ALTA 2018
19 - 26 May
Perth, Australia

23rd Annual Conference Proceedings

Uranium-REE-Lithium Conference

Including

Lithium Processing Forum

Sponsored by

OLI systems, inc.

14th Annual Uranium Event

ALTA Metallurgical Services, Melbourne, Australia

www.altamet.com.au

PROCEEDINGS OF
ALTA 2018 URANIUM-REE-LITHIUM SESSIONS

Including

Lithium Processing Forum

24-25 May 2018

Perth, Australia

ISBN: 978-0-9946425-3-0

Celebrating 32 years of service to the global mining and metallurgical industry.

ALTA Metallurgical Services was established by metallurgical consultant **Alan Taylor** in 1985, to serve the worldwide mining, minerals and metallurgical industries.

Consulting: High level metallurgical and project development consulting.

Conferences: ALTA conferences are established major events on the international metallurgical industry calendar. The event is held annually in Perth, Australia. The event comprises three conferences: Nickel-Cobalt-Copper, Uranium-REE-Lithium and Gold-PM.

Short Courses: Technical Short Courses are presented by Alan Taylor, Managing Director.

Publications: Sales of proceedings from ALTA Conferences, Seminars and Short Courses.

MetBytes: Free technical articles offering metallurgical commentary and insights.

Free Library: Conference proceedings and technical papers. The library is expanded regularly, providing a major ongoing resource to the industry.

ALTA Metallurgical Services PO Box 1211, Blackburn North, Vic, 3130, Australia

T: +61 (0)411 692 442 | www.altamet.com.au

Uranium-REE-Lithium Opening Address

THE CHALLENGES OF OPERATING A URANIUM MILL IN THE MODERN ERA

By

Dr Brett Moldovan
International Atomic Energy Agency (IAEA), Austria
B.Moldovan@iaea.org

ABSTRACT

The share of nuclear generation in global electricity supply is currently about 10%, down from a peak of about 17% in 1996. One contributing factor to the decline in the percentage of nuclear power generation globally was response to the 2011 Fukushima Daiichi accident in Japan where all 52 nuclear reactors were shut down. The reduction in nuclear power generation combined with uncertainty regarding the long-term sustainability of the nuclear power industry caused the uranium spot price to fall from about $US22.50/kg U_3O_8 in February 2011 to its current price of about $US10/kg U_3O_8. In addition, the reduction in global nuclear power reduction has resulted in an over-supply scenario with respect to uranium ore concentrate inventories and this has further contributed to the downward pressure on the uranium spot price over the past six years. The sustained low uranium spot price has put significant pressure on primary uranium production operators and several have been operating in a negative cash flow situation. As a result, several of these operators have been forced to place their uranium mines and milling facilities into care and maintenance.

The IAEA has identified that the demand for electricity globally is expected to continue to grow, in particular in developing countries. As a result, the global total electrical generating capacity is forecast to increase from 6,671 GW(e) in 2016 to 9,826 GW(e) by 2030 and to 12,908 GW(e) by 2050. Based on the IAEA forecasts, the share of nuclear generating capacity in the global total electrical capacity will be about 3% in the low scenario and about 6.8% in the high scenario by 2050.

The forecasts indicate positive growth for the nuclear industry for the medium to long term. However, when looking at the historical spot price trends for uranium, the peaks in the spot price have been relatively short lived and the valleys have been unfortunately long-lived. Primary producers of uranium ore concentrate must continuously look for innovation, optimization and collaboration with operational peers and researchers in order to make uranium mills profitable during times of extended low uranium spot pricing. This presentation will focus on key aspects that uranium producers should consider as they look to advance innovation, improve efficiencies and ultimately reduce unit operating costs, whilst maintaining safety performance and high environmental and social standards.

Keywords: Nuclear Power Forecast, Uranium Spot Price, Innovation, Optimization

Presentation Outline

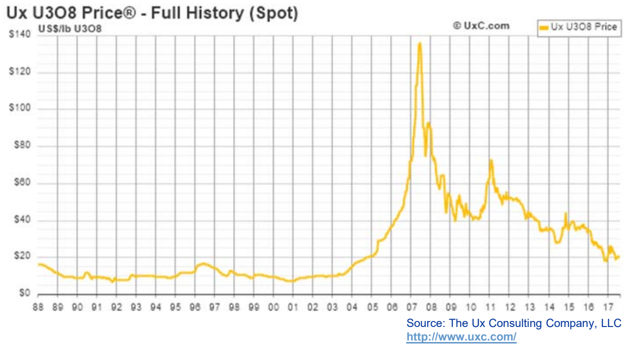
- IAEA global economic overview of the uranium industry
- UN sustainable development goals
- Measures of success in a uranium mining company
- Role and contributions of a hydrometallurgist
- Summary

