OECD – Nuclear Energy Agency
Nuclear Fuel Cycle Resources and Raw Materials

Robert Vance
Nuclear Development Division
OECD Nuclear Energy Agency
Uranium Resources, Production and Demand - “Red Book”

Recognized source for global resource information

Longstanding OECD/NEA and IAEA cooperation - published every 2 years – a “snapshot’ of a dynamic system

Relies principally on input from country representatives nominated by governments to the Uranium Group
Uranium Group

Members officially nominated by government authority

~50 members from 30 countries

Wide range of expertise: from geologists to economists, miners and fuel buyers

Meets once a year, every second year meeting hosted by country with U production
Uranium Group history

Formed in the mid 1960s - OECD, European Nuclear Energy Agency

1991: former Eastern Block countries join

1996: International Atomic Energy Agency member states formally join; re-organized as the Joint OECD-NEA / IAEA Uranium Group

Red Book - first published in 1965; series a well documented history of resource and mine development, changing supply and demand situation

Recent meetings in U producing countries: 2000 Brazil; 2002 China; 2004 Czech Republic; 2006 Kazakhstan; 2008 Australia; 2010 Canada; 2012 Ukraine; 2014 Namibia (planned)

Follows OECD general objective of collective gain through sharing knowledge and experience
Red Book

Key messages in recent editions:

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*

*All could contribute to potential supply challenges over next 5-10 years
Red Book 2014

Time slice of a dynamic system – reference date 1 Jan 2013 – Red Book outlines situation based on available information on that date

New deposit classification scheme introduced

New figure for generic reactor fuel consumption in recognition of tails assay reduction at enrichment plants (163 tU/GWe/yr; previously 175 tU/GWe/yr)

Red Book to be released as PDF free of charge (English only)

Data collection only recently complete (leading to delay in publication) – 45 Country Reports plus summary Supply and Demand chapters – expected release in September 2014

A system for classifying both fossil energy and mineral resources the United Nations Framework Classification (UNFC) was “mapped” to existing Red Book system.

Can offer today a summary of Preliminary Results
<table>
<thead>
<tr>
<th>Recoverable at costs</th>
<th>Identified resources</th>
<th>Undiscovered resources</th>
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</thead>
<tbody>
<tr>
<td>USD 130-260/kgU</td>
<td>Reasonably assured resources</td>
<td>Inferred resources</td>
</tr>
<tr>
<td>USD 80-130/kgU</td>
<td>Reasonably assured resources</td>
<td>Inferred resources</td>
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<tr>
<td>USD 40-80/kgU</td>
<td>Reasonably assured resources</td>
<td>Inferred resources</td>
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<tr>
<td>&lt;USD 40/kgU</td>
<td>Reasonably assured resources</td>
<td>Inferred resources</td>
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</tbody>
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Decreasing confidence in estimates

Decreasing economic attractiveness

INPRO, 27 August 2014
Red Book – Resources

Trend in resource inventory over last three editions of Red Book- Total increasing along with increasing costs of production.
Red Book 2014 – Resources

Total identified resources (RAR + Inferred) have increased by 5 – 10% since 2011.

Overall significant reductions of low cost resource categories continues (<USD40 and <80/kgU = <USD15 and <30/lbU\textsubscript{3}O\textsubscript{8}).

2013 data shows significant movement from <USD80 to higher cost categories (<USD130 and 260/kgU = <USD50 and 100/lbU\textsubscript{3}O\textsubscript{8}).

Notable exception: Kazakhstan increased lowest cost resources (<USD40/kgU) almost doubled.
Red Book 2014 – Distribution of Identified Conventional Resources (RAR and Inferred)

15 countries represent approx. 97% of total world U resources (<USD 130/KgU)

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

Note: numbers in black show rank in world resources, those in red show rank in world production.

INPRO, 27 August 2014
Red Book 2014 - Production

Uranium production continued to increase in 2011 and 2012, although at a slower rate than 2009 and 2010.

2012 production >58 000 tU and in 2013 projected to increase once again.

Kazakhstan responsible for 36% of production in 2012 (production rate continuing to increase but not as rapidly as previous years).

Canada (15%) and Australia (12%) remain significant producers and production expected to increase in coming years.

ISL responsible for 45% of 2012 production and projected to increase to 50% of total production in 2013.
Red Book 2014 – Demand

Safety inspections after the Fukushima accident have delayed global development of nuclear power (notably in China where most significant growth is expected)

Increased safety requirements as a result of inspections have increased costs of nuclear power generation

Both low and high demand projections to 2035 were reduced from those in 2011 edition: the low demand scenario by 26% and the high demand scenario by 8%

Decline in low case principally due to strengthened phase-out policies in Europe, proposed capacity reduction in France and reduced prospects of additional life extensions to U.S. fleet

High case declines principally because of delay in development processes in China
Uranium Market

Since Fukushima, prices have declined owing to uncertainty on the future role of nuclear power.

