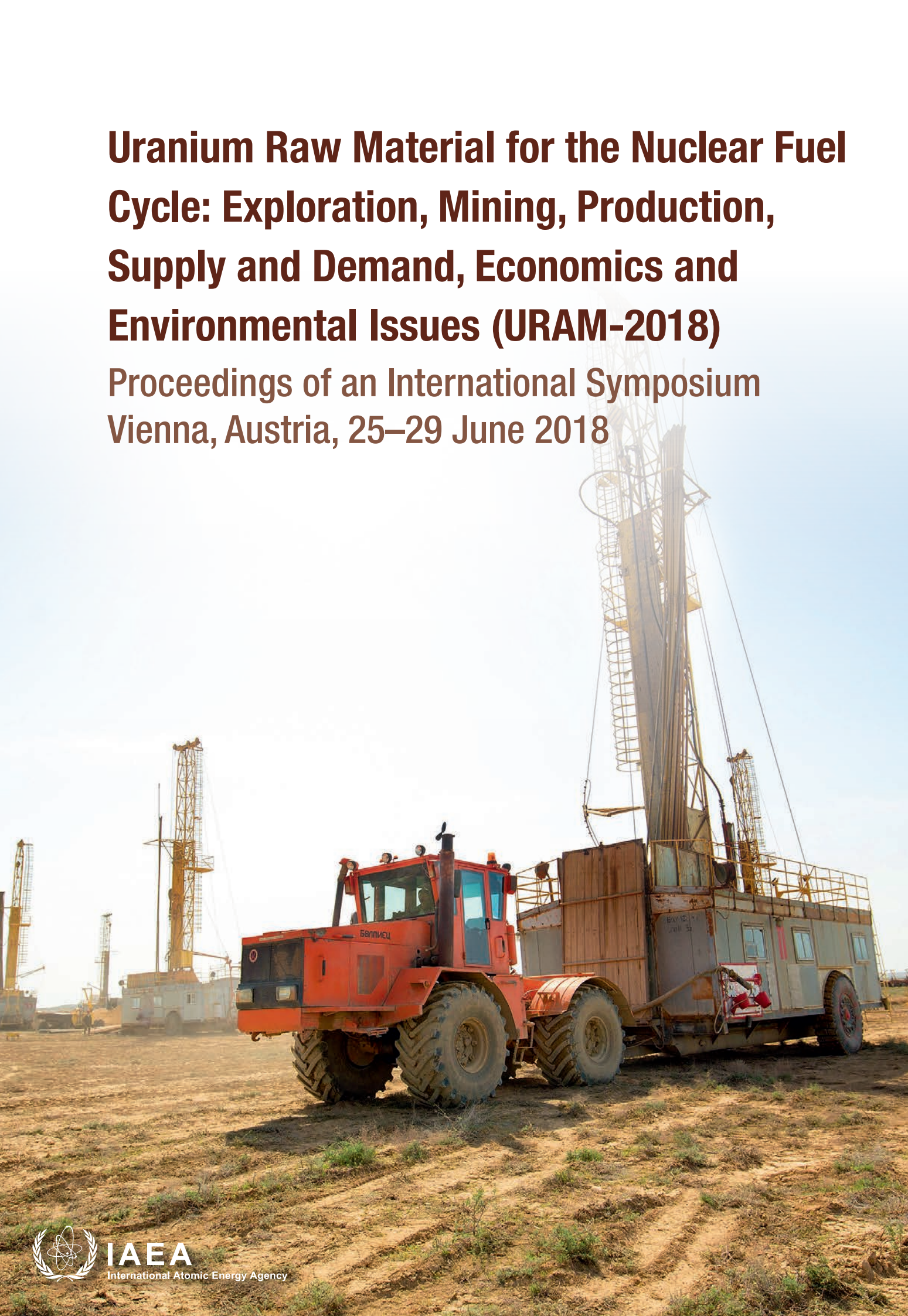
Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2018)

Proceedings of an International Symposium
Vienna, Austria, 25–29 June 2018



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URANIUM RAW MATERIAL FOR THE NUCLEAR FUEL CYCLE: EXPLORATION, MINING, PRODUCTION, SUPPLY AND DEMAND, ECONOMICS AND ENVIRONMENTAL ISSUES (URAM-2018)

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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-2018)

PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM
ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
IN COOPERATION WITH THE
OECD NUCLEAR ENERGY AGENCY
AND THE WORLD NUCLEAR ASSOCIATION
AND HELD IN VIENNA, 25–29 JUNE 2018

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2020

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Marketing and Sales Unit, Publishing Section
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1400 Vienna, Austria
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email: sales.publications@iaea.org
www.iaea.org/publications

Printed by the IAEA in Austria
December 2020
STI/PUB/1925

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Uranium raw material for the nuclear fuel cycle : exploration, mining, production, supply and demand, economics and environmental issues (URAM-2018) / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2020. | Series: Proceedings series (International Atomic Energy Agency), ISSN 0074–1884 | Includes bibliographical references.
Identifiers: IAEAL 20-01376 | ISBN 978-92-0-130620-3 (paperback : alk. paper) | ISBN 978-92-0-130720-0 (pdf)
Subjects: LCSH: Uranium industry — Congresses. | Uranium. | Nuclear fuels. | Uranium as fuel — Congresses. | Uranium mines and mining — Congresses.
Classification: UDC 622.349.5 | STI/PUB/ 1925

FOREWORD

In 2005, 2009 and 2014, the IAEA hosted international symposia on uranium production and raw material for the nuclear fuel cycle to discuss all aspects of uranium raw material for the fuel cycle to ensure the long term sustainability of nuclear power programmes. Since 2014, in response to a challenging economic environment, the industry has been seeking new and innovative ways to improve efficiencies in producing uranium. Since 2016, the long term median forecast has been for growth of nuclear power worldwide, leading to an eventual increase in uranium demand and in turn in the price of uranium. In the past few years, uranium production has been nearly meeting demand and less of the secondary supply have been used, leading to historically low spot prices for uranium oxide. This has resulted in decreased exploration activity, and some mines have been placed in 'care and maintenance'. Looking forward, there may be a reduction in the availability of secondary uranium supplies. This, combined with the exhaustion of some active uranium mines, means that the uranium resource base and global production capacity will need to be further advanced in order to meet current and future demand. The current oversupply from primary production could potentially lead to undersupply or primary production in the medium to long term. Owing to long lead times from discovery to production, re-evaluation of uranium resources is needed now.

The International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Matters (URAM–2018) was held in Vienna on 25–29 June 2018. The purpose of the symposium was to analyse uranium supply–demand scenarios and to present and discuss new developments in uranium geology, exploration, mining, milling and processing, as well as environmental requirements for uranium operations and site decommissioning.

This publication provides a summary of the conference, keynote presentations, the major findings and conclusions of the sessions, and the opening and closing addresses. The accompanying supplementary files, available on-line, include the individual technical papers.

The IAEA officers responsible for this publication were M. Fairclough, P. Woods and B. Moldovan of the Division of Nuclear Fuel Cycle and Waste Technology.

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CONTENTS

SUMMARY

URAM–2018 was held in Vienna on 25–29th June 2018. The purpose of the symposium was to analyse uranium supply/demand scenarios and to present and discuss new developments in uranium geology, exploration, mining, milling and processing, as well as environmental requirements for uranium operations and site decommissioning. A total of 234 delegates were recorded as attending, presenting 139 oral papers and 51 posters. Plenary sessions were held on Monday and Friday mornings, with other talks given in two parallel streams. Because of this, following summary is presented according to order of presentation within a particular session, or Track, of related presentations, rather than strictly in order during the symposium.

MONDAY, 25 JUNE 2018

OPENING SESSION

Y. Amano (Director General of IAEA) delivered his welcome address and opening remarks.

M. Cuney (Symposium Chairman) delivered his opening remarks.

O. Skorlyakova talked about the "World Nuclear Association 2017 Fuel Report". This report is one of the World Nuclear Association's published reports on nuclear fuel demand and supply at two-year intervals since 1975. The 2017 report is the 18th edition in the series and looks at scenarios for uranium demand and supply to 2035. This report considered three scenarios (Lower, Reference and Upper); the projections are based on assumptions of electricity demand growth, nuclear economics, public acceptance, government policies and electricity market structure within each country. The World Nuclear Association believes that nuclear energy can make a greater contribution to clean and reliable electricity generation and presents a vision for the future, called 'Harmony'.

L. Grancea talked about "Nuclear Energy and Uranium: Looking to The Future", based upon the 2016 Red Book. The presentation discussed key issues in terms of nuclear market developments and how they could impact the broader nuclear and uranium industry.

N. Carter discussed "The Impact of Global Nuclear Fuel Inventories on Forward Uranium Production". It was pointed out that there is clearly no single opinion about the inventory situation, but most market participants agree that dealing with the growing level of inventories is crucial to rebalancing supply and demand fundamentals and creating a more sustainable future. However, other producers have not been immune to the impact of inventories on the market. It was envisioned that, in future, the most likely scenario entails additional inventory growth in the near-term, followed by the gradual disposition of utility, supplier, and trader inventories, which cumulatively will be greater than any additional buying on the part of utilities or other market players in the post-2020 period.

H. Tulsidas described the "Foundational Fuels of the 21st Century: Evolving Socio-economics of Sustainable Energy Systems". The presentation discussed the socioeconomics of energy transformation, the comparative advantages and disadvantages, especially focusing on the role of nuclear energy in the post Paris Agreement era.

V. Konstantinov presented the "Uranium One development Outlook". The talk focused on the Uranium One Company, which was acquired by the Russian State Corporation Rosatom in 2010 to secure long-term uranium supply for its nuclear fuel cycle chain and consolidated on this basis high quality uranium assets in Kazakhstan and in other countries. The successful, innovative technical policy, in conjunction with the geologically and technically unique characteristics of the? deposits, provide significant competitive advantage for Uranium One as the global company with the lowest cost uranium production.

TRACK 2: URANIUM MARKETS

R. Rizvi delivered a paper entitled "Regulations for the Diversification of Partners as Part of the Security of Supply Policy". It was demonstrated that, in the present situation of the uranium industry, the objective of guaranteeing a stable and sustainable natural uranium and uranium fuel supply can be attained through the obligatory broadening of the portfolio of the uranium suppliers. An example is that the portfolio of the natural uranium supplier can be diversified by means of their own corporate policies. This could include allowing at most 10% of their needs to be met by uranium producers with one mining source and at most 20% of their needs acquired from the producers with more than one sustainable mine. It was suggested to introduce international rules on the obligatory broadening of supplies of natural uranium and uranium fuel to meet the requirements of energy companies.

L. Lopez's presentation on "Uranium Resources and Perspectives for Nuclear Supply in Argentina" provided a comprehensive vision of uranium projects, updated resources, project status with respect to the foreseeable demand for nuclear energy generation in Argentina. Also discussed briefly was raw material supply from the Latin American region. One main concern, which the presentation pointed out needs to be considered when studying the socioeconomic feasibility of projects, is that the identified uranium resources in Argentina exist mostly in provinces where no metallic mineral mining projects operate and where provincial legislations restrict uranium production. Finally, it was mentioned that, in the Latin America region, Paraguay and Brazil are potential uranium suppliers for Argentina.

B. Bulut Acar then gave a presentation on "Estimation of Uranium Requirements for Planned Nuclear Power Plants and Supply Capacity of Uranium Resources in Turkey". This presentation aimed to assess the fuel supply capacity of Turkish uranium resources in the Sinop and Akkuyu projects. To do so, data related to the identified uranium resources were reviewed first. This was followed by explanation of the methodology for estimation of the lifetime uranium needs of the planned nuclear power plants and for the assessment of the domestic potential to meet those requirements. The presentation concluded that it is sensible to concentrate on research and development in mining and milling, refining and fuel fabrication in accordance with the planned nuclear power plants.

T. Calvert outlined "Canada's Uranium Mining Industry: 75 Years of Production and Future Prospects". The presentation described first the historical background of Canada's uranium mining industry, which began in the 1930s. It was emphasized that Canada is currently the world's second largest uranium producer and exporter and that it is able to remain sustainable in a low uranium price market and could quickly ramp up production to satisfy a growth in demand. Next, Canada's uranium resources were described. It was highlighted that the Athabasca Basin remains to be highly prospective for the discovery of new deposits, that a number of large high-grade uranium deposits have been recognized that could be developed into mines in the future, and that Canada's uranium resources are expected to increase further through continued exploration. It was pointed out that Canada's success in its uranium mining industry is a result of having policies and regulations that address public concerns on health, safety and the environment, as well as nuclear non-proliferation and foreign ownership.

TRACK 8: URANIUM FROM UNCONVENTIONAL RESOURCES

P. Bruneton presented on "Unconventional Resources in IAEA Uranium DEPOsit Database (UDEPO)". These resources are defined as "resources from which uranium is only recoverable as a minor by-product, such as uranium associated with phosphate rocks, non-ferrous ores, carbonatite, black shale and lignite". At present, 280 uranium deposits and resources listed in UDEPO are classified as unconventional resources. These are linked to eight deposit types and they contain geological resources of about 51 Mt U. In view of comparable geological host rock examples worldwide, there are about 5000-6000 potential additions of occurrences of unconventional resources to the UDEPO database, and these are associated with six deposit types. Although the potential for geological unconventional resources of uranium worldwide is enormous, most of these resources will never produce uranium due

to their very low grades and the environmental impact resulting from their exploitation. However, these resources will likely play a significant role in world uranium production in the future in view of the concept of 'comprehensive extraction'.

P. Kay presented a paper entitled "Uranium: Waste or Potential Future Resource?" in the context of Australia. In Australia, several companies are developing large mines from mixed commodity resources, which include uranium, to extract for example copper and gold. Although the resources in question may have been developed for uranium in the past, current market conditions dictate that enormous uranium resources be directed to tailings repositories. This has been shown in three case studies, namely at Carrapateena, Nolans Bore and Toongi. Each of these projects has chosen not to extract the uranium values at this stage, but should the political or market conditions for uranium improve in the future, the tailings repositories at these projects could represent significant potential commercial value for a project proponent. This proposition has been demonstrated in an historical case study for the Rosebery mine in Tasmania.

R. Reyes presented the "Status of Uranium Activities on Unconventional Resources in the Philippines". Due to the Chernobyl nuclear accident in 1986, the first nuclear power plant was suspended and later on mothballed by the then government, although it was almost 100% complete, and the quest for indigenous uranium mineral deposits was discontinued. In May 1995, uranium exploration was resumed. To date, almost 70% of the entire Philippines archipelago was explored; however, results were disappointing. Hence, the strategy was shifted to sourcing uranium from unconventional resources. Investigations in the Larap–Paracale district gave promising results and so it was aimed that uranium will be produced as a by-product or co-product if this area is shown to be economically viable to mine. Another activity was a study on uranium recovery from phosphoric acid with the goal of producing cleaner fertilizers, mitigating the risk of environmental contamination, promoting maximization of resources and opening up the opportunity to utilize uranium if the Philippines decides to continue with the nuclear option.

F. Tavares presented an overview of the "Conventional and Unconventional Uranium Resources in the Carajás Mineral Province, Brazil: Prospectivity Criteria for Iron Oxide Copper Gold (IOCG) and Granite-Related Deposits" based on airborne geophysics and regional to deposit scale structural and geological data. It was demonstrated that, because three different mineralization ages are recognized, development of prospectivity models for the Carajás Mineral Province is challenging. For this, it is critical to isolate objective prospectivity criteria per metallogenic epoch and mineral system. However, there are common main regional prospectivity criteria to target uraniferous IOCG deposits in the province. For granite-related deposits, prospectivity criteria are still being investigated, although most favourable sites seem to be those indicated by anomalies of uranium concentrations normalized using thorium, which coincide with post-magmatic alteration sites.

J. Ramirez discussed the "Uranium Extraction Technology in the Philippines: The Next Step". In the Philippines, ~45 Mt of U are lost per year into agricultural fields because of fertilizer application, with potential risks for humans and for environmental safety. The Philippines Nuclear Research Institute has pioneered the uranium extraction from wet phosphoric acid (UxP) in the country to recover uranium and critical elements from phosphate processing, thereby translating these problems into opportunities. In 2011, there was a UxP project through the IAEA TC Project PHI/2/010 entitled Enhancing National Capacity for Extraction of Uranium and other Valuable Elements from Phosphoric Acid. This project ended in 2017 and demonstrated feasible laboratory scale UxP technology. As a next step, the IAEA TC Project PHI/2/013 entitled Enhancing Bench-scale Simulation for the Development of Continuous Extraction Technology of Uranium and Other Valuable Elements from Phosphates — Phase II, will be implemented during 2018–2020.

TRACK 1: NUCLEAR POWER AND ASSOCIATED MODERN ENERGY MARKETS

H. Tulsidas presented "The Emerging Uranium Industry Landscape: Push or Pull Resource Recovery?" to discuss the unavoidable impact of change drivers that cause the uranium sector to turn from a 'push' to a 'pull' business model, which is based on the notion that uranium is a critical material for climate action, not as a traded commodity. Presented were details of the essential connections of policy and

technology innovation, from which a new 'push' model can be developed, taking into account the demand that mineral resource recovery of any kind is a low or zero waste generating activity. The presentation advises to rethink uranium as a new economic resource and to place innovative uranium extraction technologies and flowsheets at the centre of process design and operation, with particular emphasis on uranium as a co- or by-product.

A.K. Sarangi presented "Uranium Mining Towards Sustainable Clean Energy: Indian Scenario". Despite a limited uranium resource base, India advances in its goal to achieve a multiple increase in uranium production and nuclear power generation through delicate balancing of community sustainability around the production facilities through an appropriate mix of technology, environmental measures, social harmony, finance and governance. Besides strengthening operations in its eight mines and three process plants, efforts were under way to set up new units in various parts of the country. It was essential to share knowledge on past practices and collective wisdom of good systems in order to establish a sustainable uranium industry, especially to engage those countries with little or no experience in such fields. The experience India has assimilated over time from working with low grade small to medium sized deposits, and the organizational structure of its nuclear power sector is a potential model for other countries.

P.E. De Oliveira Lainetti gave a detailed account of the "History of Nuclear Fuel Cycle Development, Facility Decommissioning and Site Restoration at IPEN — CNEN/SP, Brazil". The presentation was a record and tribute to the achievements of those pioneers who began their studies on the nuclear fuel cycle and related materials in Brazil. The first years of IPEN as a new research centre in the 1960s were full of problems and challenges, but these were overcome by the professional personnel employed there. In the 1990s, immediately following the nuclear R&D programme interruption, the uncertainties relating to an eventual restart of the program created some political hesitation about the decision taken to dismantle facilities. As restarting the R&D nuclear programme had been rejected, decommissioning seemed to be the obvious choice. The condition of associated facilities had been downgraded owing to a lack of resources for maintenance. There were evident signs of deterioration in infrastructure and equipment within the facilities. With the decommissioning of nuclear fuel cycle facilities at IPEN, an important cycle of the institution's life is being closed.