Global Uranium Industry

- Economic Challenges
- Stakeholder Expectations and Challenges
  - Safety (including radiation protection)
  - Environmental performance
  - Investment in communities
- Risk Mitigation
- Operational Opportunities

Complex and Diverse

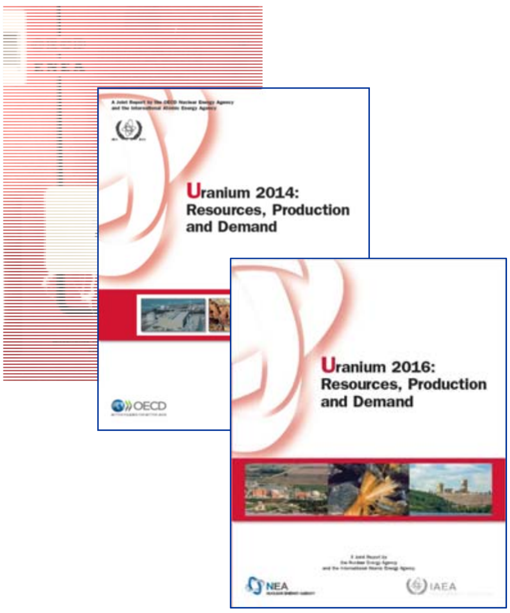
Historical Uranium Spot Price



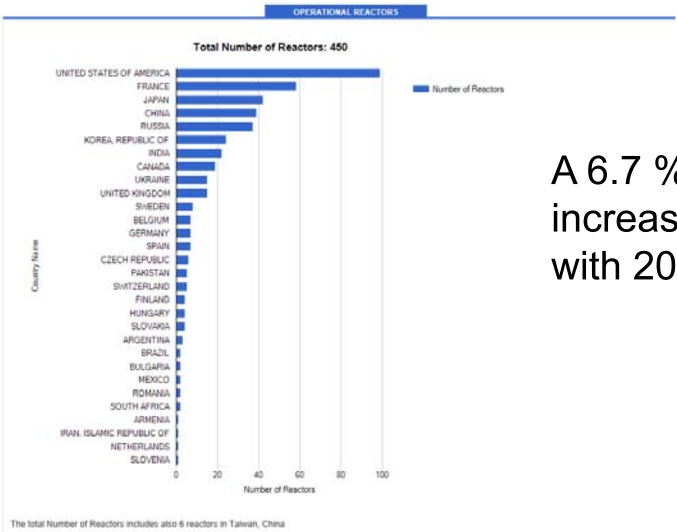
- Peaks are short lived and the valleys are long lived
- Operating costs on the rise: ever shrinking margins
- Pressure on operators – some have weathered the storm while others have not
- We are all here today because we believe in the industry
- Must look for efficiencies and innovation

Regular Biennial Publication: Uranium Resources, Supply and Demand ("RED BOOK")

- Published since 1965.
- A joint report by the OECD-NEA and the IAEA since 1969.
- The report has become widely recognized in the international nuclear community as a primary reference document on world uranium supply.
- Available as a PDF free of charge: http://www.oecd-nea.org/ndd/pubs/2016/7301-uranium-2016.pdf
- Sources: governmental reports (via questionnaire), Secretariat reports and estimates.
- Published in alternate years as WNA's Nuclear Fuel report
- Next edition Red Book (2018) in progress.



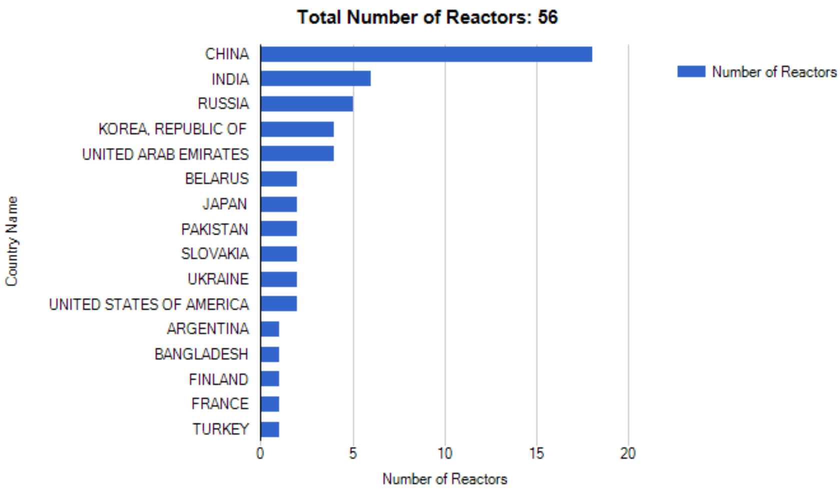
Currently 450 Reactors (393.8 Gwe)



