Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2014)

Summary of an International Symposium
Vienna, Austria, 23–27 June 2014

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URANIUM RAW MATERIAL FOR THE NUCLEAR FUEL CYCLE: EXPLORATION, MINING, PRODUCTION, SUPPLY AND DEMAND, ECONOMICS AND ENVIRONMENTAL ISSUES (URAM-2014)

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PROCEEDINGS SERIES

URANIUM RAW MATERIAL FOR THE NUCLEAR FUEL CYCLE: EXPLORATION, MINING, PRODUCTION, SUPPLY AND DEMAND, ECONOMICS AND ENVIRONMENTAL ISSUES (URAM-2014)

SUMMARY OF AN INTERNATIONAL SYMPOSIUM
ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND HELD IN VIENNA, 23–27 JUNE 2014

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Marketing and Sales Unit, Publishing Section
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Vienna International Centre
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fax: +43 1 26007 22529
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FOREWORD

This International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2014) was the fourth in a series of symposia to discuss issues related to uranium raw materials. These symposia covered all areas of the uranium production cycle — including uranium geology, exploration and mining; milling and refining of uranium concentrates; and safety, environmental, social, training and regulatory issues — and reported on uranium supply and demand, and market scenarios. The first symposium was held in October 2000, at a time of extremely depressed market prices for uranium and of mines being closed, and primarily addressed environmental and safety issues in the uranium production cycle. By the time the second symposium was held in June 2005, after nearly two decades of depressed activity, the uranium market had started to improve owing to increased demand due to rising expectations of an expansion of nuclear power. Thereafter, a dramatic rise in the uranium spot price, peaking in 2007, promoted a significant increase in uranium exploration activities all over the world. The uranium industry was still quite buoyant at the time of the third symposium in the series, held in June 2009.

By the time URAM-2014 was organized, the uranium spot price had fallen and uranium exploration had slowed. Some proposed mines were still being opened while the development of others was being postponed. Thus, the papers represent yet another snapshot in time, reflecting the cyclical nature of the uranium exploration, mining and production industry.

URAM–2014, held in Vienna on 23–27 June 2014, saw the participation of over 250 experts from over 60 Member States. About 90 oral presentations spread over 14 topical sessions covered all aspects of uranium production cycle, with additional special sessions on uranium from unconventional resources and recovery of thorium and rare earths. About 80 posters were also presented. Even though uranium markets were down to a ten year low at the time of the symposium, the meeting demonstrated that the uranium industry was taking the lead in developing innovative exploration and production solutions expected to keep the costs low while achieving high health, safety and environmental performance. New initiatives like innovative financing, ‘smart mines’, integrated exploration and ‘wealth from wastes’ were discussed extensively at the symposium. Other issues discussed included the need for priority attention to social licensing and stakeholder engagement; systematic and ongoing investment in uranium exploration; the rollout of new technologies across the uranium production life cycle; the need to focus on sustainable recovery of low cost resources; mobilization of scientific and intellectual capital; and the refined taxonomic classification and reporting systems.

The present publication constitutes the record of the symposium and includes the summaries of the individual sessions, the opening address, a summary of the panel discussion, the closing keynote addresses and the symposium president’s concluding remarks. The technical papers based on the oral and poster papers are available on the accompanying CD-ROM.

The IAEA acknowledges the contributions of the experts who participated in the pre-symposium consultancy for evaluation and selection of papers for oral and poster sessions and outlining of the symposium programme. The IAEA officers responsible for this publication were P. Woods, H. Tulsidas and M. Fairclough of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

SUMMARY

1. INAUGURAL SESSION

The opening session provided the opportunity to set the scene for the 14 technical sessions that would follow during the symposium. In his welcoming address, J.C. Lentijo, Director of the IAEA's Nuclear Fuel Cycle and Waste Technology Division, reminded delegates of the changes in the uranium sector since the optimistic times of the previous URAM symposium held in 2009 [1]. The sustained downturn in the uranium price has had profound effects on the uranium mining and milling industry, which could have two major mid- and long-term implications. Firstly, the industry may not be ready for increased demand for uranium if the nuclear energy scenario improves in future, as is expected, and current apparently surplus stocks are gone. Secondly, the industry must resist increasing financial pressure and maintain the good standards and practices that have been gained during the past decades. The uranium industry has been successful in the past couple of decades when it has become a champion of good practices, and has been a leader in adopting good practices and coming up with innovative solutions. It has become very resilient to these issues and must continue to do so.

The President of the Symposium, M. Cuney (France), then welcomed all the participants and commented on the broad international participation and high number of oral and poster papers. This year a wider range of topics is included compared to the previous URAM–2009. The long-term sustainability of nuclear power will depend on, among several factors, an adequate supply of uranium resources that can be delivered to the marketplace at competitive prices. To discover increasingly hard to find U deposits, generally at greater depth, a better understanding of the genesis of uranium ores and more sophisticated exploration technologies will be required. This meeting allows exchange of ideas and allow participants to take home some of the information they need to fulfil these challenges. Mr Cuney also paid tribute to the president of URAM–2009, the late Franz Dahlkamp (1931–2013), a world-recognized leader in uranium geology, supporter of IAEA's endeavours and friend and mentor to many in the field.

Scientific Secretaries P. Woods and H. Tulsidas of the IAEA added their welcome and appreciation of the efforts of the President, Programme Committee and IAEA Secretariat in bringing the symposium into fruition. Collaboration within the IAEA and some of its other activities in the uranium production cycle was highlighted.

In the first keynote speech, I. Leboucher[1] (France) spoke on the uranium and nuclear market, the horizon post-Fukushima. Notwithstanding the Fukushima accident, most countries have confirmed the importance of nuclear in their energy mix. We are seeing a level of new reactor construction unparalleled in decades with 61 nuclear power plants under construction and five plants under completion around the world. Further additions can be expected over the next two decades. The uranium industry is still grappling with near-term challenges, particularly in the form of depressed uranium prices. Recently several uranium producers announced production delays or cancellations in response to low prices, including major suppliers. As the current price levels, including long-term prices, are not sufficient to stimulate new production, future supplies are in question due to the long-lead nature of uranium mine development. Despite the near- to medium-term issues of our industry, the fundamentals of the uranium market remain strong over the long term. Utilities are looking for reliable, sustainable suppliers. For France's Areva, these are the drivers of the company's mining growth strategy over the coming years.

[1] On behalf of F. Lelièvre who was listed in the programme.

S. Foster of the Sustainable Energy Division of the United Nations Economic Commission for Europe (UNECE), in cooperation with the IAEA for this event, spoke of the UNECE's efforts to harmonize the world-wide reporting of energy resources including uranium [2], and the importance of security and sustainability of supply for the nuclear power industry.

The Organization for Economic Co-operation and Development–Nuclear Energy Association (OECD–NEA) was another cooperating organization for URAM–2014. R. Vance gave an overview of the NEA's activities in the uranium production cycle, in particular the imminent publication of the NEA–IAEA joint biennial 'Red Book', Uranium 2014: Resources, Production and Demand [3] and the recent release of its 'Managing Environmental and Health Impacts of Uranium Mining' report [4]. He commented that secondary supplies are still potentially available from historic highly enriched uranium stockpiles, and on the diverse and sometime contradictory trends that influence both supply and demand for uranium as a nuclear fuel.

Closing the opening session I. Emsley of the World Nuclear Association (WNA), the third cooperating organization for the symposium, outlined WNA's activities in the uranium production cycle. For utilities, security of supply is paramount in their consideration of uranium supply. The WNA provides a daily news service and many other publications, as well as holding symposia and conferences. It has developed, with its members, a sustainable development checklist that was presented later during the symposium.

2. SESSIONS 1 AND 2: URANIUM MARKETS AND INDUSTRY

Seven papers presented in this session discussed various aspects of uranium markets and the dynamics of demand and supply. The first paper on uranium supply to 2060, based on an ongoing IAEA study on the topic, discussed various scenarios for nuclear energy growth to 2060, demand for uranium fuel and production sources and projects in pipeline. Three demand cases projected the reactor uranium requirements — the reference scenario projects a 1.8% per year growth in nuclear power capacity; the high demand scenario assumes a 2.4% per year growth; and the low demand scenario projects negligible growth. The global uranium resource estimates and production plans were reviewed and it was concluded that the existing uranium resources will not constrict the use of nuclear power in the next half century.

Since the mid-1960s, with the co-operation of their member countries and states, the OECD Nuclear Energy Agency (NEA) and the IAEA have jointly prepared periodic updates (currently every two years) on world uranium resources, production and demand, commonly known as the 'Red Book'. The second talk in the session emphasised that uranium spot prices have declined by about 50% since the Fukushima accident. The early retirements and the prolonged shut-downs of some nuclear power stations led to an oversupplied uranium market, putting further downward pressure on uranium prices. The talk presented details of projections of nuclear generating capacity and mine production, which have been significantly scaled back from previous projections in the Red Book.

World Nuclear Association (WNA) publishes Nuclear Fuel Market Report on a regularly. The next talks summarized the demand scenarios of three capacity projections based on the outlook for existing and new nuclear countries. Uranium resource estimations are taken from the Red Book and the prospects for new and existing mines assessed on a site-by-site basis. Both prospective uranium requirements and primary uranium supply have decreased since the previous 2011 WNA report, the latter markedly so from the mid-2020s. Secondary supply is projected and expected to remain high to 2030. Increased uranium market uncertainty has resulted in the cancellation and deferment of a number of mining projects. As a result, the existing and expected capacity plus secondary supply will be insufficient on current plans to meet reference scenario requirements by about 2024.

The next talk summarized dynamic of the mining industry to respond of the need of the market to explore and discover new deposits. For the first time in the uranium industry, the effort was conducted not only by the established mining companies but by more than 800 ‘junior’ mining companies. These companies have introduced new methodologies, innovations and fresh approaches to uranium exploration. They discovered new deposits, transformed historical resources into standards-compliant resources and reserves. New large resources were developed in Africa, North America and Australia. However, new production from this effort still limited to less than ten percent of the global production. It is also essential that follow-up feasibility studies must confirm the resource quality and viability of profitable mining.

There are currently 28 nuclear power plants under construction in China. It will be therefore very significant to understand the nuclear growth scenarios and resultant uranium demand from China. The next talk pointed out that most the new nuclear plants will be put into operation sequentially in the next few years. China follows a three-pronged approach to ensuring the supply of uranium. Domestic production is seen as one of the channels to meet the increased requirement. With the intensive exploration in northern China focused on sandstone type of uranium deposits, some significant resources were discovered in recent years. Development of overseas uranium resources is another channel to supply, which is being actively developed by China. Many properties have been acquired by national Chinese companies in Australia, Niger, Kazakhstan, Namibia and Mongolia. Purchasing uranium in the market is the third option considered. China has been doing uranium trade for many years and signed many long-term contracts with uranium production entities.

The World Nuclear Association (WNA) has developed internationally standardized reporting (‘Checklist’) for uranium mining and processing sites. The talks on this topic suggested that this reporting is to achieve widespread utilities/miners’ agreement on a list of topics/indicators for common use in demonstrating miners’ adherence to strong sustainable development performance. The Checklist has been developed to align with the WNA’s policy document Sustaining Global Best Practices in Uranium Mining and Processing: Principles for Managing Radiation, Health and Safety, and Waste and the Environment [4] which encompasses all applicable aspects of sustainable development to uranium mining and processing. The Checklist benefits from many years of nuclear utility experience in verifying the sustainable development performance of uranium mining and processing sites. This Checklist is therefore not new and directly aims to share a common list with a view to standardize this reporting between utilities and miners at the international level.

The last talk in this session summarized IAEA’s efforts to improve the geological classification of uranium deposits. In 2009, a working group was created by the IAEA in order to review the various existing classifications and to propose a new or a modified classification to be used internationally. Since 2005, a number of publications and company data became available. This provided a wealth of new information on uranium deposit geology that has been used to revise the classification. The previous IAEA classification, used in particular in the 2012 version of the NEA/IAEA Red Book, dates back to 1993. At that time, only 582 uranium deposits were recorded in the IAEA UDEPO Database. At the end of 2013, 1525 uranium deposits were listed in the database. Fifteen types of deposits have been suggested in the currently revised IAEA classification scheme.

3. SESSION 3: EDUCATION AND TRAINING IN URANIUM PRODUCTION CYCLE

Three papers were presented on this theme. First the IAEA’s experience in large Inter-Regional Technical Cooperation Projects over the last five years was explained. These projects have involved over 40 Member States. The major aim is to address gaps in transferring a coherent body of knowledge on sustainable uranium production from a well experienced generation of experts to a new generation facing similar challenges in different geographical, technological, economic and social contexts. These projects focused on enabling the new practitioners in the uranium production industry to avoid the mistakes of the past and to apply good practices established elsewhere, adapted to local needs.

Human resource development for uranium production cycle was then discussed. It was pointed out that the hubs of growth of nuclear power have shifted from North America and Europe to Asia. Radiological safety is of paramount importance, and human resources development remains a challenge as many of the experts in the area are retiring and not many replaced by a younger generation. Based on some years of experience at the IAEA and in India the speaker recommended new courses that are required around the world to support the uranium production cycle.

The final talk emphasized the role of networking as a tool to improve education and training in environmental remediation of uranium mining and processing sites, and in particular the ENVIRONET and broader CONNECT initiatives of the IAEA. CONNECT is an online collaboration platform hosted by the IAEA on behalf of its Member States that provides a gateway for interconnecting existing (such as ENVIRONET) and planned IAEA Networks. With the full use of the CONNECT platform opportunities e-learning materials and educational videos will be made available, to complement the collected technical documents on technologies, case studies and IAEA guidance. Participants of URAM were invited to get in touch with these tools and contribute with their experience to expedite the remediation of existing legacy sites and disseminate the so-called good practices to avoid the generation of new contaminated sites.

4. SESSION 4: HEALTH, SAFETY AND ENVIRONMENT[2]

This was a well-supported session, reflecting the importance of health, safety and the environment to the modern uranium production cycle. Nine papers were presented, starting with a world-wide perspective then considering case studies from three continents.

Public support, perception and risk

Public support is critical to development of the uranium industry including aligning mining project developments with regulatory processes and achieving social-economic-environmental deals.

Useful proposals for the way forward included:

- Operators seeking upfront public input (especially interests and concerns) on their proposed mining projects;
- Accounting for public input in project development with a view to gaining and maintaining support;
- Reaching a social-economical-environmental deal with local and critical stakeholders.

For enhanced public support and trust, key issues that were highlighted include:

- Transparency in mining deals; applicable treaties, and land rights;
- Fairness in mining royalties and taxation systems;
- Benefits to local communities.

[2] Adapted from notes provided by the chairs, V. Guthrie and S. Saint-Pierre

It is critical to communicate the **risk** but manage the **public perception** — these are two very different approaches to public information and both are required to be successful. Involving the community in understanding the baseline is a useful way to overcome negative perceptions particularly around radiation.

Poor performance from the nuclear industry globally can affect all uranium mining developments.

When communicating with the community one needs to be aware of and concerned with the community's primary concern — even if this is not associated with the mining activity. As an example, at the Mkuju River deposit, Tanzania, concerns included the clothing business, elephant poaching and World Heritage Status.

Environmental assessment

Making complex technical information and risk seem simple and understandable to critical to successful communication; e.g. the discharge of tailings at McClean Lake mill and complex geochemistry in lake waters in Canada.

Environmental Impact Assessment (EIA) is moving from prescriptive approach (inflexible, concise, not site specific) to risk-based approach (with an importance/likelihood analysis).

Environmental Risk Assessment (ERA) is a matrix approach that is applied to the full life cycle at the site level. This system can be used irrespective of where the site is located.

Regulation and government in relation to mine closure and post-closure

Saskatchewan's registry of mines provides for institutional control of closed operations, taking a 'tending the cemetery' approach, such that the end point of liability and costs can be defined. This is a new model for the rest of the uranium mining jurisdictions to consider following.

A government's approach to historic uranium mine clean-up is also critical to improving public perception and trust around future operations

Simplifying regulation for new jurisdictions to follow is critical to supporting the development of the uranium industry. In particular, removing the overlap and duplication of regulation within each layer of government is the best starting point. Further useful aspects include establishing new regulations for key issues such as decommissioning plans and initial funding prior to allow new mining operations. There must be sufficient attention paid to the long-term stability and confinement of decommission work, which may be assisted by reference to current best practice regulation in operating jurisdictions.

Key issues/lessons learned

- Pay great attention to public support through shaping and developing uranium mining projects which account for public interests and concerns;
- Communicate the risk but manage the public perception;
- Do not 're-invent the wheel' in regulation — look to other jurisdictions for best practices in regulating and controlling mine closure and post-closure;
- Note that poor performance from the nuclear industry globally can affect all uranium mining developments — including historic performance and the approach to managing the clean-up and costs today.

5. SESSION 5: SOCIAL LICENSING IN URANIUM PRODUCTION CYCLE[3]

The session commenced with a paper which explained product stewardship and its applicability to the nuclear fuel cycle. The focus was how to both show current performance of the industry and also to encourage and communicate future improvements in health, safety, environment and community performance. Questions were raised about the relationship to nuclear safeguards and how product stewardship can be implanted in practice.

The next paper by described the path that Namibia had taken to develop a whole of sector approach to the management and regulation of uranium. Some high points included the development of a method to look at the cumulative impact of the number of discrete mining companies and how to use a combination of regulation and alternative mechanisms (such as the stock market) to encourage, support and regulate the performance of the miners and explorers. During questioning there was some interaction with respect to the maturity of the approach in comparison with the emerging aspects in Tanzania which were discussed in the previous session.

The relationship between geology and government with respect to a deposit becoming a viable mining operation was then presented. Although "Grade is King" was the focus of the geological component, there was substantial material on the political aspects required for an operation to develop and get the uranium out of the ground. By using comparison of a range of different factors which partially determine the potential success of an operations development, he examined the attractiveness of a range of countries for uranium development. Discussion was around the grade aspects with respect to Canada but also on the importance of a range of other factors in determining the success in developing a resource.

The historical and current performance of uranium mining and the importance of improvements, and the communication of these improvements to stakeholders were then discussed. The recent publication of the OECD—NEA MEHIUM report [4] on environmental and health impacts was discussed and examples shown of the performance. During discussion the audience was encouraged to download the report and details were provided of how it can be downloaded on a mobile phone.

The final paper was a more detailed technical paper on the specifics of solvent extraction for uranium recovery. This paper was originally scheduled for Session 11, and showed the importance of good control within solvent extraction systems particularly to allow sufficient rejection of trace elements.

6. SESSION 6: EVALUATION OF URANIUM RESOURCES

Seven talks in this section summarized current understanding on uranium resource estimation, classification and assessment. The first talk was on Wiluna Uranium Project, the first uranium mine in Western Australia to receive Government environmental approvals since government policy was changed in 2008 to allow uranium mining there. During the four years it has taken to gain environmental approval, the operator, Toro Energy Limited also progressed technical studies to validate the economic and technical viability of the Project. These included the initial Preliminary Feasibility (PFS) to define the processing train; mining optimization studies, a Resource Evaluation Pit (REP) and a commercial scale Pilot Plant to verify the mining and processing technologies; and finally, Phase 1 of the Definitive Feasibility Study (DFS) which focussed on the processing plant design.