TRACK 3: APPLIED GEOLOGY AND GEOMETALLURGY OF URANIUM AND ASSOCIATED METALS

M. Cuney, in his presentation on "The Ultimate Origin of Uranium Provinces", discussed the nature, origin, evolution, and distribution of U provinces and the characteristics of some of the major U provinces. The remainder of the presentation was about the delineation of such provinces, because of its criticality for U exploration and the evaluation of the potential resources of such provinces.

E. Afanasyeva presented a paper entitled "Uranium Provinces of the World" to discuss a research for the identification of new patterns and prognostic criteria for commercial uranium mineralization identification in various regions of the world. The research was based on a historical-geological approach, which makes possible the systematization of the data on uranium geology, geochemistry, geophysics and metallogeny in various countries and continents, and the development of a unified research base. The presentation also discussed many problems beyond the scope of uranium metallogeny but provide insights to basic factors of uranium metallogeny from a new perspective.

L. Shumlyanskyy discussed "Sr-Nd-Pb Isotope Systematics of U-Bearing Albitites of the Central Ukrainian Uranium Province: Implication for the Source of Metasomatizing Fluids". Presented were new Sr-Nd-Pb isotope data obtained for Na-metasomatites in the Central Ukrainian Uranium Province and for a large variety of host rocks to discuss the possible contribution of different sources to the origin of this type of U deposit.

S. Nuchdang presented the "Development of Handheld X-Ray Fluorescence (hXRF) Spectrometry for Major and Minor Elements Analysis in Geological Samples from Phuket Province, Thailand". The presentation demonstrated that (a) the hXRF can provide data consistent with laboratory reported values,

(b) the hXRF measurement of geological reference materials by both film types were in satisfactory agreement with certified values for all elements except for Cu, Nb, Ni, P, U, V, W, Y and Zn, and (c) that the hXRF had significant potential as a geochemical tool.

J. Manrique gave a presentation on "Geochemical Prospecting Study of the Vanadium–Uranium Mineralization of Puyango, Ecuador". The hypothesis of the research presented was that, for the formation of the mineralization studied, both vanadium and uranium were deposited in a reducing environment, in marine waters under euxinic, anoxic to sub-oxic conditions, as evidenced by V:Cr and V:V + Ni ratios and by the presence of organic matter in the samples, in which these elements can be linked in compounds such as porphyrins, where V can be complexed. The hypothesis was investigated and found to be valid by mineralogical analysis, chemical analysis and in situ gamma spectrometry.

TUESDAY, 26 JUNE 2018,

TRACK 3: APPLIED GEOLOGY AND GEOMETALLURGY OF URANIUM AND ASSOCIATED METALS

Z. Li and J. Nie presented a paper entitled "Structural Characteristics and Its Control on Uranium Mineralization in Xiangshan Uranium Ore-Field". Favourable positions for uranium mineralization include the junctions of faults with different directions, the junctions between main faults and subsidiary fractures, the junctions between branch fractures of main faults and derived fractures of subsidiary faults. E-W trending faults in basement were the main fluid conduits, whereas the linear, ring-like and radial pattern structures connected to the basement faults were the main ore-hosting structures. The presentation considered that fault structures should be the emphasis in exploring for uranium resources in the area.

Z. Huang presented the "Volcanic Type Uranium Deposits in North China", which are found in both southern and northern China. Volcanic type deposits in southern China exist within the Gan-hang uranium metallogenic belt, and in northern China within the Guyuan–Hongshanzi and the Qinglong–Xingcheng uranium metallogenic belts. In the two northern metallogenic belts, 17 volcanic uranium deposits and more than 100 showings have been found, which comprise an important uranium mining area in China. The volcanic type uranium deposits in northern China have similar metallogenic ages, genesis and characteristics, which may be related to the same tectonic settings, indicating that the northern margin of the North China Craton has undergone simultaneous and relatively large scale episodes of volcanic uranium mineralization since the Mesozoic.

J. Yan discussed the "Geological and Geochemical Characteristics of the Huayangchuan U-Nb-Pb Deposit, Shan'xi China". Based on regional geological data and on recent exploration, the authors have discussed and clarified the ore controls and genesis of the deposit, and proposed that the Huayangchuan deposit is of the magmatic-hydrothermal superposition type.

C. Bonnetti presented the "Alteration Fingerprint of the Early Yanshanian Granite-Related High-Temperature Hydrothermal Uranium Mineralization in the Nanling Metallogenic Belt, Southeast China". The alteration mineral assemblage in the Baishuizhai occurrence and in the Shituling and Zhushanxia deposits, which include epidote, chlorite, K-bearing silicate, titanite and apatite associated with Zr–Th–Ta-bearing uranium oxides, characterizes an extensive propylitic and potassic alteration strongly suggesting high temperature conditions. At the scale of the Nanling Metallogenic Belt, the alteration fingerprint of the early Yanshanian uranium event presents numerous similarities to the genetic model proposed for the giant W–Sn event in south China, which is also related to the intrusion of the early Yanshanian granites.

K. Wenrich discussed the "Rare Earth Elements (REE) in Uraninite: Breccia Pipe Uranium District, Northern Arizona, USA". The presentation confirmed that a significant percentage of the whole rock REE content is tied up in the uraninite crystal structure. Uraninite analyses show that the total REE content of the uraninite was 0.43%. Based on this and in the average uranium resource in the district, an estimated 590 t resource could be produced from the breccia pipe district's mineralized corridor.

TRACK 4: ADVANCES IN EXPLORATION

I.R. Annesley gave a presentation on the "Investigation of the Geological Processes Which Control the Genesis of Unconformity-Type Uranium Deposits Using Parallelized Numerical Simulation on a Supercomputer". The research presented focused on deformation driven flow, using numerical simulation to explore fluid flow controls. The model was subjected to horizontal shortening, and fluid flow directions were explored by changing fault dip, shortening direction, strain rate, basement rock strength, or permeability. At least 300 finite-element simulations were performed, and the results indicate that shallow fault dip, high strain and fault-perpendicular shortening favour downward flow, whereas steep fault dip, low strain, and low-angle-to-fault shortening favour upward flow. These results were then used to predict new mineralization targets.

T. Allen presented on "The Midwest Project, East Athabasca Basin, Northern Canada: Reviving old deposits to prepare for the future". It was demonstrated that data mining and quality assurance and quality control (QAQC) as well as a detailed evaluation of lithology and structures that control the mineralization are vital to the construction of a robust resource model.

M.B. Verma discussed the "Potential for Unconformity-Related Uranium Deposits in the Northern Part of the Cuddapah Basin, Telangana and Andhra Pradesh, India". Comprehensive exploration efforts in the northern margin of Srisailam sub-basin have established a resource of about 20 000 t of uranium oxide at relatively shallow depths (75–120 m); large areas of this sub-basin are still unexplored and are likely to increase resources at depths of 200–250 m. In the Palnad sub-basin, the Koppunuru uranium deposit is unique in respect to its mineralization pattern in the sediments, proximal to the unconformity contact with the basement granitoids. A 150 km long area along the northern margin of the Palnad sub-basin may warrant exploration. Intensive sub-surface exploration is envisaged in several sectors of the Srisailam and Palnad sub-basins.

P. Ledru discussed "The Challenges to Explore and Discover an Unconformity Deposit at Depth". It was envisioned that, in the long-term, the critical depth of exploration within the Athabasca Basin will likely evolve and that the deepest portions of the basin will likely be considered for greenfield exploration. It was concluded that this long-term vision can be put in perspective with the challenges that were faced by the oil and gas industry when exploration targeted deeper, more structured and remote reservoirs.

Z. Hajnal and I.R. Annesley presented a paper entitled "Integration and Cost Saving Utilization of the Seismic Reflection Technique in the Athabasca Basin, Canada". It was demonstrated that extended analysis of seismic signal attributes and full-wave data offer detailed lithological characterization, including data on anomalous alteration zones and petrophysical attributes. It was concluded that the integrated approach to exploration would translate into a significant reduction in the required number of exploratory boreholes and a commensurate saving in total exploration expenditure.

TRACK 3: APPLIED GEOLOGY AND GEOMETALLURGY OF URANIUM AND ASSOCIATED METALS

S. Hall presented a "Genetic Deposit Model for Calcrete Uranium in the Southern High Plains Region, United States of America". Exposed mineralization near a known deposit was sampled and analysed, and data were combined with analysis of regional geology to develop the genetic deposit model presented. Dating indicates periodic mineralization occurred between about 631 000 and 4000 years before present. Elevated levels of uranium in solution in groundwater were likely derived from the Triassic Dockum Group or from volcanic ash in the host sediments. Elevated levels of vanadium in solution in groundwater, coupled with areas of higher hydraulic conductivity, define the most highly prospective areas for the formation of carnotite, the major ore mineral for this deposit type. Mineral–solution equilibrium modelling indicates that evaporative concentration of local groundwater could produce saturation with carnotite, which suggests that the mineralizing systems may remain active.

P. Bruneton discussed the "UDEPO: The IAEA Uranium Deposits Database", which has been published on the IAEA web site since 2004 and has been continuously updated to include new deposits and provide more information on the uranium geology and technical characteristics of the deposits. In addition, a world map of uranium deposits has been published by the IAEA to accompany the database. As of late 2017, the total geological resources of uranium in the database is roughly 62 673 000 tU, within the 2755 deposits with known/estimated resources and distributed unevenly in 15 deposit types. With addition of new data, it will be possible to derive statistical geological information on parameters such as tectonic setting, age of mineralization and associated elements, various mining parameters, etc.

E. Afanasyeva presented the "Uranium Deposits of the Karelian-Kola Province (Russian Federation)". In this province, zones of structural-stratigraphic unconformity (SSU) are widespread and uranium mineralization in these zones have different grades. It was concluded that the SSU zones as well as fold–fault zones have the greatest potential for hosting both uranium and complex with uranium deposits.

V. Petrov presented a paper entitled "Free Thermal Convection Model for Formation of the Largest Uranium Field in the Streltsovka Caldera (Transbaikalia, Russia)". The presentation provided a summary of the preliminary results of numerical simulation of free thermal convection of fluids with reference to the formation conditions of the deposits at Streltsovka and Antei. It was concluded that the proposed thermo-convective model of the Antei–Streltsovka ore-forming system ensures the formation of the significantly large uranium reserves without restrictions on both the required quantity of ore-transporting fluids and on the quantity of the accessible uranium needed for its leaching, transport and deposition by fluid convection. It was also concluded that such model of ore-forming system is close to conceptual models of ore-forming systems of epithermal deposits.

M. Abzalov presented on the "Exploration and Resource Development of Uranium Mineralization in Central Jordan". Exploration success has become possible because of detailed geological studies, which have allowed better understanding of the geological controls of uranium mineralization in central Jordan. The close spatial relationship of uranium in central Jordan with pyrometamorphic rocks suggests a special type of surficial uranium mineralization, which has resulted from the interplay of different processes, where combustion metamorphism has played a critical role in facilitating leaching of uranium from the host rocks. Based on such studies and observations, the exploration model was revised and implemented by the Jordanian Uranium Mining Company for delineating mineralization and estimating resources.

TRACK 10: HEALTH, SAFETY, ENVIRONMENT AND SOCIAL RESPONSIBILITY

F. Harris discussed "An Internationally Standardized Reporting Tool to Understand the Sustainable Development Performance of Uranium Mining and Processing Sites", referred to as the 'Checklist' developed by World Nuclear Association. The Checklist was designed to draw on producers' existing reporting, supplemented by additional information required to achieve comprehensive supply chain risk management. It was developed to align with the Association's policy document on Sustaining Global Best Practices in Uranium Mining and Processing: Principles for Managing Radiation, Health and Safety, and Waste and the Environment. The Checklist will be reviewed over the next year to ensure that it accounts for any recent developments and feedback from user testing.

G. Schneider presented a paper entitled "Uranium, the Environment and Sustainable Development: Lessons from Namibia". The presentation highlighted that, because mining is vital for the growth of the Namibian economy, the country must reconcile development objectives and mineral exploitation with environmental protection for its long term socio-economic growth and stability, and that an integrated approach is required so that development of one resource will not jeopardize the potential of another.

A. Rocha Sciclewski presented a paper entitled "Perspectives on Social Communication in the Brazilian Nuclear Licensing Process and Challenges on Stakeholder Engagement: Caetité Uranium Mining Case". The presentation highlighted that it is essential that, to allow establishment of social participation practices as a part of the decision making process and effective stakeholder engagement and social communication approaches, there should be continuous evaluation and promotion of further efforts to

address discussions about the development of transparency culture, enhancement of credibility and public confidence, as well as timely and effective engagement and communication.

A.H. Abakar presented on "Uranium Deposit Types, Exploration Methods and Corporate Social Responsibility (CSR) Programs: Case of LERE (Chad)". It was presented (a) that Chad has an important potential in uranium ore, which, if exploited, would contribute to the national economy, and (b) that Chad is still very under-explored compared with other countries. It was highlighted that prospecting or mining research is the first step in the development of the mining sector, and that Chad Mining Services have outlined several areas that are highly prospective for uranium.

M. Franklin discussed "Societal Barriers to Uranium Mining: A Case Study from Brazil". The presentation confirmed that the dissemination of inaccurate information is very intensive, and that the notion of a lack of transparency, a lack of information and, ultimately, a lack of independency is present. The presentation highlighted that, by not having in place a continued mechanism of interaction with the population, room is left for the action of groups and individuals that clearly demonstrate an attitude against nuclear energy and related activities.

TRACK 4: ADVANCES IN EXPLORATION

P. Wollenberg presented "DASA: Africa's Newest World Class Uranium Deposit in Niger, West Africa — A Global Atomic Corporation Project". This deposit is unique amongst the uranium deposits in Niger. The uranium in this deposit is very likely derived from two main sources: leaching of uranium during erosion of the Air Massif for the Carboniferous ores and leaching of volcanic tuff and ash intercalations for the Jurassic ores. The grade and thickness of the mineralized intersections differentiates this deposit from most other sandstone deposits worldwide. It is possible to develop this deposit quickly, producing ore from both underground and open pit operations. The discovery of this deposit has given rise to new incentives for exploration in Niger.

F. Ye discussed the "Advances in Hyperspectral Remote Sensing Technology for the Exploration of Hydrothermal Type Uranium Deposits in China: A Case Study in the Xuemisitan and Longshoushan Areas". The presentation concluded that hyperspectral remote sensing has made a major contribution in identifying hydrothermal alteration minerals, analysing hydrothermal alteration and fluid activity and determining ore controlling structures in the Xuemisitan and Longshoushan areas.

D.K. Sinha described the "Uranium Potential of the Singhbhum Shear Zone, India: Future Prospects". The Singhbhum Shear Zone (SSZ), Jharkhand, India, hosts several uranium deposits and is one of the major uranium producing provinces of India. The presentation described some exploration results and the plan for future exploration by Atomic Minerals Directorate, India. Recent conceptual work carried out by the Atomic Minerals Directorate based on new exploration strategies, has paved the way for additional resources to be located, thereby extending the lifespan of the mines. The Atomic Minerals Directorate has planned substantial coring and non-coring drilling to prove the existence of additional resources.

J. Iranmanesh discussed "Uranium Exploration by Remote Sensing Methods in the Kaleybar Area, North-Western Region, Islamic Republic of Iran". The study presented used false colour composite, band ratio, principal component analysis and spectral angle mapping to detect and separate alteration patterns. The presentation highlighted the good results achieved for the detection and mapping of alterations in the Kaleybar area.

TRACK 10: HEALTH, SAFETY, ENVIRONMENT AND SOCIAL RESPONSIBILITY

M. Franklin presented a paper entitled "Sustainable Water Resource Management at a Uranium Production Site". The presentation focused on a case study to improve the understanding of the interactions between the hydrogeological system and human health in a watershed known as the Caetité Experimental Basin (CEB) in Brazil. Hydrochemical studies reveal that the chemical weathering of the silicates, ion exchange mechanisms and to a lesser extent evaporation processes are the dominant factors

controlling the chemical composition of the groundwater within the CEB. No health hazards associated with natural radioactivity in groundwater were recognized; but, if the chemical toxicity of uranium is taken into account, some wells are not safe to use for drinking. The presentation stressed that it is important to distinguish geogenic sources of contamination from those due to uranium mining activities, and that this remains an ongoing challenge.

F.P. Carvalho described the "Uranium Mining Waste, Risk Perception by Populations and Environmental Remediation in Portugal". Mining of radioactive ores for radium and uranium production took place in Portugal from 1908 up to 2001. An environmental radioactivity assessment and a public health assessment were carried out in the years 2003–2005 and based on these results and recommendations, the Government approved an environmental remediation plan. Up to the present day, more than half of the former uranium sites have been remediated, milling waste confined and mine water treatment stations either installed or upgraded. The presentation demonstrated an effective reduction in ambient radiation dose, treatment of acid and radioactive mine drainage before discharge, and abatement of radiation exposure in several areas.

S. Jovanovic presented an "Advanced Quantitative Gamma Spectrometry Software for Optimized Environmental Assessment During 'Cradle-to-Grave' Uranium Exploitation Management". The presentation outlined the ANGLE software and its applicability in uranium exploitation management.

K. Turner discussed the "Development, Evolution and Implementation of Environment Protection Standards for Uranium Mining in the Australian Tropics". The presentation demonstrated the application of the standards to the Ranger uranium mine because this mine is surrounded by the dual World Heritage Listed Kakadu National Park, and Kakadu is recognized for its significant cultural and environmental attributes. These standards were developed and overseen by the Government of Australia through its Supervising Scientist Branch, which is part of the Department of the Environment and Energy. The presentation provided an overview of the Supervising Scientist Branch's monitoring and research programmes and demonstrate how the collected data have been used to ensure protection of the environment throughout the operation and after the rehabilitation of the Ranger uranium mine.

K. Tayler presented "A Risk Based Approach to Uranium Mining Rehabilitation". The presentation provided details of the risk assessment and planning work undertaken by the Supervising Scientist Branch to systematically identify the knowledge needed to ensure environmental protection and the project work required to address these needs, align these with the mine rehabilitation schedule and inform the regulatory assessment process.

TRACK 6: UNDERGROUND AND OPEN PIT URANIUM MINING AND MILLING

S. Tumuluri discussed a "Comprehensive Extraction Scheme for Multimetal Recovery from Metasomatite–Albitite Hosted Low Grade Indian Uranium Ore". The presentation provided details of the process development studies carried out for multimetal recovery from the Rohil–Ghateswar low-grade uranium ore, which is a metasomatite-albitite hosted uranium occurrence containing Cu, Mo, Ni and Co. Because of the predominance of siliceous minerals in this ore, the chosen hydrometallurgical processing scheme for the recovery of uranium is sulphuric acid based. In addition, different options have been formulated for maximizing recovery of multimetals with minimum freshwater requirement.

