Fuel cycle risks imposed by a nuclear growth scenario

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ABSTRACT: While the global nuclear energy generation capacity has stagnated since the 1980s a new trend of increasing the commercial use nuclear power arose especially in Asia. As nuclear energy tends to bind large resources and cover long time spans it is necessary to identify the frame conditions and associated risks the future nuclear energy scene might be confronted with. This work specially focusses on the structure of the nuclear fuel cycle as the supporting basis for nuclear energy generation. Identifying risks and bottlenecks in this structure e.g. missing future capacities for enrichment and fuel fabrication is especially important for an industry with long lead- and development-times show where further investments in the infrastructure are needed. Although not all could be discussed in depth, the conference contribution shall draw a comprehensive picture of the fuel supply network, point out possible risks connected to a growing fuel market and encourage in-depth discussion on reducing future supply risks.

Keywords: nuclear renaissance, nuclear fuel cycle, fuel supply, supply risks

1. INTRODUCTION

To fight climate change and meet future energy demand, new investments in nuclear energy are proposed by several institutions (IEA, IAEA). Even in a post-Fukushima world a constant growth of nuclear energy share can be expected, at least in the developing economies of Asia. Due to the nature of nuclear energy of binding large resources and covering long time spans, it seems of high interest to have an in depth look at the front- and backend developing around a growing nuclear energy share.

The work targets towards illustrating and connecting the network of the fuel cycle. It covers uranium mining, milling, conversion, enrichment, fuel fabrication and fuel distribution to the operators and plants. Taking into account that a strong trend towards the expansion of nuclear energy prevails especially in Asia, there will thus be a shift in the priorities of the nuclear industry to this region.

2. NUCLEAR GROWTH SCENARIOS

By June 2012 there are 435 Nuclear Power Plants (NPP) in operation with a total installed nuclear capacity of 370 GWe net (IAEA, 2012). For the future there are several projections and scenarios which assume a strong growth of nuclear generation capacity in the upcoming years. To illustrate the forthcoming nuclear renaissance four scenarios were selected and compared (Figure 1).

The selected scenarios were provided by the IAEA and the IEA. Depending on the assumed policies a big difference in the installed nuclear capacity by 2030 is projected. While the low scenarios predict an installed nuclear capacity by 2030 of around 500 GWe (IAEA low, IEA current policies scenario), the high scenarios predict a capacity in a range from 699 to 740 GWe (IAEA high, IEA 450 ppm) (Rogner, 2012; Tanaka 2011).

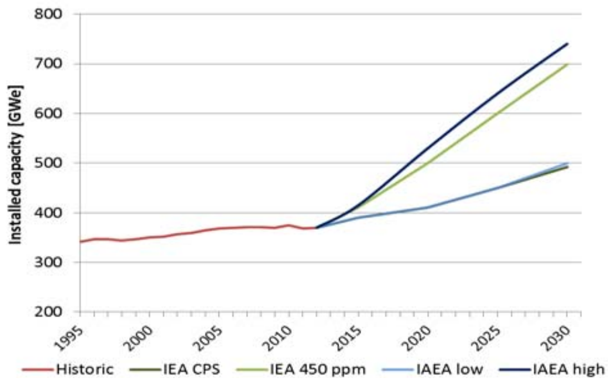

Fig. 1: Historic development of Installed Nuclear Capacity and four scenarios for a future development

The low scenarios indicate a growth of installed nuclear capacity of 35%; the high scenarios assume a growth of up to 100%. The short- and mid-term growth is mainly driven by the Asian market and CIS – States, where 90 % of the power reactors currently under construction are located (Rogner, 2012). This strong growth and the regional distribution have to be taken into account when analyzing potential bottlenecks and risks in the world nuclear fuel cycle imposed by nuclear growth scenarios.

3. NUCLEAR FUEL CYCLE

This paper is focused on the Front End of the Nuclear Fuel Cycle (NFC), which includes uranium mining, milling, conversion, enrichment, fuel fabrication and fuel distribution to the operators. The back end of the Fuel Cycle is not included so far, as the final disposal – although it might bear future risks – is not relevant for the supply risk analysis. Furthermore the reprocessing options were not assessed, as they are considered “dirty” and expensive so far and are still under assessment in many countries (Arslan, 2012). Finally new reactor concepts like breeders and thorium reactors were excluded in this work. It is not clear if these generation IV reactor types will succeed and which concepts will be able to establish themselves in future. This makes analyses of related fuel cycles afflicted with too large uncertainties to be considered at the moment.