A 6.7 % (24.6 Gwe) increase compared with 2004

IAEA PRIS database as of April 9, 2018

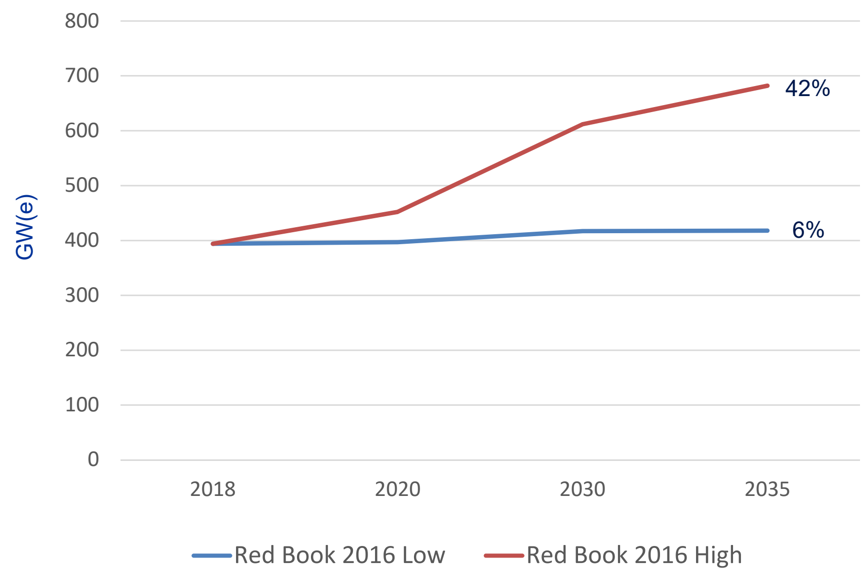
Under Construction- 56 Reactors (57.2 Gwe)