D. Princep discussed "Modern Uranium Open Pit Grade Control" for the Langer Heinrich mine. The resource definition work for this mine was based around radiometric logging of drill holes and this has been carried through to mining grade control. The blast hole logging process is a one-man operation using logging equipment installed on a small four-wheel drive vehicle. The data are downloaded at the end of each shift and are processed to an equivalent uranium grade value using software developed on site. The resulting uranium values are then used to define grade control blocks via conditional simulation software.

W. Dong presented a paper entitled "Preliminary Study on Uranium Ore Grade Control Techniques for the Husab Mine, Namibia". This mine is the first ultra-large uranium mine to be constructed and

operated by the China General Nuclear Power Corporation. The presentation focused on the entire process of mining production and described the optimization work to improve effectively the ore dilution and loss during mining and to improve further the production capacity and economics of the mine. The optimization work included establishment of a geological resource–grade control model system, optimization of mining production procedures, application and optimization of controlled blasting technology to ensure a higher precision and application of rapid and accurate grade measurement by down-hole gamma logging.

R. Bowell described "Cost Effective Heap Leaching, The Case Study of Mutanga, Zambia". The presentation demonstrated sulphuric acid leaching with ion exchange to be effective for the recovery of uranium in the Mutanga project. Test work has confirmed heap leaching is viable and permeability of the ore is good with low acid consumption at 3-18 kg/t. The process is robust, simple and has a low environmental profile. Overall uranium recovery, averaging 74-94%, varies per deposit in the project.

TRACK 10: HEALTH, SAFETY ENVIRONMENT AND SOCIAL RESPONSIBILITY

M. Roberts presented the "IAEA Coordination Group for Uranium Legacy Sites (CGULS): Strategic Master Plan for the Environmental Remediation of Uranium Legacy Sites in Central Asia". Many of uranium mining and processing activities, which have been carried out in Central Asia since the mid-1940s, ceased in the 1990s. This left several Uranium Legacy Sites (ULS) and other hazardous and radioactive wastes in populated areas, which pose a hazard to future generations if left un-remediated. CGULS was developed to implement a strategic master plan (SMP) for environmental remediation of ULS in Central Asia.

D. Mwalongo presented the "Five Years After the UPSAT Mission: Progress and Challenges". The United Republic of Tanzania has had several regulators with little experience in the uranium mining domain. However, there was lack of clarity and consistency among different items of governmental legislation and regulations. This was exacerbated by overlapping mandates between different government departments because the operators were unsure which laws to follow. The IAEA Uranium Production Site Appraisal Team (UPSAT) was formed to address the issue. It was first assistance mission of its kind sent to Africa. The presentation outlined the progress and development made by the UPSAT mission since 2013.

P. Waggitt discussed "Uranium Mining Remediation in Australia's Northern Territory", which has come a long way from the days of simple abandonment that were the normal procedure only 50 years ago. Recent and current sites are being remediated in accordance with current leading practice and considerable attention is paid to consultation with stakeholders to ensure all concerns are understood and have the opportunity to be addressed. The efforts have not stopped there with a number of legacy uranium sites being cleaned up as well. The presentation highlighted valuable lessons learned at every stage of this story, which are in turn being applied to the future work programmes for remediation of these and other mines in the region.

N. Kurinova described the "Assessment of the Impact of Uranium Production Waste Storage Facilities on the Environment Based on the Results of Hydrogeological Monitoring and Numerical Modeling". The focus of the study presented was the largest uranium mining enterprise in the Russian Federation, namely the Public Joint-Stock Company Priargunsky Industrial Mining and Chemical Union (Priargunsky), which was established in 1968. Wastes with a residual radioactivity caused by processing uranium ore are deposited in a valley in two tailings dams and neutralized with calcareous water. Leaks through earth dams within the limits of normative losses were intercepted by a system of drainage wells in the foot of the storage facility dam and are returned to the process. The main objective of the study presented was to obtain a conservative forecast of the expected spread of the contamination plume towards the intake of the water supply wellfield. The study's conservative forecast indicates that the spread of contamination in the groundwater from the tailing dumps does not reach the water supply wells even within the forecast period of 300 years.

J. Wlosok presented the "Development of Mine Water Quality, Subsequent Sediments Contamination and Passive 226Ra Treatment in Zadní Chodov, Czech Republic — Case Study". Based on available data, the passive method of mine water treatment at the site of Zadní Chodov, using zeolite adsorbents, appears to be potentially applicable. However, the study presented concluded that it would be desirable to utilize adsorbents based on synthetic zeolites, which could have much higher efficiency for adsorption of 226Ra.

WEDNESDAY, 27 JUNE 2018

TRACK 4: ADVANCES IN EXPLORATION

M. Mihalasky presented "Quantitative Mineral Resource Assessments of Roll-Front and Calcrete Uranium in Southern Texas and the Southern High Plains Province of the United States: Results and Simple Economic Filter Analysis". These new assessments include: (i) in 2015, an assessment of undiscovered roll-front uranium resources in Tertiary coastal plain sediments of southern Texas, and (ii) in 2017, an assessment of undiscovered calcrete uranium resources in Pliocene and Pleistocene carbonate-rich sediments of the Southern High Plains region of Texas, New Mexico and Oklahoma. Results of application of a simple economic filter suggest that: (i) the undiscovered calcrete uranium resources are not likely to be currently economic, and (ii) the undiscovered roll-front resources are economic in the context of regional (southern Texas) uranium production considerations and setting, but marginal to sub-economic when regarded in a larger, global context.

R. Schodde discussed "Long Term Trends for Global Uranium Exploration" by looking at when, where and who found the over 1230 deposits and by assessing the trend over time in the location of the discoveries, unit discovery cost, metres drilled per discovery, deposit style and the average size. Data were also compiled on how many of those deposits have successfully been developed into mines, and the associated time delay between discovery and development. Given the foregoing, and assuming that the historical discovery and conversion performance trends continue into the future, estimates were made of the likely amount of uranium that could be found and developed over the next 20 years under a range of different demand and price scenarios.

A. Wild presented a "Prospectivity Analysis of the Mount Isa Region (Queensland, Australia) for Metasomatite-Type Uranium". The presentation illustrated the process of knowledge-driven mineral prospectivity analysis (MPA) using a geological model and various input data to define areas prospective for undiscovered uranium resources. The work presented also used MPA as the basis for defining a prospective tract, which was the input for quantitative mineral resource assessment.

M. Bruce discussed "Continent-Scale Spatial Targeting to Delineate Permissive Areas for Sandstone-Hosted Uranium". Australia was chosen to demonstrate the usefulness of large-scale multi-criteria analyses due to the relatively large volume of publicly available data covering the entire continent and because it is host to a considerable number of spatially distributed and economically significant deposits. The presentation pointed out that although all of the deposits under consideration are similarly classed as 'sandstone-hosted', significant differences exist in their host rock and mineralisation ages, mineralogy and in their underlying mineralising processes. Because these differences imparted uncertainties in the analysis, the continental-scale model presented was not considered useful for delineating specific exploration targets but was particularly effective at identifying broader permissive areas, as well as regions of elevated favourability within these zones. The presentation stressed that the type of study discussed is possible in areas where less (or different) data are available because the analysis is built up around to the type of mineralising system under consideration and according to the available data.

J. Carranza presented a knowledge-driven "Spatial Analysis of Prospectivity for Surficial Uranium Deposits: A Case Study in British Columbia, Canada" using a geographic information system (GIS) and following the mineral systems approach to mineral prospectivity analysis. The presentation concluded that methodology discussed is quite straightforwardly implementable by using a GIS. However, a more intricate fuzzy inference system, which consists of more elaborate logical rules representing expert

reasoning for delineating zones prospective for surficial uranium, is likely to be as instructive for researchers with more profound insight to the surficial uranium system in the region.

TRACK 12: URANIUM NEWCOMERS

J. Zhang described a major, four-year interregional project on "Deploying Technology and Management of Sustainable Uranium Extraction Projects", which the IAEA is supporting and in which 52 of the IAEA's Member States are involved, from 2016–2019 inclusive. This project is a continuation of an interregional project on supporting uranium exploration and production that was active during 2012–2013. The presentation summarized the activities of the project at it halfway point, and set out the activities for the last two years, which have been refined based on feedback from the participants and the specialized experts who have assisted the IAEA.

P. Woods presented the "Supporting Sustainable Development of Uranium Resources in Africa", which is a major, four-year regional Africa project of the IAEA through its Technical Cooperation (TC) programme. This project, RAF2011, was in continuation of a regional Africa uranium themed project that was commenced in 2009, and the work will be continued with a follow-on regional project from 2018. The presentation summarized the activities of the project and described the planned activities for the follow-on project, which have been refined based on feedback from the participants and the specialized experts who have assisted the IAEA with this project.

G. Zakrzewska-Koltuniewicz described "Uranium from Domestic Resources in Poland". Poland, like many other countries, only has only low-grade conventional uranium ores. Studies have confirmed that currently there is no economic justification for the exploitation of Polish host rock with low uranium content, but the situation may change with the continuing development trend of nuclear energy in the world and gradual depletion of high grade uranium resources. Although uranium concentrations in Poland's unconventional sources are low, when combined they comprise an inexhaustible resource of uranium for future use. The most promising ones among the unconventional sources are waste from the copper industry and phosphoric acid obtained in the production of phosphate fertilizers. At present, geological exploration for uranium mineralisation is not conducted in Poland.

S. Gezer discussed "Uranium Exploration and Mining Activities of Turkey as a Newcomer". This presentation provided details of the recent uranium exploration activities, drilling efforts, identified conventional resources, environmental activities and regulatory regime of Turkey.

P. Woods presented a guide setting out a "Milestones Approach to Uranium Mining and Development: An IAEA Initiative". The information in the guide will be provided within the context of other IAEA guidance and materials relevant to development of the uranium production cycle, including the IAEA Safety Standards Series. Four generalized stages with associated milestones of preparedness are being considered (subject to amendment) in the development of the guide, namely: (1) those considering exploration or mining of uranium for the first time, or after a hiatus of many years, but without an identified project; (2) those seeking to initiate/reinvigorate uranium mining with one or more identified projects; (3) established producers of uranium wishing to enhance existing capacity/capability; and (4) historic producers with closed sites in the stage of closure and rehabilitation/remediation or aftercare.

TRACK 6: UNDERGROUND AND OPEN PIT URANIUM MINING AND MILLING

P. Zhong presented an "Overview of Uranium Heap Leaching Technology in China". The presentation discussed the status of the application of uranium heap leaching in China, including details of ore characteristics and technological processes for typical processing mills and some new technologies, developed and applied. Some existing problems in practical operation were also discussed.

C.K. Asnani discussed the "Development of Alkali Leaching Technology: Key to Self Sufficiency in Uranium Production in India". The alkali leaching technology adopted for processing the low-grade ore at Tummalapalle was the result of extensive research work by the Department of Atomic Energy. Carbonate hosted uranium mineralization accounts for the majority of India's uranium inventory and

therefore successful operation and extraction of uranium at Tummalapalle will enable the development of more uranium deposits in this area (South Cuddapah Basin, Andhra Pradesh). Newer areas in other geological basins amenable to acid leaching have also been considered for development in order to satisfy domestic requirements for uranium in the coming decades.

B. Moldovan talked about "Coagulation of Colloidal Silica from Uranium Leach Solutions for Improved Solvent Extraction". Colloidal silica generated in the leaching process by contacting clays and concrete with sulphuric acid has caused operational problems in solvent extraction at Cameco's Key Lake uranium mill throughout its history. Silica coagulation was investigated in 2014 by using POLYSIL RM1250, a polyethylene glycol coagulant. Laboratory results showed excellent clarification of the process solution, but subsequent mill trials were unsuccessful. A mill trial with POLYSIL RM1250 was performed in 2017 with doses varying in the range 170–300 ppm. The mill trial was successful in reducing solvent consumption by 85% and overall acid and lime consumption by 7%.

M. Maley presented a paper entitled "Investigation of Key Parameters for Effective SDU Precipitation". Precipitation of sodium diuranate (SDU) from leach liquors has been practiced commercially since the 1950s. ANSTO Minerals recently carried out a programme of work investigating direct SDU precipitation from carbonate/bicarbonate leach liquors. Several variables were examined to assess their impact on precipitation efficiency, including carbonate feed concentrations, terminal caustic concentration and seeding. In addition, a continuous mini-plant was also operated whereby seeding was demonstrated to be necessary for effective precipitation. The complex relationship between dissolved uranium concentration and the presence of seed on SDU precipitation has been investigated to define fully the nature and amount of solid seed required.

TRACK 12: URANIUM NEWCOMERS

Syahril presented "An Integrated Capacity Building Approach to Uranium Production Cycle Milestones for Regional Asia Pacific Technical Co-Operation". This approach provides capacity building in core technology in uranium production, feasibility and macro-economic aspect of uranium production, facilitate exchange of information and good practices, as well as provide opportunities for dissemination of research and development results through publication and participation in international conferences.

J. Karniliyus discussed the "Uranium Potential in Nigeria". Uranium exploration in Nigeria continues and is undertaken by the Nigeria Geological Survey Agency and three university research centres under the coordination of the Nigeria Atomic Energy Commission (NAEC). The investigated deposit size and potential are, at present, still inadequate to encourage resource drilling and feasibility studies. However, the NAEC is encouraging serious investors in this field to come and invest in the uranium potential that is known to exist in commercial quantities in Nigeria.

S. Katamoura described the "Uranium/Thorium Resource Assessment in Saudi Arabia". Current reconnaissance exploration has identified several uranium anomalies within the exploration sites and discovered several new uranium anomalies near the border of the exploration areas. However, the exploration programme has also failed to verify some of uranium anomalies identified in the previous exploration and radiometric airborne survey. The presentation provided several recommended to resolve exploration difficulties and to obtain a more accurate uranium resource estimation.

V. Rasoamalala presented the "Uraniferous Potential and Occurrences of Madagascar: An Overview". The presentation concluded that pegmatites in Madagascar host significant uranium mineralization and that the pegmatite-hosted Ankazobe–Vohimbohitra uranium deposit may prove to be significant and so its detailed exploration is warranted.

TRACK 7: URANIUM PRODUCTION BY THE IN-SITU LEACHING (ISL) PROCESS

A. Boytsov presented "Major Innovations in ISL Mining at Uranium Ore Mines in Kazakhstan", which include: geological 3-D modelling for resource estimation; ISL process modelling and simulation for project design and its implementation in ISL process management; implementation of modern methods

of well construction and restoration; estimation of additional technogenic and residual resources; and recovery of rare earth elements and other valuable components from leaching solutions.

Y. Yuan and Y. Niu discussed "The Fundamental Research and Industrial Application of the CO2 and O2 In Situ Leaching Process in China". The presentation described the development and characteristics of the CO2 and O2 ISL process in China, including the main principles, technological processes, well-field design, production well construction and uranium processing. The industrial application status and development potential of the CO2 and O2 ISL process in China were then summarized.

D. Aizhulov described a proposed method of "Stochastic Modelling of Uranium Roll-Front Deposits Based on Streamline Simulation" to supplement existing stochastic models with additional methods of computational hydrodynamics. The results presented demonstrate that stochastic modelling of uranium roll-front deposits based on streamline simulation provided results with higher accuracy when compared to conventional methods based on kriging or Gaussian simulation. The modelling approach was further investigated for various well placement patterns in order to identify optimal distances between exploration wells.

M. Kurmanseiit discussed "Impact of Gravity Effect on in Situ Leaching of Uranium". Accounting for the gravity effect can significantly change the way a horizontal layer is being oxidized, and consequently leached during an in-situ process. This change was demonstrated through hydrodynamic calculations using a parallelized CUDA (compute unified device architecture) based numerical solver. Resource intensive pressure calculations had to be solved on each density change, which leads to longer calculation times; thus, CUDA parallel technology was successfully used in each step to accelerate these calculations. However, for many uranium deposits to which sulphuric acid is used as a leaching solution, the density ratios between initial groundwater and the injected solution will be 1%. This means the gravity effect with respect to the Darcy equation can be neglected.

M. Maley described "Laboratory and Ion Exchange Pilot Plant Studies Supporting the Field Leach Trial at the Honeymoon Uranium Project". The presentation discussed the results from the laboratory programme, as well as highlighting the success of the field leach trial (FLT) campaign and associated ion exchange (IX) pilot plant operation. The successful FLT supported the observations and conclusions from the ANSTO Minerals leaching test work. The use of IX for uranium in elevated chloride liquors is a significant new development in the industry.

TRACK 10: HEALTH, SAFETY, ENVIRONMENT AND SOCIAL RESPONSIBILITY

A. Jagger presented a paper entitled "Effective Radiation Monitoring: Back to Basics". The presentation stressed on the following. Radiation monitoring programs should not be regarded as purely a requirement for regulatory compliance. Monitoring results are invaluable in achieving continuous improvement objectives, and in determining controls required to reduce occupational exposures to employees. Monitoring can assist operations to optimise production, and can intercept failures early so that unplanned interruptions to production for maintenance or repairs can be avoided.

J. Hondros discussed "It's Not All About the Radiation!" — Practical Radiation Management". The presentation provided some practical considerations for the effective development and implementation of a radiation management plan based on experiences at various mines and processing facilities. The key messages are that radiation management plans should: (a) be more than a compliance document; (b) be part of a broader health, safety and environmental management system; and (c) be supported by internal knowledge and competent staff.

R. Meck talked about "Action Levels for Airborne Natural Uranium in the Workplace: Chemical and Radiological Assessments". The consequence of too much intake can be chemically induced damage for which the kidney is the primary target tissue, or radiogenic cancer for which the lung appears to be the primary target tissue. The radiological risk of lung cancer depends on the radiation dose to the lungs. Neither the concentration of U in the kidneys nor the cumulative irradiation of the lungs could be measured directly but both quantities can be assessed using biokinetic models.

S.H. Brown discussed the "Radiological Aspects of Alkaline Leach Uranium in Situ Recovery (ISR) Facilities in the United States". The presentation provided a summary of the radiological characteristics of typical ISR processes currently employed in the United States. It also described the health physics and radiological monitoring programs required to adequately monitor and control radiological doses to workers.

H.B. Okyar described "A New IAEA Safety Report on Occupational Radiation Protection in the Uranium Mining and Processing Industry". The objective of the new Safety Report is to provide detailed information that will assist regulatory bodies and industry operators in implementing a graded approach to the protection of workers against exposures associated with the uranium mining and processing. The new Safety Report describes the various methods of production used by the uranium industry and provides practical information on the radiological risks to workers in the exploration, mining and processing of uranium, on exposure assessment, and on management of exposure based on the application of the appropriate standards and good working practices. The new Safety Report comprises six sections: (1) an introductory section; (2) an overview of the uranium industry and the general radiation protection aspects of uranium mining and processing stages and techniques; (3) a summary of the radiation protection considerations that apply to the uranium mining and processing industry; (4) a description of the general methodology for control with the introduction of occupational health and safety considerations; (5) details of the requirements and dose assessment, with discussion on general dose considerations for different types of exposure pathways; and (6) discussion of the essentials of radiation protection programmes to adequately protect the workers.