3.1 Uranium supply

The fleet of nuclear reactors currently operating and under construction relies on uranium, mostly enriched in the isotope ^{235}U, which then undergoes the fission process. Therefore uranium is one of the most crucial resources for the future development of nuclear energy, as long as no other fuel cycle can be developed. While the nuclear industry does not expect shortages in supply of uranium, several independent publications (Zittel, 2006; Dittmar, 2011; Arnold, 2011) and even industry presentations (Boytsov, 2012) suggest declining uranium productions and possible supply shortages in the next 10 - 15 years, driven by a rising demand of the Asian market. The following considerations shall point out why the availability of uranium may impose a serious risk for a future ^{235}U based reactor fleet.

- It has been shown, that uranium resources identified in the past could not be mined as a whole (Dittmar, 2011).
- In many industry based supply outlooks no rising demand is assumed. In addition it is often presupposed, that new discoveries will be made to cover rising demand.
- Actions and considerations of market based companies are rather short term. This is in contrast to the long term operation of nuclear power plants on one hand and the long development times of new uranium mining operations (at least 10 years) on the other.
- As an example on how long lead times and a short planning horizon may affect the global nuclear fuel market, figure 2 shows a scenario on the future uranium production in Kazakhstan. In the past years Kazakhstan grew to the biggest uranium producers, providing about 1/3 of the total global production. Based on the current production centers and resource estimates a fast decline in 5 – 10 years can be expected. In the light of the long development times of mines this results in the difficult task of compensating the decrease in production.

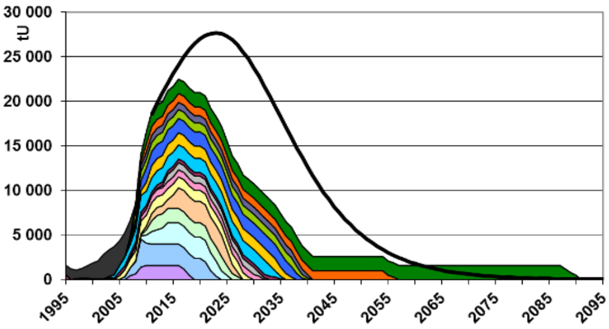

Fig. 2: Scenario on future uranium production in Kazakhstan based on operating mines and including additional country resources in bell-shaped curve (Arnold, 2011).

3.2 The Nuclear Fuel Cycle Network

Uranium mining is the starting point of the nuclear fuel cycle, followed by conversion processes, enrichment and the fabrication of fuel assemblies. To give a comprehensive view on the global fuel cycle network, material flows and the most important facilities were identified, analyzed and visualized. Step one was done by using open literature, the visualization was performed with the network analysis software Pajek (Batagelj, 2003). The first observation that can be made is that for nuclear industry a long distance between producer and the consumer is given (Figure 3). The uranium mines and milling facilities are mostly located in countries, where there are no NPPs. Therefore the uranium ore has to be transported over a long distance to be treated further. In many cases a street - rail - ship - rail - street combination is needed, in order to transport the UOC (Uranium Ore Concentrate) to the conversion facilities after the milling process and further on through the fuel cycle until the uranium finally reaches the NPPs. So far the transportation of nuclear material has shown good safety and security records (WNTI, 2010). Still constraints in transportation (denial of shipping, local opposition …) have to be considered with rising transportation needs of nuclear material.

Fig. 3: Global distribution of nuclear facilities. Map data © Google Inc.
… Uranium mining, … NFC facilities, … Nuclear Power Plants

The overall picture also shows that there are many mining and milling facilities and NPPs, while there are few conversion and enrichment facilities. Therefore one of the main risks in the nuclear fuel chain lays in the drop out of one these installations, although they cover today's needs with some reserve capacities. To visualize these bottlenecks and key nodes a network analysis was performed. Several fuzzies were identified during the process of data collection. On one hand a lack of data availability was detected, further there were variations in the available data (National Authorities – International Organizations), and differences in the reactor system types – resulting in different grades of enrichment – complicated tracing the material flow. Nonetheless some meaningful pictures could be created.

