THE FUTURE OF NUCLEAR FUEL SUPPLY

Nikolaus Arnold, Klaus Gufler
Institute of Security/Safety and Risk Sciences
University of Natural Resources and Life Sciences, Vienna
Contents

- Status quo
  - Resource estimates
  - Uranium market
  - Production figures
  - Supply – demand relationship

- Uranium supply-scenarios
  - General findings from the reviewed publications
  - Details (quotes) from publications

- Kazakhstan

- Conclusions
Future of nuclear energy?

- An increase in global nuclear energy generation capacity is widely expected (even after the Fukushima accidents).
Nuclear fuel
Reactor types in operation and planned/under construction

➔ Uranium will stay the main nuclear fuel in the coming decades
Global uranium resources (as of 1-1-2013)

- 4 600 kt U Reasonably assured resources in all cost categories
- 7 600 kt U Identified resources in all cost categories
- Large share in few countries

Data: Uranium 2014: Resources, Production and Demand, OECD 2014, NEA No. 7209
Development of the resources base

Changes in the resource base and cost categories (1999 – 2011) (Data from the respective redbooks)
The uranium market

- Data: Cameco (http://www.cameco.com/invest/markets/uranium-price)

- March 2015
  - Longterm 109$/kg
  - Spot 85$/kg

- Minimum - Mid 2014
  - Longterm 97$/kg
  - Spot 62 $/kg

- low prices after the end of the cold war

- "Uranium bubble"
  - Fukushima
  - reduced nuclear growth expectations
  - reduced demand
Uranium production 2013

- Almost 60 kt U produced
- ~ 1.8% increase to 2012
- Largest producers 2013 – 2/3 of production:
  - Kazakhstan 22450 tU,
  - Canada 9350 tU
  - Australia 6350 tU
- Demand about 65 kt U

Historic uranium production and demand relationship

[Graph showing historic uranium production and demand relationship from 1970 to 2012, with data points for different countries and regions such as USSR, Russia, Australia, Canada, South Africa, USA, Uzbekistan, Ukraine, Kazakhstan, Niger, Namibia, Malawi, and Others.]
Contents

- Status quo
  - Resource estimates
  - Uranium market
  - Production figures
  - Supply – demand relationship
- Uranium supply-scenarios
  - General findings from the reviewed publications
  - Details (quotes) from publications
- Kazakhstan
- Conclusions
Comparison of uranium supply scenarios

- As uranium is of major interest for the future of nuclear energy, supply scenarios are published by industry, academics or international organizations

→ Some of those compared in the following slides to point out common/important findings.

- As they originate from different interest groups, they have different foci and show some differences in the results - Still, some similarities in the results can be found.

- It is common practice to provide several scenarios or a bandwidth of expected future production

- Common Basis: Resource and demand figures published by the IAEA
Choice of publications

- ARMZ (2011): „ARMZ Uranium Holding Co. - Rosatom State Corporation’s Mining Arm“
- Arnold, N; Liebert, W; Zittel, W (2013): Nuclear fuel and availability.
Common findings of recent supply scenarios

- An increased future uranium demand is expected
- Expected decline in production somewhere between the beginning and the middle of the next decade – in almost all the scenarios.
  - Peaks in production somewhere between 2015 and 2025 (mostly mid next decade)
    - scenarios include all cost categories, thus a decline in production from low cost resources can be expected earlier (shift towards higher production costs)
- The necessity of the timely development of mining projects is pointed out (especially with long lead times for mine openings)
- Possible contributions from unconventional resources are discussed.
  - (Significant contributions are not expected, thus not reflected in the scenarios of most reports.)
- Opinions on the contribution of secondary resources diverge
  - (but it's clear that they are limited)
Uranium production scenarios (selection)

Excluding secondary resources to enable scenario comparison.
Details – industry

- Areva 2013
  “… However, market growth is still expected, with demand 28% greater in 2020 than in 2012 according to the World Nuclear Association (WNA). ……

Prospects for an increase in global production over the medium and long terms have declined: some projects have been postponed or cancelled, capital programs have been cut, and the global exploration effort is down, particularly on the part of junior mining companies with limited access to capital. …”

- Boytsov 2012:
  “U resources of primary uranium mines will be decreased by 2030 more than two fold, more than a half of the remaining U resources will be in the Olympic Dam ….

