing facilities.

The Development of Solvent Extraction Process Plants for High Quality Yellow Cake Production

Alan Miller & Amir Yanai: Bateman Litwin

Bateman Litwin's Solvent Extraction (SX) unit is a part of the Group's Advanced Technologies Division. Bateman Litwin (BNLN) is dedicated to the development of innovative solvent extraction technology. It delivers projects from start to finish, covering preliminary customer requirement and definition stages, through research and feasibility studies to new plant construction or expansion of existing facilities, all covered by process guarantees and mechanical warrantees.

The Solvent Extraction unit's project services are backed by ongoing research and development on advanced solvent extraction systems and equipment, including patented reverse flow mixer settlers (RFMS) and proprietary Bateman Pulsed Columns (BPC). Bateman has designed and supplied two operating Uranium SX Plants and is presently in the process of delivering two new plants in Australia and South Africa.

Case study 1 : BNLN has developed a process flow sheet to successfully extract Uranium from the Pregnant Leach Solution at Kyzylkum , scrub impurities such as iron and strip off the Uranium salt from Alamine 336 using sodium carbonate solution to achieve a purified solution rich in Uranium. This strip liquor goes to a downstream peroxide precipitation process that has been simulated in the laboratory to achieve nuclear purity grade Yellow Cake.. The development of the process started in the UMP laboratory where the basic parameters for solvent extraction where established. Amongst others these were the aqueous to organic ratio , the concentration of Alamine 336 , the limits of extraction and scrubbing efficiencies and the kinetics of the SX chemistry. The next stage was the building of a pilot plant consisting of a Bateman Pulsed Column and mixer settlers. The extraction and stripping process was run continuously . The data collected enabled the establishment of design parameters for the industrial plant.

Based on the pilot plant data a preliminary design was made for a 1000 tpa SX industrial plant. The main SX equipment are BPC for Extraction and RFMS for Scrub and Stripping. In addition equipment is provided to ensure the prevention and recovery of organic solvent from the raffinate leaving the SX Plant. This protection ensures minimum impact of organic reaching the in-situ leach solution.

Case study 2: Traditionally Uranium SX plants have used ammonia solutions for stripping. There are typically four mixer settlers , each with a pH controller. The reduced acidity enables a profile of Uranium sodium salt concentration to be developed in each mixer as the Uranium is stripped of the Alamine 336 , while it is essential not to cause precipitation of Yellow Cake in the settlers. BNLN has successfully worked with a major South African mining company to run a BPC pilot with pH control along the length of the column . The stripping efficiency was above 99% and a stable pH profile was established that easily prevented precipitation. Based on the data collected from the pilot plant the investment in the industrial plant was estimated. The results indicate a potential savings of $US 200,000 relative to mixer settlers and considerable operating advantages to the process with BPC.

Practical Aspects of Application of Ion Exchange Resins for Uranium Extraction

Claude Gauthier[1], Dr. M. Mikhaylenko[2], & Steve Soldatek[1]: [1]The Purolite Company Bala Cynwyd, PA USA & [2]Purolite International Limited, Wales, UK

For many years, Purolite has supplied ion exchange resins to companies extracting natural uranium by different methods. These methods include uranium sorption from both acid and carbonate "clean" solutions and pulps.

This paper is an attempt to summarize technical data from various testing work performed both by Purolite and outside laboratories accumulated from experience and serving customer needs.Such questions are considered as:

- Choice of resin for different processes, which processes are varied by lixiviant type, sorption circuit design;
- Technical requirements for resins to be used in fixed bed, moving bed, 'Resin-in-Pulp' or 'Resin-in-Leach' circuits
- Rate of resin loss
- Resin fouling, etc.

The case histories presented are taken from both field and laboratory data and are designed to demonstrate the rapid advances that have been made in applications focusing on ion exchange resin performance.

The Application of Molecular Recognition Technology (MRT) for the Efficient Recovery and Purification of Uranium in Mine Process and Waste Streams

Steven R. Izatt, Neil E. Izatt, Ronald L. Bruening, & John B. Dale: IBC Advanced Technologies, Inc.

This paper reviews the application of Molecular Recognition Technology (MRT) separations technology in the recovery and purification of uranium from mine process, waste, and by-product streams generated in the uranium mining industry. MRT offers the ability to greatly simplify process flowsheets, and to efficiently separate and remove various significant and difficult impurities often present, such as iron and copper.

Resin Technology – Solutions for the 21st Century Uranium Industry

John Carr[1] & Mark Proudfoot[2]: [1]Clean TeQ Ltd & [2]Kemix Pty Ltd.

Resin-based flow sheets are attracting considerable interest due to the ability to make low grade ore bodies more economically viable and environmentally sound. Cost-effective flow sheets for uranium recovery are being developed due to renewed interest in nuclear power caused by growing energy demand and future greenhouse commitments. Major advances in ion exchange means that resin technology now has the potential to revolutionize a number of flow sheets in the mining industry. The potential of resin to replace solvent extraction or solid liquid separation from circuits has the potential to result in higher recoveries, lower lifecycle costs and a greatly reduced physical and environmental footprint.

Optimizing flow sheets using resin-based technologies requires an in-depth knowledge of the interdependency of resin and process. While there exists an understanding of individual unit processes, the integration of these to develop the optimal flow sheet is the focus of this presentation.

Clean TeQ and Kemix have assembled the critical mass of capability to provide a complete and economical solution resin based solution metal recovery.

To facilitate flow sheet development, the technology provider must understand and be able to provide competent assistance with:

- The full range of resin process solutions, this would include the selection of the most appropriate process methodology eg. cRIP, cRIL, Pumpcell carousel cFLX and cLX.
- The integration of both sorption and desorption unit processes.
- Resin selection based not only on loading capacity but obtaining the appropriate resin best suited to the specific process.
- Lifecycle support, from the initial metallurgical test work, conceptual and detail deign through to commissioning of a full scale operational backing.

PhosEnergy: New Age Extraction of Uranium from Phosphoric Acid

Bryn Jones: Uranium Equities Ltd.

PhosEnergy, a subsidiary of Uranium Equities limited has developed a novel and exciting new process for the extraction of uranium from Phosphoric Acid.

This new technology directly addresses the serious shortcomings of the processes used in the 1970's and 1980's. Specifically:

- The PhosEnergy process will operate at a significantly reduced operating cost.
- The PhosEnergy process will generate no process radioactive solid waste.
- The PhosEnergy process is simple and robust.

The PhosEnergy process could potentially facilitate economic extraction of up to 8, 500t U_3O_8 per annum of uranium production from phosphoric acid fertilizer streams. This paper will review current technology and provide the up to date status of the PhosEnergy process, with a review of the laboratory and pilot plant results.

Specifics of ISR Mining of Roll-Front Uranium Deposits in Russia

Solodov, I.N.: ARMZ

The ARMZ holds assets of Uranium-producing enterprises both in Russia and Kazakhstan. The five enterprises output Uranium by underground mining method, and another five enterprises do it by ISL method. There are two ISL mines in Russia. The most interesting from geological point are the Uranium deposits of Zauralsky area of Uranium ores, where the output is carried out by «Dalur» enterprise. These deposits belong to ancient ore objects formed at the frontal edges of the areas of ground stratal oxidation. As far as is known, such genetic type of deposits was not discovered in any other place. The epigenetic ores were formed into penetrable quartz-kaolinite sandy deposits. The age of ores is 135 MY. The ores are of low grade, 0,025 – 0,040 %, and they have experienced the secondary post-ore kaolinitization and reduction. The underground waters do not contain sulphates, but H_2S presents in. The reducing geochemical conditions are the predominant ones; Eh -173 mV. The uranium and the iron are completely reduced. Under such geochemical conditions, exploitation of the ore deposit by traditional vitriolic ISL method has low efficiency. Use of artificial oxidants makes possible to increase the Uranium concentration in the productive solutions on average of 20%.

Uranium Deposits Outside of the Americas/Geochemistry

Session A – Wednesday AM – May 13, 2009

Towards Quantitative In-Situ Gamma Ray Measurements: The Next Step in Radiometrics

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Gamma-ray measurements with scintillation detectors are routinely used in geophysical and environmental applications (Jones, 2001), perhaps most prominently in uranium exploration. In most cases the aim is to obtain an indication of the concentration of one or more of the natural occurring radionuclides (i.e. the ^{238}U and ^{232}Th series, and ^{40}K) in the medium faced by the detector system. In uranium prospecting the goal often is to find elevated uranium concentrations through airborne surveys or borehole logging. In oil and gas exploration gamma logs are often found to correlate with petrophysical parameters and are commonly used to relate depths of geological formations between boreholes. In situ gamma surveys are also used to monitor environmental pollution or to assess sediment transport. In many cases the results from gamma ray measurements are used *qualitatively* as an indicator of geological parameters. However, our vision is that gamma ray measurements can be used in the field as a geochemical tool to quantify geological parameters. To *quantify* these field measurements, i.e. to

translate the gamma spectra measured in the field into actual concentrations of nuclides in ppms or Bq/kg, a sound but tedious calibration of the detector system is needed.

Traditionally, gamma sensors are calibrated in a purely empirical way by placing the system in a calibration facility (e.g. a borehole, calibration pads) and measuring the response of the system. This method is only valid, if the activity concentration of the calibration facility is exactly known and if the geometry of the calibration facility exactly resembles the geometry and density of the application. Often, empirically determined correction factors are applied to the nuclide concentrations to correct for the varying field conditions (e.g. elevation in airborne surveys, borehole diameter in logging surveys, etc).

This paper presents a novel procedure in which detectors are calibrated against any given geometry and density that could be faced in the field measurements, without having to construct calibration sources for all these situations. This new procedure combines Monte Carlo simulations of detector response with a calibration measurement in a single dedicated set-up having well-known concentrations of radionuclides. This new calibration:

1. allows for an optimized spectrum analysis method including virtually all data present in a spectrum;
2. helps to optimise the design of gamma tools (e.g. to reduce the size and weight of airborne systems);
3. yields an improved understanding of measured gamma spectra.

The power of the new approach is demonstrated by two case studies. In the first study we will describe how the method allows for reduction of detector volume (and thereby weight) in airborne systems by at least a factor of 4, without loss of data quality. This reduction in weight opens new opportunities for small aircraft or unmanned "drone" gamma ray surveys. In the second study, we will highlight how the method can be used to accurately discriminate between concentrations of radon and ^{238}U measured inside a borehole. With this discrimination, the determination of a validated ^{238}U concentration within a deposit from in situ gamma spectra comes within reach.

Geology of the Kuriskova and Novoveska Huta Uranium deposits in Slovakia

Boris Bartalsky, Rich Eliason, Dusty Nicol, Latilsav Novotny & Ravi Sharma: Tournigan Energy Ltd.

The Western Carpathian Mountain Range of Eastern Europe is host to a number of uranium deposits. Within the range are the Kuriskova and Novoveska Huta uranium deposits that are currently being explored and developed by Tourningan Energy Ltd. A recent 43-101 report on the Kuriskova deposit lists an inventory of 6,570,000 pounds of Indicated resource at an average grade of .435% U308. There is an additional 30,131,000 pounds of Inferred resource at an average grade of .299% U308. The Novoveska Huta deposit is actively being explored and a 43-101 compliant report is expected in 2009.

The Kuriskova Uranium Deposit is located in the Kjsovska Hola region of the Volovec Hills which are a component of the Western Carpathian Range. The Carpathian Mountains are the result of the Variscan and Alpine multi-cyclic collisional orogenies that each produced calc- and sub-alkaline magmatism. The mountain range at Kuriskova is composed of mesozonal to epizonal metamorphic rocks known as the Gemericum tectonic unit of the Carpathian belt. There is a nearly continuous, 0.5 to 6.0 km wide and 80 km long zone of Permian rocks along the northern periphery of the tectonic unit in which there are numerous uranium occurrences.

From the study of historical artifacts it appears that ores in the Novoveska Huta area were exploited and smelted from primeval ages. The proof of this is represented by old scoria dumps and old mine adits excavated by curling-iron and hammer. This early production was from copper mining. More recent interest has focused on uranium.

The Novoveska Huta and surrounding area are part of the North Gemeric Syncline which belongs to the Gemericum tectonic unit. The deposit itself is hosted in folded and faulted Permian age rocks. Active exploration in the area continues and is extending the limits of known mineralization. Tournigan Energy Ltd. hopes to publish a 43-101 compliant resource early in 2009.