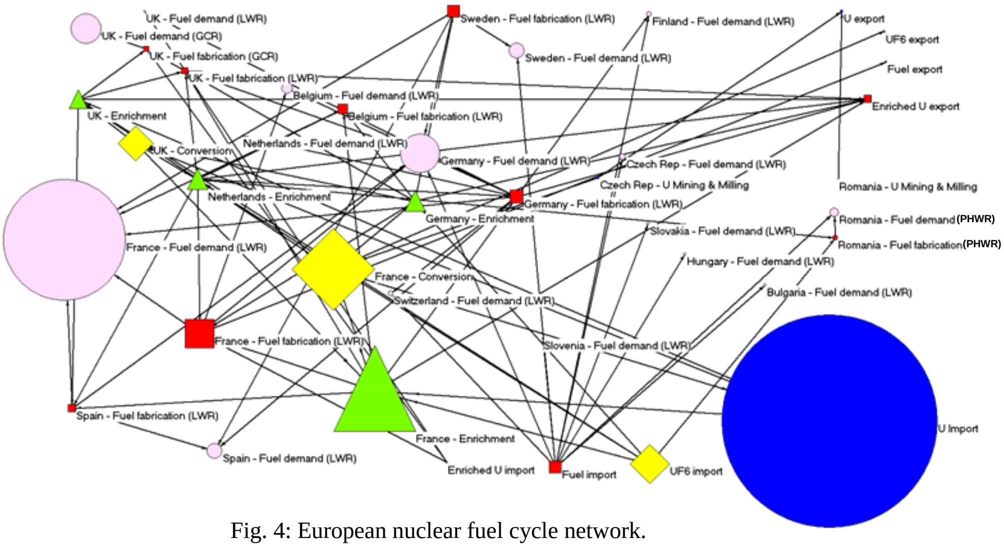

Fig. 4: European nuclear fuel cycle network.

Figure 4 depicts such a network analysis for Europe. First of all it shows Europe's large dependence on the import of uranium. Secondly it can be seen, that there are few enrichment facilities (4) and even less conversion plants (2). Finally France can be identified as the main player on the European nuclear fuel market. If the French conversion or enrichment – or both as they are located at the same site – are removed a severe impact on the European network can be expected.

3.3 Political aspects and security issues

3.3.1 Political aspects

The supply with uranium and continuative nuclear fuel has to play crucial role in nuclear growth scenarios, even though this fact is scarcely mentioned. Theoretically enough uranium is available in short and medium term (depending on the nuclear growth scenario) and nuclear fuel cycle capacities may be expanded. Those facts lead to an underestimation of the risk coming from the nuclear fuel cycle for a nuclear growth scenario. Assuming realistic boundary conditions financing and public acceptance need to be included if talking about security of supply. Especially public acceptance can play a very important role if new capacities are needed (NEA, 2012). From mining to fuel fabrication to transport of the finished goods – in each step opposition from the local population can be expected. Starting with environmental implications caused by uranium mines in the front end, to the question of final disposal at the back end of the nuclear fuel cycle a whole spectrum of open questions and public concerns must be taken into consideration.

3.3.2 Security aspects

The introduction of nuclear capacity into new countries leads to a higher proliferation risk. The need to enrich uranium in order to use it in light water reactors requires new enrichment facilities. Those facilities are very sensitive when it comes to non-proliferation issues, due to its dual use characteristics. This problem limits the number of potential sites for new facilities (NEA, 2012).

4. ADDED VALUE TO INTEGRATIVE RISK MANAGEMENT

The research on fuel cycle risks imposed by nuclear growth scenario needs a multidisciplinary approach. The fuel cycle risks imposed by a nuclear growth scenario is interconnected, complex and needs a holistic approach. If only taking into account hard facts, a very limited fraction of the risk can be identified. For the needed holistic approach social sciences along with technical sciences have to work together in order to provide a comprehensive picture of the upcoming challenges and risks. The identification of the risks is needed, in order to give the industry a chance to reduce the future risk.

To work out this problem an integrative risk approach is needed. The first step was the identification of risks. There are several risks, which have not been identified in the past. Therefore the identification of those risks is a crucial first step. Only if this step is completed, and in all its dimensions and interconnectivities are elaborated, there is the chance to start with the prevention, and intervention activities.

5. CONCLUSIONS

The uranium fuel cycle is a complex network spreading over the whole world. There is few detailed data publically available on material flows, which however would support analysts and would help mitigating future supply risks. As for the uranium supply it can be observed, that producer and consumer countries are diverse, resulting in long transportation routes and creating dependencies. Furthermore new uranium mining capacities have to be developed and enhanced exploration has to be conducted to secure future demand. Major risks are inherent in the presence of few large enrichment and conversion installations, creating a network with some crucial nodes, which might be irreplaceable on short notice. Finally an increased demand on nuclear fuel will raise future proliferation and security issues and may also increase public opposition.

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