TRACK 4: ADVANCES IN EXPLORATION

Z. Li described the "Regional Signatures and Metallogenic Models of Sandstone Hosted Uranium Deposits in Northern China". The presentation concluded that, besides the traditional interlayered oxidation–reduction (redox) metallogenic model, some new models have been established for the sandstone hosted uranium deposits in northern China, such as the metallogenic superposition model and the tectonic activated metallogenic model, which have been of great importance to exploration and to the discovery of new uranium resources.

M. Fairclough discussed "Mapping the World Distribution of Uranium Deposits". The presentation highlighted that the publication of the first edition of the IAEA map of "World Distribution of Uranium Deposits", more than 20 years ago, has allowed the creation of a more sophisticated and comprehensive database of world uranium deposits. It was also demonstrated that, increased insights, such as a new deposit type classification scheme, additional new discoveries as well as disaggregation of previously known discoveries, and enhanced GIS techniques have allowed the generation of a new, second edition map. This is a valuable decision-making tool for a wide variety of stakeholders interested in existing deposits and in assessing the potential for new uranium discoveries.

M. Fairclough then talked about "Spatial and Quantitative Modelling of Uranium Resources". This modelling approach has commonly been undertaken for a wide variety of mineral resource commodities, but rarely for uranium, using a variety of techniques, including the 'Three-Part Method' pioneered by the United States Geological Survey. This approach and other methods, which use known deposit data to provide insights into undiscovered resources, rely heavily on robust statistical inputs, which include grade and tonnage models linked with appropriate descriptive deposit models. The modelling approach discussed assists, assessments of potential future uranium resources, in answering the questions of 'where', 'how many' and 'how much'.

TRACK 8: URANIUM FROM UNCONVENTIONAL RESOURCES

C. Marie presented a paper entitled "Understanding of Uranium Extraction Mechanisms from Phosphoric and Sulphuric Media Using DEHCNPB". The presentation described and discussed mechanisms to extract uranium and iron from two different media (phosphoric and sulphuric). Thermodynamic data (i.e., extraction isotherms, slope analysis, phosphates/sulphates and water extraction) showed different behaviours depending on the initial medium. Spectroscopic techniques

such as FTIR, NMR, ESI-MS and EXAFS were also used to investigate uranium-DEHCNPB complexes formed in the organic phase, which enabled the determination of stoichiometries and coordination modes.

N. Al-Khaledi discussed "Selective Leaching of Uranium from Phosphates Ore". The presentation demonstrated the successful application (for environmental importance) of a leaching reagent to extract uranium from phosphate ores prior to processing for production of phosphatic fertilizers (and phosphoric acid), without dissolution of any amount from the phosphate mineral.

P. Britt provided an "Overview and Update on the Seawater Uranium Recovery from Technology Development Sponsored by the U.S. Department of Energy". The U.S. Department of Energy, Office of Nuclear Energy (DOE-NE) assembled in 2010 a multidisciplinary team from national laboratories, universities, and research institutes to start a technology driven, science-based research program focused on extraction of uranium from the most challenging but highest-payoff unconventional resource: seawater. The program's goal was to develop advanced adsorbent materials that can simultaneously enhance uranium sorption capacity, selectivity, kinetics, and durability to reduce the technology cost and uncertainties. These efforts have led to significant reduction in the costs of seawater uranium recovery technology.

POSTER PRESENTATIONS

F. Carvalho described "Radioactivity Monitoring and Environmental Restoration of a Legacy Mine and Milling Site". The former radium and uranium mine in Portugal operated in the period 1940–1960. Waste piles remained uncovered for decades after mine closure, until a radiological assessment detected elevated ambient radiation doses of up to 9.5 μSv/h. Natural vegetation covering the waste piles were analysed and showed that uranium progeny was easily transferred to plants. After remediation in 2015, a clean soil layer and plants were introduced. A post-remediation radiation survey confirmed a suitable degree of abatement of ambient radiation doses and conformity with basic safety standards and remediation goals.

L. Silva demonstrated a "Conceptual Model of the Fractured Aquifer of The Uranium Mine in Caetité, Brazil: Implications for Underground Water Flow". The main purpose of the study presented was to develop a conceptual model for the aquifer system, through geotechnical characterisation of discontinuities because these structures control the secondary porosity of the host medium. Hydrochemical data complement data from the physical characterisation of the behaviour interpreted for the aquifer, which is unconfined and presents points of stagnation of flow forming compartments without communication with the surrounding areas. The study showed that discontinuity distribution was not a dominant factor of the chemical parameters, but the composition of the rock was revealed as the most important factor.

U. Mirsaidov described the "Legacy Sites of the Former Soviet Union in Tajikistan: Problems and the Way Forward". Altogether, 10 uranium mining tailing dumps covering 170 hectares and containing more than 55 million t of waste were accumulated, with an activity of more than 6.5 kCi, from the beginning of the uranium industry in Tajikistan on the territory of six districts in the Soghd region. An essential limitation on carrying out the required remediation measures is a lack of relevant infrastructure. It was emphasized that re-establishment of radiation control systems on former uranium industry sites in Tajikistan is the first step to their full remediation.

U. Mirsaidov discussed the "Possibility of Uranium Industry Wastes Reprocessing in Tajikistan". Total amount of wastes in tailings of former uranium industry in Republic of Tajikistan is approximately 55 million tonnes. The total activity of wastes, according to different assessments, is 6.5–7.7 kCurie. The study presented propose a method of uranium ore reprocessing with the purpose to extend the base of raw material and allow the production of uranium oxide from uranium industry wastes with uranium content of 0.03–0.3 mass per cent. Final product is uranium ore concentrate containing 75% U3O8. Product recovery is at least 90%.

J. Iranmanesh described the “Geology, Mineralogy and Petrography of Rocks with Radioactive Element Mineralization in Anomaly 6 of the Khoshumi Area, Islamic Republic of Iran”. The lithological units containing the radioactive elements correspond to gneisses and pegmatites. Mineralisation generally consists of three groups of minerals containing radioactive and non-radioactive rare earth elements. Minerals containing rare earth elements include zircon, zirconolite, baddeleyite, allanite, ferroallanite, apatite and sphene. Monazite was observed in a number of pegmatitic samples only as small, anhedral grains inside biotites. Radioactive minerals identified in these sections are uraninite and uranium silicates, including coffinite. Non-radioactive minerals identified correspond generally to iron and titanium minerals such as pyrite, arsenopyrite, ilmenite, magnetite, haematite, goethite, lepidocrocite, rutile and anatase.

D. Rattanaphra discussed the “Characterization of Uranium, Thorium and Rare Earths in the Decomposition Process of Thai Monazite Ore Samples by X Ray Powder Diffraction and Wavelength Dispersive X Ray Fluorescence Techniques”. Monazite ore found in the tailings from tin mining in southern Thailand has been used as source of REEs, uranium and thorium. The decomposition process using alkali method, solvent extraction and ion exchange techniques were used to separate and purify those elements. XRD and WD–XRF were used to determine REE, uranium, thorium and associated mineral concentrations in samples obtained during the process. The elemental compositions of all samples measured by both methods showed very good agreement.

C.A.B. Dath presented the “Challenges and Opportunities of Small Uranium Mines in the SMR Development Era”. Small uranium deposits in Africa, which present growing interest for mining by interested nuclear operators, can be sustainable when used for serving fuels for SMRs (small- and medium-sized modular nuclear reactors), which need small quantities of fuel. This can also be an option for countries needing to increase electricity supply, in the context of a reduction of oil resources, over the coming decades. Safety considerations need to be addressed now to avoid nuclear material proliferation in future nuclear power plants in the region and indirectly during transport, fuelling and refuelling processes and waste processing. Attention also needs to be paid to uranium mine safety as safety regulations for nuclear power plants may also be applied to the smaller uranium mines in Africa.

R. Reyes discussed “Assessment of Thorium and Associated Resources: Philippine Initiatives”. The potential areas for thorium have been identified as the Ombo and Erawan coastal areas of northwestern Palawan Island. Mineralogical examination heavy minerals from panned concentrates of beach and stream samples showed major medium- to coarse-grained euhedral brown–reddish allanite (74.0–81.8%) and minor fine-grained subhedral yellow monazite (2.4–11.6%). Thorium values by gammametric analysis in panned heavy beach and heavy stream sediment samples showed values for Ombo and Erawan varying in the ranges 0.93–1.28% and 0.76–1.15%, respectively. X-ray fluorescence analysis for rare earth elements in both the panned heavy mineral stream and beach samples gave various ranges of values for lanthanum (3.00–12.24%), cerium (5.00–21.07%), praseodymium (0.04–1.71%), neodymium (2.00–6.51%) and yttrium (0.03–0.21%).

G. Haddadi presented “Indoor Radon Levels in Gachin (Islamic Republic of Iran)”. It was shown that, in houses, the average radon concentration was 39 Bq/m3. On different floors and according to the construction material used, the average effective dose equivalent of lung tissue was 0.97 mSv/year. Thus, it was concluded that the indoor radon levels in Gachin houses are within an acceptable range.

K. Changkrueng demonstrated how “Geological Samples Pinpoint for Nuclear Forensics Examination in Thailand”. It was shown that trace elements and REE are geochemical signatures of the samples studied, and XRD spectra are indicative of their mineralogy. Because the samples studied from many provinces in southern Thailand, the geochemical data (including uranium, thorium, REE and other trace elements) can used to trace the precise locations of the samples and to make deductions about unvisited locations.

J. Manrique expounded on “Geochemical and Mineralogical Characterization of the Uraniferous Phosphate Rocks of the Navay Formation, Táchira State, Venezuela”. The mineralogy of Navay Formation is typical of marine phosphatic deposits with fluorapatite/chlorapatite, collophane or

carbonate fluorapatite ($Ca_5(PO_4,CO_3)F$), uranospathite, quartz and calcite as the major phases. Uranium is present in the following forms: apatite (28–75%) and uranospathite (2–3%). The background concentration of U is 102 ppm, reaching a maximum value of 160 ppm in a calcareous phosphatic sandstone, so this occurrence can be considered as an unconventional uranium deposit type according to its U grade. Statistically sub-anomalous values of Cd (82 ppm), Cu (261 ppm), Zn (268 ppm), Sr (1832 ppm) and Zr (510 ppm) and anomalous values of Cr (1653 ppm) were determined. These elements are interesting because of their geochemical association with uranium and phosphates. In several samples, yttrium was detected (maximum of 144 ppm), which is associated with phosphates.

E. Kimaro discussed "Uranium Mining in the United Republic of Tanzania: Current Status, Challenges and Opportunities". Currently, the price of the commodity is depressed. However, demand for uranium for use as nuclear fuel is expected to increase in the near future because of several expected new nuclear power plant construction projects in various countries. The expected rise in demand and subsequent uranium spot price increase will benefit the mining companies as well as the countries hosting the uranium deposits. However, despite the expected benefits, in certain countries, the challenges can outweigh the benefits.

Y.Q. Niu China demonstrated "The Extraction of Uranium from Salt Lakes in China". During the experiments presented, the bio-adhering phenomena happened. This is similar to what is observed during uranium extraction from seawater in China, Japan and the United States of America. Because it is difficult to overcome the problem of bio-adherence in extracting uranium from seawater or salt lakes, the concept of anti-bio-adhering materials to aid the extraction of uranium was investigated. The study presented found the presence of the anti-bio-adhering mechanism of MIT functional material (isothiazolinone compounds, which are germicides that can restrain effectively the growths of bacteria, mildew and algae).

E. Calderón presented "Hydrometallurgical Tests for Vanadium Extraction from Black Limestones from Puyango Sector, Loja Province, Ecuador". It was demonstrated that the most efficient leaching agent was H_2SO_4 at a concentration of 15%, the other operating parameters being a temperature of 25°C, solid:liquid ratio of 1:10, and the duration and agitation speed being 3 hr and 300 rpm, respectively. It has also been shown that vanadium (III) cannot be leached by acids (with the exception of HF), unlike the other states of vanadium (IV and V). As oxidation is an indispensable process by which to increase the total yield, the study found from the experiments that the best concentration was 20 g/l of H_2O_2 (10 volumes).

S. Dieguez described "Yellowcake Production and Environmental Remediation at the Sierra Pintada Mine, Argentina: Lack of Social Licence". This uranium mine was in production between 1975 and 1997 but the operations were stopped for economic reasons. The mine site is currently a deposit with apparent resources, with all the facilities needed to resume production, but without authorisation to operate because of environmental concerns. In this context, the future of the project is uncertain.

M. Arrondo discussed the "Environmental Factors Control at Sierra Pintada, Argentina: Water Quality". During mine production and the subsequent stages, no concentrations were recorded above those allowed in the water courses of the El Tigre stream and the Diamante River, demonstrated not only by its own monitoring, but also confirmed by those measurements carried out by the General Department of Irrigation and the Nuclear Regulatory Authority (ARN). After CNEA's (National Atomic Energy Commission) more than 40 years of activity in the area, with almost 20 years using sulphuric acid for mineral treatment, there has been no alteration in the quality of the surface or underground water. Since the Sierra Pintada uranium mine began to produce uranium concentrates in 1979, suitable methodologies have been used for handling of acid solutions and for the management of process effluents.

J. Kraikaew described an "Alternative Database for Domestic LOF Nuclear Materials and Fuel". The data input was compiled from Office of Atoms for Peace (OAP) licensing information on nuclear material. This necessary information was intended to support law enforcement or regulatory investigations. In 2017, the nuclear forensics database was created using Microsoft Access 2010 and was intended to be the prototype for developing the National Nuclear Forensics Library (NNFL).

Additional databases were developed via Microsoft Access 2010, such as: (i) additional nuclear forensics information, including LOF (location outside facilities) database of year 2016, and (ii) OAP's Nuclear Forensics Laboratory inventory. The library data were summarised for some domain expertise, i.e. fresh fuel and irradiated fuel in the nuclear fuel cycle stage, sealed sources and unsealed sources following the NNFL master index, as well as its Microsoft Word 2010 templates. The algorithms for comparative analysis are ongoing and have been developed for interpretation of the information on the seized materials and those existing in NNFL, to identify and report, for nuclear forensics purposes, conclusions on crime investigations in the events of a nuclear security alert.

T.K.D. Nguyen explained the "Removal of Uranium and Thorium from Uranium and Rare Earth Ores Processing — Case Study of QA/QC on Environmental Analysis". During processing the ore for the main products, the mining tailing contains considerable amounts of radioactive elements such as uranium and thorium, which would be accumulated at some storage or just released at the site. To ensure a safe environment, several research projects have then been set up for the recovery of by-products including uranium and/or thorium. To ensure quality assurance/quality control of analysis of these elements, X-Ray fluorescence and other analytical techniques have been studied for supplying the demands of such research projects. The use of certified reference materials and secondary standards for quality control contribute to reliable and unbiased results and narrow uncertainties. The presentation discussed analytical results of samples and of various reference materials with focus on concentration range, matrix compositions, and determination limits.

K.X. Wang described the "Geological and Geochemical Characteristics of the Jiling Na-Metasomatism Uranium Deposit, Gansu, China". The petrology indicates that late-magmatic albitisation was followed by chlorite alteration of biotite and feldspar. The major uranium minerals are uraninite and brannerite. Abundant uranium minerals occur in fractures in newly formed albite and chlorite, indicating that the main mineralisation stage occurred later than albitisation and chloritisation. The high Th/U ratios (2.76 to 10.63) suggest that the Jiling granitoids provided uranium for mineralisation. Likewise, Pb isotopes reveal that the uranium may derive from the host granitoids. H, O, and C isotopes reveal that the CO_2 originated from the mantle, and water in hydrothermal fluid from mixing between magmatic hydrothermal and meteoric water. The geochemistry reveals that the Jiling granitoids are A-type granitoids and they were generated by mingling of crust- and mantle-derived magmas.

S.S. Maspalma presented "An Overview of Geology and Occurrence of Unconventional Uranium Resource: Potential Recoveries from Precambrian Basement and Cretaceous Sedimentary Rocks of Nigeria". The discovery of high concentration of uranium in Apaku, one of the Proterozoic pegmatites out of fourteen identified pegmatite blocks and two out of thirteen prospects of Cretaceous phosphate rocks in the Sokoto Basin makes the area prospective for uranium investors and prospectors in Nigeria. Ground follow-up and field check of previous exploration results has confirmed that altered granitic rocks in the Proterozoic Basement area and the Cretaceous phosphate rocks correlate with areas of high uranium as shown by U/Th ratios, conductivity, subsurface lineament, ternary images, and geochemical results. The well-established deposits of uranium in the Niger Republic in the Illumeden Basin, which is contiguous to the sedimentary phosphate rock of Nigeria, makes the potential of similar occurrences very high. Further work including feasibility studies is recommended in the areas that have good potentials for unconventional uranium resource.

J. Deng discussed "Advances in Geophysical Methods Used for Uranium Exploration and Their Applications in China". Integrated geophysical surveys for deeper uranium deposit exploration and 3-D geological structure surveys that were initiated in south China were presented. The results of these surveys when combined with geological and borehole data support the need for deeper uranium exploration in the survey areas. It was concluded that geophysical methods give useful results for uranium exploration and that integration of several geophysical methods and other disciplines is necessary in most cases to achieve better results.

G. Top demonstrated the "Determination of Uranium-Bearing Samples in Terms of Possible Contamination, Arikli Uranium Region, Çanakkale, Turkey". It was illustrated that the developed interdisciplinary methodology helps to analyse the characteristics of the uranium distribution originating

from the Arıklı mineralised site. The methodology characterises the geochemical and topographic units and provides insight to the mechanisms controlling the distribution of elements.

L. López explained the "Thorium and Rare Earth Element Comprehensive Extraction Projects in Argentina: Assessment Using the United Nations Framework Classification for Resources (UNFC)". The presentation, which was a summary of several studies that were conducted by the Comisión Nacional de Energía Atómica, the Argentine Geological Mining Survey and different exploration companies, examined explicitly how integrated thorium and associated rare earth element (REE) projects could contribute to the development of the minerals sector in Argentina. For the accurate assessment and for planning the progression of resources, the UNFC was used in the studies presented. The application of the UNFC scheme contributed to a better understanding of the availability of reliable nuclear and associated critical material resources, especially for development of green energies in Argentina, and this helps in gaining an understanding of where the focus should be in future. The role of REEs in contributing to Argentina's gross domestic product could be reassessed with this in view.

B. Mishra described the "Uranium Mineralization in the Khetri Sub-basin, North Delhi Fold Belt, India". Uranium mineralisation in the sub-basin is mainly associated with deep-seated fractures/shears and F2 folds affected by intense hydrothermal activities and it is preferentially hosted by sheared/fractured, albitised and altered metasediments of the Ajabgarh Group. Alterations recorded in this region correspond to albitisation, chloritisation, silicification, sericitisation, calcitisation and sulphidisation. Uraninite, which occurs in clusters, as disseminations of subhedral grains and in veins, is the dominant uranium mineral, in addition to minor brannerite and coffinite. The geochemistry of the mineralised rocks indicates polymetallic (U–Cu–Mo) mineralisation. The presence of coarse-sized dispersed uraninite in the albitite veins also supports a close relation between albitisation and uranium mineralisation.