In India, uranium and REE mineralization hosted by the Proterozoic migmatites and younger intrusives is identified over 350 km^2 in Son Valley area, Sonbhadra district, Uttar

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[3] Adapted from notes provided by the chairs, F. Harris and W. Swiegers

Pradesh. Extensive exploration carried out has established a potential province in the terrain for U, Nb-Ta and REE mineralization with complex metallogeny associated with the evolution of migmatites. Three major types of uranium mineralization are identified based on the host-rock characteristics, viz.: (a) Pegmatoid Leucosome Mobilizate (PLM) and Biotite Melanosome (BMM) hosted mineralization; (b) Potassic granite/episyenite hosted mineralization; and (c) Magmatic Pegmatite hosted mineralization. The present geological milieu in the Son Valley area has the imprints of repeated thermal, tectonic and metamorphic reactivation.

The talk on international standardization for the reporting of resources and reserves discussed the current trend towards tighter corporate governance and regulation demanded an international standard to 'good practice' in mineral reserve management as well as high standards of public reporting by responsible, experienced persons. In 2006, CRIRSCO (Committee for Mineral Reserves International Reporting Standards) released an International Reporting Template, the purpose of which is to assist with the dissemination and promotion of effective, well-tried, good practice for public reporting of Exploration Results, Mineral Resources and Ore Reserves already widely adopted through national reporting codes and standards.

Uranium resources are reported regularly by the biennial OECD–NEA/IAEA Red Book, which uses a unique scheme where different categories based on geological confidence and the expected cost of recovery. Resources reported in this report are based on national reports where the numbers are aggregated by many diverse schemes. Therefore, it will be worthwhile to know how the resources aggregated in national levels compare to each other, so that the numbers are universally understood and accepted. The United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC–2009 [2]) is a project-based system that applies to all fossil energy and mineral reserves and resources. A bridging document between NEA/IAEA and UNFC–2009 has been developed to explain the relationship between these two systems and provides instructions on how to classify estimates generated by the NEA/IAEA scheme using UNFC numerical codes. Application of UNFC–2009 is expected to support the accurate and transparent management of resources throughout the uranium production life-cycle.

The talk that followed was a case study on development of a database for mineral potential modelling and quantitative resource assessment based on data from roll-front uranium occurrences of the South Texas Mineral Belt, USA. The U.S. Geological Survey is conducting a quantitative assessment of roll-front uranium resources in the South Texas Mineral Belt using geospatial mineral potential modelling and 3-part assessment methodologies. The objectives are to: (i) delineate permissive, favourable, and prospective tracts; (ii) estimate the number of undiscovered deposits; and (iii) estimate the resource endowment of each tract. A roll-front uranium resources database has been compiled for the assessment detailing occurrence location, size, operation type, uranium production and resources, and host unit. The database contains 253 occurrences, including 165 deposits (sites with recorded production or resources), 75 prospects (sites with some level of exploration), 6 showings (sites of interest that have been investigated), and 5 anomalies (sites with indications of mineralizing processes).

The case study on geological 3–D modelling and resources estimation of the Budenovskoye uranium deposit, Kazakhstan followed, highlighted updated uranium resource estimates, which recorded significant increase in total uranium resources tonnage in Karartau and Akbastau. The resources estimation methodology is based on GT (grade × thickness) modelling as a main parameter. This improved resource estimation approach is expected to have a significant positive impact on the project.

The significance of project management to uranium projects was discussed in the next talk. Uranium projects, like most other mineral commodities, have a critical 'to do list' which is part of project feasibility studies. Understanding the complexities of the deposit geology and the application of this to mining and processing is necessary for determining optimum mine design. Ensuring effective management of the human resources, product marketing, and resolution of environmental, community and legal issues are other major aspects to be carefully considered. These all contribute to the effective management of shareholder capital and helps create the growth in value required to support the next phase in the development.

7. SESSIONS 7 AND 12: ADVANCES IN EXPLORATION AND URANIUM MINERAL POTENTIAL MODELLING

Advances in exploration and uranium mineral potential modelling were presented in 10 talks in two sessions. The first presentation put forward a genetic model for roll-front uranium deposits in the Gulf Coast Uranium Province, Texas, USA. The model suggests rhyolitic volcanic ash beds interbedded with host sandstones as the uranium source and uranium transport by hydrologically and precipitation controlled by oxidation gradients. Important deposit clusters are found within large, permeable palaeochannel systems, and other deposits are controlled by facies variations in ancient barrier bar systems. There is localized association of uranium deposits with off lap sequences caused by lowered sea level that rejuvenated groundwater flow, and increased erosion and oxidation depths. Most deposits appear to be controlled by extrinsic reductants that seeped upward from underlying gas fields. Other economic deposits are found associated with intrinsic reductants, in the form of organic-rich reduced sediments that interfingered with the palaeochannel and barrier bar systems.

Recent exploration progresses on sandstone-hosted uranium deposits in north-western China was presented next, and discussed metallogenic target selection using multiple exploration techniques and drilling program. In the Yili basin, the integrated exploration techniques of detailed sedimentary facies study, radon survey, high-precision magnetic and soil geochemical and seismic surveys have been successfully located potential targets and mineralization zones. In the Ordos Basin, an ‘energy basin’ with coal, oil and gas and uranium deposits, new metallogenic targets have been selected and progress made to increase reserve/resources in Nalinggou and Daying deposits. It has been observed that greenish sandstone is due to chlorite alteration by secondary reduction process related to oil and gas and can be used as an indicator for uranium mineralization.

The following talk presented novel geochemical techniques for integrated exploration for uranium deposits highlighted the use of geochemistry in detecting uranium deposits at depth, where the techniques include: (i) integration of geochemical with geophysical data to refine targets; (ii) element distributions in and around deposits to adequately assess the total chemical environment associated with the deposit; (iii) the use of element tracing using elemental concentrations and isotopic compositions in the near surface environment to detect specific components that have migrated to the surface from uranium deposits at depth; and (iv) understanding the effects of both macro- and micro-environments on element mobility across the geosphere-biosphere interface to enhance exploration. All of the processes that operate to produce geochemical anomalies at the surface above unconformity-related deposits are applicable to all other types of uranium deposits and should be integrated into learning curves for effective exploration of uranium.

The mineral systems approach for mineral potential assessment of uranium deposits presented probabilistic concepts to mineral deposits, was then presented, where the probability of an event (formation of a mineral deposit) is conditional on factors such as: (i) geological processes occurring in the area; and (ii) the presence of geological features indicative of those process. Moreover, mineral deposits can be conceptualized as mineral systems with emphasis on mineralizing processes. Mineral systems are defined as “all geological factors that control the generation and preservation of mineral deposits”. Seven important geological factors and five questions as a basis to understand spatial and temporal evolution of a mineral system at different scales were discussed in this talk.

A talk regarding forecasting sandstone uranium deposits in oil-and-gas bearing basins of the Fergana depression, Uzbekistan was next, providing a good example for understanding the dual role of hydrocarbon fluids and the products of their dissolution. Firstly, bituminization of permeable strata as well as pyritization, chloritization, dolomitization and other alterations associated with it create favourable geochemical conditions of a reducing character for a subsequent concentration of ore and non-metal raw materials. Secondly, the intrusion of bitumen and its dissolution in the aeration zone leads to the burial of the mineralization which formed earlier and disappearance of all traces of its formation. The comparative analysis of the sequence of multidirectional epigenetic alterations in sedimentary basins is necessary for forming the overall picture of uranium ore genesis complicated by the intrusion of various reducing agents.

The next talk presented recent updates on uranium exploration focused on the Dornogobi Province, Mongolia, in the Uneget and Zuunbayaan sub-basins, in which two deposits have been discovered recently: the Dulaan Uul and the Zoovch Ovoo deposits. Zoovch Ovoo deposit with 56 500 tU of uranium resources at 223 ppm U is a world size deposit discovered during the last decade. It is a major high tonnage low grade sedimentary-hosted roll front type deposit. It consists of a complex system of partly over-imposed elementary sub-rolls of irregular shapes that built a quite atypical sub-massive tabular looking ore body.

Drill site selection processes in the Keefe Lake Uranium Property and its vicinity in Athabasca Basin, Saskatchewan, Canada were next presented, discussing details of a study to establish trends of regional uranium mineralization vectors and incorporate these findings into the multidimensional integrated analysis of the currently available geophysical and regional geochemical data. The aim was to provide an advanced priority ranking of drill hole selection process for the upcoming drilling programmes. Close correlation between features of potential field data anomalies and the seismic signatures, together with the geochemical uranium deposit vectors, established the north-western corner of the property as a significant site for drilling.

According to the next talk, the recent spate of new discoveries in several areas in the Athabasca Basin, Saskatchewan, Canada, has been mainly due to the application of modern exploration techniques and the evolution in the understanding of unconformity uranium deposit models. Geophysical and geochemical techniques have improved considerably since the 1970s and have been used in previously explored areas to develop new targets. New showings in the Maurice Bay area on the northwest shore of Lake Athabasca were discovered mainly by the application of the Millennium basement-hosted unconformity model in conjunction with a refined ground gravity survey. The Patterson Lake South deposits were found by a combination of the age-old technique of following a train of uraniferous boulders to its source along an EM conductor and by a refined radon sampling system. The Midwest A deposit was found along the NNE extension of the Midwest trend within a grid of previous drill holes completed in the early 1980s. The Roughrider deposit was also found along the NNE extension of the Midwest structure using lithogeochemistry from historic drill holes. The Phoenix deposit was discovered on the southeast side of the Athabasca Basin on a project previously worked since the 1970s.

The next presentation was on the experience of Niger in uranium exploration since the 1960s and mining since the 1970s. Currently, 3 operating mines are permitted and about 60 exploration licences are active. One mining project, Imouraren is under development and another project, Madaouela, is in an advanced stage of feasibility studies.

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

The following presentation gave information on the work to use resin-in-pulp technique for ion exchange separation of uranium from alkaline leachate in Tummalapalle Uranium Project, India. The predominantly fine-size pulps of higher viscosity in the alkaline circuit make solid-liquid separation an arduous task. The availability of new generation resins which are mechanically resilient and possess higher exchange capacity thereby enable separation of dissolved uranium ions from the leach pulps directly in a resin-in-pulp process. The results of the current tests indicate superiority of gel type polystyrene based resins grafted with quaternary ammonium ion. Semi-continuous counter-current extraction and elution tests indicated that about 98% of the dissolved uranium values can be recovered during the loading process and practically the entire loaded uranium can be eluted using NaCl eluant.

8. SESSION 8: THE FUTURE OF URANIUM – FOCUS ON GREENFIELDS

The four presentations in this session focussed on potential new areas where uranium deposits could be found. The first talk was on the potential for finding new sandstone type deposits in Eurasia. Typically, large uranium ore provinces here were discovered in the south of the Turan Plate and in the depressions of South Kazakhstan. The common criterion established for sandstone type uranium deposits, located in oil and gas and coal bearing sedimentary basins, is the zone of interlayer oxidation that controls uranium mineralization. In the southern extremities of the Eurasian continent, especially in the region of the collision of the Indian Plate, a distinct similarity can be perceived between the location of infiltration uranium deposits of the Tien Shan megaprovince and the pattern of development of the Pacific Plate subduction. In both cases young sandstone deposits tend to occur close to the zone of subsiding geodynamic activity. It could be possible to find endogenic uranium near the contact area of such collision plates.

The second talk on undiscovered uranium resource evaluation explained detailed deposit-specific resource calculations, target generative processes and estimates of potential endowments in a broad geographic or geological area. The process of estimating large-scale potential mineral endowments is critical for national and international planning purposes but is a relatively recent and less common undertaking. In many cases, except at a general level, the data and knowledge for a relatively immature terrain is lacking, requiring assessment by analogy with other areas. Few countries report undiscovered resources, but how these figures are calculated is unknown and likely involves a range of techniques with variable degrees of robustness. Surprisingly these figures for undiscovered resources only marginally exceed those for known resources. There is a requirement for an integrated and consistent approach that is best done using statistically and geoscientifically robust methods already proven successful for other commodities such as copper.

Next was given a case study on financing growth in uranium production tracing the experience of a listed uranium exploration, development and production company. The projects include a pipeline of exploration and development properties, with ISR (In Situ Recovery, also called ISL, In Situ Leaching) operations in Texas built around a hub-and-spoke expansion model. Assets include significant conventional uranium mining properties in Arizona and Colorado, as well as potentially world-class exploration/development projects in an emerging uranium district in the Parana Basin, Paraguay, South America. With a plan to combine cash flow from operations and strategic partnerships, the company is expanding production while advancing its diversified portfolio for maximum financial and sector flexibility.

The Nyota Deposit, in south-western Tanzania, is currently the subject of a detailed feasibility study was presented next. The original mining and extraction philosophy was based around an open cast mining operation, and a conventional ion exchange (IX), resin-in-pulp processing plant. However, recent studies indicate that an opportunity might exist to convert a larger portion of the resource to reserves by extending the extraction options to include ISL. A systematic, toll-gated ISL testing program was initiated in 2012 at one of the areas where mineralisation occurs below the water table. This was followed up with a very successful push-pull test, conducted in 2013, which revealed the suitability of the mineralisation to leaching with acidic solutions. Should ISL prove to be viable, it holds the potential to unlock the region as an ISL production centre.

9. SESSION 9: URANIUM PRODUCTION BASED ON IN SITU LEACHING

Talks in this session commenced with an overview of the world-wide outlook for In-Situ Leach (ISL, also called In-Situ Recovery or ISR) uranium mining that has steadily increased over the last decade to account for 45% of the world total in 2012. Currently ISL uranium production is dominated by Kazakhstan, but with current commercial examples in Uzbekistan, the Russian Federation, Australia and the USA, and tests and small-scale efforts elsewhere. Alkaline leach dominates in the USA, and acid leach at the other commercial sites. Current forecasts are for ISL uranium production to continue to increase until 2022, followed by a gradual decline. Nevertheless, ongoing discoveries are possible both near existing ISL production centres and in other sedimentary basins with similar geology, notably in Mongolia and China, the Karoo system in Africa and the Parana Basin in South America.

This was followed by an exposition of the development of ISR in Kazakhstan. In particular, the advancements in understanding of geology as well as the technology of geophysical logging, well maintenance, re-use of mining solutions and extraction (purification) were highlighted. The possibility of by-products is being considered and the overall trend is towards becoming ‘smart mines’.

Case studies from individual mines or mining districts then followed. The history of the Nichols Ranch project was presented, the newest ISL mine to open in the USA. It required more than three and a half years to review and approve all the permits and licenses necessary to start construction of the highly automated mine. Construction of the mining facilities and the first wellfield started in late 2011 and was completed in late 2013. Mining results to date have been better than anticipated and operator was expecting to reach its 2014 production target.

Next the ISR mining of uranium in the permafrost zone at Khiagda, Russian Federation was presented. This has been a challenging project, due to its isolated location, extremely challenging climate, the presence of permafrost to a depth of about 90 m, complicated hydrogeology and unusual mineralogy (ningyoite, a calcium-uranium phosphate, is the main uranium mineral) and extraction chemistry. The formidable technical and logistical challenges are now being overcome and production ramping up towards 1000 tU/a, expected from 2018. The district is considered extremely prospective for uranium and further mining is possible.

An innovative, patented approach to ISL mining under artesian hydrogeological conditions at the Budenovskoye deposit in Kazakhstan was then described. Here, one extraction pump serves several wells, not only a saving in pumps, but meaning extraction and injection wells can be drilled to the same design (conventionally extraction wells were larger diameter and more expensive) and the extraction and injection roles can be easily reversed.

Advancements in exploration and In-Situ Recovery of sedimentary-hosted uranium developed for the Beverley and nearby deposits in South Australia were then presented. High-resolution seismic surveys and advanced interpretation techniques have been developed to allow higher resolution at shallower depths than the technique has been historically used for. A new generation pulsed neutron generator down-hole geophysical tool has been developed to measure not just uranium grade but to provide detailed other geophysical, hydrogeological, lithological and mineralogical logs. Finally, a new kinetic leaching (reactive transport) computer model has been developed, used to predict wellfield recovery curves, estimating chemical consumption and optimizing leaching chemistry.

Lastly, the latest methods for the cleaning of deep production wells in Kazakhstan were described. A method adapted from the oil and gas industry has been developed that is both effective and has doubled the time interval between well treatments, increasing the average performance of production wells by over 300%, compared to the previous technique used at the Zarechnoye deposit.

10. SESSION 10: THORIUM AND RARE-EARTH ELEMENT-ASSOCIATED RESOURCES

Thorium is seen as a potential fuel material for some current and future generations of nuclear reactors. Six talks in this session highlighted latest updates on thorium resources and production. The first talk was on a survey of world thorium resources. Thorium resources can be classified according to confidence in estimates of tonnages. In many cases official figures are either not available or not in agreement with established standards; therefore, uncertainties remain in reported numbers. However, latest estimates for the world indicates more than 6.2 Mt Th.

The next presentation discussed three examples of thorium recovery as a co-product of processing rare earth element deposits in the USA. In the Mountain Pass operations of in south-eastern California, the orebody is a carbonatite reportedly containing 16.7 Mt of proven and probable reserves grading 7.98% total REE (Rare Earth Elements) oxides. The primary ore mineral is bastnaesite. After the carbonatite is processed and REEs separated, the Th moves with other residues into the tailings impoundment. A second example is the Bear Lodge project in north-eastern Wyoming, currently in an advanced stage of permitting for their mine and processing plant. The deposits occur in a hydrothermally altered carbonatite-alkaline intrusive complex, with total measured and indicated resources of 15.2 Mt of ore averaging 3.11% total REE oxides. The REE-rich vein deposits within the Bokan Mountain alkaline intrusive complex in southern Prince of Wales Island, southern Alaska are enriched in the heavy REEs, which comprise about 40% of the total REEs.

Separation of rare earths from uranium and thorium in Kvanefjeld deposit, Greenland presents an interesting case study given next. A Feasibility Study evaluated a concentrator and refinery treating 3 Mt ore/a. The concentrator will produce a rare earth mineral concentrate which increases the grade of the rare earths by an order of magnitude. The mineral concentrate is refined using an atmospheric sulphuric acid leach which extensively leaches the uranium from the concentrate. Metallurgical studies have been successful using flotation to produce a high-grade concentrate which consists of 14% REE oxides, 0.21% U and 0.8% thorium.

Thorium and uranium separation from rare earth minerals from southern part of Turkey was another case study presented. Physical beneficiation and hydrometallurgical processes allow to the separation of U along with Zr and Ti. The obtained REEs and Th oxalate concentrate is subjected to metathesis to convert to hydroxides. The hydroxide cake is dissolved in acid and thorium is separated by pH regulation, and peroxide precipitation is applied for the final purification of thorium.

Creating a multi-national development platform for thorium energy and rare earth value chain was discussed next. Changes in thorium regulations and liabilities resulted in the development of excessive market concentrations in the rare earth value chain. Thorium bearing rare earth by-products from existing non-rare earth mining operations could potentially meet or exceed global rare earth demand if the existing ‘thorium problem’ is resolved. Initiatives to create a holding facility of thorium and utilize it as a nuclear fuel were discussed in the presentation.