The total Number of Reactors includes also 2 reactors in Taiwan, China

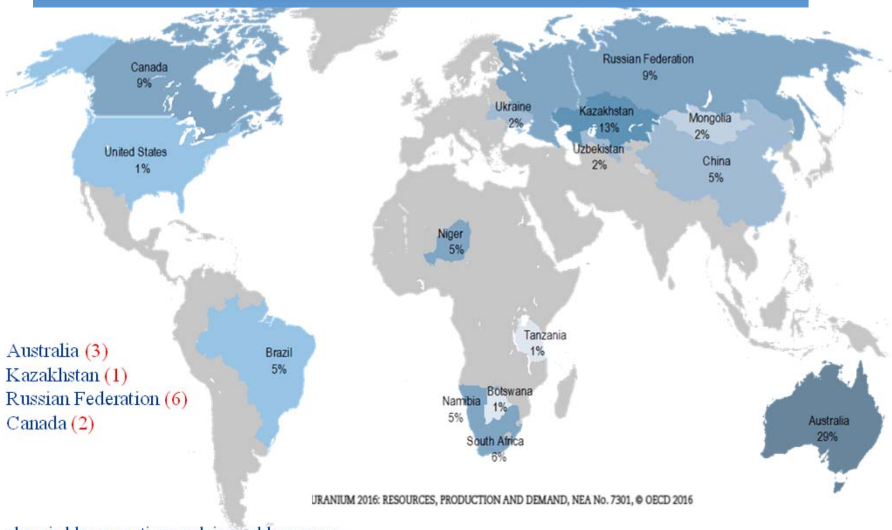
IAEA PRIS database as of April 9, 2018

World Nuclear Generating Capacity to 2035



Red Book 2016 – Distribution of Resources*

15 countries represent approx. 95% of total world U resources

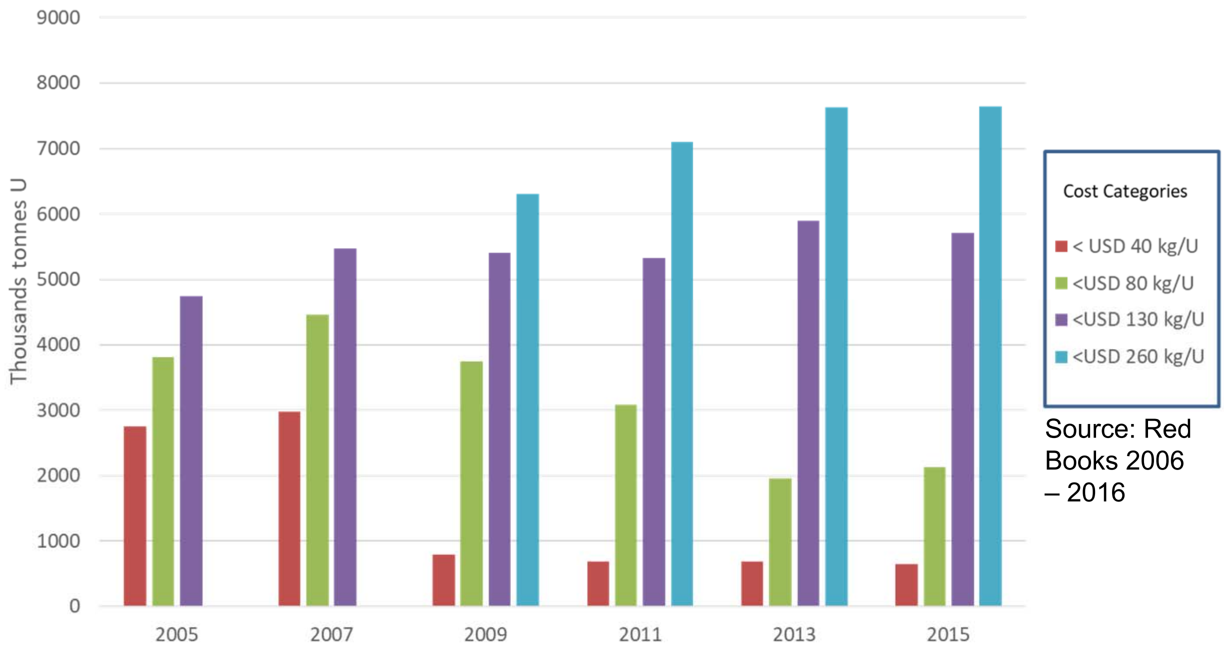


1. Australia (3)
2. Kazakhstan (1)
3. Russian Federation (6)
4. Canada (2)

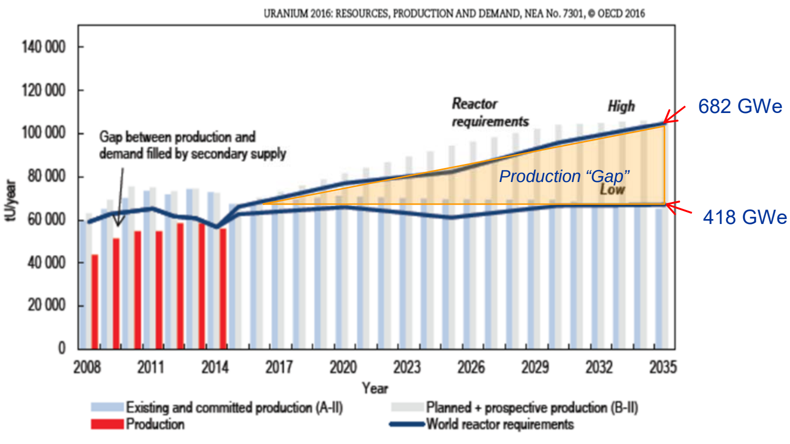
Note: numbers in blue are nations rank in world resources, those in red are the nations rank in world production.

*Identified Resources at <USD130 kg/U (as of January 1, 2015)

Red Book Identified Resources (2005 to 2015)



Uranium Production Capability vs Demand (from Red Book 2016)



* Includes all existing, committed, planned and prospective production centres supported by reasonably assured resources and inferred resources recoverable at a cost of <USD 130/kgU. Does not include the secondary supply forecast.

Key Messages

- Identified resources more than adequate to meet high case demand scenarios
- Investment and expertise required to bring resources into production*
- Production costs increasing*
- Long lead times owing to regulatory requirements and public resistance*

*Contributing to potential supply challenges over next 5-10 years

United Nations Sustainable Development Goals

"We are committed to achieving sustainable development in its three dimensions — economic, social and environmental — in a balanced and integrated manner" - Heads of 193 Countries

The IAEA and SDGs

- “Atoms for Peace and Development”
- The IAEA plays an active part in helping the international community achieve the 17 Sustainable Development Goals (SDGs). It helps countries to use nuclear and isotopic techniques and thereby contribute directly to attaining 9 of the 17 Goals
  - IAEA website https://www.iaea.org/about/overview/sustainable-development-goals-sdgs

The IAEA and SDGs (2)