R. Villegas discussed "Uranium Recovery from Acid Mine Drainage Treatment Residue — Caldas, Brazil Case". The acid solution is produced from waste rock piles and from leached residual metals, including uranium. This effluent is treated continuously with lime and the residue, an alkaline mud, is deposited into the mine pit. This alkaline mud contains uranium and rare earths and several projects are being carried out in order to recover these products. This paper presents the comparison between efforts on developing acid and alkaline leaching processes to extract and to concentrate uranium liquor from this residual material.

K. Thrane described "Uranium Potential in Greenland: An Update". The uranium potential in Greenland is considered to be relatively high, with several known uranium occurrences. Three uranium deposit types were chosen for assessment: intrusive, sandstone hosted and unconformity-related. The intrusive and unconformity-related deposits have the highest probability of having formed uranium deposits in Greenland. South Greenland is the most prospective region for additional hidden or unrecognised intrusive type uranium occurrences.

S.B. Dampare presented "Geochemical and Mineralogical Studies of Uranium Potential of the Late Devonian to Early Carboniferous Takoradi Black Shale, Sekondian Group, Ghana". Mineralogical studies of the shales, using powder X-ray diffraction, identified the main mineral phases as quartz, vermiculite, zeolite and other clay minerals as well as uranium oxide and uranyl-oxide minerals. Whole-rock geochemical analysis of representative black shale samples by ICP-MS revealed Th and U concentrations of 18–22 ppm and 7–9 ppm, respectively. Thorium, Zr, Nb, Ta, V, La, total rare earth elements and Ti are enriched in the Takoradi Shales relative to Post-Archean Average Australian Shale.

W. Laksmono described the "Uranium Mine Operations in Indonesia". The presentation focused on the regulatory requirements for the mining of nuclear material, especially uranium. Whereas mineral and coal mining in Indonesia is regulated by Act No. 4 Year 2009, the arrangement for radioactive minerals is regulated by Act No. 10 Year 1997 on Nuclear Energy. Indonesia has received support from the IAEA in relation to uranium mining. The IAEA approach to regulate mining activities is described in the Nuclear Law Handbook, which was used for developing the required regulations.

J. Alvarez presented “New Studies of Uranium Deposits Related to Granites in Argentina”. The presentation described the specific objectives and activities of a project called “Melallogenesis of Granite-Related Uranium Deposits in Argentina”, which has been underway since 2015, within the framework of the IAEA coordinated research project called “Geochemical and Mineralogical Characterisation of Uranium and Thorium Deposits”. The project aims to characterise the Devonian–Lower Carboniferous magmatic and hydrothermal systems related to granitoids of the Pampean Ranges, and to unravel the link of these systems to uranium metallogeny. The interpretation of different rare earth element and other element patterns in uranium oxides from uranium deposits helped improve the metallogenic knowledge of the uranium mineralisation related to granites, which could in turn aid in the exploration guides to be applied.

A.R. Iurian discussed “Uranium and Its Environmental Behaviour: A New IAEA Technical Reports Series Publication”. The presentation explained a new overview publication being prepared by IAEA to provide its Member States with information on the environmental behaviour of uranium for use in environmental impact assessment of routine discharges and accidental releases, for uranium impact assessment in different contamination scenarios and for remediation planning of sites contaminated with uranium.

G. Mashkovtsev discoursed on “Evaluation of the Opportunity of Production of Uranium from Phosphorite Ore”. The feasibility analysis presented was calculated based on discount rates set at 10% and 15%. The ore resources of the projected plant are sufficient for 39 years of operation. The planning horizon used was assumed to be 17 years. Development of the Shargadyk deposit of complex uranium–phosphate–REE ores appears to be commercially profitable.

O. Šálek demonstrated “The Test of New UAV Gamma-ray Spectrometer at a Real Uranium Anomaly”. The presentation explained the methodology and potential of mini-airborne gamma-ray spectrometric survey for radioactive ore prospecting using unmanned aerial vehicles (UAV). A detailed ground gamma-ray spectrometry investigation of a U anomaly enabled analysis and comparison with airborne data. The UAV mini-airborne instrument can collect the same number of counts per unit distance on a profile as a standard airborne survey. The main limitations of mini-airborne gamma-ray spectrometry are short operational time and slow survey speed making it inapplicable for regional surveys.

H. Sayed described “Using Nuclear Technology for Detection and Determination of Minerals and For Preparing Standard Reference Material”. The presentation emphasized that effective production methods must be used to provide energy and raw materials, and these methods include nuclear and analytical techniques such as X-ray fluorescence and neutron activation analysis. It was pointed out that inductively coupled plasma mass spectrometry has great potential to improve the efficiency of the results of raw material analysis.

S. K. Satpati discussed “Technological Upgrading by Recycling Effluents Generated at a Uranium Metal Production Plant, India”. The presentation discussed the insight gained from relevant developmental studies and demonstrated the upgrade of uranium metal production technology in India with respect to waste recycle schemes.

A. Khaldi explained the “Application of the United Nations Framework Classification for Resources (UNFC) to Uranium Resources Discovered in Algeria”. Uranium resources discovered in the Hoggar (southern Algeria) have been evaluated according to the generic specifications of the United Nations Framework Classification for Resources (UNFC). The example presented illustrated the application of multiple classification systems used by various groups involved in different phases of exploration and development of these resources. It was shown that the UNFC is a relevant tool for reviving the re-evaluation and development programme of uranium resources of Algeria’s mining sector.

A. Osman discussed the “Investigation of U-238 and Th-232 in Fingernails, Total Blood and Drinking Water among Well Users in Kadugli Town, a High Natural Background Radiation Area in Sudan”. Water, fingernails and blood samples were analysed for 238U and 232Th using inductively coupled plasma mass spectrometry. The results of some analyses of water supplies revealed U concentrations

higher than the WHO guidance level (15 µg/l) for drinking water. Analysis of body tissues showed that both 238U and 232Th were better reflected in fingernails than in blood. The generated data represent a valuable baseline for the decision makers to consider prior to the onset of mining activities.

T. Berg demonstrated "Remote Sensing Identification of Uranium Exploration Targets – Laguna Sirven Project, Santa Cruz, Argentina". Two prospective uranium exploration targets were identified within the project after the careful selection of remote sensing data during the acquisition phase and the later preparation, processing and interpretation of such spectral data. The analysis of the presence and abundance of sulphate and carbonate related minerals indicated by both the gypsum and the carbonate indices proved to be a very useful tool to identify uranium targets in this calcrete-type deposit.

T. Berg presented "Biogeochemical Orientation Survey for Surficial Uranium Deposits, Laguna Sirven, Santa Cruz, Argentina". Correlation analysis of the plant data showed statistically significant correlations between U and As and between U and V. The same pattern was observed for As and V but not for Th and Fe. Remarkably, the highest U levels were found in plant roots, with the U, As and V results confirming that the site around Laguna Sirven is of interest for future U and associated elemental research. Radiometric data collected during field trip have good agreement with the uranium values for plants and soils at Laguna Sirven. This confirms that field gamma radiation measurements for U, Th and K are useful for identifying sampling sites for subsequent U/Th analysis. Such measurement will help to identify specific plant species for biogeochemical prospecting.

M. Noskov discussed "Innovative Intellectual Management Technology of Uranium Mining by the ISL Method". The presentation focused on the systems of the software package used and its application for increasing the uranium mining efficiency by the ISL method. An important factor in the effectiveness of the software package application is the completeness of the line of software products that provide solutions for the enterprise covering the entire life cycle, from exploration to completion.

L. López presented "Perspectives of Phosphate — Uranium Comprehensive Extraction Projects in Argentina". However, the existence of favourable basins and different mineralisation models suggest promising conditions to set up new projects to develop the phosphate potential in the country, taking into consideration the perspective of uranium recovery from this unconventional source of nuclear raw material. The IAEA project CRP on neutral uses of HTGRs would allow accounting for a better understanding about heat processing of low-grade phosphates.

E.T. Zege described "Tailings and Waste Management at The Kenticha Tantalum Mine Site". The regulatory body has enacted an extensive radiological monitoring programme at the Kenticha mine sites and tailings dam to measure the radiation exposure of people living close to the mine by measuring radionuclides dispersed by surface water, groundwater and atmospheric pathways. This has been achieved by testing water samples from effluent, soil and cereals from the environment and converting these measurements into radiation exposure estimates. The radiation dose estimates have been lower than the annual public dose limit of 1 mSv.

F. Reitsma discoursed on a "Coordinated Research Project on Uranium/Thorium Fuelled High Temperature Gas Cooled Reactor Applications for Energy Neutral and Sustainable Comprehensive Extraction and Mineral Product Development". This project generates basic data on the availability and characteristics of various potentially suitable mineral resources and process residues, and conducts conceptual and pre-feasibility studies on appropriate thermal processes in which uranium/thorium fuelled high temperature gas cooled reactors provide the required energy.

A. Karpaeva discussed "The Mining Sector Capacity Improvement in The Kyrgyz Republic through Building Effective Cooperation among Governments, Mining Companies and Local Communities". The research presented has attempted to understand mining conflicts in the Kyrgyz Republic and around the world through comparative analysis. Its findings show that the main causes of these conflicts were environmental problems, socio-cultural misunderstanding, socio-economic conditions, mistrust and lack of dialogue among stakeholders. It examined good practices to prevent and resolve mining conflicts in different countries. It found that some Canadian mining companies worked closely with the local

population in the early stages of the project. In order to invite more foreign investments and effectively develop mineral resources, the State Agency for Geology and Mineral Resources began reforming subsoil use policies. As a result, a new law on the subsoil was adopted on 9 August 2012. In recent years, the State Committee for Industry, Energy and Subsoil Use has been working hard to reduce conflicts between mining companies. In resolving or preventing mining conflicts, the state can act as an intermediary, as it is interested in business development, local citizens' social and economic development, and the minimisation of the negative environmental impacts.

A. Hanly presented "IAEA Coordinated Research Project: Geochemical and Mineralogical Characterization of Uranium and Thorium Deposits". The main objective of this coordinated research project was to undertake geochemical and mineralogical studies of mineralised samples and apply this to understanding the genesis of uranium and thorium deposits and geochemical and mineralogical constraints on mineralisation processes. The project involves thirteen Member States: Argentina, Canada, China, Egypt, Ghana, the Islamic Republic of Iran, France, Kenya, Madagascar, Mongolia, Philippines, Ukraine, Bolivarian Republic of Venezuela.

S. Dai explained the "Recovery of Uranium from Seawater by Polymeric Adsorbent Systems". The presentation focused on the development and performance of three classes of advanced adsorbents developed as a part of the integrated research effort overseen by the U.S. Department of Energy Office of Nuclear Energy to reduce the technology cost of extracting uranium from seawater: (1) high-surface area polymer fiber adsorbents based on radiation-induced grafting, (2) polymer fiber adsorbents derived from atom-transfer radical polymerisation (ATRP), and (3) surface-functionalised polyacrylonitrile fiber adsorbents. The pros, cons, and cost of each technology were discussed along the recent developments on improving the capacity and the uranium to vanadium selectivity.

V. Vokál presented "WNU SUP — Efficient Capacity Building Tool in U-Production Cycle". The World Nuclear University — School of Uranium Production (WNU SUP) International Training Centre was founded in 2006. It is operated by the DIAMO State Enterprise under the auspices of the World Nuclear University in London and in collaboration with OECD/NEA and IAEA. From beginning, it has become a globally renowned facility of professional training.

K. Kiegiel discussed "Recovery of Uranium and Accompanying Metals from the Secondary Raw Materials". In Poland, advanced studies have been undertaken concerning the possibility of obtaining uranium from domestic resources and secondary resources such as phosphate rocks and industrial wastes, including flotation tailings from the copper industry and phosphogypsum. In these studies, solid materials were leached with using either acid or alkaline solutions in stationary reactors or with percolative leaching. The obtained liquors were separated from solid residue and then were purified by liquid-liquid extraction or ion exchange chromatography.

M. Kopbayeva described the "Concentration of Uranium from Solutions Using Nanomembranes". The conducted experiments of eluate nanofiltration showed the theoretical feasibility of uranium and sulphuric acid separation. The extraction of uranium into a concentrate is ~94%. The concentration of uranium with simultaneous decrease in the excess acid content led to an increase in the efficiency of peroxide precipitation and to a decrease in the specific consumption of sodium hydroxide.

H. Maerten demonstrated "Effective and Environmentally Compliant In-Situ Recovery of Sedimentary-Hosted Uranium" for recent in-situ recovery projects operated by Heathgate Resources in the Frome Basin, South Australia.

M. Mathuthu described "Organic Solvent Extraction of Uranium from Alkaline Nuclear Waste". The research presented aimed to evaluate organic extraction ligands that can operate in alkaline media to remove uranium from the nuclear waste and the objective was to characterise the most effective organic solvent for extracting uranium only, from alkaline media. The results of the research indicate that plutonium and thorium were not detected in the final uranium product, indicating that the organic solvent alkaline extraction method could be a valuable technique in uranium processing.

TRACK 3: APPLIED GEOLOGY AND GEOMETALLURGY OF URANIUM AND ASSOCIATED METALS

I. Pechenkin presented “Regional Forecasting of Sandstone Type Uranium Deposits”. The presentation focused on sandstone type uranium deposits in the Alpine–Himalayan tectonic belt. It was demonstrated that, within the limits of this tectonic belt, the analysis of the spatial distribution of endogenous and exogenous uranium deposits provides information on preconditions for the occurrence of metallogenic zonation. It allows reconstruction of the formation of uraniferous sandstone deposits during the formation of sedimentary basins. Thus, the leading ore localizing factors, groundwater and interlayer oxidation zones controlling uranium mineralization, have been established for all sandstone hosted type deposits. The study presented presumes a tight spatial relationship between infiltration uranium deposits and endogenous uranium deposits confined to volcano-tectonic structures.

A. Ali discussed the “Genesis of Sandstone Type Uranium Deposit in Dhok Pathan Formation, Siwalik Group of Trans-Indus Salt Range (Surghar Range), Pakistan”. The presentation focused on the Qubul Khel uranium deposit in the basal part of a sandstone belonging to the upper part of Dhok Pathan Formation. The uranium mineralization corresponds to synsedimentary/diagenetic concentrations, which have been redistributed and remobilized due to successive phases of Himalayan tectonic activity. The sandstone depositional model and geochemical data suggest that the source of uranium mineralization was contained within the sediments. The Qubul Khel uranium deposit is thought to have evolved through multiple reworking by infiltration. Continual leaching and migration of uranium to its present location occurred during successive tectonic activity and is related to fluctuations in the water table in response to Himalayan tectonism. Uranium precipitation was caused by permeability barriers combined with upwards migrating hydrocarbons, which were considered to have provided the required reductants.

V. Lusambo described “The Karoo Sandstone-Hosted Uranium Deposit at Dibwe East, Mutanga, Zambia”. The exploration data presented suggest that the likely environments of uranium mineralization are meandering stream depositional systems within paleochannels, with fine- to coarse-grained sands and silts containing some organic and pyrite material, which could serve as reductant for the precipitation of uranium. At least three mineralized zones (“sand packages”) have been identified. A stacked series of three mineralized horizons extend from near surface down to nearly 150 m.

O. Gorbatenko talked about “3D Modeling of Roll-Front Type Uranium Deposits in Kazakhstan”. Joint Venture Inkai, with Cameco corporation assistance, started to adopt 3D modeling into their workflow. Currently, the project has achieved its median of 3D implementation and is valuing all potential and advantages of using 3D tools.

F. Nie presented a paper entitled “The Fluid Flows and Uranium Mineralization in the Northern Ordos Basin, North China”. The presentation concluded that the extensive uranium enrichment in the Ordos Basin has undergone three stages, namely: (1) pre-enrichment stage; (2) interlayered oxidation stage; and (3) hydrothermal and petroleum reworking stage. It was demonstrated that hydrothermal fluids have migrated through normal faults into the uranium orebodies and redistributed the original mineralization. During this process, a large amount of pitchblende was turned into coffinite because of the addition of silica released from feldspar alteration to uranium in pitchblende, which occurred simultaneously with the formation of hydrothermal sulphide minerals. At the same time, tabular/roll-front orebodies changed into tabular and/or lenticular shapes. It was recommended that exploration geologists may use this model to predict the uranium occurrence in the Ordos Basin.

TRACK 11: TAILINGS AND WASTE MANAGEMENT

J. Hendry presented “A Review of the Geochemical Controls on Elements of Concern in Uranium Mill Tailings, Athabasca Basin, Canada”. The presentation summarized the extensive existing literature on the mineralogical controls on the elements of concern (EOCs) in tailings in in-pit TMFs in the Athabasca Basin compiled over the past two decades. The review highlighted, among others, the following.

Research shows that Fe and Al secondary minerals provide the dominant mineralogical controls of elements of concern (EOC) in the precipitates from raffinates. Co-precipitation of ferric arsenate and the adsorption of arsenate to ferrihydrite are major mechanisms of As sequestration. Most studies of EOC controls by Al and Mg minerals were determined on Key Lake samples.

T. Metschies discussed the "Remediation of Former Uranium Mill Tailings Facilities: Concepts and Lessons Learned". Between 1946 and 1990, 216 300 tU were produced by mining and milling facilities in the eastern part of the former German Democratic Republic. The operation of uranium mill tailings storage facilities impacts not only the radiological conditions at the site but also other environmental media. Remediation faces complex requirements aimed at reduction of potential risks and current impacts, in combination with the need to stimulate the long-term use of the site under strict economic constraints. The remediation of the four largest mill tailings facilities, Helmsdorf, Dänkritz 1, Trünzig and Culmitzsch, with ~160 Mm^3 of tailings stored in an area of 570 ha, is part of this remediation project. The presentation highlighted that a sound funding for these activities has to be ensured so as not to undo the good work of the initial remediation work.

O. Voitsekhovych described the "Environment Aspects of Th-230 Accumulated in Residues Components at the Uranium Production Legacy Site Pridneprovsky Chemical Plant". The presentation was an overview of the results of recent studies carried out at the former uranium production facility Pridneprovsky Chemical Plant (PChP) in Ukraine. The PChP was one of the largest facilities of the military complex of the former Soviet Union, where production of uranium for the Soviet atomic programme was carried out from 1949 until 1992. The levels of 230Th activity concentration in aerosols were measured in just a limited number of samples collected in the contaminated buildings and in the surrounding areas. The results showed that in the buildings where the uranium concentrate derived from phosphorus ore was purified, the content of thorium in dust and aerosols exceeded the activity of uranium and radium by 10–100 times. The variety of conditions and the forms of radionuclides in the U–Th series at various former sites of uranium production also determines the variety of radiological risks to personnel at/near the former uranium production complex. At most sites, the main contribution to the radiation dose was determined by direct gamma irradiation, which was mainly derived from 226Ra.