Uranium Resources in the Middle East

Abdelaty Salman[1], Philip Goodell[2], & Fares Howari[3]: [1]Nuclear Material Authority, Cairo, Egypt, [2]University of Texas, & [3]Jackson School of Geosciences, University of Texas

This work documents the uranium resource potentialities in the Middle East and North Africa (MENA) Countries. This region has an important strategic location, where it forms a part of North Africa and West Asia Continents. The Middle Eastern countries considered in this research include: Egypt, Iran, Iraq, Jordan, Saudi Arabia, Sudan, Syria, Turkey, UAE, Oman, Qatar, Kuwait and Yemen, while the North Africa countries include; Algeria, Libya, Morocco and Tunisia. This study integrated structural framework, the major geologic environments and the recognizing criteria for uranium deposits to predict some uranium-bearing provinces in the studied countries. The findings have been correlated with previous published works on current uranium deposits, for optimization.

The study found that the Pan African granites (about 600-500 Ma) are one of the most favorable environments to host vein type uranium deposits. This case is very clear in Algeria, Morocco, Egypt, Sudan, Saudi Arabia, Turkey, and other countries as well. The uranium mineralizations are hosted in these granites within some favorable structures as faults and fractures. The uranium minerals are mainly secondary (mainly uranophane) and occasionally some pitchblende and uraninites are present. They are associated with sulphide as pyrite,

chalcopyrite, galena, sphalerite and molybdenite. The gangues minerals are mainly iron and manganese oxides and fluorite. The most joined alteration features with this gangue are hematitization, silicification with black silica veins, carbonetization and presence of fluorite.

It is observed also the presence of intra-cratonic basins within many basement rocks exposures. Often theses basins are filled with late Proterozoic molasses type sediments such as Hammamat series in Egypt and can form important uranium traps according to their geochemical and geological characteristics. This feature is well known in many of the studied countries especially in Algeria, Egypt and Saudi Arabia. The present study also documented evidences on the presence of intra-cratonic basins filled with Paleozoic sequences; the lower horizons of these sequences are potential for hosting uranium resources. This was noticed in Libya (Morzok basin) and in Egypt as (Wadi El Kharite basin).

In the studied countries, volcanic rocks represented another potential source for uranium in many of the studied countries. These volcanic ranges in age from 74 to 302 MY and some of them hosting uranium or uranium/thorium mineralization. The Unconformity Uranium deposits could exist in some countries as Algeria and Egypt. Good potentialities were found in the Paleozoic rock sequences in many of the studied countries. In addition, surfacial uranium deposits were reported in Jordan nearby some uranium bearing phosphate deposits. Phosphorite belt at North Africa and Middle East can form additional non-conventional uranium resources for many of these countries. The black shales nearby the phosphorites can contribute to the uranium resources in many of these countries if they studied thoroughly. Other potentials and related evidences of uranium deposits in the MENA region are also summarized in this work with detailed with maps, data, coordinates, and analyses.

The Occurrence of Uranium in Karoo Series of Southern Africa

R.J.Bowell[1], P.Gleeson[2], J.Grogan[1], C.Large[3], P.Large[3] & A.Tunks[4]: [1]SRK Consulting, [2]SRK Consulting, [3]A-Cap Resources, & [4]A-Cap Resources

Uranium mineralization occurs sporadically throughout the Karoo rocks of Southern and Eastern Africa from central-southern Tanzania down through central Africa and into Botswana and South Africa. The occurrence of uranium reflects multiple conditions that occurred in the post Karoo basins in terms of:

- Palaeo-geomorphology of the Permian basin; the presence of uranium-bearing granites in the eroded highlands of Gondwanaland;
- Decreasing rates of sedimentation; lower but seasonal rainfall therefore deeper, more intense weathering of the source rocks;
- Suitable conditions for dissolution of primary uranium and precipitation of secondary uranium in the sediments.

These factors provided optimum conditions for leaching and dissolution of uranium in oxidizing environments, most likely as uranyl-carbonates, and subsequent precipitation associated with reducing zones in the sediments. Suitable reductive zones within the Karoo include anoxic layers in clay-rich argillic sediments; areas of decomposing vegetation where uranium is incorporated into humate complexes formed as a consequence of wood lignin breakdown and areas with high dissolved sulfide where uranyl minerals are closely associated with precipitation of sulfide minerals.

Uranium mineralization appears to have multiple phases in the Karoo with primary uranium mineralization occurring after deposition. Relative timing and shallow depth of this mineralization is limited by associated mineralogy and the presence of only partly decomposed plant material, precipitation of low temperature zeolite minerals and by the postulated maximum depth at which bacterial activity can occur. Clay mineral and zeolite alteration assemblages, sulfide formation and geochemical enrichment of elements such as As, Mo, sulfide, K, Rb and B are correlated to this mineralizing event.

During subsequent burial and digenetic processes these primary uranium zones were partially re-mobilized and in the presence of oxidizing carbonate-rich groundwaters, the uranium migrated along structural zones where secondary uranium deposits were formed in response to changes in redox and pH conditions. Re-dissolution and re-mobilization of the primary mineralization along zones of fracture permeability, primarily along faults propagated through the Karoo from the basin, resulted in the development of secondary uranium (VI) minerals in the near surface weathering environment. The uranium minerals are observed as fine powdery coatings on fracture surfaces in rock-types with a high fracture frequency (typically weathered mudstone), and can include complex assemblage of uranium species such as becquerelite, ferganite, francvillite, protasite, schoepite and tyuyamunite often associated with products of sulfide oxidation such as siderite and hematite. This second phase of mineralization occurred quite recently in geological history.

The most recent phase of Karoo associated uranium mineralization is the result of supergene remobilization and re-precipitation from the secondary and primary zones into surfical pedogenic and recent fluvial channel calcrete-gypcrete formations. The most dominant uranium phase observed in this style of mineralization is carnotite, although other phases such as fourmarierite, margarisitasite, uranocalcrite and tyuyamunite can also occur in these zones.

The Significant Thorium Deposits of the United States

Bradley S. Van Gosen: U.S. Geological Survey

Recently, thorium-based nuclear energy has experienced renewed attention as nations investigate new methods of meeting their growing energy supply requirements. Consideration of thorium as a potential energy source has reached the U.S. Congress, where in 2008 there are

plans to introduce the Thorium Energy Independence and Security Act (Geotimes, v. 53, no. 6, p. 17). If India or another country proves successful in generating electricity safely and efficiently from a thorium-based nuclear power plant, then considerable interest and activity could focus on thorium exploration across the globe. Thus, it benefits the U.S. and other countries to identify and evaluate their indigenous thorium resources. Earlier studies of thorium districts conducted by the U.S. Geological Survey and the former U.S. Bureau of Mines left a considerable legacy of published information describing the geology and available resources in the primary thorium districts of the U.S.

All of the significant thorium resources in the U.S. appear to be genetically associated with alkalic magmatism. U.S. thorium deposits occur in epigenetic veins peripheral to alkaline intrusions; in alkalic igneous complexes or carbonatites; and in alluvial stream and beach deposits (placers) derived from the erosion of alkalic igneous terranes. Thorium's genetic association with alkaline igneous rocks also places thorium in close association with minerals that host other valuable elements, such as rare earth elements (REE), titanium and niobium.

Thorium vein districts are the largest high-grade (>0.1% ThO_2) thorium resources in the U.S. Two thorium vein districts in particular comprise the majority of the known high-grade thorium resources in the U.S.—the Lemhi Pass district along the border of southwestern Montana with Idaho, and the Wet Mountains area of south-central Colorado. Currently, claim staking, exploration, and reassessment of the thorite vein deposits in the Lemhi Pass district is being conducted by private interests.

Large, but low-grade, deposits of thorium (<0.1% ThO_2) occur in carbonatite stocks and some alkalic intrusions. U.S. examples include the Iron Hill carbonatite complex in southwestern Colorado and the Mountain Pass carbonatite in northeastern San Bernardino County, California. It seems unlikely that the thorium in most alkalic intrusions and carbonatites would be developed as the primary commodity; however, thorium could be exploited as a by-product along with the extraction of associated mineral resources (such as the large undeveloped titanium reserves at Iron Hill or renewed mining of the Mountain Pass REE deposits).

Thus far, the only thorium production in the U.S. came from alluvial deposits of monazite, which were mined by placer methods (sluicing, dredging) in intermontane stream deposits of Idaho (1909-1910, 1950s), stream and river deposits of the Piedmont region of North and South Carolina (1887-1917), and in beach deposits of northeastern Florida-southeastern Georgia (intermittent monazite recovery, 1916-1978). Mining of thorium from alluvial deposits has the advantages of relative ease of mining, rapid mineral separation, and the potential for co-product development. Co-products can include: REE obtained from monazite; titanium from ilmenite and rutile; iron from magnetite; zirconium and hafnium from zircon; and industrial-grade garnet, staurolite, tourmaline, kyanite, and sillimanite, which are used as abrasives and refractory minerals.

Current Uranium Exploration in Niger

Tom Bell Ph.D. P.G.: Stratamodel Inc.

Niger is currently the fourth largest uranium producer in the world and poised to become the largest. Uranium mineralization resembles the deposits of the Colorado Plateau. Since the early 1970s, the primary producers in Niger have been joint ventures dominated by the French utility Areva. Through its joint venture companies, Areva has produced over 100,000 tons of U3O8 from Permian age mineralization in an open pit and underground mine since 1971. Now, Areva has committed over US$ 1.47 billion to open a mine on what appears to be the largest sandstone type uranium deposit every found. With inferred reserves of 146,000 tonnes of U3O8, Imouraren, a Jurassic age monster, over eight km long and two kilometers wide, has an average grade of 0.11% U3O8.

As the renewed interest in uranium exploration developed, Niger rewrote its mining laws encouraging foreign companies to apply for exploration permits for reasons that remain obscure but suggest some level of dissatisfaction with the status quo defined by decades of Areva dominance in the national economy. In response, companies capitalized to various degrees by private or public equity and/or state funds from Canada, India, South Africa, Russia, China, Britain, and Australia applied for and received permits to explore blocks from 500 to 4,000 sq kms. Noticeably absent are companies based in the United States despite its reservoir of expertise in this type of uranium mineralization developed during the decades after World War II until the precipitous decline in the price of U3O8 in the early 1980s.

Current exploration activity is conducted by three main actors, Areva, the China National Nuclear Corp, and GoviEx, a subsidy of the Canadian firm Ivanhoe Resources. Each has proven reserves from over 250,000 tonnes U3O8 down to less than 6,000 tonnes. Other active players include the South African companies Niger Uranium and Niger Mine Services, the British group Brinkley Mining and the Canadian company Uranium International Niger. The majority of permit holders have yet to make an appearance on their recently granted Saharan real estate.

The Tim Mersoi Basin is a little explored uranium province where the transition from marine to terrestrial sedimentation is punctuated by at least three significant episodes of alkaline to peralkaline volcanism along its Eastern margin. Closed basin conditions appear likely during and shortly after each episode resulting in exotic pore and surface water chemistry favorable for the mobilization of uranium from highly enriched vitric ash and entrapment of uranium in entombed organic debris. Similar geologic and geochemical conditions prevailed during deposition of the Chinle and Morrison formations on the Colorado Plateau.

Given the vast area of poorly or completely unexplored terrain, the potential for another significant discovery the size of Imouraren is a distinct possibility. Barriers to exploration include limited infrastructure, primitive field conditions, an arcane political environment, and a deteriorating security situation due to petty rural banditry and a local insurgency. And now, disarray in the mining venture capital markets may assure exclusion of late private sector actors in what may prove to be the richest uranium province on the planet.

Soil Gas Hydrocarbons: A Dual Purpose Geochemical Exploration Tool Used in the Search for Various Types of Blind Uranium Targets.

Sutherland, Dale A.: Activation Laboratories Ltd.