- “Looking at the 17 goals, I am struck by the very close overlap with the work of the IAEA,” Mr Amano has said. “The new goals cover poverty, hunger, human health, clean water, affordable and clean energy, industry and innovation, and climate change, to name just a few. These are all areas in which nuclear science and technology have much to offer.”
- IAEA Director General Yukiya Amano https://www.iaea.org/newscenter/news/how-iaea-will-contribute-sustainable-development-goals

Uranium and the SDGs

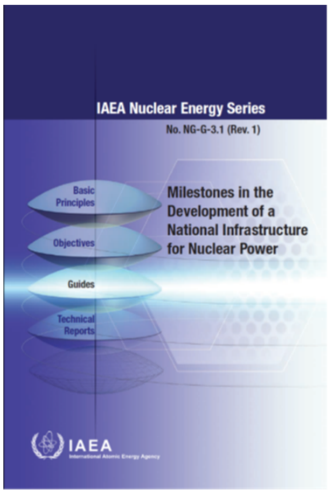
- The obvious linkage:
  - "Ensure access to affordable, reliable, sustainable and modern energy for all " and
  - "Take urgent action to combat climate change and its impacts ", by supplying fuel for low-carbon nuclear power
- But there could/should be contributions to:
  - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
  - Promote inclusive and sustainable economic growth, employment and decent work for all
- So long as uranium (and other mining) is implemented well, with proper social, health and environmental protections and appropriate wealth sharing
- Comprehensive extraction and zero waste (waste minimization) should be considered

Uranium Production Cycle "Milestones" Approach

- Following requests from Member States, the IAEA has started production of a guidance document to provide advice on a Milestones approach to responsibly entering (or re-entering) the Uranium Production Cycle
- The milestones approach in the uranium production cycle (title to be confirmed)
- Expert meetings in Vienna in Dec. 2016 and Sep. 2017
- Possible presentation at a Technical Meeting in 2018
- Publication planned for 2019

Nuclear Energy Milestones Document

- IAEA, Milestones in the Development of a National Infrastructure for Nuclear Power, IAEA NG-G-3.1 (Rev. 1) 2015
- IAEA, Specific Considerations and Milestones for a Research Reactor Project, IAEA NP-T-5.1, 2012
- There are 3 Phases:
  - Phase 1 – ready to make a knowledgeable commitment
  - Phase 2 – ready to invite bids
  - Phase 3 – ready to commission and operate



Uranium Production Cycle: Four Stages/Milestones

Kinniyai Beach, Sri Lanka; IAEA TC Project (photos courtesy Peter Woods)

Milestone 1. A MS considering exploration and/or mining for the first time, or the first time for many years, but with no current significant commitment to proceeding to mining and milling (e.g. Tunisia, Sri Lanka, Nigeria, Indonesia, Paraguay)

Uranium Production Cycle: Four Stages/Milestones

Jordan Uranium Deposit, 2017; IAEA TC Project
(Photo courtesy P. Woods, IAEA; Hussein Allaboun; GM JUMCO)

Mkuju Uranium Deposit, 2017 (Photos Courtesy Uranium One)

Milestone 2. A MS proposing to initiate or reinvigorate uranium mining, with known exploitable reserves (e.g. United Republic of Tanzania, Jordan, Botswana, Turkey, Greenland[1] and Mongolia)

Footnote: Greenland is part of the Kingdom of Denmark, which is an IAEA Member State.

Uranium Production Cycle: Four Stages/Milestones

Langer Heinrich Mine (Photo courtesy Paladin Resources)

Somair Open Pit Mine and Processing Facility (Niger)
(Photo courtesy of World Nuclear News)

Milestone 3. A MS with a long history of mining (and milling) uranium and wishing to enhance existing capacity and capability (e.g. Namibia, Niger and Brazil)

Uranium Production Cycle: Four Stages/Milestones

San Rafael Uranium Mining – Milling Complex
(Photo courtesy Luis Lopez, CNEA)

Rabbit Lake Mill (Photo courtesy Cameco Corporation)

Milestone 4. A MS with historic, closed uranium mines and mills, sites at the end of mining stage (decommissioning and closure), a remediation stage of historic mines and mills, or at a stage where mine sites are made safe but kept in a state for possible reopening in the future (e.g. Gabon, Argentina, Canada and Portugal).

Uranium Production Cycle: Four Stages/Milestones

MALARGÜE PROCESSING PLANT (Photo courtesy Luis Lopez, CNEA)

Milestone 4 (cont'd). A MS with historic, closed uranium mines and mills, sites at the end of mining stage (decommissioning and closure), a remediation stage of historic mines and mills, or at a stage where mine sites are made safe but kept in a state for possible reopening in the future (e.g. Gabon, Argentina, Canada and Portugal).