G. Dunn discussed "The Removal of Radiation and Other Impurity from Copper Sulphide Concentrates". The presentation summarized a process that has been successfully demonstrated as being able to remove very significant levels of the original radioactivity, while at the same time upgrading the concentrate so that it attracts reduced transport and treatment costs at smelters. Economically recoverable uranium can be recovered as by-product by employing ion exchange. Simultaneously, the copper in the final concentrate is raised to 55–60%. The presentation demonstrated that the upgraded concentrates satisfy the IAEA Regulations for the Safe Transport of Radioactive Material for the transport, trade and processing thereof.

B. Moldovan presented a paper entitled "Hydrometallurgical Controls on Arsenic, Molybdenum and Selenium in Uranium Mill Effluent and Tailings". Contamination of groundwater and surface water by arsenic, molybdenum and selenium derived from both natural and anthropogenic sources is an issue of global concern. In the hydrometallurgical process for uranium purification and concentration, these elements must be separated from uranium either via solvent extraction or ion exchange processes to achieve the required product quality for uranium ore concentrate. The non-economical arsenic, molybdenum and selenium must then be chemically processed to produce a thermodynamic and geochemically stable precipitate prior to final emplacement in the engineered tailings management facility. The presentation demonstrated that the selected ferrihydrite precipitation hydrometallurgical treatment method achieved excellent results at full plant scale.

TRACK 3: APPLIED GEOLOGY AND GEOMETALLURGY OF URANIUM AND ASSOCIATED METALS

A. Hanly presented on "Unconformity-Type Uranium Deposits: A New IAEA Technical Document". The presentation discussed how the new technical document will provide a summary on unconformity-

type uranium deposits including geology, mineralogy, metallurgy, mining methods, resources, genesis, exploration techniques and other topics that would be useful for evaluation.

G. Chi discussed "Fluid Inclusion Evidence for Uranium Extracted from the Athabasca Basin as a Source for Unconformity-Related Uranium Mineralization". The presented microthermometric and LA–ICP–MS analyses of fluid inclusions in quartz overgrowths from sandstones distal to ore deposits in the Athabasca Basin revealed the presence of Ca-rich and U-rich brines within the basin. This finding is important for the refining of the exploration model for unconformity-related uranium deposits.

I. Annesley reported on "New U–Pb Ages and Geochemistry from the Wheeler River Uranium Deposits, Athabasca Basin, Canada". The Wheeler River Project hosts the high grade Phoenix (sandstone hosted) and Gryphon (basement hosted) uranium deposits within the eastern part of the Athabasca Basin. The data presented provide excellent evidence for multiple uranium events related to changes over time on the Wheeler River property. Interpretation of the data posit that the evolution of the Wheeler River property, and on the larger scale of the Athabasca Basin, has been complex since the deposition of the basin, which could explain the exceptional characteristics of the unconformity-related uranium deposits.

J. Gigon presented a "Comparison between the Uranium Deposits in the Alligator River Uranium Field and the Westmoreland Area (Northern Territory and Queensland, Australia)". The presentation synthesized data on ore mineralogy, geochemistry, geothermometry, age dating and fluid inclusion data from Westmoreland–Murphy type deposits and compared them with published data from unconformity-related deposits in the Alligator River Uranium Field (ARUF). The study presented concluded that it appears that the unconformity-related U deposits from the ARUF and the Westmoreland–Murphy type U deposits share some striking similarities in terms of alteration, ore mineralogy, temperature and fluid composition, but also noticeable differences. Further work is planned to compare the composition of the Na–Ca–Cl brines, which appear to be involved in both areas.

P. Acosta-Gongora discussed the "Geochemical Signatures of U-Bearing Metasomatic Deposits of The Central Mineral Belt, Labrador, Canada". The Central Mineral Belt (CMB) hosts several U ± Cu ± Mo ± V prospects and deposits, including some with affinities to albitite-hosted uranium deposits and others with iron oxide–copper–gold (IOCG) deposits. The presented study made use of the CMB uranium geochemistry database (CMBUG) to provide a general characterization of the CMB in terms of alteration types and to investigate potential links between IOCG systems and the CMB uranium mineralization as means to advance exploration models. It was concluded that: (a) sodic alteration is the most common alkali alteration in the CMB; (b) the emplacement of iron oxide minerals is generally decoupled from potassium; and (c) uranium mineralization is not necessarily associated with alkali or iron oxide altered rocks.

TRACK 10: HEALTH, SAFETY, ENVIRONMENT AND SOCIAL RESPONSIBILITY

B. Boyer presented "IAEA Safeguards Aspects of, and Issues in, Uranium Mining and Ore Processing". To aid enhanced information analysis, the IAEA's Department of Safeguards developed the Physical Model under Task 5 of Programme 93+2. The presentation provided an overview of the Volume 1 of the Physical Model, which is entitled Mining and Ore Processing. The Volume 1 of the Physical Model, which includes all the main activities that may be involved in the nuclear fuel cycle, addresses the key aspects and indicators associated with uranium mining and processing.

D. Mwalongo reported on "IAEA-TDL-003: A Cornerstone for Nuclear Security for Uranium Ore Concentrates for Newcomers". The presentation was about the experience acquired from IAEA TDL-003 technical assistance and experience in drafting nuclear security regulations for uranium ore concentrates (UOC) in the United Republic of Tanzania. The Tanzania Atomic Energy Commission requested technical assistance from the IAEA in the form of a national training course on nuclear security for UOC in 2014. The IAEA TDL-003 publication on Nuclear Security in the Uranium Extraction Industry was the main reference during the national training course.

A. Khamzayeva discussed “Guidance and Training for Nuclear Security in the Uranium Extraction Industry”. This presentation is about the document TDL-003, entitled Nuclear Security in the Uranium Extraction Industry, which developed by the IAEA Division of Nuclear Security in response to requests for assistance from States producing UOC and those planning such activities or which are involved in the protection of UOC during transport.

B. Moldovan described a “Practical Approach to Improving Conventional Safety Performance and Culture in Uranium Mines and Mills”. The presentation provided a global overview on leadership, management oversight, operational attitudes and behaviour, and the impact that the business climate has on safety performance, competence and training, hazard identification, risk tolerance, communication and safety based reporting. The presentation highlighted some effective and proven practical steps to improve safety performance and ultimately improve safety culture in the workplace.

H.B. Okyar talked about the “UMEX Project, an IAEA Survey of Global Uranium Mining and Processing Occupational Doses”. The presentation provided summaries of: (a) the results of the information survey and a preliminary analysis thereof, (b) current practices for monitoring and reporting of occupational exposure, and (c) occupational exposures reported for 2012. Overall findings showed an industry in compliance with international standards on radiation protection and a strong commitment to optimisation of protection.

Saïdou discussed “Natural Radiation Exposure to the Public in the Uranium and Thorium Bearing Regions of Cameroon: from Measurements, Dose Assessment to a National Radon Plan”. The presentation concluded that natural radioactivity in most of the surveyed areas is normal, but there are high natural radiation areas found in most of the areas studied. In particular, radon and thoron exposure is a reality in Cameroon; however, extensive measurements of radon and thoron at nationwide scale are needed. An IAEA TC project (CMR9009) dealing with Establishing a National Radon Plan for Controlling Public Exposure Due to Radon Indoors is ongoing since the beginning of 2018. This two-year project is funded within the framework of the TC programme between the IAEA and Cameroon.

TRACK 4: ADVANCES IN EXPLORATION

M. Brouand presented a paper entitled “Contribution to the Characterisation of the Host Formation of the Francevillian Uranium Mineralization (Haut Ogooué Province, Gabon): Petrography, Sedimentology, Stratigraphy, Age and New Isotopic Data”. The studies presented were initiated by the Orano Mining Group exploration staff. These studies were combined with sedimentological, petrographic and metallographic works. The presentation highlighted new results on: (a) the volcanic origin of the yellow strips constituting a possible regional stratigraphic marker and possible syn-sedimentary sources for at least part of the uranium in the basin; (b) the ages of different mineralization types at Mikouloungou, younger than the first mineralization event at Oklo; (c) the 235U loss in the uraninite crystals of the Oklo reactors due to natural fission and giving an age of around 2 Ga, as given by former data, with other analytical techniques; and (d) the original spectra with the double tetrad effect for the same Oklo uraninite crystals.

J. Kvasnicka reported on “Radon Monitoring in the Soil Air with Nuclear Track Detectors – Uranium Exploration Method”. The presentation highlighted the method’s limitations due to the effect of the moisture content in material that covers uranium mineralization as well as the thickness and uranium concentration of that overburden. Therefore, the radon survey was carried out at the end of the ‘dry season’ when the ground was more likely to be ‘dry’. The results of the survey indicate that the source of radon is not near surface and could represent a uranium source at depth. Because the radon survey was carried out over uranium anomalies that were confirmed by drilling, the results of the survey were used to optimize targets for future exploration drilling programmes.

T. O’Connor described the “Uranium-Lithium Deposits at Macusani, Peru: Geology, Processing and Economics along the Path to Production”. The deposits in the Macusani district are genetically anomalous: although the predominant host-rocks are rhyolitic volcanics and hypabyssal intrusions with geochemical affinities with the U-rich Hercynian S-type granites, the hexavalent uranium mineralogy,

comprising meta-autunite and weeksite, is akin to that of other surficial systems, and differs fundamentally from all recognized high- and low-temperature uranium deposit clans. The uniqueness of the district, which hosts a unique class of uranium deposit, with aspects of both surficial and sandstone systems, is also highlighted by the exceptional, inherent, lithium endowment of the host volcanics. The unique origin of this deposit is key to the excellent potential economics of these near surface, low-grade uranium deposits.

P. Sorjonen-Ward presented "Advanced Technologies for Sustainable Exploitation of Uranium-Bearing Mineral Resources in Finland". The research presented was aimed at combining mineral characterization with the development and demonstration of new techniques for the effective recovery of uranium from process and mine waters, even at low concentrations. The techniques employed cover the utilization of different bisphosphonate adsorbents, hybrid materials of nanoporous silicon carbide frameworks and bisphosphonates, and biological/bioelectrochemical uranium reduction. The presentation demonstrated the effectiveness of both the biosorption of activated sludge and bisphosphonates and hybrid derivative materials in adsorption of uranium from solution, even at very low concentrations, with the additional advantage of allowing rapid and efficient recycling and reuse of sorbent materials.

M. Seredkin discussed the "Features of Geological Modelling, Mineral Resources and Reserves Estimation of Uranium Roll-Front Deposits". The presentation is about a robust methodology developed by CSA Global for geological modelling mineral resource and ore (mineral) reserve estimation of roll-front deposits in Kazakhstan from 2012 through 2017. The methodology was applied to the Budenovskoye and South Inkai deposits in Chu-Sarysu province, and to Zarechnoye and Kharasan-1 deposits in Syrdarya province. The presentation stressed that the application of 3-D modelling techniques for roll-front deposits allows the creation of lithological and resource models and reliable mineral resource/ore (mineral) reserve estimation.

TRACK 5: ECONOMIC EVALUATION OF URANIUM PROJECTS

J. Randabel presented "Falea: An Unconformity-Type Polymetallic Deposit, Mali, West Africa". The Falea project, which is located in western Mali, approximately 350 km west of the capital, Bamako, contains a polymetallic orebody hosted within the Neoproterozoic portion of the lower Taoudeni Basin, where it overlies a heavily deformed Birimian basement composed of schists and metasediments. The project consists of three exploration permits covering 225 km^2, of which the Falea permit covers 75 km^2 and hosts several orebodies. These have an indicated mineral resource of 6.88 Mt at 0.115% U_3O_8 (0.098% U (6694t U)), 0.161% Cu and 73 g/t Ag, and an inferred mineral resource of 8.78 Mt at 0.07% U_3O_8 (0.059% U (5155t U)), 0.20% Cu and 17 g/t Ag, using a cut-off grade of 0.03% U_3O_8 (0.025% U). The Falea deposits have been previously postulated to represent a combination of two mineralization events. The first event was similar to a sedimentary exhalative (SEDEX) event and the second event was interpreted to be formation of a roll-front deposit, i.e., an epigenetic uranium deposit at a redox interface occurring on top of a SEDEX deposit. Further detailed delineation of the deposits and comparison with large, rich, historic districts overseas may point to considerably larger resources occurring in the area.

H. Allaboun reported on the "Central Jordan Uranium Project: Monitoring the Project Maturity Via the Application of the UNFC-2009". The uranium deposits in the Central Jordan Uranium Project (CJUP) are primarily hosted by the Muaqar Chalky Marl Formation of upper Maastrichtian age, part of the Upper Cretaceous to lower Tertiary Belqa Group. The application of UNFC-2009 to the CJUP study demonstrates clearly the advantage of tracking the project from a lower maturity level of assessment to a higher level. Thus, classification and reporting of uranium project results using UNFC-2009 have clear advantages for policy makers in Jordan, as well as for internal company requirements for monitoring the progress of a project over time.

H. Garba Barke discussed "Economic Evaluation of Uranium Projects (Niger Case Study)". The presentation concluded that mineral project assessment requires evaluation of technical inputs such as mineable reserves, production rates, recoveries, costs and revenues. These parameters form the basis of mine project evaluation, together with the tax regime of the host country.

C. Chiwambo presented the “Regional Framework for the Classification of Uranium Deposits: Africa’s Approach to Adopting UNFC-2009 through Implementation of African Mining Vision”. After considering the African challenges at hand, and the need to have a user-friendly resource reporting framework, the presentation recommended highly the adoption of the three frameworks: The United Nations Framework for Classification of Mineral Resources, the African Minerals Resources Classification and Management System and the Pan-African Reserve and Resources Codes.

J. Randabel reported on the “Exploration Successes in the Tim Mersoi Basin (Niger): A Case Study”. It was demonstrated that the geology of the Tim Mersoi Basin is still largely unknown, that the basin is large and has a complex geology, but is similar to other sedimentary basins elsewhere in the world known to host uranium. The presentation focused on current discoveries and exploration activity, which indicate potential for further development in the region.

TRACK 7: URANIUM PRODUCTION BY THE IN-SITU LEACHING (ISL) PROCESS

O. Gorbatenko reported on the “Experience of Plasma-Pulse Action for ISL Uranium Wells”. In processing deep production horizons of the Inkai uranium deposit, which was being developed using the technology of drill hole in situ leaching, it was essential to maintain high pumping rates of wells. In support of this, the plasma-pulse action method has provided the opportunity to reduce the number and duration of repair and renewal operations.

A. Yastrebkov presented “The Results of Laboratory and Field in Situ Leaching Tests at the Nyota Uranium Deposit (United Republic of Tanzania)”. The described In Situ Leaching test at the Nyota deposit is the first one ever carried out in Africa and it yielded encouraging results. It was concluded, based on the results, that ISL mining is definitely possible, thereby making the mining business more economically efficient and environmentally friendly.

H. Maerten discussed “Effective and Environmentally Compliant in Situ Recovery of Sedimentary Hosted Uranium”. The presentation was focused on acid In Situ Recovery (ISR) as used by Heathgate, although the general principles that were outlined are applicable to alkaline ISR. It was stressed that ISR technology is highly complex and requires the application of a versatile, comprehensive methodological basis to optimize recovery economics under the primary condition of environmental compliance.

M. Noskov presented on “Groundwater Contamination and Self-Purification at Uranium Production by the In-Situ Leaching Process” at the central part of the Khokhlovsk uranium deposit. The talk presented a mathematical simulation model of uranium sulphuric acid leaching and software for forecasting the groundwater state during deposit development by the In-Situ Leaching (ISL) method. Simulations were carried out based on the deposit’s hydrogeological model based on data from exploration and geophysical investigations. The simulations were carried out from the beginning of operation up to the present-day but forecast calculations presented were for a 20-year period after the cessation of uranium mining. The simulation results show that, in the case of uranium ISL, the region of groundwater contamination is local and situated mainly within the boundaries of the operational units.

S. Brown explained “A Uranium Isotopic Perspective on the Formation of Roll-Front Mineral Deposits and Implications for Post Mining Remediation”. The presentation was about an investigation on whether a two-dimensional spatial analysis of U and U isotope distributions in a roll-front can resolve the aforementioned problems with interpreting the U data from associated groundwater. It demonstrated that the spatial distribution of U and the U isotope ratios are not random but a result of reactive transport that can be approximated to a pipe flow model and that this information can be used to place constraints on the formation and migration timescales of the roll-front.

A. Omirgali discussed the “Actual Problems of Development and Carrying out of Repair and Restoration Works of Underground Uranium Leaching Wells”. The issues discussed were the complex problems of well development at the stage of their construction, ERW, and the ways of their solution, methods and technology. Also presented was an analysis of the causes of problems in well development. The talk

also introduced advanced technologies and methodologies to improve well productivity, both at the construction stage and at the stage of the ERW.

TRACK 9: THORIUM AND ASSOCIATED RESOURCES

H. Tulsidas talked about “Thorium as Nuclear Fuel: What, How and When?”. The presentation discussed the advantages and disadvantages of thorium as a nuclear fuel, the various ways of utilizing thorium as a nuclear fuel, research which has been ongoing for over 50 years, and the potential of thorium utilization in the future.

A. Hamed presented “Black Sand in Sudan for Economics Thorium Fuel Cycles”. The presentation is about the research project of the Sudan Mining Department on the potential use of the thorium fuel cycle by tracing alpha radiation emitted from isotopes of uranium and thorium found in the surface marine sediment on the Sudanese coast of the Red Sea at Port Sudan localities. The project also considers and evaluates the potential benefits that the thorium fuel cycle may offer as an alternative to the existing uranium fuel cycle.

J. Zhong described “Thorium Resources in China: Spatial Distribution, Genetic Type and Geological Characteristics”. The presentation highlighted that thorium deposits in China are mostly concentrated in the northern margin of the North China Craton, the Central Asian Orogenic Belt, South China and the Mian’ning-Dechang metallogenic belt; and the major Th mineral systems recognized in China are magmatic, hydrothermal and placer genetic types. The unique characteristics of these genetic types were described.

R. Hazan discussed the “Effect of Caustic Soda Fusion Temperature on Malaysian Xenotime”. The presentation described an alkaline fusion method for the preparation of waste arising from thorium and rare earth element extraction. It was demonstrated that, with this method it was possible to extract almost 90% of the thorium, rare earths and phosphate in xenotime.

CLOSING SESSION

A. Boytsov discussed “Sustainable Development of Uranium Production: Status, Prospects, Challenges”. The presentation aimed to answer the question “Are uranium resources and mining capacities sufficient to meet future long-term NPP requirements?” It was highlighted that, despite depressed market, uranium production continued to grow steadily during the last decade and reached a historical maximum of 62 ktU in 2016, although this dropped back to 59 ktU in 2017. It was pointed out that Kazakhstan provided the major input in the last decade; its share was 40% of the world total in 2017, followed by Canada’s 22% share. It was stressed that, because in situ leach is the main uranium mining method, uranium companies may face economic and technical challenges in new ISR projects development due to higher costs and resources availability.