11. SESSION 11: URANIUM MINING AND PROCESSING

The session on uranium mining and processing commenced with two talks on the heap leach technique of uranium recovery. First, an overview and the general advantages of heap leaching were discussed, with acknowledgement of some disadvantages. Heap leaching for uranium was mainly developed from its use in copper recovery, with it has several similarities, and early experience was with gold. In particular, the importance of sufficient early and ongoing testing was emphasized, together with proper preparation of material before it is placed in heaps, especially the process of agglomeration, and correct addition and maintenance of the mining solution to allow evenly distributed recovery. Good project management on during operations is also required, although the technique appears to be simple and straightforward, ongoing good implementation and quality control is required to achieve good results and avoid failures.

The second talk explained the application of heap leach uranium recovery in Niger and Namibia. The importance of ore characterization, and again extensive testing at different scales and agglomeration was emphasized. Experience was presented on both the acid (Niger) and alkaline (Namibia) extraction chemistries.

At the Caetité uranium mine in Brazil, the current heap leaching process is intended to be replaced by conventional tank agitated leaching, with a number of other improvements and modifications to physical ore preparation and metallurgical methods, as described in the next talk. Testing has extended over some years, and the new arrangements to double the annual uranium production to 800 t/a as U_3O_8 (~680 tU/a) go with an enlargement of the mill facility and the addition of underground mining.

A new technique to increase the grade and decrease the mass of ore to be treated was then presented. The patented ablation method, developed in the USA but also tested on ores from around the world, uses mechanical forces to upgrade suitable sandstone uranium ores. The mass of the enriched ore is between 5-10% that of the original, but contains >95% of the uranium. Not only are ore transport and processing costs greatly reduced, but two major advantages environmental are reduced tailings requirements at the mill site and cleaner waste dumps at the mine site.

Descriptions of metallurgical testwork for three uranium deposits currently being considered for possible development followed. The Kintyre project in Western Australia has been known for some decades, but recent testwork after a change of ownership was undertaken as part of a feasibility assessment. Leach optimization was undertaken, with extensive testing of different aspects of extraction. Notwithstanding the relatively high levels of carbonate minerals in the ore, following a detailed assessment acid leach was chosen. Mini-pilot plant tests with an acid leach followed by solvent extraction and precipitation showed uranium recovery of >99.5%.

The Reguibat calcrete uranium project in Mauritania is large but of very low grade, and the economics will rely on ore beneficiation and rapid leaching. Testing has shown an upgrade factor of 7 using simple techniques, with the possibility of further improvement, before a rapid alkaline leach process.

In Mali, the polymetallic Falea project is prospective for the production of copper, silver and uranium. Different extraction flow sheets were assessed, a simple acid leach and a more complex scheme with both acid and alkaline leach. Despite the complexity a development of the second route is currently recommended. Both the recycling of reagents and water recycling (minimized addition of fresh solution) are critical to economic viability. Testing is ongoing.

The next talk described the ‘Resin-in-Pulp’ (RiP) process which mixes ground ore and resin beads, later separating the two after the absorption of uranium by the resin. The development of RiP worldwide, and its application to alkaline-route uranium production in India was explained, with many tests undertaken before the choice of the most appropriate resin and physic-chemical condition.

India is developing some of its carbonate-hosted uranium deposits. The final talk of this session described a large, low-grade resource at Tummalapalle that is being mined by underground methods, with challenging geotechnical conditions in the upper lode where a number of roof collapses lead to suspension of mining until the problems can be satisfactorily resolved. Mining continues in the lower lode and the ore is treated by alkaline extraction. Leaching is in a series of autoclaves at 130°C. The plant is designed to process 3000 t/d of ore and produce a sodium sulphate by-product. Testing, developments and improvements are ongoing.

12. SESSION 13: URANIUM FROM UNCONVENTIONAL RESOURCES

The session on uranium from unconventional resources heard eight papers, ranging from uranium from phosphates and seawater to its extraction from polymetallic alum shale and coal ash.

The first speaker explained that uranium has not been extracted commercially from phosphoric acid for some years, but research and development is ongoing. Factors encouraging this include the consideration of the recovery of an energy source otherwise lost forever when phosphate fertilizers are spread, ‘cleaning up’ those fertilizers to reduce the addition of heavy metals including uranium to agricultural land, and for diversity of uranium supply. Good use of technology improvements and careful techno-feasibility studies is considered imperative.

In addition to uranium, rare earth elements (REEs) are also present in phosphate processing streams, and the solvent extraction method has potential to extract both. The extraction of REEs could provide an additional impetus for uranium recovery; but in the case of the USA, where the described work is being done, careful consideration must be made to ensure regulatory requirements for the fate and concentration of radium and thorium could be met.

New ideas for extracting uranium from phosphate rocks are being investigated in France, as described in the next talk. A new extracting molecule with improved selectivity for uranium over iron has been developed for use in the liquid-liquid extraction pathway (solvent extraction). Its performance can be simulated in a new software code, and the technique has been tested at a small scale, first on a synthetic solution and then on an industrial phosphoric acid.

Uranium from phosphate rocks could make a significant contribution to fuels for current light-water reactors, but this can be shown to be limited to <20% of current world demand. To extend this further uranium could be considered the primary product of phosphate rock mining, but the economics are generally not favourable, especially if uranium has to bear the full cost of mining and processing.

As described next, exceptionally large resources alum shales exist in Sweden, which among other possible metals contain large quantities of uranium, albeit at low grade. A recent scoping study considers a large-scale operation using bioleaching, a bacterially assisted process, to produce uranium and other metals from the Jämtland Alum Shale, which has favourable characteristics of high pyrite and low carbonate content. Costs were projected to be within the lower quartile of current uranium producers’ cost curves.

One additional source of uranium is its extraction from coal ash, or as a deliberate co-product from high-uranium coal. The early stages of a study were described, that intends to estimate both the world resources and potential uranium production capacities. Although it could be locally attractive, the overall potential uranium quantities are modest, at an estimated 4–5 MtU total and an annual production of less than 700 tU/a, assuming a cut-off of 200 ppm U.

The final two papers examined the USA seawater uranium recovery research programme, summarizing recent advances and current cost estimates. The low average concentration of uranium in seawater, approximately 3.3 ppm, remains a challenge to accessing this potentially very large resource. Recently developed polymeric absorbents show greatly improved selectivity and adsorption capacities, and justify a new economic analysis. Uptakes after 60 days of seawater immersion averaged approximately 3µU/g of absorbent. Taking into account the costs of absorbent fabrication, mooring at sea, recovery and purification, the estimated cost to produce 1200 tU/a was estimated at US $640/kgU (range US $470 to 860). If the durability of the adsorbent could be improved, the cost could drop further to US $360/kg U, which corresponds to the peak uranium spot price reached during the 2007 boom.

13. SESSION 14: CLOSING KEYNOTE PAPERS

The first closing keynote paper was on ‘A market in transition’, by N. Carter (USA). He reviewed the current supply and demand figures and current oversupply situation that has driven the uranium spot price below the estimated production costs of 50% of current uranium production. With low prices causing delays in new production centres and cutbacks elsewhere, it is possible that in a few years there will be a problem in the market as demand slowly rises and the effects of under-investment in uranium exploration and production. One paradox is the parallel development of uranium being sold in the open market, and less price sensitive production linked to security-of-supply for some countries with significant nuclear power expansion programmes.

Next J. Hilton (UK) presented on the scope, purpose and practice of feasibility studies for critical resources in an era of sustainable development. He proposed that a new Pre-Feasibility Study will go further than recent experience, to meet a wide range of new appraisal criteria against which ‘feasibility’ can be determined. Strategic solutions should be sought, where it is critical to consider uranium in a context of responsible use of multiple resources over their whole life cycle. This could transform current ‘waste’ into a resource. Stakeholder engagement and the ‘social licence to operate’ are key elements.

Thirdly, T. Gitzel (Canada) presented on Cameco’s view of the uranium market and the recent start of production at its Cigar Lake uranium mine in Canada. He reflected that the situation for the uranium industry changed after the 2011 tsunami in Japan, but that these challenges are temporary, and there remains a bright long term future for nuclear energy. More reactors will mean more demand for uranium. He then described the official start up of the high-grade Cigar Lake uranium mine, an operation using new techniques to mine a rich orebody about 500 m below the surface.

The final keynote paper comprised closing remarks by the symposium chairman, M. Cuney of France. After a quick review of some of the major topics and themes discussed at the symposium, and the current low uranium price, he concluded the audience should remain confident in the future of uranium.

14. SESSION 15: PANEL DISCUSSION

The panel discussion was opened by Symposium Chair M. Cuney, who handed over to J. Hilton as the moderator of the discussion.

The panel members were:

M. Cuney, France, Symposium Chair
J. Hilton, UK, Moderator
A. Boytsov, Russian Federation
F. Harris, Australia

O. Gorbatenko, Kazakhstan
S. Hall, USA
Z. Li, China
C. Polak, France
R. Villas-Boas, Brazil

Additional symposium delegates from Canada and Namibia were invited but unable to join the panel.

J. Hilton opened with a comment highlighting the need to educate the general public and the passing on of experience of the older to the younger generations of workers in the uranium production cycle. Comments from the floor included examples of the effectiveness of free or low-cost tours for school teachers, and the use of 'travelling road shows' for schools, clubs and festival events. M. Cuney commented that such efforts could be more effective coming from international groups such as the IAEA or WNA rather than directly from industry. The importance to the public and governments of safeguards and the demonstration of peaceful use of uranium was also mentioned, and the importance of the preservation of corporate knowledge and institutional memory, and acknowledging, identifying and filling knowledge gaps. Regarding formal education, A. Boytsov reported good progress in Kazakhstan in the last several years, such that there is no longer a fear of skills shortages there, whilst O. Gorbatenko stated that social assistance is now written into all uranium miners' contracts in that country. F. Harris commented that the development of uranium mining skills and personnel can sometimes be done better in 'developing' countries, for example Namibia, where uranium is a significant player in the local mining industry, compared to a 'developed' country like Australia where uranium is only a small segment of the local mining industry and not seen as a place for an attractive career.

Comments from the floor included a reminder not to confuse the education of workers and professionals to work in the uranium industry with the education of the general public, which includes the aim to improve the 'social licence' and acceptance of the industry generally. The role of private companies in supporting education for professionals and tradespeople was also raised.

The moderator then asked each of the panel members to mention a highlight or an important question emerging from the talks, posters and discussions at the symposium.

S. Hall asked if the remediation of recently closed and older current mines is still a concern, for example in Niger but also in the USA. Is bad practice totally in the past? Industry needs to apply good standards throughout the world. She also commented that the paradigm that 'when we look we will find' may be starting to change for uranium. Finding uranium deposits is not so easy any more for most areas. We should also remember the significant number of discovered deposits that never get developed. However, it was good to hear about advances in technology, such as in ore upgrade technology, the jet boring mining method at Cigar Lake, Canada, advances in generic models and geophysical exploration leading to successful discoveries in already-explored areas, and regarding the extraction of uranium from seawater.

Z. Li's highlights included the links between oil and gas basins and sandstone-hosted uranium basins, and he suggested that this concept could be more widely applied, after progress in Kazakhstan, Russia, Australia and elsewhere. He noted advances in uranium exploration techniques and technology, the interest in China's nuclear power expansion plans and the securing of its long-term uranium supply, and the role of international cooperation in this.

R. Villas-Boas noted the diverse views and approaches to 'social licence', and reminded the meeting that this 'licence' is not a document. Communities associated with current or planned uranium mining need to know what is in it for them, including; jobs, protection of water resources, and where royalty monies will be spent. The benefits of taxes or royalties paid by mining companies may not be noticeable locally if they are all collected and spent by regional or national governments.

M. Cuney opined that despite difficulties, there are still new discoveries being made. The possibility of recovering uranium from seawater is still moving forward. Technology can overcome technical challenges, but the need for social acceptance is of great importance.

Recalling some of the papers presented, J. Hilton pointed out the need for healthy scepticism of estimates and forecasts, be they for the number of nuclear power plants and their uranium requirements into the future, uranium resources in the ground or being mined, and the assumed ease of access to deposits [regarding both technology, economics, approvals and social support].

From the floor, H. Schnell also commented that the 'easy places' to mine uranium are harder to find. The importance of by-product and non-conventional uranium is emerging, although the complexity of the associated technical challenges should not be overlooked. Also from the floor the suggestion was offered that perhaps a mechanism to incentivize the production of non-conventional uranium could be useful, e.g. by requiring users to buy a certain percentage of their supplies from such sources.

F. Harris commented on the difficulty in communicating the message of high performance in uranium mining around the world, in areas of technology, occupational health and safety and the environment. As a precautionary tale, if one has the best performance in the world, but no-one believes it, what does it count for? Perhaps the failure is in the communication. Further, we should remember that uranium metal in the ground is worth nothing unless one can successfully and profitably mine it.

A discussion on the variable acceptance and public support around the world for uranium mining, and mining with uranium as a by-product, was prompted by the moderator. In some countries, nuclear power is accepted better than uranium mining, e.g. in Slovakia and Argentina, compared to a place like Australia that has a reasonable acceptance of uranium mining but has little public support for nuclear power. Some countries in Africa have mixed views, and the views of at least some nationals may be different to that of international companies mining in their nation. Companies, communities and nations are still on a learning curve, and the situation might be different for mines established decades ago under very different circumstances, compared to mines opened in the last decade or currently under consideration. From a potential developer of by-product mine, it was considered that the gaining of local community support for a project was instrumental in prompting change of national policy to allow consideration of the project, where previously the project was subject to a broad prohibition.

Kazakhstan uses ISL now, said O. Gorbatenko, but despite the high current production continues to explore. It could produce more, but is now the time to do that?

A. Boytsov contrasted the expectation of low uranium prices, perhaps until 2020 according to some prognostications, to a likely uranium shortfall compared to demand after 2025. He noted that these scenarios only really applied to low cost resources [as opposed to some government-sponsored strategic mining]. The moderator asked some of those from the audience involved in uranium from seawater research for comments. A response from E. Schneider was that the USA group considered uranium from seawater a backup, against which other uranium sources could be compared, rather than a short-term prospect for production.

C. Polak suggested more involvement of uranium users (utilities) in uranium production cycle events such as URAM, and of the links of education about uranium to that about nuclear power.

Finally, R. Vance warned of déjà vu in a meeting like this. In the cycle of uranium price, uranium production compared to consumption and uranium reserves, the current circumstances have been experienced before. The industry needs to be careful of being too inward-looking. Also, whilst the price of fuel is not as important to a nuclear power plant as for fossil fuel power plants, the uranium industry should not assume too much that the price of uranium is not a concern for nuclear power utilities. The efforts to produce uranium cost-effectively should not be reduced.

The moderator asked the Scientific Secretaries for their brief comments. H. Tulsidas commented on the importance of environmental aspects, the cleaning up of wastes and tailings for example, and the industry's need to provide benefits to society. He encouraged a holistic view of the nuclear cycle including the obtaining of raw materials. P. Woods noted the contrasts and paradoxes presented in a meeting as broad as this symposium; short and long-term views of uranium supply and prices, opportunistic versus strategic mining plans, the spot market and raising capital in a free-enterprise system contrasting with inelastic supply under long-term national security-of-supply arrangements. The meeting gives workers in these different circumstances and opportunity to hear of different approaches and learn from them. Other contrasts include that of collaboration versus intellectual property, and cooperation and coordination versus competition for finance and markets.

The meeting was closed by the chair, M. Cuney.

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[4] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT NUCLEAR ENERGY AGENCY, Managing Environmental and Health Impacts of Uranium Mining, NEA No. 7062, OECD, Paris (2014).

OPENING ADDRESS

J.C. Lentijo
International Atomic Energy Agency

Good morning ladies and gentlemen,

On behalf of the IAEA, I am very glad and very pleased to welcome you all, delegates, observers and members of the press, to this International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle, the so called URAM–2014. On behalf of the IAEA, let me also express our gratitude to your Governments and Home Institutions for allowing you to attend this Symposium.

As you know, this IAEA's premier uranium mining and milling meeting is being held after a 5 years' gap.

The previous URAM symposium in 2009 was held at an optimistic time, when nuclear energy was emerging as a revitalized alternative to meet the ever-increasing demand of electricity in a sustainable manner. At that time, the price of uranium was still high compared to the preceding 20 years. This positive trend was demonstrated in the increase of identified uranium resources by 75% since 2000, as well as significant increases in exploration expenditure, development of a large number of greenfield and brownfield mining sites, and a general upward trend in the production of yellowcake.

But, after the Fukushima accident in March 2011, we saw unanticipated shutdowns of Japan's large fleet of reactors, which are still under extended shut-down. The growth in new builds did not happen as intensely as earlier anticipated, with considerable delays in many countries to give them time to assimilate lessons learned from the Fukushima accident and to consolidate and strengthen their Safety Action Plans. In some cases, nuclear power phase-out plans were also decided.

In the uranium sector, uranium markets went down by biennium 2012–2013, with the prices in 2014 the lowest in 10 years. A few uranium mines suspended production, most plans for new production have been delayed, and a number of instances of employee cut-backs have been reported.

This could have two major mid- and long-term implications. Firstly, the industry may not be ready for increased demand for uranium if the nuclear energy scenario improves in future and current apparently surplus stocks are gone. Secondly, the industry must resist increasing financial pressure and maintain the good standards and practices that have been gained during the past decades.

Let us look into the first challenge. We have seen a significant drop in exploration and developmental expenditure in uranium, including from major and mid-size companies. More and more 'junior' companies are finding it difficult to raise money and therefore sell up, look for other commodities or simply disappear. Much green-fields exploration has been suspended. This will mean lesser rate of resource discovery in the near- and mid-term, and may not be commensurate with depletion of resources we see as existing mines progress through their reserves.

A vast majority of earlier-planned uranium mining development has been delayed; for example, some projects of the very large uranium mining companies that were envisaged to have large production capacities, up to in excess of 5000 tU per year. These projects require considerable time and preparation to come on-line, and it is a matter of concern whether stalled projects can be ready for production when the market picks up.

Nevertheless, the large Husab uranium mine in Namibia is proceeding towards production, and some small to mid-sized in situ leaching projects in the USA and Australia are going ahead.

Disruption of production in some of the postponed projects has major socio-economic ramifications. Loss of revenue and employment are immediate shocks that the local economy has to bear, and on other hand cash strapped companies have to find resources to maintain facilities with no returns. In some of the countries where uranium mining is being carried out, especially in the least developed economies of Africa, these impacts are very significant to the local and national economy.

Even though no long-term shortage of uranium has been foreseen by the IAEA studies so far, some short-term demand–supply gaps could be anticipated, once demand again exceeds production from mining and supply from secondary sources.

Let me bring the attention to the second major challenge. In this scenario, how can the industry continue to maintain its responsible behaviour? Companies are under increased pressure to cut-back costs, which is now translating into cut-backs in production and jobs. Now the question is whether this will mean cost cutting to health, safety and the environment and social programmes.

The uranium industry has been successful in the past couple of decades when it has become a champion of good practices. Uranium mining industry has been a leader in adopting good practices and coming up with innovative solutions. This has come about after a long and painful process of learning from past mistakes, adapting and configuring to diverse local requirements. Any let up on health, safety and environmental performance could end up in serious consequences that could threaten the industry itself as a whole. Negative social experiences can lead to entrenched opposition locally and politically.

In this scenario, let me give some positive notes. The uranium industry, after coming a long way with good and bad experiences of the past, has become very resilient and open to these issues. The IAEA is a natural platform for facilitating support for the uranium industry, national institutions and professionals to come together and find and share solutions for these challenges. Over the past five years IAEA has increased activities in this area and promoted a number of new initiatives with active support and participation of our Member States, international institutions, companies and individual experts.