After 2020, uranium market may face shortage of low cost U resources needed to maintain production. … It is necessary to intensify uranium exploration aimed at discovery new low cost uranium resources. “
Details – industry

- WNA 2013:
  “The greater uncertainty in the prospects for nuclear power have greatly impacted expectations of future mine development.”
  “Increased uranium market uncertainty has resulted in the cancellation and deferment of a number of mining projects. Our uranium production methodology has also become more objective. As a result, existing and expected capacity plus secondary supply will be insufficient on current plans to meet reference scenario requirements by about 2024.”
  “Beyond 2030 Generation IV reactors could change future uranium requirements but not to a significant degree before 2050.”
Details - academics

- **Dittmar 2011** evaluated the past mining histories, resources and amounts of extraction and applied those for future uranium mining

  “Using this model for all larger existing and planned uranium mines up to 2030, a global uranium mining peak of at most 58 ±4 ktons around the year 2015 is obtained. Thereafter we predict that uranium mine production will decline to at most 54 ±5 ktons by 2025”

- **Guidolin and Guseo 2011**

  “Despite a recent increase, probably due to the Kazakhstan boom, the global production of uranium seems to be doomed to decline severely in the next twenty years, in accordance with the predictions of the Energy Watch Group “
Hall / Coleman 2013:

“Production of resources in both operating and developing uranium mines is subject to uncertainties caused by technical, legal, regulatory, and financial challenges that combined to create long timelines between deposit discovery and mine production. This analysis indicates that mine development is proceeding too slowly to fully meet requirements for an expanded nuclear power reactor fleet in the near future (to 2035), and unless adequate secondary or unconventional resources can be identified, imbalances in supply and demand may occur.”

“Additional concerns include the possibility that the stability of future primary uranium supplies will decrease. More primary uranium will be supplied from Kazakhstan, Africa (Namibia, Niger), Australia, and Canada, with production from other countries remaining flat.”
Secondary resources

- Secondary sources of uranium
  - Over-production of uranium before 1990, Uranium from weapons
  - Also in "waste products" in various places of the nuclear fuel production and use
    - Depleted uranium, tailings from other mines, reprocessing
  - (Reduction of uranium use by using plutonium fuel (MOX))
- Opinions on a possible contribution of secondary resources to fill the supply-demand gap diverge.
- Expected amounts range from 3 ktUeq to 18 ktUeq per year in the next 15 years.

Estimates on the bandwidth of the future availability of secondary resources, including MOX use in Japan (IANUS 2011, unpublished)
Unconventional Resources
Uranium from phosphates

- U from phosphate: by-product or primary product?

**Phosphate production**
- 176 Mt
  - (U by-product)

100 ppm U
- 72% phosphoric acid
- 83.7% recovery

**10.6 ktU/yr**
- 100-150 $/kgU

**Uranium production**
- (U primary product)

Phosphoric acid cost: 257 $/t
- Specific cost for U recovery: 130 $/kgU
  - 100 ppm U
  - 72% phosphoric acid
  - 83.7% recovery

« No limit capacity »
- ≈ 3,000 $/kgU

Source: A Monnet (2014) Extending conventional resources with unconventional uranium to feed nuclear fleet

IAEA | 4th NOVEMBER 2014 | PAGE 8
Contents

- Status quo
  - Resource estimates
  - Uranium market
  - Production figures
  - Supply – demand relationship

- Uranium supply-scenarios
  - General findings from the reviewed publications
  - Details (quotes) from publications

- Kazakhstan

- Conclusions
Kazakhstan

- Tenfold increase in production 2000 - 2010
- Since 2009, the largest uranium producer
- Helped to reduced the dependence on secondary resources
- Since 2010, the annual growth of production is declining, although still growth in the total production
  - Initial plan to produce 30 000 t U per year by 2015 unrealistic
Kazakh future?

- Short-term growth vs. Long-term perspective
  - New mines will have to compensate for the expectable decline in Kazakh production
  - Low cost production in Kazakhstan hinders new mine development

Production scenario based on 2011 Kazakh resources
Conclusions

- Uranium will stay the fuel used by the majority of the NPPs – at least for the next decades. Thus the availability of uranium as a nuclear fuel is relevant for at least this timeframe and the availability of uranium will have a significant impact on growth prospects of nuclear energy.

- A growth in nuclear energy and thus uranium demand is widely expected

- A decline in production is expected mid of next decade
  → Based on the current production outlooks strong nuclear expansion scenarios can be de facto ruled out
Conclusions

- Secondary resources are not the solution for mid and long term supply issues
  - use of secondary resources, may delay the commissioning of new mines to some extent

- A shift towards higher production costs in uranium mining can be observed

- Timely action to develop new mining capacities is necessary, considering the long lead times (which to some extent contradict the limited planning horizon of companies)

- Delays of projects and capacity expansions can have a critical impact on security of supply (depending on the size of the projects), especially with respect to the expected decline in production the next ten years.
Contact information

Nikolaus Arnold
Institute of Security and Risk Sciences
Borkowskigasse 4
1190 Vienna

nikolaus.arnold@boku.ac.at