Soil Gas Hydrocarbons (SGH) is an extractive procedure which releases organic compounds absorbed from the surface of particulates in surficial soil samples, lake bottom sediments, humus, frost boil, peat and other sample types. These samples act as collectors of organic compounds that have been shown to migrate to the surface from the direct interaction of bacteria with deposits at depth. SGH has the ability to locate and identify a wide variety of commodities including Uranium, Gold, SEDEX, VMS, Nickel, Copper, Kimberlite formations and Petroleum plays. This geochemistry can vector to the vertical projection of a target as well as confirm the identity of the buried target through forensically determined signatures. SGH surveys are focused on the hydrocarbons in the C5 to C17 carbon range which are not gaseous at ambient temperatures. Traditional gaseous C1 to C4 compounds have been studied in the past, however these compounds are actively cycled by the biosphere, affecting both their abundance and their flux from natural systems. The alteration of C1 to C4 signals by the biosphere and the effect of barometric pressure and precipitation on gas flux reduce their use in delineating buried targets. Through the analysis of the more chemically and physically stable C5 to C17 compounds a more robust and reliable geochemistry has been developed. The SGH procedure is a highly selective and sensitive method which can detect the organic compounds in the parts-per-trillion (ppt) quantities necessary to both identify and vector to buried uranium targets using Gas Chromatography-Mass Spectrometry. Over 160 specific hydrocarbons are reported for each sample. The capabilities of this information rich geochemistry has been researched and developed for over 12 years including projects with the Canadian Mining Industry Research Organization (CAMIRO). SGH survey results typically have very easily interpretable anomalies once the specific target signature has been separated. The resultant templates have been used to interpret the results from over 320 surveys since 2004, 48% of these specifically for Uranium type targets. SGH has been shown to have the ability to differentiate the presence of Petroleum plays from Uranium targets often a concern in the Canadian Athabasca and Thelon basins, as well as being able to discriminate between barren and ore bearing conductors. A proper SGH survey has often been used to confirm the identity of magnetic anomalies prior to the use of more expensive techniques and has been found to correlate well with Radon gas surveys. SGH case studies from the Athabasca basin as well as those over Breccia and Roll Front style Uranium deposits will be shown and discussed in this presentation.

In Situ Recovery I – Groundwater

Session B – Wednesday AM, May 13, 2009

Geochemistry of Uranium In-Situ Leach Aquifers after Restoration

Janet A. Schramke, Hal Demuth, & Mark S. Pelizza: Enchemica LLC, Petrotek Engineering Corporation & Uranium Resources Inc.

In situ leach (ISL) methods are an important means of uranium production in the U.S. Oxidants and complexing agents such as carbonate are used to mobilize and recover uranium; the ISL methods have significant effects on groundwater quality in the ore zone aquifer due to alteration of the original reducing conditions. In addition to uranium, other constituents present in ore zone minerals may also be mobilized, including radium, selenium, arsenic, molybdenum, iron, manganese, and sulfate. Chloride concentrations are also typically increased during ISL operations because ion-exchange systems are used to remove uranium from the production fluid, which is subsequently reinjected into the production zone. Consequently, groundwater restoration is required to protect water quality in adjacent aquifers after ISL operations have ended. Restoration methods typically include groundwater sweep followed by recirculation of treated groundwater through the production zone. At some sites, restoration is then completed by injection of reductants into the production zone. After restoration, a number of factors can influence constituent migration away from the restored ISL production zone, including the redox conditions, water chemistry and mineralogy in remnant ore zones and host rock; changes in geochemical conditions in ore zones, host rock, and groundwater caused by ISL operations; the processes used and duration of aquifer restoration; and natural attenuation of groundwater constituents.

Evidence that restoration of acceptable water quality can be achieved is available from laboratory data as well as groundwater monitoring data at a number of restored ISL sites in the U.S. The key parameter for achieving successful restoration is re-establishment of chemically reducing conditions in the ore zones, which limits uranium mobility as well as the mobility of most constituents mobilized by ISL operations. The site monitoring data also indicate that reducing conditions can be maintained over the long term following restoration, which is necessary for demonstrating long-term protection of groundwater resources adjacent to the mined aquifer zone.

Application of Geochemical Modeling to ISR systems

Tom Meuzelaar: RockWare Consulting

Solution mining is an increasingly attractive alternative to conventional recovery methods for roll-front uranium deposits. Since ISR-suitable roll-front deposits must occur in fully saturated porous media and are highly reactive relative to fluid transport rates, they are ideal candidates for aqueous geochemical modeling.

Since the end of the last uranium boom, the advent of the PC, affordable access to desktop processing power, significant advances in geochemical theory, and the coupling of aqueous geochemical and transport theory have combined to make it possible to build detailed spatial and temporal geochemical process models of reactive hydro-geologic systems.

Geochemical models can be applied to all phases of an ISR operation - exploration, site characterization, production planning, operations, and post-production restoration. A well constrained geochemical model can aid in recovery enhancement, well field design, compliance and permitting, waste treatment scenarios and aquifer restoration.

Analytical data from a viable, ISR eligible uranium roll-front deposit have been used to constrain a series of models created to demonstrate a range of potential applications:

- Model time-based dissolution of uranium ore (Uraninite, Coffinite et al.)
- Model formation of secondary precipitates including the effects of sorbing mineral surfaces on solution concentration levels (eg. uranium complexation on Ferrihydrite), cation exchange on clays, and the formation of well scale (Gypsum, Calcite et al.)
- Predict distribution of uranium among aqueous complexes (uranyl carbonates, uranyl hydroxides et al.) and final concentration levels in the pregnant solution.
- Test various lixiviant chemistries and concentrations and examine their effects on the reducing (Pyrite, Magnetite et al.) and pH-buffering capacities (Calcite, Siderite et al.) of the aquifer
- Design well fields by experimenting with well spacing and various well array patterns
- Vary fluid extraction and injection rates
- Evaluate the potential for excursions
- Consider various waste treatment scenarios (bleed water settling ponds, injectant re-circulation)
- Design aquifer restoration models (natural attenuation, microbially aided attenuation, other active remediation options)

Geochemical models are now frequently required as due diligence to state and federal regulatory agencies for permitting and compliance purposes. ISR operations that incorporate geochemical simulations into their workflow can avoid expensive re-drilling, streamline design and build processes, enhance ore recovery, and reduce non-compliance penalties.

The models allow ISR operations to rapidly test numerous real-world scenarios before they are actually implemented, which can result in countless man hours saved and substantial cost reduction. The geochemical modeling process bears a resemblance to ore deposit modeling - initial models tend to be broad in scope, and point out first-order trends. Aspects of the model that are deemed significant can then be refined using additional site-specific data.

Investigation of Iron Monosulfide as a Scavenger of Uranium from Ground Water

Tanya Gallegos[1], Samuel Webb[2], & William Betterton[1]: [1] U.S. Geological Survey & [2]Stanford Synchrotron Radiation Laboratory

To leach uranium (U) from host rocks, most in-situ recovery (ISR) U mining operations in the United States inject a lixiviant solution of water enriched in oxygen and carbon dioxide to dissolve the U by oxidizing U(IV) minerals and forming aqueous carbonate complexes. Following ISR operations, dissolved U concentrations in local ground water commonly exceed pre-mining baseline values. Natural or introduced sulfides may facilitate the establishment of reducing conditions that promote the precipitation of relatively insoluble uraninite and other U(IV) mineral species. This study examined the effectiveness of mackinawite, a nanoparticulate, reduced-iron monosulfide, in lowering concentrations of dissolved uranyl (UO_2^{2+}) over a range of solution conditions chosen to simulate conditions typical of ISR mining; to determine the effects of pH, carbonate, and re-oxidation on uptake of U by mackinawite. Under anoxic conditions, suspensions of 5 g/L mackinawite removed 12 to 120 mg/L dissolved U(VI) from pH 5 to 9 in the presence and absence of 1000 mg/L carbonate (added as sodium bicarbonate). The corresponding solid reaction products (mackinawite loaded with approximately 2,379 and 23,790 ppm U) were studied using x-ray absorption spectroscopy (XAS) including x-ray absorption near edge (XANES) and extended x-ray absorption fine structure (EXAFS). XANES data showed that solid-phase U reaction products exhibit a shift in absorption edge position from the original U(VI) location to a lower energy, indicative of a reduced oxidation state (i.e. U(IV)). EXAFS data indicated that near-neighbor coordination consisted of U-O and U-U bonds consistent with the formation of uraninite (UO_2) regardless of pH and the presence of carbonate. Furthermore, upon exposure to air, U exhibited an absorption edge consistent with the original dissolved uranyl indicating a U(VI) valence state and near-neighbor coordination of U to Fe, typical of sorption of U(VI) onto Fe surface groups. Thus, upon oxidation, the FeS-U(IV) association converts to an FeS-U(VI) association that still provides uptake capacity for U(VI). Mackinawite synthesized with a higher loading of 237,900 ppm U was analyzed using scanning electron microscopy with energy dispersive analysis of x-rays (SEM-EDAX) and x-ray diffraction (XRD). Elemental mapping conducted during SEM-EDAX analysis demonstrated that U occurred in areas where iron and sulfur (i.e. iron sulfide) were absent, suggesting the formation of a discrete U precipitate. XRD indicated that this precipitate was UO_2(s).

This research provides a basis for future, planned investigations including batch and column studies to stimulate fixation of U onto solids using mackinawite following leaching of natural U ore samples.

Groundwater Modeling Application to Uranium In-Situ Recovery Projects: Relationship of Sweep Efficiency to Pore Volume Removal

Errol Lawrence, Ken Cooper, & Hal Demuth: Petrotek Engineering Corporation

Groundwater modeling can be a valuable tool when correctly applied to Uranium Insitu Recovery (ISR) Projects. Beneficial applications of groundwater modeling cover the full scope of ISR, from permitting and initial design, through production and restoration phases. Groundwater models can range from simple analytical solutions used to determine maximum anticipated drawdown at a well, to complex multi-layer numerical models that simulate concurrent production and restoration within stacked sand sequences of several mine units.

For production phases of ISR, groundwater models can be used to assist with the design and optimization of hydrologic testing programs and mine unit wellfields, monitor well spacing and layout, optimization of sweep efficiency, and horizontal and vertical flare determinations. Additionally, water balance calculations for contemporaneous production and restoration operations to determine well interference between adjacent mine units can be effectively simulated with groundwater models

With respect to restoration of ISR projects, modeling can be used to estimate maximum rates that can be sustained to reach PV goals, the number of pore volumes (PVs) of treatment that will be required to attain targets, identify potential migration pathways, optimize groundwater sweep, and design groundwater treatment/reinjection operations. Groundwater modeling can also be used to support post restoration-monitoring and natural attenuation or alternate concentration limit strategies for aquifer restoration.

A simple modeling application is presented that demonstrates one of many ways that simulation can be used as a tool to evaluate operational issues. This example illustrates the relationship between sweep efficiency and pore volumes removed in a typical ISR well pattern. A general rule of thumb in the uranium ISR industry is that economically successful leaching of uranium within a well pattern can take between 30 and 40 pore volumes (PVs) of groundwater extraction. A pore volume in this context is defined as the fluid-filled volume within a well pattern. The model presented was used to simulate a generic five-spot pattern in an ideal isotropic homogenous system with a single extraction well surrounded by four injection wells. In a homogeneous system, initial breakthrough (arrival of lixiviant) from the injection well to the extraction well occurs along the shortest flowpath between the wells. The longer pathways may take up to three times as long to initially reach the extraction well. This means that the removal of 40 PVs from a well pattern actually results in the equivalent displacement of over 50 PVs along the shorter flowpaths and less than 20 PVs along the outermost, longer flowpaths. Simulation can also be used to visualize howchanging the sequence of injection/extraction wells without increasing the total volume of fluid pumped through the wellfield can result in more uniform and homogenous contact with the ore body. While the rate of recovery is obviously determined by injection rate, the sweep efficiency is not strongly impacted by rate of injection/extraction.

Permitting In-Situ Wastewater Disposal Wells in Wyoming

Pete Vogel: Wyoming Department of Environmental Quality

Wyoming Class I wells have historically been permitted to inject water and wastewater derived from uranium in-situ recovery (ISR) aquifer restoration and remediation activities into Upper Cretaceous formations (e.g. Lance, Mesa Verde). While Wyoming currently has no Class I injection wells permitted to receive hazardous waste it has the authority to permit hazardous waste injection wells.

The Wyoming DEQ (WDEQ) has developed a new policy that permits injection of ISR wastes into Class V (5F2 – other) injection wells. A Class V facility is defined as “any property which contains an injection well, drywell or subsurface fluid distribution system which is not defined as a Class I, II, III or IV well in Chapter 13, Water Quality Rules and Regulations.