Inventories building as a result of sudden German reactor closures and idling of all Japanese reactors.

Key to turn around: Japan begins re-starting reactors (2014?), but it will take time for the inventory to clear after re-starts.

Excess enrichment capacity encourages underfeeding of plants to build additional inventory…utilities reportedly well supplied.

The longer this goes on, the more challenging it gets for producers.

INPRO, 27 August 2014
Supply - Demand

Several mine development plans postponed due to low uranium prices post Fukushima (e.g. Trekkopje, Namibia; Imouraren, Niger; Millennium, Canada, etc)

Some projects still moving ahead (e.g. Cigar Lake, Canada and ISL in U.S.), including “non-market” based projects (e.g. Husab, Namibia)

72 reactors under construction and several more planned – growth in China and India expected to be significant – slumping demand expected to reverse and increase in coming years

How long until demand increases? – primarily dependent on return to service of reactors in Japan (how many and how quickly) but will take some time owing to inventory build-up in 2011 and 2012

Supply shortage unlikely – several projects in advanced stages of regulatory and mine development processes – ramping up production should take less time than usual
Red Book 2014 Conclusions

Identified resources 2013 already more than adequate to meet high case demand projections – in the new Red Book the high case demand projection scenario to 2035 requires only 40% of existing resource base

Mine developments delayed but several primed to meet any increase in demand after having passed significant development hurdles – waiting for appropriate market signal

Existing and committed mine development sufficient to meet projected low case demand to 2035; high case demand to 2023

Inclusion of planned and prospective production centers sufficient to meet high case demand scenario through 2033

Excess enrichment capacity (now all centrifuge) is creating inventory; operators are considering additional production from depleted U tails (a significant secondary source)
OECD-NEA uranium activities
Not just production, but how it is produced

- 1999: Environmental Activities in Uranium Mining and Milling
- 2002: Environmental Remediation of World Uranium Production Facilities
- 2014: Managing Environmental and Health Impacts of Uranium Mining

Lessons Learned

• Red Book Retrospective (2006):
  – Resources and mine development driven by uranium price
  – Typically considered scarce in face of increasing demand, but more than enough always identified
  – 1966: Global resource base of economic interest: 525 000 tU
  – Since then, > 2.5 million tU mined and identified global resources now >7 million tU
A Preliminary Assessment of Raw Material Requirements for Rapid Growth in Nuclear Generating Energy

• Pre-financial crisis – prospects for growth in nuclear generating capacity bright

• Identify any limits (nuclear fuel, materials for construction, operation and decommissioning of NPPs) arising from a rapid 10X expansion of nuclear energy

• Based on Environmental Product Declarations for NPPs – that include info on CO₂ and emissions, energy inputs

http://www.environdec.com
A Preliminary Assessment of Raw Material Requirements for Rapid Growth in Nuclear Generating Energy

- The declared unit is defined as 1 kWh net of electricity generated and thereafter distributed; Ringhals – Gen II (3 PWRs, 1 BWR)

- Additional data provided by Vattenfall for study on materials required in small amounts (not published in EPD report)

- Data divided into fuel cycle components (mining, conversion, enrichment, fuel fabrication, operation of NPP, construction and decommissioning of NPP, operation of waste facilities, construction and decommissioning of waste facilities)

Example - Fluorspar use in fuel cycle % of total amount; none used in enrichment, construction / decomm NPP, construction and decomm of waste facilities
A Preliminary Assessment of Raw Material Requirements for Rapid Growth in Nuclear Generating Energy

• Requirements defined in EDPs (scaled up overnight to hypothetical 10X expansion of nuclear generating capacity) compared to U.S. Geological Survey global reserve and resource estimates and production

• Current resource base adequate for all raw materials (requirements consume <2% of existing resource base)

• Current rates of production - only raw material in short supply – uranium (15 times increase required to meet rapid build-up requirements – once through fuel cycle); fuel requirements >650 000 tU/yr at 10X nuclear capacity 2085

• “Items of concern” (req. exceed 4% production) – bentonite (86%), fluorite/fluorspar (25%), indium (23%), magnesium (8%), zircon sand (7%) and gadolinium (4%)
A Preliminary Assessment of Raw Material Requirements for Rapid Growth in Nuclear Generating Energy

- Waste build up with exclusive once-through fuel cycle an issue
A Preliminary Assessment of Raw Material Requirements for Rapid Growth in Nuclear Generating Energy

- Conservative approach: overnight expansion - future requirements compared to current resource inventories (with no trade barriers, no increased competition from other uses)

- Raw material requirements for a Gen III, III+ and IV reactor fleet? Likely less, but uncertain – potential for use of materials not used in Gen II

- Economically driven exploration and production has worked in the past; in the future…?

- Fleet of nuclear generating capacity of the size assessed in this report unlikely in the aftermath of the Fukushima accident. A revolution in public acceptance required for all aspects of the nuclear fuel cycle