In this context, I am glad to see around 300 participants from 70 different countries and organizations in the Symposium. This year we have close to 200 technical papers being presented in 14 sessions. We have received on-going support in our activities from international organizations like NEA, WNA and the UNECE, and they are also supporting this symposium.

This in itself is a proof of the seriousness and willingness of the institutions and the industry to continue performing and looking for possibilities in improvement. This symposium aims to be a land-mark helping define the path forward in these troubled times for the uranium industry.

Let me reiterate our welcome to all of you to Vienna and wish you a successful week ahead. I hope that you will find time to enjoy your stay in Vienna.

And finally, let me now invite Mr Michel Cuney, a veteran uranium geologist from France, who is personally known to many of you, to chair this symposium. I declare this symposium open and invite Mr Cuney to give the Chairman’s address.

OPENING REMARKS OF THE SYMPOSIUM CHAIRMAN

Chairperson:
M. Cuney
France

Distinguished Delegates, Colleagues and Friends,

It is my pleasure and honour to give a very warm welcome to all the participants who have honoured us by taking part in the URAM–2014 International Symposium and especially those which have had a very long journey to attend it.

The symposium is really international, with 70 countries and international organizations involved. Some countries are represented here for the first time. International liaison and co-operation is crucial for improving the efficiency of our actions.

The response to this Symposium has been tremendous, and from this respect is already very successful with almost 300 attendees. A total of 239 abstracts were submitted from which about 90 oral presentations and over 100 poster presentations have been selected.

URAM–2014 is intended to bring together professionals in the fields of uranium production cycle: scientists, exploration and mining geologists, engineers, operators, regulators and fuel cycle specialists together with business leaders, experts in the international uranium market, and government officials involved in regulation and permitting. The paramount objectives of this meeting are:

- Exchange information and discuss updated research and current issues in uranium geology and deposits, exploration, mining and processing, production, supply and demand, economics and environmental and legal social issues; and
- Discuss on educational and best practices experience for members of the uranium industry.

In a more general way this symposium is a good opportunity for us to learn together, to foster cooperation, to interchange ideas, and build capacity to get ready for any upcoming challenges to develop an energy source that is vital to keeping world’s economy strong,

Since the 2005 and 2009 URAM symposia, held by the International Atomic Energy Agency (IAEA) in Vienna, despite the world global recession of 2009 which is still having an influence into 2014 for many countries, the Fukushima Daiichi nuclear accident in 2011, the production of cheap shale gas in the USA, there continue to be strong expectations as to the growth of nuclear power worldwide, which should lead to an increase in uranium demand and in turn of the price of uranium.

The long-term sustainability of nuclear power will depend on, among several factors, an adequate supply of uranium resources that can be delivered to the marketplace at competitive prices.

To discover increasingly hard to find U deposits, generally at greater depth, a better understanding of the genesis of uranium ores and more sophisticated exploration technologies will be required.

Exploration, mining and milling technologies should be environmentally benign, and site remediation plans should meet the requirements of increasingly stringent environmental regulations and societal expectations.

The purpose of this symposium is to analyse uranium supply–demand scenarios and to discuss new developments in uranium geology, exploration, mining and processing, environmental requirements for uranium operations and site decommissioning.

The presentations and discussions at URAM–2014 should:

- Lead to a better understanding of the adequacy of U sources (both primary and secondary) to meet future demand;
- Provide information on geological models, new exploration concepts, knowledge and technologies that will potentially lead to the discovery and development of new uranium resources;
- Describe new production technologies that have the potential to more efficiently and sustainably develop new uranium resources; and
- Document the environmental compatibility of uranium production and the overall effectiveness of progressive final decommissioning and, where required, remediation of production facilities.

I am confident that you will bring home new ideas at the end of these days.

In the organization of the symposium, the following 6 sessions from the previous URAM–2009 symposium will be repeated:

- Uranium markets and industry;
- Uranium geology;
- Health, safety and environment;
- Social licensing in uranium production;
- Education and training in uranium production cycle; and
- Uranium mining and processing.

Besides the above, we have added 6 new topical sessions on:

- Evaluation of uranium resources;
- Future of uranium with a focus on greenfields;
- Uranium production based on in-situ leaching — this now assures nearly 40% of the world U production, allowing Kazakhstan to be by far the largest world uranium producer;
- Advances in exploration and uranium mineral potential modelling — this discipline has become important with the development and wide application of GIS based systems;
- Thorium and rare-earth element-associated resources — to respond to an increasing number of projects considering Th-fuelled reactors concepts in several countries, and to the strong increase in the needs of Rare Earth Elements (REEs) for the development of new technologies. REEs are commonly associated to thorium in most ore deposits; and
- Uranium from unconventional resources — hosted in phosphates, black shales and other environments, which may assure the uranium supply for long term, especially if co-valuation of associated other metals is taken into consideration.

I also wish to take the opportunity of this address to give a tribute to the memory of Franz Dahlkamp (1931–2013), who was the President of the previous International Symposium on Uranium Raw Material for Nuclear Fuel Cycle (URAM–2009), in June 2009, in Vienna. He left us in spring of last year (2013), at an age of 82, a few days after having chaired his last meeting for the UDEPO database at the International Atomic Energy Agency (IAEA) here in Vienna. He was known among geologists as the Uranium-Pope. As an economic geologist he served in particular as:

— The Head of worldwide uranium exploration for the Uranerz Group in 1974 for which he conducted reconnaissance surveys for uranium in many countries;
— Member of Executive Advisory Board of Strathmore Minerals Corp and Uranerz Energy Corp;
— Expert for the IAEA;
— Consultant for several mining companies, utilities and both national and international institutions;
— Lecturer at the Universities of Leoben and Salzburg in Austria, and Munich in Germany.

Dr Dahlkamp has published over 50 papers, including books on Uranium Ore Deposits and especially the first 2 of the 4 volumes of "Uranium Deposits of the World", offering an unprecedented compilation of data and overviews of the U deposits throughout the globe. It is a great loss as a friend and for the world of uranium geology.

For the sake of uranium science and business, I wish that every one of you would find the Symposium inspirational and rewarding, and I wish the symposium every success. May your deliberations be fruitful and may all countries and scientists greatly benefit from the knowledge which will be acquired here.

I would also like to express my sincere appreciation to the organizers for all their efforts to make this symposium a success and to the companies who sponsored it financially. I have to inform all of you that the sessions are open to the press.

I have great pleasure in declaring this symposium officially opened.

Thank you.

CLOSING KEYNOTE PAPERS

THEORY TO PRACTICE: THE SCOPE, PURPOSE AND PRACTICE OF PREFEASIBILITY STUDIES FOR CRITICAL RESOURCES IN THE ERA OF SUSTAINABLE DEVELOPMENT

J.K. Hilton, M. Moussaid
United Kingdom

T.K. Haldar
India

H. Tulsidas
IAEA

Abstract

While the fundamental goal of a mining and mineral processing Pre-Feasibility Study, (PFS) to justify the technical, financial, social and environmental case for a given project, remains unchanged, the way this goal is met in the era of sustainable development must adapt to meet a wide range of new appraisal criteria against which first, project 'feasibility' can be determined, and secondly, projects given the green light can be successfully implemented. These criteria include: Whole Basin Resource Management; Comprehensive Extraction; Life-cycle Resource Management (Primary, Secondary, Circular); adherence to the Waste Hierarchy; a constructive, coherent NORM (Naturally Occurring Radioactive Materials) Industry Policy Framework; Stakeholder Engagement and the Social Licence to Operate. The criteria do not work in isolation, but are interdependent and mutually reinforcing. They have all contributed to the development of third and fourth generation business models in uranium extraction, all implicitly or explicitly referencing the goal of 'smart' mining and processing.

1. BACKGROUND

In analyzing the challenges faced in many IAEA Members States in converting potentially successful research and development concepts and studies into commercially viable projects, it became clear that 'soft' aspects such as project management, teamwork, communications or social licensing, as much as, or more than, 'hard' technical and scientific capabilities determine the success or otherwise of the outcome. As a result in late 2011, the Uranium Extraction from Phosphates (UxP) Expert Working Group set about addressing this issue.

Following intensive discussions with representatives from some 40 participating Member States and a consultancy meeting in Vienna, April 2012, it was agreed that two complementary strategies should be given priority for pilot testing on a number of national, regional and inter-regional projects the UxP team was supporting. These included national projects with Philippines Nuclear Research Institute, the Nuclear Materials Authority, Egypt and Groupe Chimique Tunisien, Tunisia, the UPSAT Mission to Tanzania (2013)[4], the African regional project RAF 3007 and the inter-regional project INT 2015. The priority areas were:

[4] Uranium Production Site Appraisal Team; see TULSIDAS, H., Mining Uranium; With an eye on 'sustainable' mining, Tanzania hosts Uranium Production Site Appraisal Team, IAEA Fuel Cycle and Waste Newsletter 9 2 (Sept. 2013) 11 (http://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/documents/uranium/Tulsidas_2013_UPSAT_Tanzania.pdf) [Accessed April 2015]

1) The development of a new style pre-feasibility study (PFS) template focused on project progression for related critical resources such as uranium, rare earths and phosphates, from laboratory through pilot to commercial scale;
2) The creation of a virtual Leadership Academy to fast-track the development of critical "soft" skills associated with project design, management and social acceptance.

The initial results have been sufficiently encouraging to start to systematise these strategies for Member State support in the coming work-cycles, starting with the concept note and early stage design even of laboratory-scale activity. In particular, with the world of mining and mineral processing projects in rapid and profound transition, there is also an opportunity for new entrant states into these fields to skip one or more generations of project management and leadership orthodoxy, saving time and resources and enhancing their chances of success. Since the UxP team launched its initiative two of the 'big five' consulting organisations have also come out with studies confirming key aspects of their analysis. Ernst and Young include such matters in prominent positions in their periodic review of business risks in the mining and minerals sector [1] while KPMG have made the 'community dividend' — their term for quantifying the benefits back to a community from the social licence to operate — a critical dependency for the success of mining and processing projects [2].

2. CRITICAL RESOURCES

While susceptible of widely-differing practical outcomes influenced by a cocktail of geographical, political, cultural and economic factors, the identification and management of critical resources are now central to the sustainable development agenda [3, 4]. This agenda is anchored in finding sustainable ways of meeting critical needs (Brundtland's primary driver [3]), of which food, energy and water (the 'FEW') predominate as competition among the many for these resources grows daily on the planet. What John Nash (1950) understood writing in the aftermath of World War Two [5], is that sustainability depends economically and socially on finding a new, negotiated point of equilibrium, based on the premise that there are certain critical economic transactions in which either both parties win or both lose. Managing critical energetic resources such as uranium, rare earths [6] and phosphates [7, 8], which are geologically connected (perhaps even genetically related) [9] and which are also on the front line of the battle to meet the FEW needs, depends on finding and keeping that point of equilibrium in a realistic, transparent and equitable manner. This has some similarity with the 'too big to fail' model used by governments to rescue failing banks during the financial crisis of 2008.

The business community has increasingly understood this need to rethink business processes from a socially responsible point of view, following Elkington's crystallization (1994) of Nash's model into the 'Triple Bottom Line' business strategy [10]. The Triple Bottom Line retains the necessary and proper adherence of business to generating profit and returning reward to shareholders but aligns the financial requirements for success with complementary social and environmental indicators, such as the development of social capital and resource conservation. At the same time, more specific to the mining and processing industries, since 2002 and the publication of the seminal report 'Breaking New Ground' [11] it is now widely agreed that no major project can be broached without the social licence to operate being included as a critical success factor from the outset [12] i.e. from the point the first exploration geologist puts a boot on the ground. Of course, key concepts such as safety and environmental responsibility [13–16] and adherence to the principles of the waste hierarchy and Fundamental Safety Principles [17–19] — in which end disposal of waste is the least desired outcome — are fundamental to the social licence from the perspective both of the workforce and the wider community of stakeholders.

3. CHANGE DRIVERS

The change drivers for sustainability include:

Whole Basin Resource Management — new upstream approaches to estimating and managing resources across whole basins, such as sedimentary basins containing oil, gas, coal, phosphate, uranium on Rare Earth Elements [20];

Comprehensive Extraction — new comprehensive extraction technologies based on integrated flow-sheets designed to extract all resources of interest from a single ore body in the best economic, social and environmental manner, as for example, extraction of P, U, Th, REE, etc from a P ore body [21];

Life-cycle Resource Management (Primary, Secondary, Circular) — based on models of criticality and substitutability, life-cycle resource management requires the approach to all resource management to be similar to that required for non-substitutable resources such as phosphates — even when substitutes are available [7];

Waste Hierarchy — progressive / step-wise transformation of waste to resource, with a hierarchy of waste itself premised as: i) prevention (or transformation to resource); ii) minimization; iii) reuse; iv) recycling; and v) disposal (Fig.1);

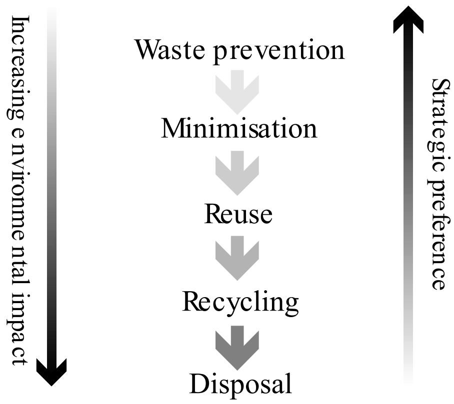

FIG.1. The waste hierarchy (adapted from the European Union).

Constructive NORM Industry Policy Framework — the regulatory framework in regard to NORM industries such as the extraction of uranium and rare earths from phosphates is typically driven either by legacy waste issues or cross-over regulations from the nuclear power sector, or both. Neither is appropriate to NORM industries and tends to inhibit or prevent their development. As a number of other energetic NORM industries such as oil and gas are likely to be under development in a given country as well as uranium, the definition of a suitable framework for these industries, balancing environmental and economic interests and objectives is both necessary and timely. Countries such as Spain and UK[5] are leading the way in establishing a new-style strategy for managing these industries based on thirty years of operational experience [22].

[5] For a Scottish example see reference [17]

Stakeholder Engagement and Social Licensing – a project can no longer be regarded as either safe or sustainable if it does not earn and retain a social licence to operate, based on stakeholder communications and engagement. Key determinants of success will be the aggregate beneficial or detrimental impact on Food, Energy and Water (FEW) security [11, 12].

4. THE NEW-LOOK PRE-FEASIBILITY STUDY TEMPLATE

The operational fulcrum of these changes, and hence the core of the new-look PFS (Table 1), is that the driver of sustainability is the resource set itself, such that once ground is broken or holes are drilled, the return from that activity is optimised across all resources, not just a single target. The example given is provisional and generic in that each actual PFS template used will be adapted to the particular conditions in which a given project's feasibility will be assessed. But the primary consideration is that the review process is whole resource-management driven. Hence the key determinant in the PFS is to work out the best strategic solution to managing virgin and secondary resources in a comprehensive manner rather than taking the traditional, project-based tactical solution of selecting single mineral targets and their cut-off grades as the key determinants.

TABLE 1. SAMPLE NEW LOOK PFS TEMPLATE

1.	**Project – Nature and objectives**
1.1	Project background
1.2	Project team
1.3	Business case (high level)
1.4	Technical Advisory Committee/ Experts
1.5	Major stakeholders
1.6	Partners
1.7	High-level road map with major milestones, timeline, life-cycle
1.8	Sustainable development objectives and dependencies
2.	**Present state analysis (people, process, purpose)**
2.1	Laboratory and pilot studies / Status within a progressive Project Development Model (e.g. RD^3[6])
	2.1.1 Fundamental process chemistry
	2.1.2 Results and findings from scaled-up experiments
	2.1.3 Pilot plant operations
	2.1.4 Project formulation (high level summary)
	2.1.5 Good Laboratory Practice (GLP)/ ISO 17025
2.2	Existing facilities
	2.1.1 Buildings and infrastructure
	2.1.2 Technology
	2.1.3 Consumables
	2.1.4 Environment
2.3	Human resources and social infrastructure
	2.3.1 Capacity-building
2.4	Mineral projects
	2.4.1 UNFC 2009 resource reporting[7]
	2.4.2 CRIRSCO or equivalent[2]

[6] Research, Development, Demonstration & Deployment (RD^3) is a methodology originally promoted by Dr Anil Kakodkar, former Chairman of the Indian Atomic Energy Commission, for commercialisation of new technologies by IAEC. Its success in India for reliable, step-wise execution of industrial projects involving new technologies has led to its adoption into the new look pre-feasibility study template.

[7] See reference [28].

2.4.3 Resource description and comprehensive extraction opportunities
2.4.3.1 Primary target(s) and co-products (a. economic grade; b. low-grade)
2.4.3.2 Secondary targets and by-products
2.4.3.3 Residues
2.4.3.4 Tailings
2.4.3.5 Other sources (including 'wastes')

2.5 Gap analysis

2.6 Change drivers
2.4.1 Economic / financial
2.4.2 Social
2.4.3 Environmental

2.7 Business case – desired outcomes/ triple bottom line returns
2.5.1 Economic
2.5.2 Social
2.5.3 Environmental

2.8 Sustainable development and performance indicators
2.8.1 [Proposed] sustainable development framework
2.8.2 Metrics and indicators

3. Proposed future facilities (structures) including planning and building regulations

3.1. Site location and justification [brownfield / greenfield], including socio-economic factors

3.2. Operational context within which site works including physical infrastructure, roads, utilities, communications and regulatory framework, communications.