Under this policy, classification of groundwater as Class VI (unusable or unsuitable for use) by the WDEQ is required for ISR wastewater injection. The Class VI designation is critical as it specifically defines the water in the aquifer to not be an underground source of drinking water (USDW). This classification is dependent upon groundwater within the proposed injection zone meeting at least one of the following criteria: Total Dissolved Solids concentration greater than 10,000 PPM, or is sufficiently contaminated to be economically or technologically impractical to make the water useable, or is located in such as way, including depth below the surface, to make its use economically and technologically impractical. The classification of groundwater as Class VI based on the depth and location criteria will be the exception and will require a rigorous analysis and defense.

In addition to the Class VI groundwater classification, consideration of injection into a Class V well under this new policy also requires that the waste stream must be non-hazardous or exempted as a hazardous waste by federal law or rule.

The Policy also specifies minimum permit application requirements such as a comparative analysis to demonstrate that obtaining a permit for a Class I well is likely to be impossible or impractical; a comparative analysis of the practicality of using other methods of waste treatment or disposal; demonstration that confining lithologic seals exist above and below the injection zone; and a plan to monitor the groundwater.

High Resolution Resistivity Imaging to Monitor Groundwater Flow

Ronald. S. Bell: hydroGEOPHYSICS, Inc.

Mapping the lateral and vertical variation in lithology and relative moisture content within the subsurface between borings and wells is routinely done through the use of high resolution resistivity imaging techniques. Through time-lapse resistivity imaging and electrohydrodynamic (EHD) monitoring of fluid injections, it is possible to determine the direction and velocity of localized groundwater flow in real time. A logical step forward is to use the geophysically obtained information about the hydrodynamic behavior of the groundwater system to constrain groundwater flow models.

HGI successfully applied its large channel resistivity data acquisition system to time-lapse three dimensional (3D) imaging of a series of pressurized (Hydro-Jex) and gravity-flow fluid injections into a heap leach pad. A series of 3D resistivity inverse models were calculated at select points in time and evaluated to assess the spatial influence of the injections as well as hydrodynamics of the rock pile during periods of drain down. The resistivity imaging and modeling results clearly show the direction of flow and relative change in pore water content. This information was provided in nearly real time to the mine operator who subsequently modified the plan of injections.

Because of the relative close proximity and number of wells within the well field, the typical facilities design for the in-situ recovery (ISR) of Uranium readily lends itself to the application of resistivity monitoring techniques. By monitoring the groundwater flow in real time, the ISR mine operator is provided with knowledge of hydrodynamic behavior of the extraction operation which can then be used to optimize recovery.

Case Studies

Session A – Wednesday PM, May 13, 2009

Overview and Recent Exploration Success at the McArthur River Uranium Deposit Athabasca Basin, Saskatchewan, Canada

Jason T. Craven & C. Trevor Perkins: Cameco

The McArthur River P2 North deposit discovered in 1988 is the world's largest high-grade uranium mine. In 1992, Cameco went before a joint federal-provincial review panel seeking approval to proceed with underground exploration. In 1993 approval was granted and shaft sinking commenced that year. Mine construction began in 1997 after the project received regulatory approval, and full production capacity was achieved in November 2000.

McArthur River is located in the southeastern Athabasca Basin 70 km northeast of the Key Lake mill and 620 km north of Saskatoon, Saskatchewan Canada. The deposit is hosted by late Paleoproterozoic Athabasca Group sandstones, conglomerates and mudstones that unconformably overlie Paleoproterozoic meta-sedimentary and Archean rocks of the Hearne Province, close to the transition between the Wollaston and Mudjatik lithostructural domains.

The main structural control to the mineralization of the P2 North deposit is the southeast-dipping P2 fault, a thrust fault zone that has moved a wedge-shaped block of Wollaston Group basement rocks into a position structurally overlying the lower Athabasca Group sediments. The P2 fault is the most prominent structural feature in the area and is directly related spatially to the P2 North ore-bodies.
The McArthur River mine contributes approximately 20% of annual global uranium mining production. At current levels the mine has a life expectancy of at least 19 years with a production capacity of 18.7 million pounds of uranium per year. As of December 31, 2007, proven and probable reserves at McArthur River stood at 766,500 tonnes averaging 20.66% U_3O_8 totalling 349.1 million lbs U_3O_8 (Cameco Annual Report 2007).

Surface exploration along the P2 trend resumed in 2004 as part of Cameco's brownfield program. The P2 trend (as currently defined) is at least 18 km in length and less than 30% has been fully tested. Recent drilling results have been encouraging as exploration moves northward. Several more years of dedicated exploration will be required to fully realize the total uranium resource endowment of the fertile P2 structure.

Permitting of the Whirlwind Mine

Frank Filas: Energy Fuels Resources Corporation

Energy Fuels Resources Corporation (Energy Fuels) received final approval for the Whirlwind Mine with a Finding of No Significant Impact (FONSI) from the Bureau of Land Management (BLM) on September 10, 2008. This was the final permit needed to develop the mine and capped a 20 month permitting effort. The Whirlwind Mine is the first large (greater than 10 acres) uranium mine permitted in Colorado in nearly two decades. Because the permitting climate has changed dramatically in the last 20 years, the level of effort expended toward technical design, environmental mitigation, and public relations was several orders of magnitude greater than what was common during the late 1970s and early 1980s when most of the existing uranium mines were permitted on the Colorado Plateau.

Background

The Whirlwind Mine is an underground uranium mine located on the Colorado/Utah state line near Gateway, Colorado. It consists of the former Urantah Decline and Packrat Mine that were reclaimed in 2002 by Cotter Corporation and Umetco Minerals Corporation, respectively. The reclamation bonds were released in early 2005 and all existing permits were dropped. Energy Fuels acquired the mining lease in December 2006 and immediately began permitting the project.

Permitting Requirements

The following four major permits were needed to operate the mine.

1. Mine Water Discharge Permit
2. County Conditional Use Permit
3. State Mine and Reclamation Permits (Colorado & Utah)
4. BLM Plan of Operations and Environmental Assessment

Many smaller permits (e.g., air quality, stormwater), environmental plans (e.g., ore transportation, spill control) and health and safety plans (e.g., ventilation, emergency response) were also required and proved to be invaluable during the public comment process.

Permitting Strategy

1. Acquire prospect permits to allow work on site during the permitting process
2. Obtain detailed input from company's operation & engineering personnel
3. Permit for life of mine rather than a phased approach
4. Utilize smaller consulting firms with relevant experience
5. Start public relations early with heavy reliance on local company personnel
6. Adjust quickly to address regulatory concerns and permitting deficiencies

Conclusions

The Whirlwind Mine was successfully permitted in 20 months despite active opposition from environmental groups and the need to develop detailed plans to address local, state, and federal informational requirements. Much of the work completed for the Whirlwind Permit covered new ground that will hopefully streamline permitting of future uranium mines on the Colorado Plateau.

Uranium Mineralization in Singhbhum Shear Zone, India

A. K. Sarangi[1] & M. Das[2]: [1] Uranium Corporation of India Ltd, & [2] Utkal University

The Precambrian Eastern Indian Shield broadly comprises of three prominent tectono-stratigraphic units. From south to north they are – a) the Archean cratonic massif of Singhbhum; b) the Paleo Proterozoic mobile belts of north Singhbhum and Gangpur and c) the Chottanagpur migmatite-granulite massifs of the Archean period. The Singhbhum craton and its northern mobile belt is separated by a deep seated crustal furrow – known as Singhbhum Shear Zone (SSZ) with intense deformation, basic volcanism and hydrothermal mineralisation. The NW-SE trending SSZ forms a 200 km long arc bordering the Singhbhum granitic craton. With its long geological history (extending from 3.7 to 1.0 Ga), SSZ is known for its rich wealth in mineral resources. In the central and south-eastern part, this zone is less than 1 km wide and gradually widens towards NW and hosts a number of Cu and U deposits with associated Ni, Mo, Bi, Au, Ag, Te, Se and magnetite. Deposits of apatite-magnetite and kyanite are also located in this zone. CU and U mineralisation has taken place along the shear zone in the central and southeastern sector. This zone contains lion's share of India's uranium reserves.

The southern Singhbhum granitic craton (3.0 – 2.9 Ga old, mU = 7 ppm) is believed to be the main source of U. The weathering of the Singhbhum granite started before (during ?) the Paleoproterozoic (non-availability of oxygen) and the sediments derived from its erosion led to the syngenetic deposition of detrital U minerals (U^{+4} state) forming a thick pile of sediments with conglomerates. Along the cratonic margin, basic rocks are interlayered with the sediments. With gradual availability of oxygen in the atmosphere, detrital U minerals were solubilised (U^{+6} state), transported through favorable pathways and precipitated where in contact with reductants. The Singhbhum orogenic cycle (2 Ga), represented by regional metamorphism, emplacement of basic rocks, shearing, helped in concentration of U in favourable structural and / or stratigraphic locations. Various geochronologic studies in the area also indicate different episodes of mineralisation from 2000 Ma to 850 Ma.

Uranium mineralisation in SSZ are confined to well defined zones of deformation and intimately related to the metamorphic, tectonic and depositional evolution of the area. The richest U ore lodes in Jaduguda-Bhatin sector in central part of SSZ are hosted in quartz-granular rock and brecciated quartzite, and occur as veins having uraninite grains associated with Cu, Ni and Mo. Towards the eastern part of the SSZ (Bagjata – Kanyaluka area), the mineralisation is found in quartz-biotite-sericite schist. In the western sector from Narwapahar to Turamdih and further west, discrete uraninite grains are found disseminated in quartz-chlorite, crushed sericite-chlorite schist and feldspathic schist. Here, low grade U mineralisation exhibits a stratabound character. The ore lenses of Turamdih deposit extends westward and coalesce to form a massive ore zone very close to surface at Banduhurang. Mineralisation at Mohuldih is found in tourmaline bearing quartz schist and occurs as veins.

Uranium deposits in the SSZ are of low grade and most of them are of small to medium size. Jaduguda is the deepest underground mine in SSZ extending down to depth of 905 m.

Uranium Exploration and Development in the Athabasca Basin of Northern Saskatchewan, the World's Premier Uranium District

Gary Delaney, Colin Card & Sean Bosman: Saskatchewan Ministry of Energy and Resources

For 55 years, Saskatchewan, Canada, has been producing uranium, first from the Beaverlodge area (1953 – 1982) and then from the Athabasca Basin (1974 – 2008). In 2007, the Athabasca Basin, the world's premier uranium district, accounted for about 23% of global uranium production. There are currently more than 200 active uranium exploration projects in and adjacent to the basin, much of which is still very prospective as highlighted by recent discoveries.

In 2008, Saskatchewan uranium production is forecast to be about 24.4 M pounds (lbs) U_3O_8, down slightly from the 24.6 M lbs U_3O_8 produced in 2006. Mining and milling continued at three operations. The McArthur River Mine (Cameco Corporation (Cameco), operator, 69.805%; and AREVA Resources Canada Inc. (AREVA), 30.195%) /Key Lake Mill (Cameco, operator, 83.333%; and AREVA, 16.667%) was expected to produce about 17.6 M lbs U_3O_8 and continues to be the world's largest uranium producer. Production from Cameco's 100% owned Eagle Point Mine, at Rabbit Lake, is forecasted to be 3.6 M lbs U_3O_8. At McClean Lake (AREVA, 70%; Denison Mines Corp. (Denison), 22.5%; and OURD Canada Co. Ltd. (OURD), 7.5%), production is expected to be 3.2 M lbs U_3O_8.

A number of uranium projects are in development or the subject of feasibility studies. At the Cigar Lake Mine (Cameco, operator, 50.025%; AREVA, 37.100%; Idemitsu Uranium Exploration Canada, 7.875%; and TEPCO Resources Inc., 5.0%), the largest high-grade uranium deposit in the world, operator Cameco is assessing a new water inflow problem. The water has forced a hiatus in mine recovery and remediation work related to two earlier water incursion events; production is targeted for 2011. Production at the Midwest uranium project (AREVA, 69.16%; Denison, 25.17% and OURD, 5.67%) is also forecasted to begin in 2011. Feasibility studies are underway at UEX Corporation's West Bear and Raven-Horseshoe projects, located near Rabbit Lake, as well as Cameco and its partner's Millennium Project, located ~35km north of the Key Lake Mill.