Aspects of Milestones

- National Position
- Legal Framework
- Stakeholder Involvement
- Safety and Radiation Protection
- Environmental Protection
- Protection/Enhancement of Cultural, Tourism, Farming, Pastoral and Similar Interests
- Management/Coordination/Facilitation

Aspects of Milestones (cont'd)

- Funding and Financing
- Safeguards and Security
- Transportation/Export Route
- Human Resource Development
- Site and Supporting Facilities (Infrastructure)
- Contingency Planning
- Waste (Including Tailings) Management and Minimization
- Industrial Involvement Including Procurement

Perspective from a Former Metallurgist and GM

Photo by Brett Moldovan

The next several slides are intended to provide information based on my personal experience and are not official IAEA Policy

Measures of Success in a Uranium Mining Company

Photo courtesy Orano Group

- Mature safety culture and strong safety performance (including radiation protection)
- Environmental stewardship
- Community and stakeholder support
- Strong financial performance

Role of a Hydrometallurgist


Photo courtesy Cameco Corporation

Goal is to maximize operational uptime and ensure safe steady state production at the lowest unit cost possible.

- Innovation - Continual Improvement
- Mill Process Optimization
- Cost Reduction
- Metallurgical Accounting
- Data Interpretation
- Training
- Research and Development
- Effluent Quality
- Tailings Geochemistry and Geotechnical Performance
- Project Management
- Life of Asset Planning
- Sustainable Development
- Maintenance Strategies

Existing Uranium Mills


Photo courtesy Paladin Resources


Photo courtesy ERA

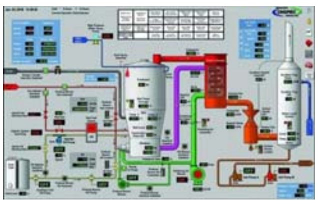
- Do not have the opportunity to do a clean sheet approach
- Corporate funds invested in capital must show a return on investment (ROI) – typically 3 year payback
- Must optimize what we have in place
  - Chemical optimization
  - Process optimization
  - Organization/Work Flow optimization

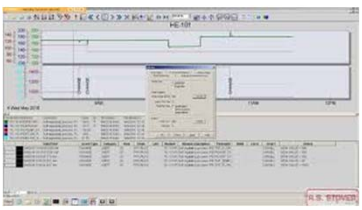
Chemical Optimization

Photos courtesy Cameco Corporation

- Look for opportunities to chemically optimize the process
- Eliminate upstream/downstream bottlenecks – improved unit throughput
- Reduce reagent consumption
- Reduced time to reach steady state production
- Keep operators involved and informed
- Example is Si reduction in pregnant aqueous feed
- ~$1M CDN/yr net savings in SX organic, acid and lime

Process Optimization



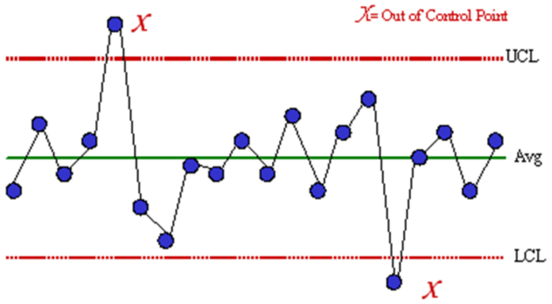


- Hydrometallurgists play a key role
- Significant opportunities for reagent reduction, improved process control and reduced operating costs
- May include fine tuning of instrumentation control loops
- May require additional instrumentation - justification
- Need to collaborate with instrumentation
- Must keep operations personnel involved – use tools of change management

Organizational Optimization

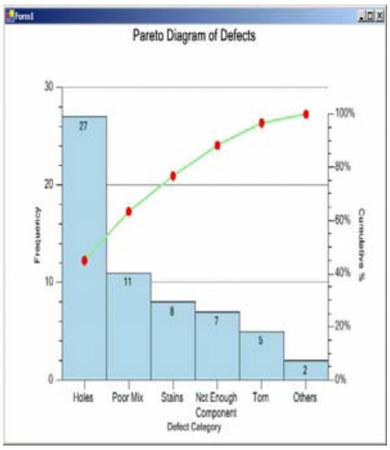
- Geology, mining, metallurgy, maintenance and operations must work together as a cohesive team
- Working in silos has shown to be ineffective
- Opportunity for metallurgy, maintenance and operations to report to the same functional manager should be considered
- Accountability based organization design with clear roles, responsibilities and interactions should be defined