3.3. Site master plan, location of buildings, facilities and major structures

3.4. Preparation and development of additional facilities (if required)

3.5. Engineering infrastructure and materials of construction

3.6 Permits and licences

4. Architectural and construction requirements

4.1 Mechanisms / constraints for defining calculating space requirements
4.2 Climate and related conditions
4.3 Geology and hydrology
4.4 Special construction requirements
4.5 Architectural and construction Solutions
4.6 Seismic activity/ risk
4.7 Corrosion and Environmental Impact
4.8 The Working Environment – heat, light, ventilation
4.9 Sanitation and other services

5. Health, safety and environment

5.1 All hazards approach (biological, chemical, physical, radiological)/ risk and exposure pathways
5.2 Culture of safety [ISO 18000] and associated training and oversight
5.3 Good Laboratory Practice (GLP)
5.4 Environmental Impact Assessment
5.4.1 Baseline data
5.4.2 Environmental safety case
5.4.2 Environmental management plan
5.4.3 Permits and licences
5.5 Standard operating procedures
5.6 Lead and lag Indicators
5.7 Personal protective equipment
5.8 Fire prevention and emergency procedures
5.9 Noise and vibration protection
5.10 Safety stakeholders
5.11 Inspections and audits
5.12 Safety, security, safeguards

6. Emissions, residues and wastes

6.1 The waste Hierarchy / zero emissions and discharges
Characterisation of waste streams and emissions
6.2 Application of waste hierarchy across project life-cycle
6.2.1 Prevention
6.2.2 Minimisation
6.2.3 Reuse
6.2.4 Recycling
6.2.5 Disposal / discharge
6.7 Added value options
6.8 Permits and Licences

7. Utilities, roads, engineering support, infrastructure

7.1 Electric power supply
7.1.1 Power generation equipment
7.1.2 Electric lighting
7.1.3 Controls systems
7.1.4 Communications
7.1.5 Alarms, signaling
7.2 Water supply, wastewater and sewage
7.3 Roads and transportation
7.4 Engineering dependencies

8. Technical specifications

8.1 General information, including process and equipment selection criteria
8.1.1 Production capacity and operating assumptions
8.1.2 Licences, patents, uses of third party intellectual property
8.2 Raw materials/ feedstocks
8.3 Energy
8.4 Reagents/ solvents
8.5 Consumables / coefficients
8.6 Process Description and Flowsheet
8.7 Layout – Block Diagrams
8.8 Equipment List
8.9 Human Resources including detailed Job Descriptions
8.9.1 Human resource development/ Capacity-building
8.10 Process controls
8.11 Maintenance and upkeep
8.12 End of Life (EOL) plan

9. Market analysis

9.1 Supply analysis (including key assumptions)
9.1.1 Domestic
9.1.2 International
9.2 Demand analysis (including key assumptions)
9.2.2 Domestic
- Volume
- Price
9.2.2 International
- Volume
- Price
9.3 Competitors / market resilience
9.4 Market risks
9.5 Supply chain / raw materials and other inputs
9.6 Transport and distribution
9.7 Taxes

10. Financial assessment and investment requirements

10.1 Analysis of financial standing of project initiator, its capacity to implement project including strategic (business) plan
10.2 Capital costs (CAPEX) (mapped to length of expected loan / investment)
10.2.1 Reasonable/ realistic case (base case)
10.2.2 Pessimistic case
10.3 Operating costs (OPEX) (mapped to length of expected loan / investment)
10.3.1 Reasonable/ realistic case
10.3.2 Pessimistic case
10.4 Working capital and cash flow
10.5 Internal Rate of Return (IRR) / Return on Investment (ROI)
10.6 Permits and licences
10.7 Off-take agreements, contracts
10.8 Bonds and special Provisions
10.9 Life-cycle analysis

11. Costs of construction including timelines / drawdown requirements / contingencies

12. Cross-cutting issues and requirements

13. Regulatory and licensing requirements

14. Project risks

14.1 Operational and technical
14.2 Environmental
14.3 Financial and economic
14.4 Social
14.5 Political and regulatory

Appendix A
National policies
Legal and regulatory framework

Appendix B (etc, as required)
Project outline
Partnership and collaboration agreements
Current state analysis
Gap analysis
Regulatory framework and requirements

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5. EXPECTED OUTCOMES

Seen through the lens of classical "People, Process, Purpose" project management approach, its is the social dimension of the TBL, the investment in Human Resources to generate social capital, which is the primary driver. For if the outcome from social capital development is a sustainable social licence, then the social and economic aspirations of any mining and minerals project can demonstrably converge, whereas they are so often perceived to be conflicted. The complementary environmental driver calls for a commensurate process solution (whether for mining or processing) to reflect the economic and social outcomes measures. Such a solution will be reviewed in the environmental and social impact assessment which is increasingly a mandatory requirement for all projects.

This socially responsive approach enables a stable synthesis of the three TBL objectives (Fig. 2) based on alignment of: 1. the social licence to operate (SLO) (social), with 2. zero waste (0W) (environmental / waste hierarchy) and 3. comprehensive extraction (CX) (economic), whether from primary or secondary resources.

FIG.2. The sustainable Triple Bottom Line.

From this normalized, sustainable position, the anticipated outcomes are:

- De-risked financials/ return on investment (protects lender / investor);
- Stable, equitable, long-term partnerships with stakeholders;
- Reduced risk of project-related social conflicts / conflict-free supply chain / compliance with EITI[8] objectives;
- Positive contributions to / reduced impact on health, culture and heritage;
- An equitable balance of economic and environmental interest, e.g. new, NORM industry specific regulation (U, P, oil and gas, REE, etc);
- Innovative (3G and 4G) business models (see below);
- A sustainable point of equilibrium.

6. OPPORTUNITIES AND CHALLENGES — 3G AND 4G BUSINESS MODELS FOR MINING AND PROCESSING

The investment community is increasingly asking whether or not Moore's 'Law' – that computing power doubles in capacity and halves in cost every 12–18 months — could (or even should) be applied to other business sectors than ICT. The UxP team has been examining new and emerging business models, which can also act as reference cases for the PFS studies envisaged, which take this line of enquiry into account. Presented simply, there are already examples of a 3G approach, characterised by joint ventures between partners that would not traditionally have seen each other as allies. In this case, the reference example is the joint venture between INB Brasil and Galvani phosphates to produce 500 000 t/a of fertiliser (diammonium phosphate, DAP) and 1500 t/a yellowcake. This joint venture intends to make a complex deposit, Santa Quitéria, which from a single mineral perspective would be unpromising, into a TBL project with a single flowsheet [23].

In similar vein, process innovation of a 3G kind does not necessarily involve partnerships; but can come from within an established sector, as was eloquently explained and powerfully illustrated at URAM 2014 by Olga Gorbatenko [24] and A. Matunov [25], both speaking to the objective of "smart" mining. "Smart" is a composite measure derived from a number of performance indicators some of which are enhancements of existing processes while others introduce completely new technologies and methodologies. In both cases, "smart" was tied by the presenters to social acceptance — the smarter the thinking the higher the acceptance.

[8] Extractive Industries Transparency Initiative, see https://eiti.org/

There is however, yet more radical business model redesign in hand, as for example shown by Wengfu Group, China. Starting from two premises, that phosphogypsum is a resource not a waste, and that zero waste is a defining proposition for a sustainable business, Wengfu has not only greatly broadened its product range in the phosphate industry to include ammonium sulphate, but it now sees itself as a provider of construction materials of various kinds and of a range of minerals, such as iodine not just phosphate. Wengfu has also included carbon capture (through the generation from phosphogypsum of calcium carbonate for the cement industry) as a measurable TBL objective. This comprehensive approach, leveraged off an initial engagement with the Chinese 'green mine' policy, speaks to a new (4G) model with a very diverse range of potential partners, customers and stakeholders. It is not commodity, DAP model driving the business any more but the capacity to achieve maximum value add from all the primary and secondary sources in play across all Wengfu's facilities, from the mine to the customer and the consumer. Wengfu publishes on its website a set of five reports on its "Enterprise Innovation" achievements[9].

While such 3G and 4G models offer a host of opportunities, their adoption and success is by no means self-evident, notably in a change- and risk-averse industrial sector. Hence extensive work remains to be done to support these new approaches, notably in agreed procedures for classifying, quantifying and reporting resources. This involves addressing a range of matters such as:

— **Resolving definitional uncertainties:** in addition to the long-standing uncertainties surrounding the distinction between resources and reserves, and under what conditions ore bodies can move backwards and forwards between these categories, in the uranium field the distinction between conventional and unconventional resources gets harder and harder to defend and seems, if anything, misleading. It was reported at the UNECE April 2014 meeting that the United States Security and Exchange Commission (SEC) is now challenging the distinction on these grounds, but for all minerals not just uranium [26]. As defined in the Red Book conventional U may include sources of U as a by-product if the quantity is 'important' or 'significant'. This begs the question of what either term might mean, and whether significance is to be understood as a quantitative judgement or, for example as framed by more qualitative environmental expectations. That is, it may be seen as 'significant' that trace quantities of uranium remain in phosphate fertiliser almost irrespective of quantity, with the inference that it would be preferable to remove them. From a quantitative point of view by contrast, in the light of conventional mining activities often having very low grades (and hence are now being taken out of production) the distinction based on an undefined 'importance' measure does not really hold at either a quantitative level or a taxonomic level.

— **Data unreliability**: Steve van Kauwenbergh's observation in the 2010 IFDC (International Fertilizer Development Center) report about phosphate resources and reserves, that much of the data he evaluated for that report is fundamentally unreliable [27], obviously carries across into UxP in general. The underlying causes of this problem — age of data, poor surveying and analytical techniques, conservatism of the Responsible Person signing off for the bank etc. adversely affect, and even undermine, accurate resource and reserve reporting in general. Where U, REE and P resources intersect there may therefore be data unreliability at an order of magnitude higher even than for the more

[9] Wengfu Group website http://wengfu.com/list-en-463.htm accessed April 2015.

classically estimated resource, however precisely the U content in phosphoric acid can be measured.

— **Transparency:** the data unreliability issue is compounded by the reluctance on the part of governments and companies to declare what they have for a compound of strategic and commercial reasons. Presumably as new U, P or REE projects depend more and more on external finance this issue is going to come to some sort of head, at least for the less wealthy countries. This highlights the need to extend the scope and upgrade the analytical capability of the United Nations Framework Classification (2009) [28] to address this problem.

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POSITIONING FOR A POSITIVE FUTURE: CIGAR LAKE STARTS PRODUCTION[10]

T. Gitzel
Canada

Thank you very much Michel, merci beaucoup, for that kind introduction. Good morning everyone.

Ladies and gentlemen, let me start by saying how delighted I am to be here in Vienna with you today at the home of the IAEA. I have to say Vienna really is one of the most beautiful places on the planet. So, it wasn't difficult for me to accept the IAEA's generous invitation to speak with you today.

I am today, and always have been, a very strong supporter of the great work done every day by the team here at the IAEA. I had the opportunity to listen to a number of presentations yesterday and found them to be first class and of highest quality. So on behalf of my colleagues at Cameco and in the nuclear fuel business, I say thank you to the IAEA for the great work you do for us.

I would also say that one of my favourite parts of attending these events is having the opportunity to meet new industry friends and renew old acquaintances. Whether we are competitors, partners, customers, regulators or just friends, I get the sense that we are, to some extent, all in the same boat. Our future success depends on how we can collectively advance the nuclear story and conferences like this give us the chance to do just that. Don't underestimate the value of these relationships.

I've been asked to speak to you today about Cameco's view of the uranium market and more specifically, about the start-up of the Cigar Lake mine in Saskatchewan, Canada. So this morning, with apologies for perhaps repeating information that others have presented, I'd like to start with some thoughts about the nuclear industry and the uranium market in a post-Fukushima world.

I'll then turn to an overview of the Cigar Lake project, including a brief discussion of some of the technical innovations that allow us to mine this important deposit. I'll then close then with some thoughts on why I think it's imperative that we, as leaders in the nuclear industry, continue to be actively involved in telling the nuclear story so that countries around the world will continue to view nuclear power as an essential part of their electricity mix.

Let's start with the big picture.

As the past chair of the WNA and as CEO of Cameco, one of the world's largest uranium producers, a good portion of my time is spent studying the nuclear energy industry, and especially the uranium market. I've often said that this is not an industry for the 'weak of heart'. It can be challenging, divisive and controversial. Yet, for those who take the time to understand it and believe in its virtues, it can be extremely rewarding… and its benefits can be world-changing.

Today, however, some three years and three months post Fukushima, I would say that we are in a very challenging situation. It's not an easy time for nuclear but it wasn't always like this.

I like to remind people what it was like the day before the Fukushima accident on March 10, 2011. The nuclear industry was on a roll with almost every country that had nuclear power looking to expand it … and many countries without nuclear power looking to install it. Uranium

[10] Closing industry keynote paper

prices were behaving accordingly, with both the spot price and the long-term price at about US $72 per pound. At Cameco, we were sitting in Saskatoon, wondering how we were going to keep up with this growth. We wondered where we would get the people and how we could prudently advance new mining projects. But those were what we now call the "good old days".

Then, of course, on March 11, 2011, the mighty earthquake and tsunami hit the shores of northern Japan, causing the damage that we are all too aware of at the Fukushima site. This is an accident that has had a significant effect on the entire nuclear world, leading to where we are today with Japanese reactors still shutdown, countries debating the future of their nuclear units and, uranium prices at a nine-year low. That's the bad news.

The good news is that I believe these challenges are temporary and that there remains a bright long-term future for nuclear energy. The reality is that the world needs more energy. I heard this several times yesterday, yet, it's a little hard for us to fathom that, in the 21st century, there are still two billion people in the world that don't have access to electricity, and many of those that do are demanding more.

Over the next few decades, as the world's population grows from seven billion to nine billion people, there will be many more who need access to electricity. That's more than 150 000 more consumers on the planet every single day. We're not just talking about lacking a plug-in to run luxuries like iPads, smartphones and blackberries. We're talking about lacking the large-scale base-load electricity required for systems like healthcare, education, transportation, and communication.

Governments in many countries are under enormous pressure to add to their grids, and they are doing just that. They have to. Their populations will demand it but the decisions on what power sources to choose are not easy. These decisions must be made in the context of a growing awareness of the world's need to reduce our dependence on fossil fuels, the desire for clean air, and the risk of over-dependence on a single source of electricity.

So you can see why governments in countries with rapidly expanding economies and growing populations are continuing to choose nuclear. It's an option that provides the base-load power they need, while also meeting their clean air goals and helping to diversify their energy portfolio.

China is a great example and I know it has been talked about many times this week. With a burgeoning population and a rapidly growing appetite for clean energy, China, today, has about 20 reactors operating, and another 30 under construction, and they plan to have about 58 in operation by the end of the decade with another 30 under construction. This is breath-taking growth, and they're just getting started.

But China isn't the only country building nuclear: India, Russia, South Korea, and now the Middle East all have aggressive new build programs. The result is that reactor growth is occurring at a pace we haven't seen in decades. Today, there are 435 operable nuclear power plants in the world, with another 70 under construction, and many, many more in the planning stages. We at Cameco, see more than 90 net new reactors coming on stream over the next 10 years. That's growth we haven't seen since the 1970s when the US, Europe and Japan were building their fleets.

Of course, more reactors mean more uranium demand…at a time when new mining projects are being shelved and secondary supply from sources like the HEU agreement is reducing. This, we believe, will lead to a real and growing gap between supply and demand over the long term. That is why we're excited about the future, and why we keep our sights set on it, even while navigating the fog of today's market uncertainty.

We know that more uranium is going to be needed but licensing, permitting, aboriginal relations and many other factors all play an important role. We also know the challenges of bringing on a new mine. In many countries, it often takes 7 to 10 years to bring a new mine into full production.

However, in today's market, and at today's prices, producers cannot justify the capital expenditures required to bring on a new project. It's a situation that in my view is not sustainable. So I think that going forward, the primary producers will be under some pressure to fill what will become a real and growing gap between supply and demand.

That's the kind of challenge we want to see and, at Cameco, we are well prepared for it, primarily because of our presence in the Athabasca Basin in northern Saskatchewan. Our Rabbit Lake and Key Lake properties were the world's biggest uranium producing mines in the 1980s and '90s, and, today, our McArthur River and Cigar Lake mines are following in those footsteps.

Before I get too far, I want to acknowledge the great relationship we have with our partner AREVA at both McArthur River and Cigar Lake as well as our other Cigar Lake partners, TEPCO and Idemitsu.

The McArthur River mine is the largest high-grade uranium mine in the world, and boasts an average ore grade of about 16%. The Key Lake mill has the distinction of being the world's largest uranium mill. Together, they achieved the highest output from a uranium facility ever — 20.13 million pounds[11]… in 2013. That makes it easy to remember. This is a staggering number — and more than all of Australia's production combined last year. The McArthur-Key operation is really what has kept Canada the second largest uranium producing country in the world.

It's about to have some help. On March 13 of this year, we announced the official start-up of mining at the Cigar Lake operation. Once in full production, Cigar Lake will be second only to McArthur River/Key Lake … with plans of producing 18 million pounds [~6900 tU] per year and, its ore grade is 18.3%, making it number one in that category. So how did we get this point?

Well, it wasn't easy and it took us a long time. I can still remember the buzz back in 1981 in the industry when the Cigar Lake ore body was discovered. With its astonishing ore grades, Cigar was the richest prize in uranium mining but it was also the most challenging. With the difficult geology and some serious setbacks … there are many in our industry who thought this mine could never be brought into production.

Right from the beginning, we knew it wouldn't be easy and over time, we proved to be right about that. After making the decision to develop the mine in late 2004 … the project experienced two serious water inflows which have caused years of delays and added hundreds of millions of dollars to the cost. So, what are the characteristics of this mine that make it so challenging?

Probably the most complicated characteristic of this ore body is its location. The ore deposit is about 500 m below surface. It is located in the transition zone between water-bearing sandstone and a strong granite basement and it is surrounded by a clay halo. The strike distance, or length, is nearly two kilometres with a width ranging from 20 to 100 m and an average thickness of about 5.4 m, although there are areas where ore thickness is up to 13.5 m.

To control water inflow and provide ground stability, we use freezing technology to mass freeze the entire ore body, including that halo of clay and sandstone that surround it. At surface, this requires high capacity, freeze plants that send brine at -30°C underground through pipes to freeze the ore body.

The mining process itself is also unique. Originally, we were going to use the same method as at McArthur — raisebore mining, where you have a tunnel above and below the ore and you bore up through it. But the ground above the Cigar Lake ore body was not suitable for this. So we had to find a way we could mine from under the ore body, in the dry, stable basement rock.

[11] 7743 tU. Other conversions elsewhere in the article added by the editor are in brackets []

The solution was jet boring — a process that has been used in other applications, but never uranium mining. So we took it and, with the help of our partners and other experts, adapted it specifically for Cigar Lake. Basically, from a special purpose jet boring machine, we use high pressure water to cut the ore into chips that are fed into an underground initial processing circuit, where it is crushed and thickened and eventually pumped to surface in a slurry form.

Once the ore has been carved out, we send a different pipe up into the cavity and backfill it with concrete. This restores structural integrity when we move over to carve out an adjacent cavity. The ore circuit is completely self-contained, and includes ore extraction, storage and transport. As a result, workers never come into contact with the ore itself because it stays in the piping and tanks, which is important for radiation protection.

At full production, we expect to have about 600 full time employees at the site – over half of which will be aboriginal people from northern Saskatchewan. We will have spent over US $2.5 billion dollars since the development decision to get this mine into operation.

So, the long-anticipated start of the Cigar Lake mine has begun and it's a pretty exciting time for everyone involved in Cigar Lake right now. With each new cavity of ore that we remove, we are gaining the experience to sustain operations for years to come.

Once the mill is up and running at AREVA's McClean Lake mill, we expect to start producing yellowcake, and ramp up to full production of 18 million pounds [~6900 tU] annually over the next several years. With over 200 million pounds [~77 000 tU] of reserves for phase one alone, this project will be a strong producer for many years to come and that's important, because as I said earlier, the world is going to need it.

So that's Cigar Lake in a nutshell, a project that will have an impact on the nuclear world for many years to come.

Let me move away from Cigar like now and put on my WNA hat. I would like to close this morning with a 'call to action' to each of you out there who are involved or interested in the future role that nuclear energy can play in an energy-hungry world. Let me encourage you to do these key things to help our industry:

First, whatever your job might be and wherever your operations are, keep safety as a top priority. We need to work hard today to convince people that nuclear energy is safe and the best way to do that is to BE safe. Second, I urge you to continue to be actively involved in associations like the IAEA, WNA, WANO and others, where you can work collaboratively and share important information — like we are doing here this week. Finally, let's stand up and get actively involved in discussions about nuclear, not only here at our own events, but at other global gatherings and in our communities.

We need to tell the nuclear story to the world because, as we say, if we don't tell the nuclear story, who will?

Thank you for the invitation to be here with you today. Enjoy the rest of the conference.