In 2008, exploration expenditures for uranium were forecasted to be about $196 M, a substantial increase from 2007. Most of the expenditures were focused on properties in and adjacent to the Athabasca Basin. Projects in the latter group were targeting basement-hosted deposits similar to those at Millennium and Eagle Point. Large exploration programs were undertaken by majors Cameco and AREVA as well as junior UEX Corp. UEX is involved in grassroots to advanced-stage exploration programs across the Athabasca Basin. One of the most encouraging of these is that of the Shea Creek Joint Venture, operated by AREVA, where planning is underway to sink an exploration shaft. Other junior and mid-tier companies were advancing their exploration programs. Hathor Exploration's Roughrider Zone discovery, near the Midwest deposit, was the most significant discovery announced in 2008. This and other exploration successes highlight the potential for new discoveries in the Athabasca Basin. Improved understanding of the geological context of the Athabasca Basin and advances in geophysical and geochemical techniques are facilitating the new discoveries.

Uranium Mine Development Challenges Throughout the Colorado Plateau

Stephen Antony: Energy Fuels Resources

With the upturn in the domestic US Uranium market which began in earnest in 2004, historic mining areas throughout the Colorado Plateau are receiving renewed interest as a location for this primary source of material which will fuel the nations' as well as the world's next generation of Nuclear reactors. This interest driven by the worlds growing demand for new "clean" power generation. The Colorado plateau was a base of significant production during the last uranium boom which ended in the early 1980's. Mines which were shut down for purely economic reasons are being evaluated as renewed production opportunities by an abundance of new, as well as previous players' the industry. Much of the landscape has changed since these mines saw their last ore shipped to a local mill. Stringent new environmental and health & safety regulations, escalating equipment & material costs, a depleted workforce (including a shortage of qualified regulators), local public acceptance of the uranium mining/milling industry and the number of ever expanding NGO's opposed in principle to any nuclear power development, are all challenges that today's uranium mining companies must overcome to reestablish a viable production industry. This presentation will focus on how Energy Fuels has accepted this challenge, and our progress to date in bringing back this once vibrant and substantial contributor to the improved welfare and prosperity of the general populace throughout the US and the world.

First Uranium's Projects

Jim Fisher: First Uranium Corporation

First Uranium was listed on the TSX on the 20th December 2006 (TSX: FIU, JSE:FUM) and is focused on the development of its South African uranium and gold mines with the goal of becoming a significant low-cost producer through the re-opening and underground development of the Ezulwini Mine and the expansion of the Mine Waste Solutions tailings recovery operation. First Uranium also plans to grow production by pursuing value-enhancing acquisition and joint venture opportunities in South Africa and elsewhere.

This presentation reviews the progress of each operation and the output of the latest technical reports.

In Situ Recovery II – Case Studies

Session B – Wednesday PM – May 13, 2009

Powertech Uranium – A New In-Situ Producer

Wallace Mays: Powertech Uranium Corp.

This presentation describes Powertech Uranium Corporation and it's projects.

- Description of Powertech Uranium Corporation.
- History of Powertech Uranium Corporation.
- Dewey-Burdock Project
- Centennial Project Description
- Aladdin Project Description
- Current Status
- Prognosis

Design & Construction of a State-of-the-Art ISR Uranium Recovery Plant Cameco Resources Smith Ranch SR2

Bob Hembree: Cameco

As a result of the increase in uranium demand and the corresponding increase in the market price of uranium, Cameco Resources (Cameco) started expansion of its' ISR uranium mining operations at the Smith Ranch Highland (SRH) property near Douglas, Wyoming in 2005. An integral part of the expansion program is the construction of a two satellite mining facilities, one in the southwest area of the property designated SR2 and one in the Reynolds Ranch area (scheduled for construction in 2009 to 2010). Design of the SR2 satellite started in early 2006 and construction of the plant started in January of 2008. Start-up of the SR2 satellite took place in October, 2008 and the plant was in steady operation by the end of 2008. The SR2 satellite is designed for a flow rate of 4,500 gallons per minute with a projected average annual production rate of 500,000 pounds of U_3O_8. The plant is an ion exchange recovery facility from which loaded resin is transferred by truck seven miles to the Smith Ranch central processing facility for uranium stripping, precipitation, drying and packaging. The design of this new satellite incorporates lessons learned through operations of the other three operating satellites on the SRH property and new technologies that have been perfected since the last satellite was constructed in 1998. This effort was accomplished utilizing both contractors and Cameco personnel. The SR2 project was successfully completed while overcoming several roadblocks including regulatory issues, weather, and process changes.

The Challenges of Developing Uranium Resources in Today's Market

William Paul Goranson, P.E.: V.P. Mesteña Uranium, L.L.C.

As late as the early 1980's, the United States was the largest producer of uranium in the world. The production supplied a growth in the domestic nuclear industry that by the late 1980's reached a peak of 112 reactors with several more either under construction or planned. As a result of the incident at Three-Mile Island, several of those planned reactors and reactors under construction were cancelled. During this period, with a significant reduction and cancellation of uranium deliveries, the majority of the U.S. mines were shutdown and mills shuttered.

However, globally, particularly in Asia, the love affair with nuclear power was just starting. Additionally, with production in the U.S. declining to a few in-situ and alternative feed recovery facilities, primary production was moved to large uranium projects in Australia, Canada, Central Asia, and Africa. Consumption continued to grow as the result of increased nuclear generating capacity from existing reactors, and the supply gap was filled with secondary sources such as excess reactor inventories, government inventories, and weapons down blend (Megatons to Megawatts). During this period, the price of uranium ventured to levels below $10 per lb,

In 2003, as the market began to respond to the consumption of the excess inventory, increased prices brought about a resurgence of uranium mining industry. In addition, the global nuclear renaissance provides the potential for significant new demand. In the United States, increased interest in uranium mining brought about a re-look at historic uranium projects that either were planned or cancelled during the previous downturn.

However, since the last major uranium production cycle, the U.S. gave up its dominance of the market to other global competitors as a result of minimal investment in the domestic industry due to low market prices, a perception of perpetual secondary sources, and loss of infrastructure, (e.g. the reduction from 24 mills to 4 mills). Additionally, during this period, environmental regulations changed and became more restrictive. Without its former significance in local and State economies, the uranium industry lost its status as a source of jobs and tax revenue, and allowing groups who oppose uranium mining to gain a upper hand in mischaracterizing the industries environmental and economic impacts. These mischaracterizations have created hostile permitting environments in some locales and created significant delays and uncertainty in reaching production. These issues coupled with a loss of institutional knowledge in the industry and regulatory agencies,

significant cost increases, and competition for resources with other industries is creating a significant challenge for the domestic uranium industry to compete directly in the global nuclear fuel cycle.

Lost Creek Project Update

W. William Boberg: Ur-Energy

Ur-Energy is developing the Lost Creek Uranium In-Situ Recovery (ISR) project in the Great Divide Basin of Wyoming. This presentation will review and update information on the general geologic setting, local geologic setting and mineralization along with the significant developments in permitting, engineering design and mining plans.

Uranium mineralization in the basin is confined to the Eocene Battle Spring formation which is composed of up to 6000 feet of unconsolidated interbedded arkosic sandstone, siltstone and mudstone beds. The mineralization at Lost Creek is located at multiple oxidation/reduction fronts within a series of stacked sandstone horizons along a three mile trend. Individual very sinuous mineralized beds are 25 to 200 feet wide and average 12 feet thick. Average grades run between 0.04% and 0.06% U_3O_8.

Ur-Energy is advancing the project permitting with the US Nuclear Regulatory Commission (NRC), US Bureau of Land Management (BLM) and Wyoming Department of Environmental Quality (WDEQ). The presentation will include Ur-Energy's current expectations for completion of the permitting process along with information on the progress of the facility design and production plan.

Permitting the Nichols Ranch ISR Project – What it Takes to Start a New ISR Facility in Wyoming

M. Thomas: Uranerz Energy Corporation

What does it take for a junior uranium company to license a new in situ recovery (ISR) uranium operation in the state of Wyoming? For the past two years, this has been the question and the process that one junior has been working on in order to become one of the newest uranium producers in the United States. Uranerz Energy Corporation began the licensing and permitting process in 2006 for their Nichols Ranch ISR Project. After a year of collecting baseline information, Uranerz submitted permit applications for the Nichols Ranch ISR Project in December of 2007 to the Nuclear Regulatory Commission (NRC) and the Wyoming Department of Environmental Quality (WDEQ). Uranerz Energy Corporation was one of three companies in over two decades to submit permit applications to the NRC and the WDEQ for a new ISR operation. Currently, the Nichols Ranch ISR Project application has been accepted by the NRC for a detailed technical and environmental review, and the application has been deem "complete" by the WDEQ also allowing further detailed review. Commencement of operations at the Nichols Ranch ISR Project is currently projected for late 2010 or sometime in 2011 depending on the timing of regulatory approval.

UEC Goliad Project Update

Harry Anthony: Uranium Energy Corp

The history and current status of UEC's Goliad Project permitting and production status will be reviewed and discussed.

Poster Session

Mineralogical Analyses of Selected Uraniferous Sheeted Leucogranites from the Goanikontes, Ida Dome and Velencia Deposits, Namibia

G. Freemantle

Research on granite-hosted uranium mineralization in the Central Zone of the Damara Orogen has predominantly focused on the Rössing area where mining commenced in 1976 on the SJ anomaly. Mineralization occurs in leucogranites which are preferentially located at the redox boundary between underlying Khan schists and overlying Rössing marbles. Two other areas near the main pit, namely the SH and SK, have also been the focus of more recent research work. In the open pit, uranium deportment was stated by Berning (1986) to be 50% in uraninite, 5% in betafite and 45% in secondary minerals dominated by betauranophane. In contrast, there appears to be a greater proportion of primary betafite in the nearby SH and SK areas. Previous studies have shown contrasting structural and stratigraphic controls on betafite formation between these different areas (Cuney, 1980a and 1980b; Nex et al., 2001; Kinnaird and Nex, 2007) and fluid extraction studies Nex et al. (2002) showed different H2O and CO2 proportions in betafite and uraninite-bearing leucogranites.

QEMSCAN data for 14 samples from the main Rössing pit (Figure 1), show varying proportions of primary and secondary U phases: with uraninite 40-70%, betafite 2-18% and secondary uranophane-coffinite 5-45%. These results compared favorably with previous metallurgical assays although the proportion of secondary phases appears to have been underestimated, probably due to their fine grain size. Sample NG06 from the Goanikontes granite-hosted anomaly compares with one of the open pit samples. In contrast, two samples from the SH area 2 km to the west of the main pit, (Figure 1) are betafite-dominated. QEMSCAN data for the SK area, 2 km to the east of the open pit (Abraham,

2008) shows significant betafite occurrence in some leucogranite sheets. In addition, there is a decrease of secondary U phases with depth in core samples. Since uranium is not released from betafite during processing, it is important to assess betafite abundances prior to any mining development or expansion. One of the aims of this project is to extend the QEMSCAN investigation to other uraniferous projects at Goanikontes, Ida Dome and Valencia.

The Valencia anomaly consists of a single granite body, the deposit shows marked contrasts to the Rössing open pit; marbles are strongly attenuated and the uraniferous granite has intruded at a disharmonic fold hinge to a higher stratigraphic level. The Goanikontes anomaly has a similar structural setting to Rössing, but is also characterized by thinned marble packages along the attenuated flanks of the Goanikontes Dome. The Ida Dome has several anomalies, including Garnet Valley and Holland's Dome, each with their own structural characteristics. At Garnet Valley, leucogranites have intruded at the lower contact of a thick marble succession, whereas at the Holland's Dome area there has been significant interaction between carbonates and granites producing large uraniferous skarn pods. A systematic approach to QEMSCAN analysis will make an important contribution to the further quantification of the role of structural and lithological controls on uranium mineral population variability. The inclusion of three other deposits with different characteristics adds greater scope to the assessment of the roles that structure and lithology play in the formation of uranium mineral phases. Fig. 1. Uranium mineral distribution of HMS sink fractions of selected leucogranites from the Rössing Mine SH and SJ areas. Samples lavelled RD are from the open pit.