A. Hanly talked about “World Uranium Resources and Production”. It was pointed out that the need for a long-term view on uranium resources and supply was recognized early in the development of the civilian nuclear power sector. It was highlighted that, over the course of its history, the IAEA-OECD/NEA publication, “Uranium Resources, Production and Demand”, also known informally as the “Red Book” has become recognized as an authoritative source of government-sponsored information on the uranium industry. The Red Book summarizes information from more than 100 countries, analysing the evolution of the market and developing conclusions about the evolution of the global uranium resource base, mine production and uranium demand.

S. Gorlin presented a paper entitled “Harmony — the Future of Electricity and Nuclear Delivering its Potential”. Arguments were presented that ‘Harmony’ is the nuclear industry's vision for the future of electricity and sets the goal of building 1000 GWe of new capacity and providing 25% of global electricity in 2050. The presentation then explored possible answers to the question “What might be the consequences for fuel supply of such a nuclear programme?”

M. Cuney (Symposium Chair) gave his Closing Remarks.

C. Xerri (Director of NEFW) delivered his closing remarks. He thanked all participants for their contribution and active participation in the Conference. He noticed the lively discussion that took place in the last session. He reminded that many countries in the world have or are developing a nuclear power program, and that nuclear power is an energy that can contribute to achieve the SDGs, address climate change and carbon emission reduction. Thus, nuclear power is here for a long time, counting in decades, if not centuries (a power plant planned today is designed to operate for anything between 60 to 80 years). In addition, uranium should be available to fuel these reactors, at least until a full closed cycle is implemented worldwide with technologies such as fast neutron reactors — something which will also take several decades. He took note of the different views on short term and medium trends of the uranium market discussed during the conference. He highlighted that a common conclusion was that discovering and bringing a deposit to mining takes more than a decade; in this respect, it was important to maintain exploration efforts. He also gave appreciation for the many Member States which are building capacity, revising or developing their general mining and uranium specific regulation and framework to be ready to become an exploration and production country when the market will pick up. He also mentioned the scientific and technology innovations that are taking place. Finally, he reiterated the importance that IAEA is giving to uranium and ensured continuous support to all Member States.

OPENING SESSION

WELCOME ADDRESS AND OPENING REMARKS

Y. AMANO
Director General
International Atomic Energy Agency (IAEA)

Uranium is the principal fuel used in nuclear power, a key low-carbon technology for generating electricity. There are presently 450 nuclear power reactors in operation in 30 countries, generating 11% of the world's electricity. Global nuclear power capacity is likely to increase by 2030, according to IAEA projections, although it remains to be seen whether this increase will be modest or substantial.

Estimates suggest that the world will have enough uranium for decades. But it is important that it is mined, produced and managed sustainably to avoid a shortfall. New generations of nuclear power reactors that require less uranium, including small, medium sized or modular reactors, will have a pivotal role to play in the sustainable management of this vital resource.

It is up to each country to decide whether or not to use nuclear power or to mine uranium. The IAEA does not attempt to influence their decision. But if countries opt for nuclear power or decide to explore the possibility of producing uranium, our job is to help them do so safely, securely and sustainably. Nuclear safety and security are also national responsibilities; the IAEA's job is to bring countries together to agree on international standards and learn from each other's experience. Through our advisory services, missions and expert advice, we help national authorities to ensure that uranium, throughout its entire life cycle, is handled safely and securely.

This symposium is the latest in a series of IAEA international uranium symposia and is the IAEA's premier event for discussion of a full range of issues associated with the Uranium Production Cycle, brings together experts and interested parties from many fields to discuss the latest research and current issues related to all aspects of the front end of the nuclear fuel cycle.

Starting with a consideration of the existing and expected future demand for mined uranium as a nuclear fuel, the symposium will hear speakers from around the world discuss technical, economic, environmental, safety and social aspects of exploration for and mining of uranium. This will cover the early aspects of exploration for uranium, geology and economic evaluation of deposits and different mining and processing methods. The planned and appropriate closure of mines and the remediation of historic, legacy sites will also be discussed.

Additional sessions will discuss the so-called unconventional resources of uranium, such as uranium associated with phosphate deposits or in seawater, as well as the potential additional nuclear fuel, thorium.

I draw your attention to a special uranium edition of the IAEA's flagship publication, the IAEA Bulletin, prepared to accompany this symposium, which is available electronically or as a hard copy.

I welcome you all to the URAM–2018 symposium, and wish you a fruitful time of learning, exchanging ideas and renewing or making new contacts in the field of uranium as a raw material for the nuclear fuel cycle.

OPENING REMARKS

M. CUNEY
Symposium Chairman
CNRS — Georesources
CNRS — Université de Lorraine

Mr Director General, Ladies and Gentlemen, Good Morning,

It is a great honour indeed to have the opportunity this morning to say a few words before starting this symposium.

First of all, on behalf of the Agency, I would like to express our great pleasure in giving all of you a warm welcome to the fourth URAM International Symposium in Vienna

I am particularly pleased to welcome all the delegates coming from abroad who have honoured us by taking part in this International Symposium to share their knowledge and experience and to explore new avenues for progressing in the development and management of the Raw Material for Nuclear Fuel Cycle, from Exploration to Mining, Production, Supply and Demand, Economics and Environmental Issues.

Thank you for coming. That so many of you travel long distances serves to remind us all just how important is the involvement of an increasing number of countries in the cycle of Raw Materials for nuclear fuel despite the difficult years we are experiencing since 2011 due to low U prices

I would like to take this opportunity to express particularly my deep appreciation for next five keynote speakers which have undertaken the challenging task of predicting the future of uranium:

- Mrs Olga Shorlyakova from the World Nuclear Assoc.: fuel report;
- Mrs Luminita Grancea from the OECD–NEA: Looking to the future of U;
- Mr Nicolas Carter from UX consulting comp: global fuel inventories & U prod;
- Mr Harikrishnan Tulsidas: from UNCE: Foundational Fuels of the 21st Century;
- Mr Alexander Boytsov: from Uranium One: on the development of its company.

A particular thanks goes:

- To the persons which have accepted to chair the sessions this Symposium;
- To the speakers;
- And to the presenters of posters.

The response to this Symposium internationally, has been tremendous. More than 200 papers have been submitted, these oral talks and posters will be presented during the next five days in front of nearly 300 participants from dozens of different countries.

This shows that the subject and the objectives are still of worldwide interest.

This Symposium will be also the occasion to present you a series of new publications achievements on the geology of U deposits:

— A Technical document on the UDEPO data base which have integrated now more than 3,000 U deposits worldwide;
— A Technical document on the new classification of U deposits;
— A Technical document on the “U Resources as Co- and By-products of Polymetallic, Base, Rare Earth and Precious Metal Ore Deposits";
— A new multi-layered World Map of Uranium deposits.

All these documents and can be freely downloaded on the Agency site.

I am certain that this meeting, in the presence of the qualified persons from international organizations, major and junior exploration companies, researchers from all over the world, will greatly contribute to the discovery of new deposits and to improve the ore deposit genetic and exploration models, processing techniques, and the management of the environment around the mines.

I hope you will have five productive days of interesting and stimulating discussions. I sincerely wish that this symposium will be a great success not only as a chance to share knowledge and experience but also as an opportunity to build stronger ties between specialists in different fields and from different countries with the beginning of new cooperation and friendship between you

And before I handover to Peter Woods, the Leader of the Team: Uranium Resources and Production of the Nuclear Fuel Cycle & Materials Section and the Co-scientific secretary of the 4th URAM Symposium, I want to say once more on behalf of the IAEA organizing committee, welcome. It's a pleasure to see so many of you here.

Thank you very much for your attention.

OPENING REMARKS

P. WOODS
IAEA
Scientific Secretary, URAM–2018

Distinguished guests, delegates, colleagues.

Let me add the IAEA Scientific Secretaries' welcome of to this URAM-2018 Symposium. We trust it will be a very worthwhile time for you all, both professionally and personally. Enjoy the sights, cultural attractions, food and drink of our marvellous host city of Vienna.

Immediately I want to acknowledge and thank my colleagues at the IAEA who have worked behind the scenes to make this meeting possible. Funding has been provided by the Departments of Nuclear Energy and Technical Cooperation to assist many of you to attend, and countless hours of organization by many IAEA colleagues have been necessary. I would like to particularly thank Ms Julie Zellinger of the Conference Services Section, without whom the symposium could not have taken place. Further, I acknowledge and thank the programme committee, including our chair and vice chair Mr Michel Cuney of France and Ms Olga Gorbatenko of Kazakhstan, and our returning cooperating organizations, the OECD Nuclear Energy Agency, the World Nuclear Association and the United Nations Economic Commission for Europe.

We will share much during the technical sessions. All speakers are reminded that English is a second or third language for many of our delegates. We should all therefore speak as clearly as possible, and not too fast. Also, time must be allowed to ask and answer questions, an important part of the value of the symposium. So please stick to your time allocated for speaking. Chairs have been asked to keep a close watch on the time of each talk.

Further to the spoken talks, please pay attention to the posters, and to the abstracts and extended abstracts that have been provided in electronic format only. Importantly, this is also a valuable time to network with your peers from all over the world. Make sure you take time to talk among yourselves during breaks, and do not be shy to introduce yourselves to any of your fellow experts gathered here. Many of the delegates will be pleased to exchange email addresses with you and may be able to correspond with you when you return home.

On behalf of the Scientific Secretaries, I welcome you again and wish you all a successful symposium.

WORLD NUCLEAR ASSOCIATION 2017 FUEL REPORT

O. SKORLYAKOVA
World Nuclear Association
London, United Kingdom

Abstract

The World Nuclear Association has published reports on nuclear fuel demand and supply at two-year intervals since 1975. The 2017 report is the 18th edition in the series and looks at scenarios for uranium demand and supply to 2035. 'The Nuclear Fuel Report' considers three scenarios (Lower, Reference and Upper); the projections are based on assumptions of electricity demand growth, nuclear economics, public acceptance, government policies and electricity market structure within each country. From 2000 until the Fukushima accident in March 2011, successive editions of The Nuclear Fuel Report projected increasing nuclear capacity. But since the Fukushima accident, the reports have reduced nuclear capacity projections year-on-year, with a corresponding reduction in uranium requirements. The extensive range of mining projects that were developed over 2000-2010 have largely fallen away in the light of historically low uranium prices. The World Nuclear Association believes that nuclear energy can make a greater contribution to clean and reliable electricity generation and presents a vision for the future, called 'Harmony'. In this vision, 25% of global electricity in 2050 would be provided by nuclear energy. We can be confident that sufficient uranium resources exist in the world to allow such a rapid expansion.

NUCLEAR ENERGY AND URANIUM: LOOKING TO THE FUTURE

L. GRANCEA
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Abstract

In recent years, nuclear power has continued to supply significant amounts of low carbon baseload electricity, despite strong competition from low cost fossil fuels and subsidised renewable energy sources. However, there is ongoing debate on the role that nuclear energy will play in meeting future energy requirements. Key factors that will influence future nuclear energy capacity include projected electricity demand, public acceptance of nuclear energy, proposed waste management strategies as well as the economic competitiveness of nuclear power plants. Concerns about the extent to which nuclear energy is viewed as being beneficial in meeting greenhouse gas reduction targets could contribute to even greater projected growth in uranium demand. Key issues in terms of nuclear market developments will be discussed in this presentation and how they could impact the broader nuclear and uranium industry.

THE IMPACT OF GLOBAL FUEL INVENTORIES ON FORWARD URANIUM PRODUCTION

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United States of America

1. INTRODUCTION

The March 2011 Fukushima accident has not only led to a significant reduction in global uranium demand, but it has resulted in the enormous growth of nuclear fuel inventories. Uranium producers have been unable to compete with the current situation of large and growing nuclear fuel inventories and have recently begun to curtail primary production as these low-cost inventories have pushed uranium prices to levels below the production cost of many uranium projects, making these projects uneconomic in the near- and medium-term.

2. DESCRIPTION

Global nuclear fuel inventories are held by numerous entities, including:

- End-user nuclear power utilities and their relevant nuclear fuel procurement/management subsidiaries;
- Suppliers throughout the supply chain, including uranium producers, converters, enrichers, fabricators, and even reprocessors and mixed-oxide (MOX) fuel fabricators;
- Investors, traders, and financial institutions, as well as other non-end users;
- Governments that have historically been involved in the production of nuclear fuel for both civilian and military applications.

Among global utility inventories, UxC data shows that the desired level for 2017 was 392 Mlb U_3O_8e (150,769 tU), with actual inventories amounting to 759 million pounds U_3O_8e (291,923 tU), or an excess of 367 million pounds U_3O_8e (141,154 tU) [1]. The U.S. Energy Information Administration (EIA) reported in its 2016 Uranium Marketing Annual Report that U.S. utility inventories held nearly 129 million pounds U_3O_8e (49,615 tU) at the end of 2016, up 43% from 90 million pounds U_3O_8e (34,615 tU) in 2011 and 182% higher than the historical low of 46 million pounds U_3O_8e (17,692 tU) in 2003 [2]. The Euratom Supply Agency (ESA) shows that European Union (EU) utility inventories increased from 123 million pounds U_3O_8e (47,308 tU) in 2011 to a peak of 142 million pounds U_3O_8e (54,615 tU) in 2013, but have since decreased slightly to 134 million pounds U_3O_8e (51,538 tU) [3]. Interestingly, given numerous reactor closures since 2011, EU utilities now hold more inventories per reactor than just a few years ago. Given the highly uncertain situation regarding the future of reactor restarts in Japan, the question of the country's utility inventories has become even more important to the uranium market. UxC estimates that Japanese utility inventories total 126 million pounds U_3O_8e (48,462 tU), with very little consumed since 2011, and enough fuel to last most Japanese utilities through most of the next decade and some utilities even beyond 2030. UxC's Base Case reactor restart/operations forecast for Japan assumes that only 21 of 40 operable units will eventually restart [4].

China's three main utilities — China National Nuclear Corporation (CNNC), China General Nuclear Power Corporation (CGN), and State Power Investment Corporation (SPI) — are estimated to hold 450 million pounds U_3O_8e (173,077 tU) at the end of 2017, an increase of 151% compared to an estimated 179 million pounds U_3O_8e (68,846 tU) in 2011. Starting in 2010, the import of uranium supplies tripled, and net uranium imports have surpassed domestic uranium demand by a huge margin in every year since.

Supplier inventories have also built up inadvertently to the extent that global uranium demand has dropped off and utilities cancel out of previously contracted commitments. Traders hold inventories as well, although they do not produce or consume uranium. Since traders facilitate the flow of supply in

the market, in some cases with offtake agreements, they end up holding inventories. After Fukushima, traders also became heavily involved in mid-term contracting wherein they purchased low-priced spot uranium to hold in inventory for future delivery.

Another recent development stemming from the Fukushima accident and subsequent reactor shutdowns has been the use of excess SWU capacity to underfeed enrichment plants and/or re-enrich depleted tails to natural uranium. This underfeeding of enrichment plants has caused the demand for newly produced uranium to decline even further. Thus, enrichers have been "creating" or accumulating uranium inventories and have turned around and sold this excess uranium into the market. Additionally, depending on how enrichers elect to use their excess capacity, they can choose to build inventories in the form of enriched uranium product (EUP).

UxC estimates that inventories from all the world's suppliers, traders, and investor-related entities totalled ~231 million pounds U_3O_8e (88,846 tU) at the end of 2017, with this group holding 53 million pounds U_3O_8e (20,385 tU) more than it did in 2015.

Governments, including the U.S. and Russia, continue to hold uranium inventories for military purposes. Much of the uranium is held in the form of highly enriched uranium (HEU) contained in nuclear warheads and strategic stockpiles, which can enter the market if it is considered excess to national security interests. U.S. Government inventories, declared as excess or commercial, total ~145 million pounds U_3O_8e (55,769 tU), but its disposition of natural UF_6 and HEU inventories are expected to be largely completed by the end of this decade. The true wildcard going forward is the success of the U.S. Department of Energy's proposed tails re-enrichment program.

The Russian government is the holder of an estimated 368 million pounds U_3O_8e, (141,538 tU) although most of its material must undergo some type of processing to be utilised. A large portion of the inventory consists of depleted uranium. Furthermore, tails that are deemed suitable for re-enrichment have low assays, but with Russia's large excess enrichment capacity, the volume of re-enriched tails has increased since the Fukushima accident. Two other major components of Russia's inventory are slightly irradiated uranium and reprocessed uranium. Among the country's inventory that does not require further processing is primarily natural UF_6 stemming from the monitored inventory that became available following the end of the HEU Agreement.

3. DISCUSSION AND CONCLUSION

Although current inventory accumulation has taken several years to take shape, it has clearly become a major concern for market participants in the post-Fukushima environment. There is clearly no single opinion about the inventory situation, but most market participants agree that dealing with the growing level of inventories is crucial to rebalancing supply and demand fundamentals and creating a more sustainable future.

In early 2017, the world's largest producer Kazatomprom stated that it would reduce planned 2017 production in Kazakhstan by ~10%, noting that its decision "was based on the current glut of the uranium market [5]." And, in late 2017, Kazatomprom announced its intention to reduce further the Kazakh planned uranium production by 20% under Subsoil Use Contracts of Company enterprises for the 2018 through 2020 period, "in order to better align its output with demand [6]." More importantly, the cuts come to a country with the majority of its production in the lowest cost tier, with UxC showing a weighted average full cost of ~$15 per pound U_3O_8 across Kazakh operating uranium projects in 2016 [7].

Other producers have not been immune to the impact of inventories on the market. In November 2017, Cameco Corporation elected to suspend production from its low-cost McArthur River mine in Saskatchewan for a period of at least 10 months starting in January 2018 [8]. A primary driver in cutting production by ~16 million pounds U_3O_8 (6,154 tU) in 2018 was the fact that Cameco's inventory position had ballooned up to ~28 million pounds U_3O_8 (10,769 tU), which is nearly twice the level of its preferred 6-month inventory position. More than a year earlier, in April 2016, Cameco suspended production at its Rabbit Lake mine in Saskatchewan and began curtailing production at U.S. in-situ

recovery (ISR) operations, resulting in the aggregate decline of ~6 million pounds U_3O_8 (2,308 tU) per year [9].

In Africa, AREVA has reduced production from its two operating projects, SOMAIR and COMINAK, in Niger by 25% since 2015, citing difficult market conditions. Meanwhile, Paladin Energy adjusted its Langer Heinrich mine plan in August 2016, choosing to process stockpiled low and medium grade ores through 2019 and effectively shift higher-grade ore processing into later years when uranium prices may be higher [10]. Because of the change, Langer Heinrich production was about 1.6 million pounds U_3O_8 (615 tU) lower over the last year.

Going forward, the mostly likely scenario entails additional inventory growth in the near-term, followed by the gradual disposition of utility, supplier, and trader inventories, which cumulatively will be greater than any additional buying on the part of utilities or other market players in the post–2020 period. Inventories will displace primary uranium production on a larger basis, especially after 2020, and as such, they will continue to have a price suppressive effect on the uranium market as existing supply outweighs new demand for inventories. However, this situation should slowly dissipate by the late 2020s, especially with significant uranium resource depletion projected in the mid–2020s. Accordingly, any new production decisions within the next several years will likely be premature unless market fundamentals change significantly in that timeframe.