CONCLUDING REMARKS OF THE URAM-2014 SYMPOSIUM CHAIRMAN

M. Cuney
France

Distinguished Delegates, Colleagues and Friends,

It's my great pleasure to thank all meeting participants for their contribution as speakers, as poster presentations, as well as participants to the discussions, and the IAEA and the organizers of this symposium.

This symposium has been a tremendous opportunity to meet old friends to make new ones and to develop relations with colleagues from different disciplines and from different countries.

During these five days we have seen that from the Cradle to the Grave, from scientific research to environmental remediation, the field of Uranium Raw Material for the Nuclear Fuel Cycle is in constant improvement and extremely innovative.

I am still more confident after these five days of symposium, than at the opening of it, that you have learn a lot from each other and that you will bring home new ideas for the development of your activities.

You have seen that during the last five years, since the last URAM–2009 Symposium, despite fluctuating economic conditions, new deposits have been discovered, in already intensively explored areas such as the Athabasca Basin, as well as in newly explored basins as in Africa or in southern Mongolia and new exploration technologies have emerged.

We have seen also that considerable progresses have occurred for the extraction of uranium from the phosphates with new molecules, from the black shales with bio heap leaching, and even from the sea water.

The Red Book report and the UDEPO data base also show that there is plenty of uranium available in the world. However, the transformation of these reserves into resources will require a lot of investment and a tremendous amount of work.

The main limiting factor for the development of new projects is the depressed price of uranium. The projections made for the uranium demand during the first day of the symposium have shown that we may have to wait at least until the middle of the twenties to see the demand exceeding the supply. These projections will certainly discourage the investors to put money into uranium exploration, this may push companies to reduce their geological staff, and this will encourage geologist to move toward the exploration of other metals.

However, looking back to the systematic failure of the analysts in forecasting the evolution of the uranium prices and the future needs in uranium, I recommend you stay confident in the future of uranium.

The development of the world economy will need a considerable increase of the energy production, and especially of greenhouse effect-free energy, and nuclear energy is one of the most significant in this respect.

We are just living a difficult period which will be rapidly forgotten when the present turbulences will be overcome.

I wish all of you a safe way back in your country and remain confident in the future of uranium. Waiting to meet any of you again, very soon, anywhere in the world.

Thank you all once more for your contributions

Au revoir.

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	P. Woods	IAEA

LIST OF PARTICIPANTS

ARGENTINA

Bonetto, J.P.	Autoridad Regulatoria Nuclear, Avenida del Liberatador 8250, BUENOS AIRES Fax: +54 11 44800160 Email: jbonetto@arn.gov.ar
Dieguez, S.	Comisión Nacional de Energía Atómica (CNEA), Casilla de Correo 527, 5600 SAN RAFAEL, Mendoza Fax: +54 260 4430833 Email: dieguez@cnea.gov.ar
Lopez, L.E.	National Atomic Energy Commission, Av Del Libertador 8250, Ciudad Autonoma, 1429 BUENOS AIRES Fax: +54 11 4781 1478 Email: lopez@cnea.gov.ar

ARMENIA

Kirakosyan, M.	CJSC Armenian Russian Mining Company, 12 Saryan Street, 0002 YEREVAN, Fax: +374 10569472 Email: info@armc.am
Vardanyan, V.	Ministry of Energy and Natural Resources, Mining Department, Government House 2, Republic Square, 0010 YEREVAN Email: vvrula@rambler.ru

AUSTRALIA

Bartsch, P.	Alchemides Pty Ltd, 19 Claremont St, Mile End, 5031, South Australia Email: pjbartsch@gmail.com
Becker, E.	Paladin Energy, 4/502 Hay Street, SUBIACO WA 6008 Email: ED.BECKER@PALADINENERGY.COM.AU
Beeson, R.	AURA Energy Ltd, Suite 3, Level 1, 19-23 Prospect ST, Box Hill, VIC 3128 Email: bob.beeson@auraenergy.com.au

Bradford, R.
Jem-Met,
17 St Lucia Road Iluka,
6028 PERTH
WA
Email: jem-met@bigpond.com

Butcher, D.J.
Paladin Energy Ltd,
13 Darbon Crescent,
WA 6009 SUBIACO
Email: darryl.butcher@paladinenergy.com.au

Carnegie, G.M.
The Sentient Group,
Level 44,
Grosvenor Place,
225 George Street,
SYDNEY
Email: gmcarnegie@thesentientgroup.com

Ehrig, K.
BHP Billiton,
55 Grenfell Street,
SA 5000 ADELAIDE
Email: Kathy.J.Ehrig@bhpbilliton.com

Ford, M.A.
Paladin Energy Ltd,
PO Box 201,
WA 6904 SUBIACO
Email: merrill.ford@paladinenergy.com.au

Guthrie, V.
Toro Energy,
Level 2,
35 Ventnor Avenue,
WEST PERTH 6005,
WA
Email: Vanessa.Guthrie@toroenergy.com.au

Harris, F.
Energy Resources of Australia,
Level 26,
123 Albert Street,
4000 BRISBANE,
Queensland
Fax: +61 7 36253001
Email: frank.harris@riotinto.com

Hondros, P.J.
JRHC Enterprises Pty Ltd,
26 Kanmandoo Road,
5154 ALDGATE
Email: jim@JRHC.com.au

Jaireth, S.
Geoscience Australia,
Cnr Jerrabomberra Avenue,
Hindmarsh Drive,
Symmonston ACT,
GPO Box 378,
CANBERRA ACT 2601
Email: Subhash.Jaireth@ga.gov.au

Jones, B.
Uranium Equities/PhosEnergy,
Level 5,
29 King William Street,
SA 5000 ADELAIDE
Email: bryn.jones@uel.com.au

Krebs, D.

Greenland Minerals and Energy Ltd,
PO Box 2006,
Subiaco WA 6904
Fax: +61 8 9382 2788
Email: damien@ggg.gl

Maley, M.D.

ANSTO Minerals,
Locked Bag 2001,
2232 KIRRAWEE DC,
Fax: +61 2 97179129
Email: mkm@ansto.gov.au

McMaster, S.

RMIT University,
School of Applied Sciences,
GPO Box 2476,
3001 MELBOURNE
Email: Scott.mcmaster@student.rmit.edu.au

Paxton, C.

Paladin Energy Ltd,
4/502 Hay Street,
WA 6008 SUBIACO
Fax: +61 8 9381 4978
Email: cathy.paxton@paladinenergy.com.au

Ring, R.J.

ANSTO Minerals,
Locked Bag 2001,
Kirrawee DC,
NSW 2232
Fax: +61 2 97179129
Email: bjr@ansto.gov.au

Waggitt, P.W.

Northern Territory Department of Mines and Energy,
Level 5,
Darwin Centrepoint,
Smith Street,
0820 DARWIN NT
Fax: +61 8 8999 6527
Email: Peter.Waggitt@nt.gov.au

AUSTRIA

Arnold, N.

Institute for Security/Safety and Risk Management,
University of Natural Resources and Life Sciences,
Borkowskigasse 4,
1190 VIENNA
Fax: +43 1 47654 7709
Email: nikolaus.arnold@boku.ac.at

Bannon, J.

Vienna University of Technology Atominstitut,
Stadionallee 2,
1020 VIENNA
Fax: +43 1 58801 14199
Email: jbannon@ati.ac.at

Gufler, K.

Institute for Security/Safety and Risk Sciences,
University of Natural Resources and Life Sciences,
Borkowskigasse 4,
1190 VIENNA
Fax: +43 1 47654 7709
Email: Klaus.gufler@boku.ac.at

Liebert, W.	Instiute for Security/Safety and Risk Management, University of Natural Resources, Borkowskigasse 4, 1190 VIENNA Fax: +43 1 476547709 Email: liebert@boku.ac.at
Michalke, F.S.	University of Natural Resources and Life Sciences, Institute of Safety/Security and Risk Sciences, Borkowskigasse 4, 1190 VIENNA Fax: +43 1 47654 7709 Email: franz.michalke@boku.ac.at
Michalke, F.S.	University of Natural Resources and Life Sciences, Institute of Safety/Security and Risk Sciences, Borkowskigasse 4, 1190 VIENNA Fax: +43 1 47654 7709 Email: franz.michalke@boku.ac.at
Rengifo, C.	Margaretenstrasse 56/3/37, 1050 VIENNA Email: christhian.rengifo@uxc.com
Wildpaner, V.	Technische Universitaet Wien, Atominstiut, Stadionallee 2, 1020 VIENNA Email: wildpaner@ati.ac.at

BAHRAIN

Bin Daina, M.M.	Supreme Council for Environment, PO Box 1823, BAHRAIN Fax: +973 17920205 Email: mbindaina@pmew.gov.bh

BANGLADESH

Majumder, R.K.	Bangladesh Atomic Energy Commission, Nuclear Minerals Unit, PO Box 3787, Ganakbari, Savar, DHAKA 1000 Fax: +88027789620 Email: ratankm@yahoo.com

BENIN

Kaffo, A.B.	Ministere de l'Energie des Recherches Petrolieres et, Minieres de l'Eau et du Developpement et des Energies, Renouvelable, 2049 COTONOU, Fax: +229 21377383 Email: masterkaffo@yahoo.fr

BRAZIL

Avelar, A.C.	Universidade Federal de Minas Gerais UFMG, Department of Animal Sciences, School of Veterinary, UFMG, Avenida Antonio Carlos, 6627 Campus Pampulha, BEL HORIZONTE Fax: +55 31 33322881 Email: avelara@ufmg.br
Azevedo Py Junior, D.	Industrias Nucleares do Brasil, INB, Rod. Poços Andradas, Km 20,6, Caldas, MG, 37701970 CALDAS, MG Email: delcy@inb.gov.br
Da Silva, L.F.	Industrias Nuclares do Brasil S/A/ - INB, 400, Joao Cabral de Mello Neto, Ave 3rd Floor, RIO DE JANEIRO Fax: +5521 25379428 Email: filipe@inb.gov.br
de Souza Pereira, W.	Grupo de Estudos de Temas Ambientais, Laboratorio de raiobiologia e Radiometria Petrdo Lopes, dos Santos, Departamento de Biologia Geral, Universidade Federal Fluminese –UFF, CEP 24.001-970, RIO DE JANEIRO Email: pereirarsj@gmail.com
Gomiero, L.A.	Industrias Nucleares do Brasil S/A – INB, Fazenda Cahoeira s/n, zona rural, Distrito de Maniacu, PO Box 7, 46400-000 CAETITÉ Fax: +55 77 34544803 Email: gomiero@inb.gov.br
Oliveira Lainetti, P.E.	Nuclear and Energetic Research Institute, (IPEN-CNEN/SP), Brazilian Nuclear Energy Commission – CNEN, Centro de Quimica e Meio Ambiente – CQMA, Av Professor Lineu Prestes 2242, C. Universitaria, Butanta, 05508-900 SAO PAULO Fax: +55 11 3133 9349 Email: lainetti@ipen.br
Pires, F.	Rio de Janeiro University, Geology Department, Rua Sas Francisco Xavier 524, Maracana, 20550900 RIO DE JANEIRO Email: bbmppig.com.br
Portella, P.J.G.	Industrias Nucleares do Brasil SA, Fazenda Cachoeira, caixa postal 07, 46400-000 CAETITÉ Fax: +557734544803 Email: ricardomassao@inb.gov.br

Shigueoka, R. — Industrias Nucleares do Brasil SA,
Fazenda Cachoeira, caixa postal 07,
46400-000 CAETITÉ
Fax: +557734544803
Email: ricardomassao@inb.gov.br

Sodre Villegas, R.A. — Comissao Nacional de Energia Nuclear,
Laboratorio de Pocos de Caldas,
Rodovia Pocos de Caldas,
Andradas, km 13,
CEP 37701-970,
Fax: +55 3537223622
Email: rvillegas@cnen.gov.br

Villas-Boas, R.C. — Centre for Mineral Technology (CETEM),
Av. Ipe 900,
Ilha da Cidade Universitaria,
21941-590 RIO DE JANEIRO
Email: villasboas@cetem.gov.br

CAMEROON

Chakam Tagheu, P.J. — National Radiation Protection Agency (NRPA),
Ministry of Scientific Research and Innovation,
PO Box 33732,
YAOUNDE
Fax: +237 22203371
Email: pulchakam@yahoo.fr

Kouske, A. — University Institute of Technology,
PO Box 8698,
DOUALA
Fax: +237 33 40 2482
Email: arnaudpatricek@gmail.com

CANADA

Adnani, A. — Uranium Energy Corporation,
1111 West Hastings Street,
VANCOUVER V6E2J3,
British Columbia
Email: aadnani@uraniumenergy.com

Annesley, I. — University of Saskatchewan,
Department of Geological Sciences,
114 Science Place,
SASKATOON S7N 5E2, SK
Fax: +1 306 966 8593
Email: irvine@gmail.com, jnrirvine@gmail.com,
ira953@mail.usask.ca

Barsi, R. — Golder Associates Ltd.,
1721 8th Street East,
S7H 0T4 SASKATOON, SK
Fax: +13066653349
Email: kaylin_stuckel@golder.com

Brown, G. — Boswell Capital Corporation,
96 Avenue Road,
Ontario,
M5R 2H3 TORONTO
Fax: +416 962 0020
Email: grbrown@boswellcapital.com

Clark, G. — The Sentient Group,
1001 Square Victoria,

	H2Z 2B1 MONTREAL Quebec Email: gclark@thesentientgroup.com
Cunningham, K.	Saskatchewan Ministry of the Economy 300, 2103 - 11th Avenue Regina SK S4P 3Z8 Email: keith.cunningham@gov.sk.ca
Flaman, N.B.	BHP Billiton, 10 Marina Blvd #50-01, Marina Bay Financial Centre, Tower 2, 018983 SINGAPORE Email: nathan.Flaman@bhpbilliton.com
Gitzel, Tim	Cameco Corporation, 2121 11th Street West, SASKATOON S7M 1J3, Saskatchewan Email: Dorothy_Slawinski@cameco.com
Hajnal, Z.	University of Saskatchewan, Department of Geological Sciences, 114 Science Place, Saskatoon S7N5E2 Fax: +1 306 966 8593 Email: zoltan.hajnal@usask.ca
Kyser, K.	Dept. Geological Sciences & Geological Engineering, Queen's University, 36 Union St, Kingston, K7L3N6 ONTARIO Email: kyser@geol.queensu.ca
Potter, Eric	Geological Survey of Canada, 679-601 Booth St, ON K1A OE8 OTTAWA,Ontario Fax: +1 613 943 1286 Email: epotter@NRCan.gc.ca
Schnell, H.	HA Schnell Consulting Inc, 4305 Eagle Bay Road, V0E 1T0 EAGLE BAY, British Columbia Email: hatschnell@xplornet.com
Wheatley, K.L.	Forum Uranium Corp, Suite 1158, 409 Granville Street, V6C 1T2 VANCOUVER Email: wheats@forumuranium.com
Yang, J.	University of Windsor, Department of Earth and Environmental Sciences, 401 Sunset Avenue, Windsor, N9B 3P4 ONTARIO Email: jianweny@uwindsor.ca
Zhu, S.W.	The Sentient Group, 1001 Square Victoria, Suite 450, H2Z 2B1 MONTREAL Email: szhu@thesentientgroup.com

CENTRAL AFRICAN REPUBLIC

Bangoto, R.R.	Ministry of Mines, Energy and Hydraulics of the Central African Republic, PB 2481, BANGUI Email: ricbangoto333@yahoo.fr

CHILE

Fleming Rubio, P.A.	Nuclear Energy Chilean Commission, Amunategui 095, Santiago Centro, SANTIAGO Fax: +562 24702512 Email: pfleming@cchen.cl
Orrego Alfaro, P.A.	Nuclear Energy Chilean Commission, Amunategui 095, Santiago Centro, SANTIAGO Fax: +562 2470 2512 Email: porrego@cchen.cl

CHINA

Chen, S,	Beijing Research Instiute of Chemical Engineering and Metallurgy, Email: samcss@163.com
Gao, S.	China Uranium Corporation Ltd, 1Sanlihe Nansixiang, Xicheng District, BEIJING Fax: +86 10 68555464 Email: Gao_SHX@CNNC.COM.CN
Ke, Dan	CNNC Beijing Research Institute of Uranium Geology, 10 Xiaoguangdongli, Anwai Street, Chaoyang District, 100029 BEIJING Email: kedan1125@126.com
Li, G.	Earth Science Faculty, East China Institute of Technology, NO.418, Guranglan Road, Jiangxi Province, 330013 NANCHANG Fax: +86-791-83897320 Email: liguanglai@ecit.cn
Li, Z.	Beijing Research Institute of Uranium Geology, PO Box 9818, 100029 BEIJING Email: zyli9818@126.com
Liu, X.	East China Institute of Technology, No. 418 Guanglan Road, Jiangxi, NANCHANG 330013, Jiangxi Fax: +86-791-83897320 Email: xdliu@ecit.cn, liuof99@163.com

Nie, J.
CNNC Beijing Research Institute of Uranium Geology,
No.10, Xiaoguandongli, Anwai,
100029 BEIJING
Email: niejiangtaonjt@163.com

Qin, M.
Beijing Research Institute Of Uranium Geology,
10 Anwai Xiaoguan-Dongli,
Chaoyang District,
100029 BEIJING
Fax: +86-10-64917143
Email: qinmk9818@163.com

Wang, K.
East China Institute of Technology,
No.48 Guanglan Road,
Jiangxi Province,
330013 NANCHANG
Email: xy2gmo02@gmail.com

Xia, F.
East China Institute of Technology,
Fax: +86 791 83897568
Email: fxia@ecit.cn

Zhang, Y.
Beijing Research Instiute of Uranium Geology,
No 10 Anwai Xiaoguangongli,
Chaoyang District,
100029 BEIJING
Fax: +861064917143
Email: yyzhang_521@163.com

Zhou, S.
China Atomic Energy Authority
Email: zhousicong.caea@gmail.com

COLOMBIA

Moreno, G.
Servicio Geologico Colombianco SGC,
Diagonal 53 No 34-53,
BOGOTA DC
Email: gmoreno@sgc.gov.co

Perez, A.
Servicio Geologico Colombiano SGC,
Diagonal 53 No 334-53,
BOGOTA DC
Email: adperez@sgc.gov.co

CÔTE D'IVOIRE

Koffi, Konan Ange
Direction Generale des Mines et de la Geologie,
BP V 28,
ABIDJAN,
Email: angekonankoffi_cgia@yahoo.fr

CZECH REPUBLIC

Benes, V.
DIAMO, s.p.,
Máchova 201,
47127 STRÁŽ POD RALSKEM
Email: hvbenesovi@seznam.cz

Matolin, M.
Charles University in Prague,
Albertov 6,
128 43 PRAHA 2
Email: matolin@natur.cuni.cz

Šedina, M.
CEZ, a. s.,
Duhová 2/1444,

14053 PRAHA
Fax: +420211042043
Email: miroslav.sedina@cez.cz

Toman, F.
DIAMO state enterprise,
branch plant GEAM Dolni Rozinka,
59251 DOLNI ROZINKA
Fax: +420 566 593 512
Email: tomanf@diamo.cz

Trojacek, J.
DIAMO state enterprise,
Machova 201,
47127 STRAZ POD RALSKEM
Fax: +420 487 851 456
Email: trojacek@diamo.cz