A systematic approach to QEMSCAN analysis will make an important contribution to the further quantification of the role of structural and lithological controls on uranium mineral population variability. The inclusion of three other deposits with different characteristics adds greater scope to the assessment of the roles that structure and lithology play in the formation of uranium mineral phases.

Strength in Diversity: Evaluation of Four Electrical Geophysical Tools for Exploration and Production of Uranium Roll-Front Deposits

Sophie Hancock: Colorado School of Mines

Geophysical methods utilized in uranium exploration include radiometrics, airborne gravity, surface, airborne and surface magnetic, and 2-D and 3-D seismic surveys which have been used in the last decade to assess unconformity type deposits, particularly in Canada. Borehole radiometric and geophysical tools are being increasingly used for ore trend delineation and to provide resource estimates. Down-hole geophysical techniques commonly applied to uranium deposits include induced polarization, spontaneous or self-potential, and resistivity. In addition there are new geophysical tools capable of measuring important related hydrogeological parameters such as transmissivity. The following geophysical techniques are evaluated: Self- potential measurement of redox state; self-potential measurement of hydrogeology; spectral induced polarization; and DC-resistivity.

Self-potential measurement of redox state: This technique measures the variation and distribution of self-potential as proxy for redox potential. Since roll-front uranium deposits typically form at a reduced: oxidized interface, such as tools are valuable for property-scale evaluations. Surveys of a cross section between two well locations and can be repeated to create a surveyed grid. At the surface above the metallic body, a negative self-potential anomaly is detected, related to the redox potential of the groundwater. The distribution of the redox potential is produced using a least-squares inversion of the self-potential data, modeled using a 2-D finite difference simulation. Potential imitations are related to organic compound contamination of groundwater self-potential measurement of hydrogeology. Subsurface water flow generates an electrical current the resulting electrostatic self-potential signals that can be measured non-intrusively, quickly, and inexpensively at the ground surface. The data can then be modeled to interpolate the thickness of the vadose zone, and the variation of the water table in unconfined aquifer settings between measurement locations. Thus, self-potential techniques can be used directly to survey the depth and 'shape' of the water table on a potential uranium property and illuminate groundwater flow patterns relevant to well field design and environmental management considerations. SP signals can also be used with pump test data to estimate aquifer transmissivity variation, critical for evaluating in-situ recovery (ISR) production.

Spectral induced polarization (IP): IP can be used to map the location of metallic uranium gains and clays. The polarization of current is measured at the fluid-grain boundaries; measuring this boundary will yield important information to predict the well field efficiency of uranium removal, and could be used to design a site specific lixiviant.

Direct Current (D.C.) – resistivity: D.C. resistivity measures the earth resistivity to a direct current electrical resistivity signal, as resulting voltage potentials. This quick and relatively inexpensive method has become a preferred reconnaissance mapping tool for uranium exploration targets in unconformity type plays and could be used in sediment-hosted, roll-front uranium exploration. The D.C. resistivity method, in favorable environments, can detect lithologic contacts including the presence of clay layers and the water table. This method is a relatively quick survey, data processing and interpretation with moderately low costs.

The Role of Dissolved and Particulate Organic Carbon in Acetate Bio-stimulated Uranium Attenuation

J. Hartmann[1], Emily Lesher[1], Linda Figueroa[1], James Ranville[1], Kate Campbell[2], James Davis[2], Kenneth Williams[3] & Philip Long[4]: [1]Colorado School of Mines, [2]USGS Menlo Park, [3]Lawrence Berkeley National Lab & [4]Pacific Northwest National Lab.

The Integrated Field Challenge Site at Rifle, CO (RIFC) is home to a legacy of subsurface uranium contamination resulting from mill operations. Research at RIFC has shown that acetate amendment (as an electron donor and carbon source), and the consequential growth of

iron-reducing microbial communities results in the bio-reduction of uranium. As microbial communities metabolize the acetate; dissolved and particulate organic carbon concentration and composition changes. Subsurface oc affects the bio-geochemistry of an aquifer through equilibrium metal complexation and microbially mediated electron transfer and metabolic reactions. Accordingly, an understanding of DOC composition and evolution over the course of bio-remediation is useful in modeling the fate and transport of uranium. Operationally defined fractions of organic carbon in both particulate and dissolved phase can give insight into the microbial and chemical reactively of the organic carbon fractions. Both oxic course-grained, and bio-reduced fine-grained sediments, and groundwater from the RIFC were analyzed before, during and after acetate bio-stimulation for total and operationally defined fractions of uranium and organic carbon. Uranium in the sediment was fractionated using both anoxic and oxic bicarbonate and acid extractions. The DOC fractionation scheme involved XAD-9 and XAD-4 resins to isolate and measure hydrophobic, transphyllic, and hydrophilic organic carbon. Fractionated DOC was further analyzed for specific UV absorbance and characteristic fluorescence spectra. The unfractionated DOC was analyzed by HPLC for short change organic acids. The POC fractionation scheme involved sequential extraction using acid and base solution in conjunction with particulate organic carbon analysis. Research findings include: higher organic carbon content in bio-reduced sediments and the enrichment of the transphyllic organic carbon fraction in groundwater as a result of acetate stimulation. Additional data will be presented outlining the changes in uranium and oc composition from temporally and spatially varying Rifle groundwater and sediment samples. The evaluation of the composition of the sediment and groundwater before and after bio-stimulation allows for a direct comparison of the extent of natural U(VI) bio-reduction to acetate-stimulated bio-reduction. This information will facilitate the design of a more effective bio-remediation strategy for the Rifle IFC. More importantly, it will aid in the design of uranium bio-remediation strategies for other sites with subsurface uranium contamination.

Improved Methods of Uranium Leach and Recovery with Special Emphasis on Heap Leaching Techniques

Erik Hunter: Colorado School of Mines

The purpose of this research will be to investigate improved methods of uranium leaching and recovery, with special emphasis on heap leaching techniques. The leaching tests will be performed using columns containing low grade uranium ore (approximately 0.1 to 0.05% U3O8). Several different reagent schemes will be utilized to leach the ore, including surfuric acid, sulfamic acid, Caro's acid, and sodium carbonate-bicarbonate. Various oxidizers will be used, including sodium chlorate, sodium hypochlorite and hydrogen peroxide.

The uranium ore used in this study will be collected from the waste dumps of mines in western Colorado and eastern Utah. Bulk samples will be taken and analyzed for their mineralogical and chemical characteristics. The author has visited many of these dumps in the past and has found material that assayed 1% uranium and 1% vanadium.

Heap leaching technology is perceived by some regulators as environmentally unfriendly. The aim of this project is to prove that heap leaching can be one of the most environmentally sensitive methods for extracting uranium. Since the source of the material is considered by many to be hazardous waste, this study would be considered an environmental remediation project. The "environmental" focus of this research may lead to greater cooperation with regulatory officials. It is possible that there may be federal funds available for the removal of uranium-bearing waste material from public lands. A detailed study of the economics of this type of operation will be made. It is hoped the revenue gained from the recovery of the uranium and vanadium in the ore will exceed the costs associated with procurement and processing of the waste dump material.

This study will be guided by previous research in the field of uranium heap leaching. There is a wealth of data available from research done in the late 1970's by the Colorado School of Mines Research Institute (CSMRI). These studies involved batch and column leaching tests performed with low grade uranium ore (0.04 - 0.06% U3O8). Reagents such as sulfuric acid, ammonium carbonate, sodium carbonate, and sodium chlorate were used in the CSMRI tests. Extraction efficiencies for the column leaching tests were as high as 100% for U3O8 and 46% V2O5. The extraction rates for the bench scale percolation tests (200 grams to 2 kilograms of ore) were similar to the column tests involving approximately 2,500 pounds of ore. A field scale heap leaching test was performed by CSMRI using approximately 2,500 tons of uranium ore. It was determined that the flow rates and uranium extraction rates experienced in the field scale tests were similar to the column test. In light of the CMSRI research, tests involving relatively small amounts of ore could provide valuable data for this research.

The first phase of the research utilized small scale agitated leach tests using a sulfuric acid solution and an experimental lixiviant. The second phase involved the design and operation of a bench-scale apparatus for testing the effectiveness of ion-exchange recovery of uranium from acid solutions. Although bench scale testing is common in laboratories, it is difficult to find information on how to build and operate a low-cost bench scale ion exchange unit for uranium recovery. The unit constructed and operated for this study utilized commonly available materials, reagents and Dowex 21K XLT resin.

Mobility of Uranium in Desert Sediments and Ground Water under Natural and Anthropogenic Influences, Tuba City, Arizona

Raymond H. Johnson, James K. Otton, & Tanya J. Gallegos: U.S. Geological Survey, Denver, CO

The occurrence and mobility of uranium are being studied in desert sediments and ground water near Tuba City, Arizona, in relation to a landfill with a ground-water plume containing uranium. Solids (dune sand, reworked dune sand, and sandstone bedrock) and ground water were analyzed to determine major element, metal, and uranium concentrations. High concentrations of salts (mainly sodium chloride, calcium carbonate, and sodium/calcium sulfate) consistently occur in caliche horizons in the unsaturated zone, along with slightly elevated uranium

concentrations. Salt concentration zones are typical for desert soils in the arid southwestern United States and are thought to be caused by atmospheric deposition (including wind blown movement of sediments), reactions with local sediments, and concentration due to evaporation. These salts have generally not been associated with uranium in the past because the uranium concentrations are near the crustal abundance. However, the mobility of the elements in these salts (especially uranium) to the ground water under natural and anthropogenic influences is of great concern for people using this water for drinking.

The shallow ground-water geochemistry reflects the influence of these salt zones where much higher concentrations of sodium, calcium, chloride, sulfate, and uranium are found compared to the deeper ground water, which is dilute calcium-bicarbonate water. Dissolved uranium concentrations in the shallow ground waters generally range from 15 to 60 parts-per-billion (ppb) versus the deeper ground waters with less than 5 ppb. However, uranium concentrations in the landfill plume are as high as 250 ppb. We hypothesize that anthropogenic disturbances created conditions favorable for additional salt dissolution, with an associated release of uranium and other metals. During the Tuba City Landfill operations, unsaturated zone sediments and bedrock with high salt concentrations were deposited in waste trenches for use as cover material. This potentially placed salt-bearing materials that had remained unsaturated for thousands of years into an area below the water table. Mobilization of uranium and other elements with distilled water and simulated landfill leachate has been confirmed through leaching of sediments and bedrock in the laboratory.

The mobility of uranium in the contaminant plume emanating from the Tuba City Landfill has very complex geochemistry. Uranium can be mobile under the oxidizing conditions in the surrounding ground water, but is expected to be less mobile in the core of an anoxic landfill plume. Laboratory sorption studies indicate that local sediments and bedrock, containing sand grains with iron-oxyhydroxide coatings, provide a strong sorptive control for uranium mobility, even under oxidizing conditions. Any sorbed uranium is a potential source of contamination which can be remobilized by changes in ground-water geochemistry. A conceptual reactive transport model will be presented as a way to understand the complex geochemical and hydrogeologic controls on uranium mobility in and around the Tuba City Landfill.

Measuring Uranium Binding to Nanoparticulate Ligands in Natural Waters

Emily K. Lesher, James F. Ranville, Bruce D. Honeyman: Colorado School of Mines

Uranium can be released to the environment as a result of mining, milling, disposal, or natural processes. Mobility, bioavailability, and toxicity of uranium contamination are largely controlled by its speciation, or its physicochemical form. While thermodynamic equilibrium constants are known for many inorganic solution complexes, U (VI) may also complex with naturally occurring nanoparticles, organic matter, and/or microbial exudates, for which binding constants are often conditional or nonexistent. This makes speciation modeling difficult and necessitates an analytical technique for measuring binding with species encountered in environmental samples. We have coupled flow field-flowfractionation (Fl FFF), a techniques that separates colloids by their diffusion coefficients, with inductively coupled plasmamass spectrometry (ICPMS), which measures U concentrations in the partspertrillion range. Since a particle's diffusion coefficient can be related to its diameter by the StokesEinstein relationship, we are able to correlate concentrations of U with the associated size fraction.

We will present results of characterization studies of U sorption to synthesized hematite nanoparticles and U complexation with natural organic matter. Results to date show that measurements using Fl FFFICPMS compare well with measurements of partitioning using more traditional techniques. Furthermore, Fl FFFICPMS has advantages over other techniques including a small sample volume requirement (20 µl), fewer measurementinduced artifacts, and applicability to samples containing polydisperse particles. We will also discuss possibilities of using the method to better understand the mobility risks posed at sites where in situ recovery or milling operations occur.