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FOUNDATIONAL FUELS OF THE 21ST CENTURY: EVOLVING SOCIOECONOMICS OF SUSTAINABLE ENERGY SYSTEMS

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Abstract

The last few years saw the end of the commodity super-cycle, the gradual fall in oil and gas prices, the carbon crunch and the wide-ranging revolution that is going on in technology, often termed Industry 4.0. Rapid digitisation, which is taking over all areas of the industry and society, including transportation, means that energy in general will be increasingly electric. How the electricity will be produced, stored, distributed and utilised will depend on the acceleration of this change and the bare realities of economics. Three fuels assume importance as foundational fuels in this scenario — natural gas, uranium and renewable resources. This paper will discuss the socioeconomics of energy transformation, the comparative advantages and disadvantages, especially focusing on the role of nuclear energy in the post Paris Agreement era.

URANIUM ONE DEVELOPMENT OUTLOOK

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Abstract

The Russian State Corporation Rosatom acquired Uranium One in 2010 to secure long- term uranium supply for its nuclear fuel cycle chain and consolidated on this basis high quality uranium assets in Kazakhstan and in other countries. Uranium One has increased annual production almost 5 times during the last 7 years and became the fourth largest global producer of uranium. It has a diversified production base in Kazakhstan and the USA and a development project in Tanzania. Known resources and mining capacities secure further sustainable uranium production growth at favourable market conditions. Through its shares in five joint ventures and six mines, Uranium One owns 20% of attributable uranium production and 17% of attributable resources in Kazakhstan, being the second after Kazatomprom and the first among foreign companies there. The designed production capacity of the six uranium mines is 12 kt U, half of which is attributable as Uranium One's share. The successful, innovative technical policy, in conjunction with the geologically and technically unique characteristics deposits, provide significant competitive advantage for Uranium One as the global company with the lowest cost uranium production.

CLOSING SESSION

SUSTAINABLE DEVELOPMENT OF URANIUM PRODUCTION: STATUS, PROSPECTS, CHALLENGES

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Recent WNA [1] and UxC [2] reports demonstrate similar approaches for uranium supply demand forecasts until 2035 in the reference case scenario. Both reports show uranium oversupply at least until 2023. About 10% of global requirements will be provided during this period from secondary sources. The share of the secondary sources will gradually decrease in time. Primary uranium has no alternatives in a long-term perspective. According to the WNA report, uranium production is expected to increase in about 40% by 2035. Primary uranium production from existing mines will decrease by 30% in 2035 due to resources depletion and mines closure, while new planned mines will only compensate exhausted mines capacities. Both reports show, that during 2023-2026 uranium demand may exceed supply and new prospective mines from so-called supply pipeline, which development is not yet confirmed by companies' plans, must start production during the next 10 years to fill the gap and ramp up to 30 ktU/y by 2035. Are uranium resources and mining capacities sufficient to meet future long-term NPP requirements?

Despite depressed market, uranium production continued to grow steadily during the last decade and reached 62 ktU in 2016, which was a historical maximum since 1983. However, in 2017 it dropped back to 59 ktU. Kazakhstan provided the major historical input, increased uranium production six times during the last decade and keeps the world leadership since 2009. Its share comprised 40% of the world total in 2017, followed by Canada with 22% share. Kazatomprom keeps leadership in companies ranking with 21% share, followed by Orano, Cameco (both 16%) and Rosatom (Uranium One + ARMZ) with 14% share.

In Situ Leach is the main uranium mining method. Its share in the world total production has increased from 20% in 2005 to 50% in 2016 and 2017. Kazakhstan contributed 40%, while five other ISL producing counties (Uzbekistan, Russia, USA, Australia, China) - 10% of the world total. ISL mining capacities will start to decline after 2028 and production from low cost ISL mines will sharply decline starting from 2022 due to resources depletion, while higher cost ISL production may partly replace it and only until 2028 [3]. Thus, uranium companies may face economic and technical challenges in new ISR projects development due to higher costs and resources availability.

Statistics in ranking operating mines by costs and mining capacities show that 95% of mines with full cost below current spot price are located in Kazakhstan [3]. While keeping only 27% of total existing production capacities, they produce 40% of world total. All six Uranium One mines in Kazakhstan are in top 20 of low-cost mines and five of them are in top 5. Today is the era of Kazakhstan, however in the new mines supply pipeline there are only seven small new ISL mines, and only one of them in Kazakhstan.

Only 40% of 43 currently operating mines produce U at a cost below spot market price. That means than only companies with low cost production or favourable long term contracts may survive in current challenging uranium market. Low uranium prices do not boost production and force companies to stop, revise or defer their exploration and development projects. In addition to low U prices, companies face technical constraints, political, social and environmental factors. These risks hamper development of several world-class uranium projects in Canada, Australia, Africa, Russia and other countries. Kazakhstan has recently announced that production will be about 20% below 2018 contracts requirements, whilst Cameco announced that mining at the McArthur River mine will cease in 2018. This may result in further decrease in uranium production in 2018 by at least 10%. However, the companies do not refuse from new mining projects, but focus more on their optimisation and effective

technologies development.

Reliable and low cost uranium resources is a key factor for sustainable long-term production development. Global uranium resources are more than sufficient to ensure the long-term needs of nuclear industry. At the same time, the great share of resources belong to high cost categories and after 2020 uranium producers may face the shortage of low cost resources [4]. During the last decade the total global known uranium resources increased by 21%, however resources in low cost category <80$/kgU decreased by 48%.

Kazakhstan is currently a world leader in uranium production, but it may also face all above-mentioned challenges in future. Kazakhstan U resources amounted to about 1 MtU in 2015 [4], 70% of which are in low cost sandstone type, amenable for ISL. Remaining resources belong to lignite, vein and phosphate types. However, 95% of ISL amenable resources belong to operating and under construction mines. Kazakhstan plans to maintain current annual uranium mining capacities at a level of 65Mlbs until 2020, however actual uranium production during this period may be below capacities from 10 to 20% due to unfavourable uranium market. After 2020, Kazakhstan may face a gradual decrease in uranium production by 40% in 2030 and by 70% in 2035 due to resource depletion and old mines closing. In order to extend existing mining capacities for a long-term period, new uranium mines must start operation during the next five years, but potential for stand by uranium deposits development is limited.

The history of uranium discoveries in Kazakhstan shows that almost all deposits in Kazakhstan for ISL mining had a significant initial huge resource base (1,238 MtU), which was identified between 1970 and 1990. Uranium exploration during the last decade was focused more on prognosticated resources conversion into measured and indicated categories. The exploration potential to discover new large uranium deposits amenable for ISR mining within the largest uranium provinces in Kazakhstan is far from being exhausted. Favourable transparent legislation must facilitate investments in uranium exploration, when the investor has a State guarantee to mine discovered resources and possess produced uranium under strict compliance with established national standards and regulations.

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WORLD URANIUM RESOURCES AND PRODUCTION

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Abstract

The need for a long-term view on uranium resources and supply was recognised early in the development of the civilian nuclear power sector. In 1965, a working group was formed to compile worldwide uranium resource estimates by the precursor to the Nuclear Energy Agency, and in co-operation with the International Atomic Energy Agency since the mid-1980s this group has been producing reports on global uranium supply and demand, currently every two years ('Red Book'). Over the course of its history, the Red Book has become recognised as an authoritative source of government-sponsored information on the uranium industry. More than 100 countries have contributed data to the 26 editions published to date. The Red Book summarises information from various countries, analysing the evolution of the market and developing conclusions about the evolution of the global uranium resource base, mine production and uranium demand.

HARMONY — THE FUTURE OF ELECTRICITY AND NUCLEAR DELIVERING ITS POTENTIAL

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Abstract

Nuclear power is in demand globally and growing at its fastest rate in 25 years, with new countries and new designs coming online for the first time. However, to meet climate and development goals nuclear must grow faster still. Harmony is the nuclear industry's vision for the future of electricity and sets the goal of building 1000 GWe of new capacity and providing 25% of global electricity in 2050. What might be the consequences for fuel supply of such a nuclear programme? The 1250 GWe of nuclear capacity envisaged in 2050 would require about 200,000 tU annually, assuming similar fuel efficiencies to current reactors, and it would require nearly 4.5 million tU of cumulative consumption up to 2050. Sufficient uranium resources exist in the world to allow such a rapid expansion: the 2016 edition of the 'Red Book' identifies over 10 million tU of conventional and unconventional resources. More could undoubtedly be discovered with scaled-up exploration programmes. Of course, a very rapid expansion of the mining sector would also be needed to supply such an industry.

CLOSING REMARKS

M. CUNEY
Symposium Chairman
France

Thank you, distinguished delegates, Ladies and Gentlemen. It has been a great pleasure to see such a sustained level of focus and energy from such a large group where we have over 200 registered participants. With about 24% women we have make another effort to have a little more next time. Participants were from 64 countries and four international organizations, and more than 200 papers have been submitted, despite all this activity, despite the up-turn we have seen of oil industry, and because of the strong decrease of uranium prices, which has induced a strong decrease in the exploration expenditure. However, the interest on the raw material cycle has remained very high as we have seen in the last four days. It has been already said we have only a few people attending from the mining companies, also from the utilities. But these directly reflect the state of the uranium market. However, even for example non-conventional resources such as seawater, with the presentation, there were 4 in 2014; phosphate-black shale and also thorium have been considered.

First of all, I would like to thank the moderator for the excellent management of the sessions and, of course, it is relatively difficult to summarize these two days of conference in a few minutes; and in fact you have all the extended abstracts on the USB key, and very soon I think the presentations will be available on the web. I've seen that the majority of the speakers have allowed us to release their presentation. Therefore, I will take these few minutes to reflect what we have seen in the past five days and after this, it is my utmost pleasure to conclude this conference by recalling first the objective of this five days symposium. It was intended to cover the following aspect of the uranium raw material cycle — exploration, mining, correction, supply and demand, economics and other aspects. We have largely covered all these aspects by the presentations, with some additional few on the Uranium newcomers, presentations on thorium resources, some presentations on capacity building and training. Then concerning the main outputs, we have nearly 40 papers on the geology of uranium deposits as for example sandstone hosted uranium deposits (and associated ISL technology), the cheapest deposit to mine presently, and represented by far the major contribution of the symposium. This was followed by unconformity type deposits, which are the richest ones in the world and also some granite related deposit mainly from China and Argentina, and a series of other deposit types which have been the subject of a few presentations. We may regret that another major deposit type, the Iron oxide copper gold deposit, has not been quite widely considered — that is a challenge. I can also just remark that we had few presentations on the sodium metasomatic related deposit; but in my opinion, while they have not been sufficiently explored in the world, they are not so easy to discover because we do not have a strong clay alteration associated. I think there is probably a great potential to discover more but, unfortunately, they are not in the low-cost category for the present time; but we have to keep a looking.

Then, the next big contribution is on ore processing technologies where there were about 48 papers and the third largest contribution is on environmental, social and security aspect which are, all we know, of extreme importance, especially for public acceptance of our projects. We saw only few papers on exploration techniques — not so much, but it reflects on the uranium market. But what was very nice, we have a really impressive contribution on potential modelling of uranium resources which is further outlined I think in the TecDoc which has been coordinated by IAEA and which has brought really a new contribution to this symposium compared to the previous URAM ones. Then, we have heard a series of papers on the global

resource evaluation at the scale of countries like Greenland, Saudi Arabia, Nigeria, Madagascar and so on; I will not cover all the countries. Then we have had a session on the future development of uranium requirements, which was not always the most attended one. The 'spice' is always prediction and predictions are generally always wrong and we hope that some not so nice predictions will be wrong. Then, we had a contribution on the economic aspect of the uranium raw material cycle and then a series of presentations on the activities of the Agency about UPC projects related to the publication of a series of books and maps.

There has been a great deal of clarification on many issues during discussions that have taken place. This debate was extremely interesting and has shown what are the main points that people have in mind and I think one of the big issues, the key message was the projection of the uranium prices in the future and apparently the low oil prices which may stay for some time, maybe until the next URAM meeting. But we have seen that, when we see the projections from the electric utility point of view, maybe we have a more brighter future; but we have a great need to bring the messages to our colleagues, neighbours, all the people we know to change the image that nuclear energy has. We are faced with an extremely challenging contradiction between the policies for the so-called renewable energy which is intended to cover all the needs in the future. But this energy also needs the huge extraction of rare metals in the world, but it is not so much considered. Two of the presentations that we have seen discuss that this green energy will not meet the objectives we have in 2030 or 2050 for the reduction of the greenhouse gases and we have to change the weak support we have now for nuclear energy. Therefore, for the next URAM, there are a series of points I would suggest. We have had some proposals during this panel discussion that we have to look to more advanced techniques to cut costs in uranium mining and processing and also for the waste storage, which may help to maintain low production cost. We have to also continue to look at sustainable mining, for example, the uranium and other metals which are left as a waste of some polymetallic deposit like Olympic Dam and other new deposits which will come in for production that does not intend to extract the uranium. Maybe this has to be related to regulations that encourage comprehensive extraction and not to leave rare earth elements and thorium, etc. We could look at suggestions to recover other resources which are associated to uranium production like vanadium, radium, Scandium and other metals, and this also has to probably go for regulation. The next big challenge, which has been widely discussed, is public perception of nuclear energy; we have to look for ways for more efficient transmission to the public of the advantages of nuclear energy with respect to other energy resources. This is a major challenge and I don't know what is the policy of the Agency, but I am surprised that for this closing session we have no media, no press to show them what are our conclusions, what are our capabilities. I think it will be good to may be engage a little more with the media. We have moved beyond an earlier time when everything was secret but people extrapolated it and now uranium is still something mysterious.

In conclusion, despite a prolonged downturn in the market price of uranium, which has led to several mines and advanced projects going into 'care and maintenance', and a slow-down of exploration, the demand for uranium as a nuclear fuel remains steady. The current oversupply situation is expected to remain for a few more years, but in the medium to long term new mining projects will need to be brought into production. Although sufficient uranium is discovered to cover nuclear fuel requirements for many decades, the time and effort to bring new projects into production is considerable, and to avoid any possible future shortage of supply, exploration, feasibility studies and licensing activities need to continue through this period of low uranium prices.

With all this in mind, I would sincerely thank all the speakers and poster presenters and participants of this conference for their essential contribution to the success of this event and I hope that this conference will contribute to the success in mastering the challenges in exploration. I would also like to recognize contributors who have prepared a truly impressive set up for the poster presentation. Finally, I would express my great appreciation again to the conference co-organiser and particularly the IAEA staff and the people we don't see here, but who are behind and preparing everything (I don't have all the names but they will recognize themselves) and who have worked so hard to put this meeting together and to bring us to this point. On that note, I wish you a great week and a safe journey home and I think that, despite the many bad news, we had at least two contributions which speak about a much brighter future for Uranium. Thank you very much!

IAEA'S CLOSING REMARKS

C. XERRI
Director, IAEA
Division of the Nuclear Fuel Cycle and Waste Technology

Thank you very much. So, thank you for all Committee members for your strong support and special thanks also to the invited speakers and to all chairmen of different sessions, and that's an additional responsibility for which we are very grateful.

One of the things that we are always looking at, when organizing a conference, is diversity. - diversity in terms of gender and diversity in terms of all five continents which are represented and were represented both in terms of participation and also in terms of papers. It's important that young scientist, young geologists and young engineers have the opportunity to benefit from the information exchange we have here. I think that here were some participants who made their first international presentation and we are happy to have been able to provide them this opportunity. And, certainly, ensuring diversification in age is also something which is important for us. We can certainly to be positive and assertive on what nuclear energy is bringing to the climate, to energy security and to energy needs. When we're talking about nuclear energy, the nuclear power plants that we, or rather some of your countries, are setting up today will be running beyond 2080. So indeed, in a decimal system, we need milestones 2025 and 2050; and we certainly need to address the problem of the day, that is: shall we look beyond 2050? If you think firstly that nuclear energy is an important solution for the future, it won't stop at 2050, and second because all the reactors with a capacity close to 1000 Giga watts that you expect to be there by 2050, we'll see, will still be there in 2100.

Redbook is one of the flagship things we do and I want to remind that we do it with OECD and NEA. If you could encourage everybody to report, that would be helpful for the future of the Redbook.

It was mentioned that supporting sustainability and rehabilitation is important - we are doing it. We do encourage everyone, as it was said, before even starting to consider to make the first recovery of uranium from the ground, you already have a plan for any remediation for waste management.

We certainly want to keep on providing support and services to you, obviously some technical publications that we will keep on doing and certainly capacity building. I heard that we're doing a good job and I'm happy for that. We should do an even better job. We're supporting countries that want to develop and there are milestone documents on which we are working for your easement. It's something that is coming from the ground, discussing with some of you here and some of your government, and our colleagues in the technical corporation, that there is a need to support for this type work. What you could do and what you could get organized and structured, when you want to move on a project or when you have a project with some government maintenance and you want to restart it.

I want to take this opportunity to commend the work which has been done in that last 3–4 years on the UDEPO and the thorium database. I say we can do it better; we can increase the number of information in it; we can have better quality information, we can have better visualization of information and Martin did good work for that but fortunately he was not alone. I know that many of you in this room were strong contributors, strong supporters and I would also like to

thank all of you for that. We do recognize that when there is a boom everybody has plenty of money to do plenty of things; and we do recognise that the Agency has a role to play in terms of sustainability and in terms of being a repository of information which may be lost because of the downturn and also supporting Member States and Organizations to be ready for the next step. It was encouraging to listen to many presentations where we see what is happening or ready. It's encouraging to see that many of your countries, where you're not already engaged in mining, are also preparing the regulatory framework, mining aspects and all that in this respect and we will be happy to support that even more if we can.

Another keyword I heard is innovation. I think innovation is a driver everywhere, as much in exploration and mining as in anything else. We have a tool called Coordinated Research Project, and yes, I think we had the first CRP for a while in uranium If you think that there are things which could benefit from this type of coordinated research project, we would be very happy to speak to you.

As a last thing that I wanted to mention as part of this conference, we hope this conference has been for all of you not only an occasion to learn a lot of things and to see a lot of things but also to strengthen or develop new relationships. Networking is important and we hope that it is an additional benefit. The last thing before closing, I just want to recognize two of the staff. The regular staff in the Agency is not very many, and within the Agency we have a strict policy of rotation every seven years; we have two staff that have interacted with you since close to seven years now and will leave us soon. One is Adrienne Hanly, who was being extremely effective in many respects, especially on the Redbook, and the other one is Peter Woods, and I suggest that we recognise their efforts.

I think that's all I wanted to say, except, thank you very much again.

SUPPLEMENTARY FILES

The on-line supplementary files for this publication can be found on its individual web page at www.iaea.org/publications.

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No. 26

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