Vinkler, P.
DIAMO state enterprise,
Branch plant GEAM Dolni Rozinka,
59251 Dolni Rozinka
Fax: +420 566 593 112
Email: vinklerp@diamo.cz

Vostarek, P.
DIAMO state enterprise,
Machova 201,
471 27 STRAZ POD RALSKEM
Fax: +420 487 851 571
Email: vostarek@diamo.cz

DENMARK

Thomasen, G.
The Danish Institute for International Studies,
Oestbanegade 117,
2100 Oe COPENHAGEN
Fax: +45 32 69 8700
Email: gth@diis.dk

Thrane, K.
Geological Survey of Denmark and Greenland (GEUS),
Department of Petrology and Economic Geology,
Oster Voldgade 10,
1350 COPENHAGEN
Fax: +45 3814 2050
Email: kt@geus.dk

Vestergaard, C.
Danish Institute for International Studies (DIIS),
117 Østbanegade,
2100 Ø COPENHAGEN
Fax: +45 32 69 8700
Email: cve@diis.dk

EGYPT

Abdel Geleel, M.
Nuclear and Radiological Regulatory Authority,
3 Ahmed El zomor. St. Nasr City,
11762 CAIRO
Fax: 00 202 227 40238
Email: mageleel2000@gmail.com

El-Fawal, M.M.
Nuclear and Radiological Regulatory Authority,
PO Box 7551,
3 Ahmed El Zomor St.,
Nasr City,
11762 CAIRO
Fax: +202 22740239
Email: mohamed_elfawal@hotmail.com

Farag, N.
Nuclear Materials Authority,
PO Box 530,
El-Maadi,
CAIRO
Fax: +20227585832
Email: nagdy.farag@yahoo.com

Gadalla, A.A.A.A
Nuclear and Radiological Regulatory Authority (NRRA),
Division for Safety of Nuclear Installation,
2 Ahmed El-Zomor St,
Nasr City, El-Zohor District,
CAIRO
Fax: +202 227 40238
Email: aagadalla@hotmail.com

Ibrahim, M.
Nuclear Materials Authority (NMA),
Al Kattamya,
PO 530,
El Maadi,
CAIRO
Email: dr_mahmadi@yahoo.com

FINLAND

Pohjolainen, E.
Geological Survey of Finland,
PO Box 96,
Betonimiehenkuja 4,
02151 ESPOO
Email: esa.pohjolainen@gtk.fi

FRANCE

Auger, F.
AREVA MINES,
Service d'Etudes Procedes et Analyse (SEPA),
2 Route de Lavaugrasse - CS 30071,
87250 Bessines sur Gartempe
Fax: +33 1 34964846
Email: frederic.auger@areva.com

Bernier, G.
CEA,
Nuclear Energy Division,
Radio Chemistry & Process Department,
SMCS, BP 17171,
30207 Bagnols-sur-Ceze Cedex
Fax: +33 4 66 79 65 67
Email: gilles.bernier@cea.fr

Brouand, M.
AREVA-Mines/DGS (GeoSciences Department),
1 place Jean Millier,
Bureau 0562A-3A,
La Defense Cedex,
92084 PARIS
Email: marc.brouand@areva.com

Bruneton, P.
4 Place de la Wantzenau,
8500 LE CHALARD
Email: p.bruneton@orange.fr

Bustos Munoz, S.	AREVA MINES, 1 Place Jean Millier, 92084 PARIS LA DÉFENSE Email: sergio.bustos@areva.com
Cardon, O.	COGEGOBI LLC/AREVA Mongol LLC, 11th Floor, Express Tower, Peace Avenue, Chingeltei District, ULAANBAATAR MONGOLIA Email: olivier.cardon@areva.com
Cuney, M.	CREGU & UMR GEORESSOURCES, Domaine Scientifique Victor Grignard, Entrée 3B, BP 70 239, Vandoeuvre les Nancy Cedex Fax: +333 83 68 47 01 Email: michel.cuney@univ-lorraine.fr
Farmer, K.	AREVA, Tour AREVA, 1 Place Jean Millier, 92084 Paris La Defense Cedex, Email: Karilyn.farmer@areva.com
Laloua, M.	Geoplus Environment, 2 Rue Joseph Leber, 45530 Vitry-aux-loges Fax: +33 2 38 59 3814 Email: m.laloua@orange.fr
Langlais, V.	AREVA Mines, 1 place Jean Millier, Tour AREVA, La defense Cedex, 92084 PARIS Fax: +33134963749 Email: Valerie.langlais@areva.com
Lelievre, F.	AREVA, Tour AREVA - 1 place Jean Millier, 92084 PARIS LA DEFENSE Email: tarik.choho@areva.com
Mercadier, J.	GeoRessources, Campus Aiguillettes entrée 3B, rue Jacques Callot, BP 70239, 54506 VANDOEUVRE-LÈS-NANCY Fax: +33383684701 Email: julien.mercadier@univ-lorraine.fr
Mojica Rodriguez, L.	Atomic Energy Commission (CEA), BP 17171, 30207 BAGNOLS SUR CÈZE Email: luz-adriana.mojica-rodriguez@univ-lorraine.fr

Mokhtari, H.
AREVA Mines,
Service d'Etudes Procedes et Analyse (SEPA),
2 Route de Lavaugrasse -CS 30071,
bessines sur Gartempe
Fax: +33 1 34964846
Email: hamid.mkhtari@areva.com

Monnet, A.
CEA/SACLAY,
DEN/DANS/I-tese,
BAT 125,
91191 GIF SUR YVETTE
Fax: +33 1 69083566
EMail: antoine.monnet@cea.fr

Pacquet, E.
Mines Paris Tech/AREVA Mines,
1 Place Jean Millier,
La Defense,
92084 PARIS
Email: eric.pacquet@areva.com

Pallier, J.P.
AuroVallis / Aurania Resources Ltd,
Ch de Champlan 32,
1997 HAUTE-NENDAZ
Email: janpolp@aurovallis.com

Peychaud, J.
Company Enviroconsult,
Espace Thomas Edison - Bat I,
Impasse Thomas Edison,
84120 PERTUIS
Email: c.bellet@enviroconsult.fr

Plasari, E.
Reactions and Process Engineering Laboratory,
1 rue Grandville, BP 20451,
54000 NANCY
Fax: +33383178056
Email: edouard.plasari@univ-lorraine.fr

Polak, C.
AREVA Mines,
1 Place Sean Millier,
La Defense Cedex,
92054 PARIS
Email: christian.polak@areva.com

Rejeb, A.
AREVA Mines,
1, place Jean Millier,
92400 COURBEVOIE
Email: amel.rejeb@areva.com

Richard, Y.
AREVA,
Tour AREVA - 1, place Jean Millier,
BAL 0550B-1,
92084 PARIS LA DÉFENSE CEDEX
Fax: +33134963750
Email: yoann.richard@areva.com

Thiry, J.
AREVA Mines,
1 Place J Millier,
La Defense Cedex
92084 PARIS
Fax: +33 1 34963806
Email: jacques.thiry@areva.com

Toubon, H. | Mines Paris Tech/AREVA Mines,
1 Place Jean Millier,
La Defense Cedex
92084 PARIS
Email: herve.toubon@areva.com

Virlogeux, D. | AREVA Mines (DGS),
Tour Areva,
1 Place Jean Millier,
La Defense Cedex,
92084 PARIS
Email: denis.virlogeux@areva.com

Willemin, S. | AREVA NC Malvesi,
Zi Malvesi,
Route de Moussan,
BP 222,
11100 NARBONNE
Fax: +33468425550
Email: Stephanie.willemin@areva.com

GERMANY

Barthel, F. | Dresdener Strasse 30,
31303 BURGDORF
Email: fritz.barthel@t-online.de

Foehse, H. | PO Box 1101 Buchenstrasse 9,
78084 BRIGACHTAL
Email: minexplore@aol.com

Haneklaus, N. | Lindigstrasse 6,
98448 BAYREUTH
Email: nilshaneklaus@yahoo.de

Jakubick, A. | UMREG,
Uranium Mining & Remediation Exchange Group,
Eichenweg 14,
78269 VOLKERTSHAUSEN
Email: umreg@gmx.net

Maerten, G.H. | Healthgate Resources Ptd Ltd,
Level 7,
25 Grenfell Street,
SA 5000 ADELAIDE,
AUSTRALIA
Fax: +61 8 8212 5559
Email: horst.maerten@healthgate.co.au

Ohnemus, J. | Urenco Deutschland GmBH,
Roentgenstrasse 4,
48599 GRONAU
Email: joachim.ohnemus@urenco.com

Ruhrmann, G. | Private Consulting Firm,
Hochheimer Weg 3,
53343 WACHTBERG
Fax: +49 2289536566
Email: ruhrmann@mining-consultant.com

Schauer, M.

Federal Instiute for Geosciences and Natural Resources (BGR),
Geozentrum Hannover,
Stilleweg 2,
30655 HANNOVER
Fax: +495113663
Email: michael.schauer@bgr.de

Sterneberg, M.

AREVA,
Advanced Nuclear Fuels GmbH,
Am Seitenkanal 1,
49811 LINGEN
Fax: +49 591 9145 553
Email: markus.sterneberg@areva.com

GHANA

Ahialey, E.K.

Ghana Atomic Energy Commission,
Nuclear Chemistry and Environmental Research Centre (NCERC),
PO Box LG 80,
LEGON-ACCRA
Fax: +223 302 400807
Email: e.ahialey@gaecgh.org

INDIA

Acharya, D.

Uranium Corporation of India Ltd
Jaduguda Mines
Singhbhum (East)
Jharkhand 832102
Email: d.acharya@ucil.gov.in

Ganguly, C.

Birla Institute of Technology and Science (BITS),
Department of Chemical Engineering,
Pilani, KK Birla Goa Campus,
Zuarinagar,
403726 GOA
Email: chaitanya.ganuly@gmail.com

Kothari, M.K.

Atomic Minerals Directorate for Exploration & Research,
Department of Atomic Energy,
Southern Region, Nagarabhavi,
560072 BANGALORE
Fax: +918023211511
Email: kmahendrakumar.amd@gov.in

Mohanty, P.R.

Heavy Water Board,
Department of Atomic Energy,
5th Floor, Vikram Sarabhai Bhavan,
Anushaktinagar,
400094 MUMBAI
Fax: +22 25563360
Email: prmohanty@mum.hwb.gov.in

Pandey, P.

Atomic Minerals Directorate for Exploration and Research,
Department of Atomic Energy,
Northern Region, West Block, VII, R.K. Puram,
110 066 NEW DELHI
Fax: +011 26107358
Email: pradeeppandey.amd@gov.in

Parihar, P.

Atomic Minerals Directorate for Exploration
and Research (AMD),
1-10-153 AMD Complex, Begumpet,
HYDERABAD

Prakash, R.	Heavy Water Board, Department of Atomic Energy, 5th Floor, Vikram Sarabhai Bhavan, Anushaktinagar, 400-094 MUMBAI Fax: +22 25563360 Email: ce@mum.bwb.gov.in
Sarangi, A.K.	Uranium Corporation of India Ltd Jaduguda Mines Singhbhum (East) Jharkhand 832102 Email: aksarangi@ucil.gov.in
Sreenivas, T.	Bhabba Atomic Research Centre, Department of Atomic Energy, Government of India, Trombay, 400085 MUMBAI Fax: +914027762940 Email: tsreenivas@ymail.com
INDONESIA	
Muchsin, A.	Centre for Nuclear Fuel Technology - National Nuclear Energy Agency, Kawasan PUSPIPTEK, Tangerang, 15314 SELATAN Email: ganisa@batan.go.id
Sumaryanto, A.	Centre for Technology of Nuclear Material, Jl. Lebak Bulus Raya No 9, Pasa Jumat, JAKARTA Fax: +62 21 7691977 Email: aguss@batan.go.id, agus@batan.go.id
Syaeful, H.	Center for Technology of Nuclear Mineral, National Nuclear Energy Agency (BATAN), Jl. Lebak Bulus Raya No 9, Pasar Jumat, 12440 JAKARTA Fax: +62 21 7691977 Email: ppgn@batan.go.id, syaeful@batan.go.id
IRAN, ISLAMIC REPUBLIC OF	
Davarkhah, R.	Nuclear Science and Technology Research Institute, PO Box 11365-8486, TEHRAN Fax: +982188221116 Email: rdavarkhah@aeoi.org.ir
Ghanbari, Y.	Atomic Energy Organization of Iran (AEOI), North Karegar Ave, TEHRAN Email: yghanbari@aeoi.org.ir
Iranmanesh, J.	Atomic Energy Organization of Iran (AEOI), North Karegar Ave, TEHRAN Fax: +9802188221128 Email: jiranmanesh@aeoi.org.ir
Nikgoftar, M.	Atomic Energy Organization of Iran (AEOI), North Karegar Ave, TEHRAN

Fax: +982188221090
EMail: mnikgoftar@aeoi.org.ir

ITALY

Abbate, G.

ENEA,
Centro Ricerche Casaccia,
Via Anguillarese 301,
00100 ROME
Fax: +390630484147
Email: giulia.abbate@enea.it

JAPAN

Kamei, T.

Kyoto Neutronics Co Ltd,
ASTEM 8F, 134 Chudoji Minamimachi,
Shimogyo-ku,
KYOTO 600-8813
Fax: +81 75 326 2190
Email: hae00675@nifty.com

JORDAN

Allaboun, H.

Jordan Atomic Energy Commission (JAEC),
PO Box 70,
11934 AMMAN
Fax: +962 6 5200 471
Email: hussein.allaboun@jaec.gov.jo

Kahook, S.

Jordan Atomic Energy Commission (JAEC),
PO Box 70,
11934 AMMAN
Fax: +962 6 5200 471
Email: samer.kahook@jaec.gov.jo

Saleh, H.

Al-Hussein Bin Talal University,
Department of Physics,
PO Box 20,
MA'AN
Email: hanhas2002@gmail.com

KAZAKHSTAN

Avdassyov, I

NAC Kazatomprom,
JV Zarechnoye JSC,
58/5 Hodzhanova Str.,
050060 ALMATY
Fax: +7-727-2980096
Email: trotilkz@rambler.ru

Gorbatenko, O.

Kazatomprom,
10 D Kunayev St,
010000 ASTANA
Fax: +7 7172551285
Email: ogorbatenko@kazatomprom.kz

Kunanbayev, D.

NAC Kazatomprom,
JV Betpak Dala LLP,
160 Dostyk Ave,
050051 ALMATY
Fax: + 7 727 2596350
Email: dkunanbayev@betpak-dala.kz

Matunov, A.

NAC Kazatomprom,
JV Karatau LLP,

98 Djandosov Str,
050035 ALMATY
Fax: +7-727-2434890
Email: amatunov@karatau.kz

Niyetbayev, M.	Uranium One Inc., 139, Luganskogo St, Business Centre "Keruen", 050051 ALMATY Fax: +7-727-2980096 Email: marat.niyetbayev@uranium1.com
Sakharova, Y.	National Atomic Company Kazatomprom, JSC, 10 D. Kunayev Str, 010000 ASTANA Fax: +7 717 2557399 Email: esakharova@kazatomprom.kz
Sauatova, Z.	Kazakhstan Atomic Energy Committee, Orynbor str. 10, House of Ministries, 13 Entrance 010000 ASTANA Fax: +77172503073 Email: z.sauatova@kaec.kz
Selezneva, V.	JV "KATCO" Lpp, 282 Dostyk Avenue, 050020 ALMATY Email: viktoriya.selezneva@areva.com
Vassilevskiy, O.	Kazakhstan Nuclear University LLP, 168 Bogenbay batyr st, 050012 ALMATY Fax: +77272448180 Email: knu@knu.kz
Yermilov, A.	Uranium One Inc., 139, Luganskogo St., Business Centre “Keruen”, 050051 ALMATY Fax: +7-727-2980096 Email: artem.yermilov@uranium1.co

LATVIA

Hasikova, J.	Baltic Scientific Instruments, Ganibu Dambis 26, 1005 RIGA Email: office@bsi.lv

MADAGASCAR

Randriamananjara, L.H.	Direction de la Geologie, Ministry of Mines, Lot II E25 H, Ambohimirary, ANTANANARIVO Email: louis_herve@yahoo.fr

MALAWI

Chiwambo, C.

Ministry of Mining,
PO Box 251,
LILONGWE
Fax: +22651757235
Email: chiwambocass@gmail.com

MONGOLIA

Batbold, M.

The Nuclear Energy Agency of Mongolia,
2 th Khoroo, Uildverchin Street 2,
Khan Uul District, PO Box 865,
ULAANBAATAR
Fax: +97662263144
Email: office@nea.gov.mn

Batgerel, B.

Nuclear Energy Agency of the Government of Mongolia,
Uildverchin-2, Khan-Uul dist. 2nd khoroo,
17032 ULAANBAATAR
Email: b.batgerel@nea.gov.mn

Demberel, B.

Nuclear Energy Agency of the Government of Mongolia,
Uildverchin-2, Khan-Uul dist. 2nd khoroo,
17032 ULAANBAATAR
Fax: +976 70139019
Email: d.baatarkhuu@nea.gov.mn

MOROCCO

Ghazlane, H.

CNESTEN,
BP 1382 RP, Rabat Principal,
10001 RABAT
Fax: +212537803067
Email: ghazlane@gmail.com

NAMIBIA

Solomons, S.

Langer Heinrich Uranium (Pty) Ltd,
10 Einstein St, New Industrial Area,
PO Box 156,
SWAKOPMUND
Fax: +264 64 410 6332
Email: simon.solomons@lhupl.com

Swiegers, W.

Namibian Uranium Institute (NUI)
P.O. Box 2747
Swakopmund
Email: director@namibianuranium.org

Tibinyane, A.

Ministry of Health and Social Services,
Harvey Street, Private Bag 13198,
WINDHOEK
Email: atibinyane@gmail.com

NIGER

El Hamet, M.O.