Corrections to the Diffuse Layer Model Database for Uranyl Absorption on Hydrous Ferric Oxide – Ramifications for Solute Transport

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The diffuse layer model (DLM) database compiled by Dzombak and Morel (D&M) in 1990 was developed to quantify the adsorption of dissolved species onto the hydrous ferric oxide (HFO) surface. The D&M database contained numerous metal and metalloid surface-complexation reactions, including two surface complexation reactions for uranyl (UO_2^{+2}). Surface complexes consisted of Hfo_sOUO_2^+ (log K_1^{int} of 5.2) and Hfo_wOUO_2^+ (log K_2^{int} of 2.8). However, the constants were not based upon experimentally-obtained adsorption data, but rather were derived from linear free energy relationships (LFER) of complexation reactions in solution (log K_{MOH} values). When compared to experimental data the LFER derived constants were shown to be in error by a factor of 10 in some cases. Unfortunately, these particular surface-complexation constants have been promulgated through various databases for geochemical modeling programs and have become accepted by numerous regulatory agencies.

Review of available experimental data indicated that at least 14 different uranyl-HFO complexation laboratory data sets have been published by five different research groups. These data sets were re-compiled and used to re-estimate surface complexation constants for the original DLM by coupling PHREEQC based surface complexation models with UCODE_2005 (UCODE), an automated parameter optimization program. Five uranyl bearing surface complexation reactions were finally selected; the constants were optimized by allowing UCODE to incrementally vary selected log K_x^{int} values until the best fit to the experimental data was obtained. To maintain consistency with the commonly used uranyl complexation reactions, the published WATEQ4F.dat database available with PHREEQC was used for this study. Other assumptions consistent with the original DLM assumptions, such as surface site densities and K_{a1}^{int}, K_{a2}^{int} values were not changed.

Surface complexation reactions between HFO and carbonate were also included in the models. Following tenets in the original D&M compilation, only monodendate surface complexes were considered.

The five surface complexation reactions considered occur over overlapping ranges of pH, consequently a step wise fitting process was implemented. Thus, each K_x^{int} was only fitted using the data points and/or data sets which were most applicable for the associated surface complexation reaction. After best-fits were obtained, two additional data sets were added to test the robustness of the fits and resulted in no change to the best-fit parameter estimates. Table 1 summarizes the optimized K_x^{int} values obtained during UCODE fitting and indicates the number of data sets and points available to estimate each surface complexation reaction constant.

Changes to the K_1^{int} and K_2^{int} constants, and addition of uranyl carbonate surface complexes, update and correct the uranyl sorption reactions in this widely used database. These changes have significant ramifications for solute transport models. The previously reported constants, in addition to overestimating retardation under low pH conditions, did not handle the changes in carbonate concentration, which are an overriding factor when dealing with uranium transport in groundwater systems. The importance of including a uranyl carbonate surface complex in transport models will be demonstrated.

Uranium Transport at the Intermediate Scale – Macro-Scale Effects Related to Micro-Scale Process

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Long term stewardship of sites contaminated with radioactive elements requires a modeling construct sufficiently robust to describe contaminant migration over large scales, and long periods of time. However, much of the data collected related to radionuclide migration has been at either the bench scale, to determine fundamental migration behavior, or at the field scale in the course of a performance assessment. Currently, there is an information gap between the bench and field scales; that is, there is little knowledge in how to defensibly up-scale reactive transport models from the bench to the field scales. In this presentation we report on experiments that are taking place at the intermediate scale (between lab and field scales) which are designed to elucidate methodologies to 'link' pore- and field-scale processes. Three intermediate scale tanks (2.44m x 1.22m s 7.6cm, 2.44m x 0.61m x 7.6cm, and 2.44m x 0.61m x 0.61m; LXHXW) have been constructed and three separate packings of uranium contaminated sediment from the Naturita Uranium Mill Tailings Remedial Action (UMTRA) site have been completed. The variables of the interest are: physical heterogeneity in terms of varying arrangements of size separated fractions of contaminated sediment, temporal chemical heterogeneities exhibited by alterations in influent, spatial chemical heterogeneities caused by weathering of the sediment, and dimensionality (2-D vs. 3-D). In the 2-D tanks, samples for uranium and water quality analysis as well as measurements of pressure head were taken through bulkhead fittings installed through the wall of each tank. In the 3-D tank, sampling ports akin to groundwater sampling wells were used. Uranium distribution within all of the tanks was found to vary with local chemical conditions (i.e. pH, alkalinity, dissolved calcium), the rate of release of U from the different particle size categories, the nature of the heterogeneity distribution and dimensionality. The spatial gradients of the major chemical constituents were generally smooth, but were variable both as a function of time and space. In the larger of the 2-D tanks (homogenously packed), effluent uranium concentrations ranged from 7.3 $_{1/4}$OM at early time points, and decreased to ~1.51/4OM as the tank began to exhibit tailing behavior (a period of about 90 days). Effluent concentrations in the smaller 2-D tank (heterogeneously packed) started higher (12.31/4OM) and declined much faster (a period of about 30 days) to ~2.01/4OM. Uranium flux out of the smaller 2-D tank was roughly half that of the larger tank when normalized to hydraulic loading and sediment mass.

Criteria of an Estimation of Uzbekistan Uraniferous Regions

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Geological Modeling of the Coles Hill Uranium Deposit Pittsylvania County, Virginia

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The Coles Hill uranium deposit is hosted in sheared Paleozoic quartzo-feldspathic augen gneisses and amphibolites adjacent to the Chatham fault, at the northwest border of a Triassic half-graben. This fault may have reactivated an earlier shear zone marked by protomylonitic foliation. Uranium mineralization and alteration are within steeply to moderately-dipping brittle fracture zones of uncertain and possibly multiple ages. Uranium mineralization in the unoxidized portion of the deposit mainly consists of coffinite and uraniferous apatite. Extensive zones of alteration surround the ore zones and are characterized by sodium enrichment, potassium depletion, hematization and silica depletion in the outer alteration envelope. Uranium mineralization is associated with chloritization, hematization and silicification.
Marshall Miller and Associates, Inc. generated the Coles Hill three dimensional geological block model with Maptek's Vulcan™ 3D geological modeling and mine planning software, version 7.5. Laboratory assay data for U_3O_8 wt% were available for 80 historic core holes and one new core hole, totaling 55,311 sampled feet and 20,863 samples. Radiometric equivalent U_3O_8 wt% data were available for approximately 230 holes, totaling 180,973 feet of borings.

The geological block model incorporates a basal schist unit, the ore host gneiss unit, the Chatham fault and overlying Triassic sedimentary rocks and the topographic surface. Two main block sizes were chosen to represent the three lithologic units in the model. A maximum block

size of 100x X 100y X 100z (feet) was chosen for the two, non-ore bounding units, while a smaller maximum block size 20x X 20y X 10z (feet) was chosen to represent the main ore-bearing gneiss. The smaller block dimensions were chosen to approximate common underground and open-pit mining block unit sizes.

A variographic analysis was performed to determine directions of ore continuity. Search parameters were chosen based on this analysis as well as from visual inspection of the data. A search ellipsoid was developed with three orthogonal axes as follows: a horizontal axis oriented N30E (strike direction) with a search radius of 250 feet, an axis plunging 40º in a S60E direction (dip direction) with a search radius of 250 feet and a subvertical axis orthogonal to the other two, with a search radius of 50 feet. The selected orientation of the search ellipsoid mimics the strike and dip of compositional layering and a major orientation of brittle fractures in the host rock. Data declustering was performed via an octant search method using eight sample points maximum and two sample points minimum per octant.

Grade shells of 0.20, 0.10, 0.05 and 0.025 wt% U_3O_8 were created. Grade estimations were performed within the boundaries of each grade shell interval using an inverse distance cubed algorithm. Rock volumes and tonnages were computed for each grade shell interval estimated in the model, and additional grade intervals were also selected to report. Demonstrated (within 200 feet of a drill sample) and inferred resource estimations from the model total approximately 124 million pounds of U_3O_8. This is strictly an in-situ resource estimation, with no property restrictions or recoveries applied and no economic evaluation performed.

Discriminating High Natural Background and Contaminant Sources at the Fry Canyon Uranium Upgrader and Copper-Uranium Heap Leach Site, Southeastern Utah, U.S.A.

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Discriminating background uranium (U) concentrations from U contamination is important in establishing the extent of contamination at sites of historic U mining or processing and for assigning reasonable cleanup standards at such sites. The Fry Canyon project site in San Juan County, southeastern Utah, was affected by processing of uranium and copper-uranium ores from 1957-1968. Relict uranium tailings and related pits occupy a bench adjacent to the modern channel of Fry Creek, and a large copper heap-leach pile sits on bedrock just south of this bench.

Bedrock at the site in Fry Canyon, consisting of the Cedar Mesa Sandstone Member of the Permian Cutler Formation (U < 1 ppm), is covered by reddish-brown eolian sand, colluvium, and alluvium. Surface and ground-water samples collected upvalley from the site are Na-H_2CO_3-SO_4 waters that range from 44-70 µg/L U (USEPA drinking water standard for U is 30 µg/L). These high natural background levels may result from the leaching of uranium from the eolian sediments and from mudstones of the Triassic Chinle Formation exposed along the valley walls. Ground water beneath the ponds on the bench ranges from 770-18,700 µg/L U. These contaminated waters become more dilute as they move downvalley and enter the waters and modern alluvium of adjacent Fry Creek, its surface water, as well as the broader, deeper alluvial paleochannel that underlies the modern creek channel and adjacent terraces and benches. Water from monitoring wells at one terrace approximately 0.4 km downstream contains from 380-578 µg/L U. Contaminated surface water ranges from 150 µg/L near the site to ~250 µg/L near the highway bridge 3.3 km downvalley. The increase is likely due to evaporative concentration. Evidence of uranium contamination based on U concentrations can be further confirmed and quantified using U isotope measurements. The $^{234}U/^{238}U$ isotope activity ratios for background water (seven upstream water samples) average 1.235±0.069, and for site water samples (four wells) the average is 0.939± 0.011. Mixing calculations show that the downstream monitoring wells contained 78-87% site-derived U, and in downstream surface water U was ~67% site-derived regardless of the degree of evaporative concentration.

The most U-rich (18,700 ug/L) well water on the site displays distinctive Ca-Mg-SO_4-dominant chemistry, indicating that some uranium may have been derived from heap leaching of Cu-U ores with sulfuric acid. This same water has strongly negative $\delta^{34}S$ of sulfate (-13.3 ‰) compared to most local waters of -2.4 to -5.4 ‰. Stream sediments show dispersion of particulate contaminants; for example, particles of chalcopyrite (CuFeS) and variably weathered pyrite (FeS_2) were identified in tailings at the site and also in stream sediments 1.3 km downstream based on inspection of polished grain mounts of magnetic mineral separates.

The methods used in this study to characterize and trace contamination are applicable at other sites of uranium mining, ore stockpiling, and processing. Measurements of U isotopes can be particularly useful for waters that are marginally contaminated in U compared to natural background (baseline) concentrations or where the presence of uranium-contaminated wastes (uranium ore or mill tailings) is alleged but not established.