Sustainability and Continual Improvement



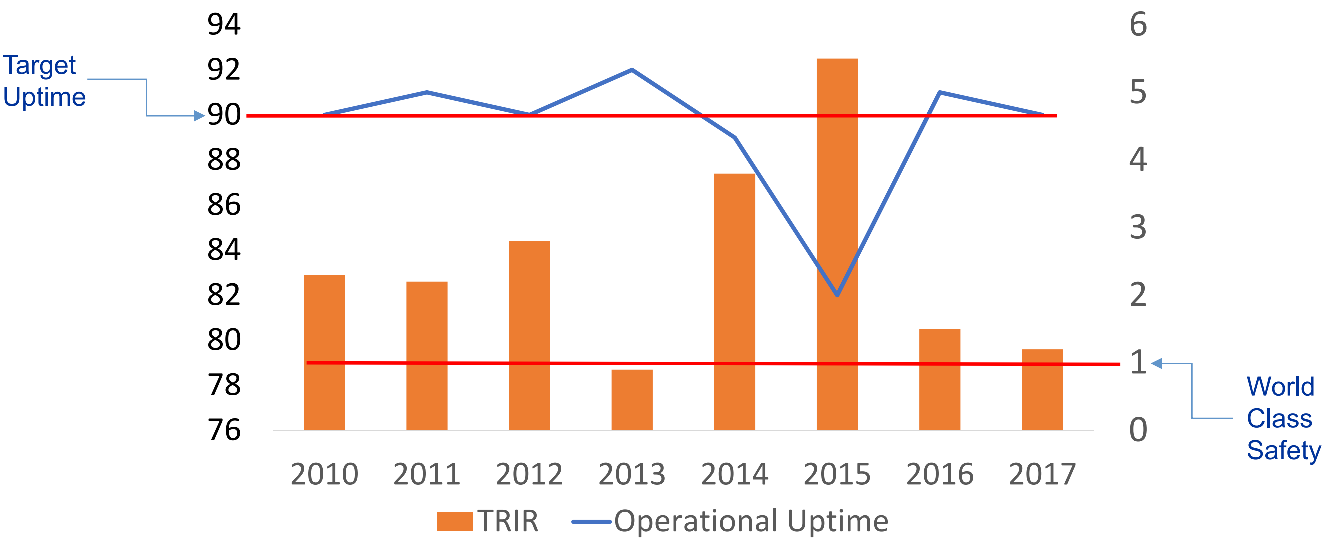
- Consider using statistical process control (SPC) to enhance sustainability and promote continual improvement
- "What gets measured gets managed"
- Define specific Key Point Indicators (KPI's) and measurement frequency
- Requires buy in and involvement of operations personnel
- A root cause reason should be identified for measurements outside of either upper or lower control limits

Sustainability and Continual Improvement



- A pareto chart should be created based on the outliers in the KPI control charts
- Data should be reviewed on a regular basis (e.g. daily/weekly) with manager, metallurgy, maintenance and operations
- Action plans with person responsible and deadline should be developed to eliminate out of control points
- Key point is continual improvement to reach sustained stable production

Operational Uptime vs Safety Performance



Steady state production can improve safety performance

R&D and Project Management

- Drive innovation and continual improvement to build competitive advantage
- Simplify the flowsheet
- Consider life cycle costs
- Consider upstream, downstream and environmental impacts
- Manage risk
- Involve operations, maintenance, environment, safety, radiation protection in process optimization

Rules of Thumb – Production Rate

- The production rate (scale of operations) proposed in a feasibility study should be approximately equal to that given by applying Taylor's Law

Taylor's Law (Taylor, H.K. Rates of Working of Mines – A Simple Rule of Thumb, IMM Transactions, Oct, 1986)

The optimum extraction rate = 5 x (expected reserves)$^{3/4}$ / (operating days per year)

In which "Expected Reserves" are generally interpreted to mean *proven + probable reserves*

Example:

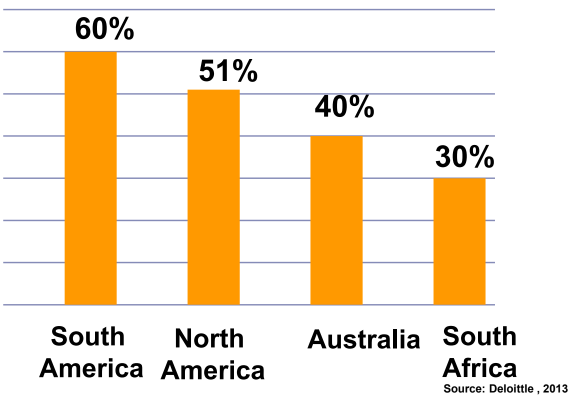
Facts:
1. Expected reserves = 450,000,000 lb
2. Mine five days/week and a three week maintenance S/D = 240 days/yr
3. Mill seven days/week at 90% plant availability and three a week maintenance S/D = 308 days/yr