Centre de Recherche Geologique et Miniere (CRGM),
BP 10855,
NIAMEY
Fax: +227 20 330377
Email: ousmaneamet@yahoo.fr

Kache, M.
Ministry of Mines and Industrial Development,
NIAMEY
Fax: +227 20731810
Email: mamkache07@yahoo.fr

Moussa, M.
Ministry of Mines and Industrial Development,
10855 NIAMEY
Email: dabokad@yahoo.fr

NIGERIA

Karniliyus, J.
Nigeria Atomic Energy Commission,
P. M. B. 646 Garki Abuja, 9, Kwame Nkrumah Crescent,
Asokoro, PMB 646 Garki ABUJA, FCT
Email: justin.salu@nigatom.org.ng

OMAN

Al Hosni, T.K.S.
Sultan Qaboos University,
Department of Earth Sciences,
PO Box 36 Al-Khod, PC 123
Fax: +968 2441 3415
Email: hosni@squ.edu.om

PAKISTAN

IQBAL, S.
University Of The Punjab,
Hostel No.3 Room No.326 New Campus Punjab,
University Lahore,
54000 LAHORE
Email: pioneer.sajid@gmail.com

PHILIPPINES

Reyes, Rolando
Philippine Nuclear Research Institute,
Commonwealth Avenue,
Diliman,
Quezon City
Email: rolyreyes@yahoo.com

POLAND

Gadja, D.K.
Institute of Nuclear Chemistry and Technology,
Dorodna 16,
03-195 WARSAW
Fax: +48 22 811 1532
Email: d.gajda@ichtj.waw.pl

Kiegiel, K.
Institute of Nuclear Chemistry and Technology,
Dorodna 16,
03-195 WARSAW
Fax: +48228111532
Email: k.kiegiel@ichtj.waw.pl

Maruniak, K.
KGHM Polska Miedz S.A.,
ul. M. Sklodowskiej-Curie 48,
59-301 LUBIN
Email: k.maruniak@kghm.p

Matuszewski, M.
KgHM Polska Miedz S.A.,
ul. M. Sklodowskiej-Curie 48,
59-301 LUBIN
Email: m.matuszewski@kghm.pl

Mielnicki, S.	University of Warsaw, Faculty of Biology, Laboratory of Environmental Pollution Analysis, Miecznikowa 1, 02-096 WARSZAWA Fax: +48 22 5541006 Email: smielnicki@biol.uw.edu.pl
Sadowski, Z.	Wroclaw University of Technology (WUT), Department of Chemical Engineering, Wybrzeze Wyspianskiego 27, 50-377 WROCLAW EMail: zygmunt.sadowski@pwr.wroc.pl
Sklodowska, A.	University of Warsaw, Faculty of Biology, Laboratory of Environmental Pollution Analysis, Mieznikowa 1, 02-096 WARSZAWA Fax: +48225541006 Email: asklodowska@bio.uw.edu.pl
PORTUGAL	
Carvalho, F.	Univerdidade de Lisboa Lisbon Email: carvalho@itn.pt
ROMANIA	
Filip, D.	National Uranium Company, 68 Dionisie Lupu Street, 010458 BUCHAREST Email: Dorin.Filip@cnu.ro
Pop, L.	National Commission for Nuclear Activities Control, 14 Libertatii Blvd, PO Box 4, 050707 BUCHAREST Email: lorena.gheorghe@cncan.ro
Toderas, C.D.	National Uranium Company SA, 1 Dumbravii Street, Feldioara, 507065 Brasov Country Fax: +4068265445 Email: feldioara@cnu.ru
RUSSIAN FEDERATION	
Akopian, I.	NAC Kazatomprom, JV Betpak Dala LLP, 160 Dostyk Ave, 050051 ALMATY Fax: +7 727 2596350 EMail: yuri.akopyan@betpak-dala.kz
Andriyash, M.	State Atomic Energy Corporation ROSATOM, Yasenevaya St. 10-2-310, 115582 MOSCOW Email: MIAndriyash@Rosatom.Ru

Boytsov, A.	Uranium One Inc, Bay Adelaide Centre, Suite 1710, Box 23, TORONTO ON M5H 2R2 CANADA Fax: +1 647 7888501 EMail: alexander.boytsov@uranium1.com
Egorov, A.	JVC Science and Innovations, 40 bld 1 Bolshaya Ordinka Str, 119017 MOSCOW Fax: +7 4993245441 Email: egorov@vniiht.ru
Golovko, V.	OJSC VNIPI promtechnologii, 33 Kashirskoe Road, 11540 MOSCOW Fax: +7 985 300 178 Email: golovko@vnipipt.ru
Kabashev, K.	NRNU MEPhI, Nizegopodskaya st 92-119, 109029 MOSCOW Fax: +74999492635 Email: kkabashev@yandex.com
Karamushka, V.	OJSC VNIPI promtechnologii, 33 Kashirskoe Road, 115409 MOSCOW Fax: +74993245025 Email: Karamyshka@vnipipt.ru
Litvinenko, V.	Priargunsky Industria Mining and Chemical Union (JSC PIMCU), 11 Prospect Stroiteley, Krasnokamensk, 674673 Zabaikalsky Krai, Fax: +8 30245 2 67 47 Email: litvinenkovg@ppgho.ru
Martynenko, V.	JSC RUSBURMASH, 10/4 Letnikovskaya St, Business Center Svyatogor-IV, 115114 MOSCOW Fax: +74999516060 Email: martynenkovg@rbm-armz.ru
Mashkovzev, G.	All Russian Scientific Research Instiute of Mineral Resources, 31 Staromonetny per, 119017 MOSCOW EMail: vims@df.ru
Pechenkin, I.	All Russian Scientific Research Institute of Mineral Resources, 31 Staromonetny per, 11907 MOSCOW Fax: +7 495 9515043 Email: pechenkin@vims-geo.ru
Petrov, V.	Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry Russian Academy of Sciences (IGEM RAS) 35 Staromonetny per., 119017 MOSCOW Fax: +74959511587 Email: vlad243@igem.ru

Seredkin, M.
CSA Global Pty Ltd,
Level 2, 3 Ord Street,
West Perth WA 6005
Fax: +61 8 9355 1977
Email: maxim.seredkin@csaglobal.com

Tarkhanov, A.
JSC "Scientific Research Institute of Chemical Technology,
Kashirskoye Shosse 33,
115409 MOSCOW
Email: tarhanova@mail.ru

Yurtaev, A.
OJSC VNIPI promtechnologii,
33 Kashirskoe Road,
115409 MOSCOW
Fax: +7 499 324-65 74
Email: urtaev@vnipipt.ru

SENEGAL

Dath, C.A.B.
Ministere de l'Enseignement superieur et de la,
Recherche (MESR),
Building Administratif,
5e etage aile droite,
BP 36005,
DAKAR
Fax: +221 33 822 45 63
Email: bambadath@yahoo.fr

Kanoute, M.
Ministry of Energy,
15 Boulevard de la Republique,
DAKAR
Fax: +221 33 823 4470
Email: makanoute@hotmail.com

Ndao, A.S.
Autorite de Radioprotection et de Surete Nucleaire (ARSN),
Building Administratif,
9eme Etage,
PO Box 36005,
99000
Fax: +22 1338246318
Email: asndao@yahoo.com

Tall, M.S.
Autorite de Radioprotection et de surete nucleaire (ARSN),
Building Administratif,
9eme Etage,
PO Box 36005,
DAKAR
Email: moustall@refer.sn

Wague, A.
Instit de Technologie Nucleaire Appliquee,
Universite Cheikh nta Diop,
DAKAR
Fax: +221338246318
Email: ahmadou.wague@ucad.sn

SERBIA

Radenkovic, M.
Vinca Institute of Nuclear Sciences,
Radiation and Environmental Protection Laboratory,
PO Box 522,
11001 BELGRADE
Fax: +381 1 16455943
Email: mirar@vinca.rs

SLOVAKIA

Demko, R.
State Geological Institut of Dionýz Štúr,
Mlynská dolina 1,
81704 BRATISLAVA
Email: rastislav.demko@geology.sk

Janova, V.
Ministry of Environment of the Slovak Republic,
Nam. L. Stura I,
81235 BRATISLAVA
Fax: +421257783218
Email: janova.vlasta@enviro.gov.sk

Turner, M.
Nuclear Regulatory Authority of the Slovak Republic,
Bajkalska 27,
PO Box 24,
82007 BRATISLAVA
Fax: +421 2 58221166
Email: mikulas.turner@ujd.gov.sk

SOUTH AFRICA

Chirenje, E.
Council for Geoscience,
280 Pretoria Road,
Silverton,
PRETORIA
Email: echirenje@geoscience.org.za

Kenan, A.O.
Council for Geoscience,
280 Pretoria Street,
Silverton,
PRETORIA
Email: akenan@geoscience.org.za

Mohajane, E.
National Nuclear Regulator (NNR),
Eco Glades Office Park,
420 Witch Hazel Avenue,
0157 CENTURION
Fax: +27 86 588 4843
Email: pemohajane@nnr.co.za

SPAIN

Bellon del Rosal, F.
Berkeley Minera Espana,
CRTRA SA 322,
KM 30, Retortillo,
37495 SALAMANCA
Fax: +34 923191684
Email: acantalejo@berkeley.es

Colilla Peletero, J.
Berkeley Minera Espana,
CRTRA SA 322,
KM 30, Retortillo,
37495 SALAMANCA
Fax: +34 923191684
Email: acantalejo@berkeley.es

Garcia-Bermejo Fernandez, R.
Iberdorola Ingenieria Y Construccion SAU,
Avda de Manoteras,
20 Edificio D,
28050 MADRID
Fax: +34 91 7132152
Email: elena.mazorra@salud.madrid.org

Martínez Colado, E. Berkeley Minera España,
Crta. SA 322, KM 30,
37495 RETORTILLO,
Salamanca
Email: acantalejo@berkeley.es

Perez-Sanchez, D. CIEMAT,
Avenida Complutense 40,
28040 MADRID
Fax: +34 913466714
Email: d.perez@ciemat.es

Pérez-Sánchez, D. CIEMAT,
Avenida Complutense, 40,
28040 MADRID
Email: d.perez@ciemat.es

SWEDEN

German, O. Vattenfall AB,
Evenemangsgatan 13,
16992 STOCKHOLM
Email: olga.german@vattenfall.com

TAJIKISTAN

Mirsaidov, I. Nuclear and Radiation Safety Agency,
17a Hamza Hakimzoda,
734003 DUSHANBE
Fax: +992372245578
Email: i.mirsaidov@nrsa.tj

Mirsaidov, U. Nuclear and Radiation Safety Agency (State RegulatoryAuthority),
17 Hamza Hakimzoda,
734003 DUSHANBE
Fax: +992 372245578
Email: m.ulmas@nrsa.tj

Nazarov, K. Nuclear and Radiation Safety Agency (State RegulatoryAuthority),
17a Hamza, Hakizmoda,
734003 DUSHANBE
Fax: +992 372245578
Email: holmurod18@mail.ru

THAILAND

Kraikaew, J. Office of Atoms for Peace,
16 Viphavadee-Rungsit Road,
10900 BANGKOK
Email: jarunee@oaep.go.th

Laowattanabandit, P. Chulalongkorn University,
Department of Mining and Petroleum Engineering,
Faculty of Engineering,
10220 BANGKOK
Fax: +66 02 2186920
Email: pipat.1@chula.ac.th

TUNISIA

Abbes, N.

Groupe Chimique Tunisien,
Direction de la Recherche Scientifique Centre de GABES,
110 Rue Habib Chagra,
DAP/BP 72
Email: abbes.nour85@gmail.com

TURKEY

Cetin, K.

General Directorate of Mineral Research and Exploration,
Universitelcr Mah,
Dumlupinar Blv,
MTA Genel Mudurlugu,
MAT Dairesi, Cankaya,
ANKARA
Fax: +90 312 287 5409
Email: kamer.cetin@mta.gov.tr

Unal, I.

General Directorate Of Mineral Research and Exploration,
Demirlibahçe Mah. Agaçli Sok. Demir Ap. No:12 / 7,
06000 ANKARA
Email: ibrahimhunal@gmail.com

Unal, I.H.

General Directorate of Mineral Research and Exploration,
Üniversiteler Mahallesi Dumlupinar,
Bulvari No:139,
Cankaya,
ANKARA
Fax: +90 312 201 12 68
Email: ibrahimhunal@gmail.com

Uzmen, R.

AMR Metallurgy AS,
Sariyer cad.,
Bogazici D Bloklari 4, Bl. D.3 Istinye,
Sariyer,
ISTANBUL
Fax: +90 212 229 5463
Email: ruzmen@amrmineral.com

UKRAINE

Emetz, A.

MP Semenenko Institute of Geochemistry Mineralogy
and Ore Formation,
34 Palladina Av,
142 KIEV
Email: alexander_emetz@yahoo.com

Riazantsev, V.

State Nuclear Regulatory Inspectorate of Ukraine,
9/11 Arsenalna Str.,
01011 KIEV
Fax: +380442543311
Email: Riazantsev@hq.snrc.gov.ua

UNITED KINGDOM

Emsley, I.

World Nuclear Association,
22a St James Square,
SW1Y4JH LONDON
Email: emsley@world-nuclear.org

Hilton, J.	ALEFF Group, Cross Keys Centre, 36 Erith High Street, Erith, LONDON DA8 1QY Email: juliankh@aol.com
Kunze, C.	AMEC Earth & Environmental UK Ltd., 11th floor, International House, Dover Pl., ASHFORD TN23 1HU, Kent Email: christian.kunze@amec.com
Saint-Pierre, S.	SENES Consultants, Arcadis Echq, 24 York Way, LONDON N1 9AB Email: ssaintpierre@senesuk.com
Kidd, S.	East Cliff Consulting, 5 Keverstone Court, 97 Manor Road, BH1 3EX BOURNEMOUTH Email: steve@eastcliffconsulting.com
Titley, M.	CSA Global UK, 2 Peel House, Barttelot Road, HORSHAM RH121DE Email: malcolm.titley@csaglobal.com

UNITED REPUBLIC OF TANZANIA

Gurisha, M.S.	KEPCO International Nuclear Graduate School (KINGS), 1456-1 Shinam Ri, Saosaery Myeon, 689-882 ULSAN Email: salehegs@yahoo.co.uk
Kileo, A.	Tanzania Atomic Energy Commission, PO Box 743, ARUSHA Email: abdalahkileo@gmail.com
Mwalongo, D.A.	Tanzania Atomic Energy Commission, PO Box 743, ARUSHA Email: dennis_mwalongo@yahoo.com

UNITED STATES OF AMERICA

Britt, P.F.	Oak Ridge National Laboratory, One Bethel Valley Road, PO Box 2008, MS-6129, Oak Ridge, TN 37831-6129 Email: brittpf@ornl.gov
Carter, N.	The Ux Consulting Company, LLC, 1501 Macy Drive, L1 ROSWELL 30076, Georgia Email: nick.carter@uxc.com

Catchpole, G.J.	Uranerz Energy Corporation, 1701 East "E" Street, Casper, WYOMING Email: GCATCHPOLE@URANERZ.com
Doelger, M.	Stakeholder Energy LLC, 225 South David Street, Suite A, CASPER WY 82609 Fax: +1 3072341576 Email: mjdoelgerbh@bresnan.net
Gavila, F.	F&J SPECIALTY PRODUCTS, INC., 404 Cypress Road, 34472 OCALA, Florida Fax: +1352-680-1454 Email: diane@fjspecialty.com
Gill, G.A.	Pacific Northwest National Laboratory, Marine Sciences Laboratory, 1529 W. Sequim Bay Road, SEQUIM, WA 98382 Fax: +1 360 681 3699 Email: gary.gill@pnnl.gov
Hall, S.	U.S. Geological Survey, Pox 25046, Denver Federal Center, MS 939, DENVER, CO 80225 Fax: 013032360459 Email: susanhall@usgs.gov
Kennedy, J.	ThREE Consulting Inc, 5 Shardue Lane, ST LOUIS, MISSOURI 63141 Email: jimnina9@aol.com
Kung, K.S.	Office of Nuclear Energy, United Department of Energy, NE-52 Germantown Building, 1000 Independence Ave, S.W., WASHINGTON, DC 20585-1290 Fax: +1 301 903 5057 Email: Stephen.kung@hq.doe.gov
Mahoney, J.J.	Mahoney Geochemical Consulting LLC, 892 S. Newcombe Way, Lakewood, CO 80226 Email: jmahoney@mahoneygeochem.com
Marks, N.	Lawrence Livermore National Laboratory, 7000 East Avenue, LIVERMORE, CA 94551 Fax: +1 925 422 3160 Email: marks23@llnl.gov
Mihalasky, M.	US Geological Survey, 904 West Riverside Ave, Room 202, SPOKANE, WASHINGTON 99201 Email: mjm@usgs.gov

Miller, D.	Miller and Associates LLC, 131 Davis Lane, RIVERTON, WYOMING 82501 Email: davidmiller@wyoming.com
Pool, T.	International Nuclear Inc, 2024 Goldenvue Drive, GOLDEN, CO 80401 Fax: +1 303 278 1076 Email: TPOOL2@QUESTOFFICE.NET
Schneider, E.A.	The University of Texas at Austin, 1 University Station C2200, AUSTIN, TX 78712 Fax: +1 512 471 4589 Email: eschneider@mail.utexas.edu
Scriven, D.	Ablation Technologies LLC, 6911 Casper Mountain Road, CASPER, WYOMING 82601 Fax: +1 307 265 1420 Email: +1 307 265 1420
Van Gosen, B.	US Geological Survey, MS 905, Box 25046, Denver Federal Center Fax: +13032361425 Email: bvangose@usgs.gov

VENEZUELA

Manrique, John	Instituto de Ciencias de la Tierra, Universidad Central de Venezuela, Av Los Ilustres, Universidad Central de Venezuela, Facultad de Ciencias, Instituto de Ciencias de la Tierra, Caracas, Distrito Capital, 1100 CARACAS Fax: 582126051152 Email: johnmancar@gmail.com

ZIMBABWE

Severa, R.	Radiation Protection Authority of Zimbabwe 1 McCaw Drive, Avondale 002634 HARARE ZIMBABWE EMail: rsevera@rpaz.co.zw

OECD Nuclear Energy

Vance, R.	OECD Nuclear Energy Agency (NEA), Le Seine St Germain, 12 Boulevard des Iles, 92130 ISSY-LES-MOULINEAUX FRANCE Fax: +331 45241111 Email: robert.vance@oecd.org

WORLD NUCLEAR ASSOCIATION

Kim, H. — Exelon Generation Company LLC,
4300 Winfield Road,
Warrenville, ILLINOIS 605555,
UNITED STATES OF AMERICA
Email: Haksoo.kim@exeloncorp.com

IAEA

Borio Di Tigliole, A. — Division of Nuclear Fuel Cycle and Waste Technology (NEFW),
Department of Nuclear Energy
Email: A.Borio-Di-Tigliole@iaea.org

Dattani, K. — Division of Nuclear Fuel Cycle and Waste Technology (NEFW),
Department of Nuclear Energy
Email: K.Dattani@iaea.org

Degnan, P.J. — Department of Nuclear Energy
Email: P.Degnan@iaea.org

Fairclough, M. — Division of Nuclear Fuel Cycle and Waste Technology (NEFW),
Department of Nuclear Energy
Email: M.Fairclough@iaea.org

Hanly, A. — Division of Nuclear Fuel Cycle and Waste Technology (NEFW),
Department of Nuclear Energy
Email: A.Hanly@iaea.org

Kronenberg, Andreas — IAEA Department of Safeguards
Email: A.Kronenberg@iaea.org

Monken-Fernandes, H. — Division of Nuclear Fuel Cycle and Waste Technology (NEFW),
Department of Nuclear Energy
Email: H.Monken-Fernandes@iaea.org

Pappinisseri Puthanveedu, Haridasan — Division of Radiation, Transport and Waste Safety
Department of Nuclear Safety & Security
Email: H.Pappinisseri-Puthanveedu@iaea.org

Phaneuf, Marcelle — Environmental Laboratory, Seibersdorf
Department of Nuclear Sciences and Applications
Email: M.Phaneuf@iaea.org

Reitsma, Frederik — Division of Nuclear Power,
Department of Nuclear Energy
Email: F.Reitsma@iaea.org

Tulsidas, H. — Division of Nuclear Fuel Cycle and Waste Technology (NEFW),
Department of Nuclear Energy
Email: H.Tulsidas@iaea.org

Voitsekhovych, Oleg — Division of Radiation, Transport and Waste Safety
Department of Nuclear Safety & Security
Email: O.Voitsekhovych@iaea.org

Woods, P.H. — Division of Nuclear Fuel Cycle and Waste Technology (NEFW)
Department of Nuclear Energy
Email: P.Woods@iaea.org

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