Evaluation of Various Ion Exchange Resins for Determining Uranium Groundwater Flux

Valerie Stucker, James F. Ranville, Steven Cabaniss, & Kirk Hatfield: Colorado School of Mines

Ion exchange resins were evaluated for use in passive flux meters (PFM). The PFMs will be installed in uranium-contaminated aquifers to measure groundwater flow by the use of a displaced tracer, as well as the uranium flux through the meter. Resins were tested in the laboratory for maximum adsorption of uranium in various solution compositions and also in contaminated Rifle, CO groundwater. Recovery of uranium from the resins by acid desorption was also investigated. Adsorption studies involved addition of a fixed amount of resin to solutions of variable uranium concentrations. After a 24-hour equilibration time the solution and resins were separated. Percent sorption was determined by difference following analysis of the original solution and the solution exposed to the resin. In order to examine recovery,

which is essential to determining uranium flux, resins were extracted with 1% nitric acid solutions. Uranium analyses were performed by inductively coupled plasma-mass spectrometry and by inductively coupled plasma- atomic emission spectroscopy for other solution constituents. At a pH of 7.3 in synthetic waters, Dowex 21K and Purolite A500 anion exchange resins adsorbed over 99% and 94% of the uranium, respectively. These resins performed equally at 99% in natural waters. Effect of pH on the aqueous uranium speciation has some influence on the adsorption of uranium, but these effects are complicated by the presence of nitrate in the system. A solution acidified by hydrochloric acid showed little to no sorption by anion exchange, which is expected due to the dominance of UO_2^{2+} at the pH examined (3.8). However, pH adjustment with nitric acid showed a similar or reduced amount of sorption when compared to pH 7.3, at similar acidic pH. Acid treatment showed 100% recovery of the adsorbed uranium from both resins. Tracer capacity and cost analysis will be done on these resins before a decision is made regarding the material used in the PFMs. These meters will be a useful tool in determining the effectiveness of the bioreduction of uranium remediation strategies employed at contaminated sites.

Structured Geomembranes in Final Closure Designs

Clark West: Agru America

Geosynthetic – lined slope failures on final cover systems for municipal and hazardous waste cells have been well documented over the past 20 years with many failures of note within the past 3 years - this in spite of known geotechnical reasons for failures and known design methods to avoid slope failures. Many of these failures occur at interfaces with the geosynthetics – most notably at the geomembrane/geotextile interface or geomembrane/soil interface. Early failures in the 1980's prompted some manufacturers to provide a geomembrane with a "textured" surface that increases frictional characteristics and thus increases the factor of safety against sliding failures. However, the most common type of "texturing" manufactured by the blown film co-extrusion process (HDPE and LLDPE) has proven to be less than acceptable in both surface frictional values and quality of sheet (consistency in asperity height, textured surface and cross roll friction values). Deficiencies in quality have led to catastrophic slope failures.

Structured or embossed HDPE and LLDPE geomembranes have been available to landfill owners and designers for over 10 years and their use in final closure designs has been steadily increasing, especially over the past 5 years as owners and designers discover and demand the consistent high quality characteristics of this type of geomembrane due to the unique manufacturing process. This paper will discuss the structured or embossed geomembrane concept and manufacturing process as well as present comparative testing, case histories and failure examples illustrating the major advantages to the implementation of this type of product in landfill closure applications. Both technical and economic advantages will be illustrated with examples of recent cost-effective case history solutions.

This information is very relevant to other industries like mining.

Advances in Uranium Facility Characterization Techniques and Compliance with NRC Regulatory Guide 4.14

Randy Whicker: Tetra Tech, Inc.

Many uranium reserves in the U.S. are currently being evaluated or actively planned for development, including reserves that are suitable for in-situ recovery (ISR) mining. While not specific to ISR considerations, the U.S. Nuclear Regulatory Commission currently recommends following NRC Regulatory Guide 4.14 protocols (as outlined for conventional uranium mills) to provide acceptable baseline characterizations and operational monitoring programs as part of ISR licensing/permitting applications. This presentation highlights advances in certain radiological characterization approaches that have recently been developed and implemented at conventional uranium mills as well as multiple proposed ISR sites. Although some aspects of these approaches exceed minimum Regulatory Guide 4.14 specifications, additional up-front costs are not prohibitive and overall benefits to licensees, regulators and public stakeholders alike are expected to easily outweigh such costs in a context of long-term economic, environmental, and health and safety considerations.

Effects of Uranium Mineralization and Historical Uranium Mining on Water Quality and Stream Sediment Chemistry: Results of a Regional Geochemical Survey West of Denver, Colorado.

Robert A. Zielinski, James K. Otton, & R. Randall Schumann: U.S. Geological Survey, Denver, CO

The Colorado Front Range west of Denver includes numerous historical mining districts of base and precious metals that date back to the late 19th century. Uranium (U) is a commonly associated element in the vein-type sulfide ores and, at some locations concentrations were sufficient to support small amounts of historical U production, particularly in and around the Central City area. More substantial vein-type U deposits were discovered after 1950 in areas closer to the mountain front and outside the former metal-mining districts. One of these deposits, the Schwartzwalder, is the largest vein-type U deposit in the United States, having produced approximately 20 million pounds of U_3O_8.

Upon consideration of the number of U-enriched deposits, the identification of U-rich drainage from some metal mines, the proximity of some U deposits to streams, and the large downstream population in metropolitan Denver, the U.S. Geological Survey conducted sampling of U and other elements in 82 streams and 87 stream sediments in the Clear Creek drainage and surrounding areas in October, 1994. Interpretation of the spatial-chemical data for these waters and sediments indicate (1) aqueous processes that control the mobility of dissolved U and other elements, (2) the mode of occurrence of U in sediments, (3) lithologic and anthropogenic controls on the spatial distribution of U

in the study area, and (4) effects of U on water quality and aquatic life. The results provide an important basis for comparison with more recent measurements of surface-water quality by other agencies and private groups. Such comparisons document the effects of ongoing cleanup of abandoned mines and mine wastes.

Dissolved U concentrations range from less than 1 to 65 µg/L and, at the circum-neutral pH of these streams, U occurs predominantly as U(VI) complexes with dissolved carbonate. Dissolved U concentrations are limited by sorption reactions and all sampled stream waters are greatly under saturated with U minerals.

The fine-grained (<0.09 mm) fraction of stream sediments contains 5–50 µg/g U and hosts greater abundance of relatively insoluble U-bearing accessory minerals such as zircon and apatite. Secondary ferric oxides that coat grain surfaces are ubiquitous U hosts and can incorporate additional U by sorption. In areas underlain by Precambrian granitic and metamorphic rock, insoluble U-bearing minerals and strong sorptive uptake of U produces relatively U-rich sediment, but low U concentrations in stream water.

Streams that drain heavily mined areas with local U-rich acid mine drainage do not contain particularly high concentrations of dissolved U. This indicates dilution of acid drainage and (or) uptake of dissolved U by adsorption to stream sediments. Fine-grained sediments collected from Ralston Creek at sites downstream from the Schwartzwalder U mine have locally anomalous concentrations of U and contain rare particles of uraninite and radium-bearing barite that are the products of mining-related activities. Slow dissolution of such particles contributes dissolved U and radium to Ralston Creek.

With three exceptions, concentrations of dissolved U in the sampled streams are below the USEPA drinking-water standard of 30 µg/L, and all dissolved U concentrations are well below locally applied aquatic-life toxicity standards. Concentrations of U in stream sediments are also below a proposed aquatic-life toxicity standard for sediment of 100 µg/g. Natural processes of dilution and sorption have apparently limited the environmental impact of U mobilized by metal mining.

Genetic Classification of Uranium Deposit Types

Philip Goodell: University of Texas El Paso, Fares Howari: University of Texas at Austin, Abdelaty Salman: Nuclear Materials Authority

Many uranium deposit type classifications have been proposed. Uranium is found in many geologic environments, and since countries have different geologic endowments, countries report exploration and production successes from different geologic sources. Classification usage has converged on the IAEA classification, first used in 1988, based on total production reported from different deposit types to the IAEA, and lacking USSR and China data. Usage of the IAEA classification continues today and is convenient. Class #15, Other, contains 7 items, illustrating the ackwardness of the classification.

Proposed here is a genetically based reclassification of uranium deposits. Prior recognized deposit types are reordered into a smooth sequence of reasonable geological and tectonic events and locations.

The greatest insights of the present work are in organizing various IAEA deposit types into an integrated model of intracratonic behavior and characteristics.

Cratons are characterized by older stable blocks and repetitious mobile belts. The boundaries of such regions are most important. Some stable blocks or fragments appear slightly thicker at their boundaries. Is this because of Wilson Cycle thickening of stable blocks at their edges, or because of the presence of some unusual, enriched, cratonic fragment? Does the enrichment of an unusual cratonic fragment extend into the mantle?

Thermal upwelling superimposed upon a Stable Block/Mobile Belt boundary (SB/MB) with an enriched cratonic/mantle? fragment on the SB side may be the primary origin of uranium in the crust. (Large Igneous Provinces (LIPs) of oceanic character, change to include Silicious Large Igneous Provinces (SLIP) in the craton.) Thermal upwelling at a SB/MB boundary can produce anatexsis, metasomatism, magmatism, pegmatites, contact metamorphism, and hydrothermal processes. These may be present in the margins and extended crust of the stable blocks, and in isolated granitic/gneissic blocks within the mobile belt. Diatremes of deeper origin may be present in the mobile belt, such as carbonatites. IAEA classifications/deposit types of magmatic affiliation , granites and in addition to all 7 otherwise unrelated deposit types grouped in Other, all fit reasonably into this model.

Volcanogenic uranium deposits have been updated from an earlier model. Upon the release of geologic knowledge from Russia and China, it was realized that before 1995 most Chinese production and after 1990 most Russian production came from the volcanogenic environment.

Sedimentary uranium deposits are reorganized sequentially from surface deposits through continental sedimentary basins, basal conglomerates, and into the metamorphosed basement. Now, instead of having two IAEA classes, the two shallow marine facies which sometimes have uranium enrichments, actually lie adjacent on the floor of the shallow shelf. Air fall and ocean transport from SLIPs can now suggest an explanation in the variability of uranium concentration in these environments.

The present effort places the IAEA uranium deposit types into geologically related sequences. No prior integrated relationships have been suggested for magmatic hosted deposits. Thermal upwelling and an extensional regime superimposed upon stable block/mobile belt boundaries is proposed here as the regional tectonic setting. This may be categorized as post compression relaxation.

The better understanding of uranium geochemistry and tectonics may lead to better exploration success.

Natural Gamma Log Processing for Equivalent Uranium Grades

Smith, Mark S. and Newton, M. Claiborne, III: Marshall Miller and Associates, Inc.

The Coles Hill uranium deposit, in Pittsylvania County, Virginia, is being explored by Virginia Uranium, Inc. (VUI). In November 2007, Marshall Miller & Associates, Inc. (MM&A) was retained by VUI to perform geophysical logging, data processing, and three dimensional resource modeling and to assist in preparation of a Canadian NI 43-101 report. This poster discusses the methodology of geophysical log processing performed by MM&A.

MM&A was supplied by VUI with historical data on about 230 drill holes. These data consisted of geological logs and cross-sections, downhole analog geophysical logs, laboratory assay data for 80 core holes and partial downhole orientation survey (drift) data. Historical natural gamma logs, typically recorded along with spontaneous potential and resistivity downhole measurements, were run by Minerals Service Company (MSC) and Century Geophysical Corporation (Century) in boreholes for the Marline Uranium Company from 1977 to 1984. The MSC and Century logs were hard copies of either digital or analog recordings of total natural gamma radiation. The hard copy logs were digitized to acquire natural gamma values to be used in ore grade equivalency calculations. The geophysical logs were first scanned into tiff images and then digitized via software such as Neuralog™, with digitized points on the curves reported every 0.5 feet. The data were recorded in LAS (log ascii standard) format. Additionally, three new drill holes and four old drill holes were geophysically logged by MM&A in 2008 utilizing Century Geophysical digital logging systems. The combined historical and new logs totaled 180,973 surveyed feet of exploration borings.

The natural gamma values were converted to radiometric equivalent U_3O_8 wt% grade by MM&A using the appropriate water factor, casing factor, digitizing scaling factor, uranium equivalency ("K") factor and probe dead time. Each of the 230 historic logs was reviewed individually and the appropriate factors for each hole and probe combination, and the depths to apply them, were tabulated. These factors were then used in converting the digitized natural gamma counts to equivalent U_3O_8 wt% grade. The water factor is a correction for the attenuation of natural gamma radiation due to fluid in the hole and is applied from the top of the water column in each hole to the bottom of the hole. The casing factor is a correction for attenuation of gamma radiation due to traveling through casing and can be significant for steel casing but is negligible for PVC casing. This correction is a function of casing thickness and is applied only to the cased portion of each borehole. The K-factor and dead time are specific to each probe and can be determined by calibration at U. S. Department of Energy (DOE) model test pits designed specifically for this purpose. The historic MSC and Century logs recorded the K-factor and dead time for each probe and these were utilized as reported on each log. To determine the appropriate K-factor and dead time of each of its probes used, MM&A calibrated the probes at the DOE model test pits TH and TL located at George West, Texas.