Solution:
1. Mining rate = 64,400 lb/day or 29,200 kg/day
2. Milling rate = 50,200 lb/day or 22,800 kg/day

Life of Mine at this rate = 29 years

Project Management Challenges

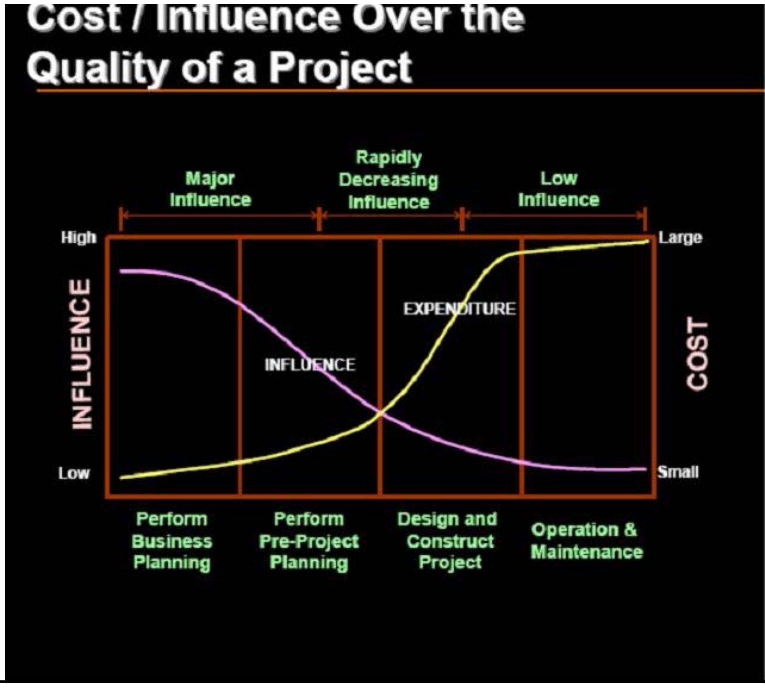
Estimated Average Percent Project Cost Overrun (By Region)



Some contributing factors

- Scope creep
- Lack of stakeholder involvement
- Ineffective testing up front – design errors
- Ineffective estimating
- Ineffective planning – procurement
- Ineffective management
- Unplanned conditions/conditions change

Project Influence



IAEA-TECDOC-885

TECDOC 885, 1996

'The search for a mineral commodity, uranium included, and its eventual production is basically an economic activity. A realistic assessment of the economic viability of a project, whether to fulfil domestic needs or to meet world demand, should therefore be carried out as early and as frequently as possible.'

Steps for preparing uranium production feasibility studies: A guidebook

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

Key Points

- Design and operate our uranium mills as economically and socially acceptable as possible
- Hydrometallurgists play a key role
- Metallurgy, operations and maintenance should report to the same line manager
- Keep the flowsheet as simple as possible
- Consider life cycle costs, safety, radiation and environmental performance in design
- Hydrometallurgy plays a key role in the sustainability of the industry
- Steady state production (metallurgy, operations, maintenance) = safe production

Acknowledgement and Disclaimer

- Although this presentation is based closely on official IAEA reports, the choice of themes to emphasize, the summarizing of the salient text, addition of some additional material and choice of references remain the responsibility of the author
- The permission of IAEA management to present this talk is appreciated
- Always refer to the IAEA website and formal IAEA publications for official information and positions

Further Reading – NEFW Technical Meetings

- IAEA Technical Meeting on Optimization of In Situ Leach (ISL) Uranium Mining Technology, Vienna, Austria, 15-18 April 2013 http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/uranium-production-cycle-tm-ISL-2013.html
- IAEA Training Meeting on Effective Regulatory and Environmental Management of Uranium Production, Darwin, Australia, 13-17 August 2012 https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/uranium-production-cycle-TR-Darwin-2012.html
- IAEA Technical meeting on the Uranium Production Cycle Pre-feasibility and Feasibility Assessment, Vienna, Austria, 7-10 October 2013, https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/uranium-production-cycle-tm-pre-fesibility-2013.html
- IAEA Technical Meeting on Public and Community Acceptability of Uranium Mining and Milling, Vienna, Austria, 8-11 December 2015 https://www.iaea.org/OurWork/ST/NE/NEFW/Meetings/2015/repository/2015-12-08-2015-12-11-TM-Public-Uranium.html
- For a fuller list, see https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/uranium-production-cycle_technical_meetings.html