UNDERSTANDING THE NUCLEAR FUEL CYCLE INDUSTRY

The nuclear fuel cycle is the backbone of the global nuclear power industry. Companies that are working in the field create a complex network covering a wide variety of processes from uranium extraction and enrichment to fuel fabrication and reprocessing. The *Fukushima Daiichi* accident, changes in the global demand for nuclear fuel and technological advancements have profoundly influenced the industry.

On June 2, 2015, the VII ATOMEXPO International Forum hosted a round table on *The Role of the Nuclear Fuel Cycle at the Current Stage of Nuclear Power Industry Development*. The event was moderated by *TENEX*. The round table benefited from participation of the leading experts from the industry and consulting firms: Ms. Anna **Bryndza**, Vice President of *The Ux Consulting Company*; Mr. Sergey **Yashin**, First Deputy Chairman of the Management Board at *NAC Kazatomprom JSC*; Mr. Philippe **Hatron**, Senior Vice President, Mining & Front-End Sales at *AREVA*; Mr. Gene **Clark**, President of *Trade Tech Energy*; Mr. Aleksey **Dolgov**, Head of Department at *TVEL*; Ms. Dominique **Dapei**, *EDF Group's* Director of International Affairs; Mr. Dmitry **Anufriyev**, Head of Division at *Rosenergoatom* Concern; Mr. Fletcher **Newton**, President of *TENAM Corp*; Mr. Ladislav **Havlíček**, Head of the Fuel Cycle Strategy and Services Department at *CEZ Group*; Mr. Aleksey **Lebedev**, Director-General of the *International Uranium Enrichment Center*; and Mr. Andrey **Tovstenko**, *TENEX* Deputy Director-General for strategy and marketing.

BRYNDZA: Nuclear energy remains very important, but there is a whole range of new factors that have an impact on its development. I am not just talking about the post-Fukushima syndrome; I am also talking about shale gas, renewables, and deregulation of the electricity markets. The latter trend makes it more difficult to predict electricity prices and that planning is part of any decision on whether to build or not to build an NPP. All that being said, however, the *Ux Consulting Company* projects a growth of the global nuclear energy market. Most of that growth is expected in the so-called CRIS group, which consists of China, Russia, India, and South Korea. It will also be important to maintain the current level in three other key markets: the United States, France, and Japan.

The markets are slowly trying to adapt to the new environment. For example, on the uranium market, supply will outstrip demand in 2015. Meanwhile, market players took time to react even to the Fukushima accident; companies initially cancelled plans to build more generating capacity, but they did not reduce their output at that time. Also, there is the secondary uranium market, which emerged thanks to supplies under the HEU-LEU deal.

That market is now being supplied by enrichment companies, from the United States Department of Energy stockpiles, and from stockpiles accumulated by some individual companies. As a result, in the short and medium time frame, the excessive supply in the uranium market will persist.

Uranium conversion is often regarded as the weak link in the nuclear fuel cycle. Unlike many other markets, the conversion market is fairly balanced, on a global scale. The supply on that market is limited, so if some of the existing capacity is taken offline, there is an immediate threat of disruption of supply. There are also regional imbalances; there is an excessive supply in North America, for example, but a shortage of supply in the UK.

As for the enrichment services, the balance there has yet to be found. A reduction in demand after Fukushima coincided with long-term trends in the industry, including the changing geography of demand and the transition from gas diffusion enrichment technology to gas centrifuge technology. At this time, the market is oversupplied, but because it is difficult to stop the centrifuges once they have been launched, companies use their spare capacity to enrich the tails — which turns them into players on the uranium market.

The launch of new reactors in Japan will have a positive psychological effect on the markets, but in the medium term, the price will return to the levels dictated by supply and demand.

YASHIN: The speed of the nuclear energy industry's growth will directly depend on the safety of nuclear power plants, and one of the key factors in their reliable work is uninterrupted nuclear fuel supply. On the one hand, many new states have plans to build a nuclear energy industry, but most of them do not have the required nuclear expertise. On the other hand, only a limited number of companies offer nuclear fuel supply services.

The most widespread practice at this time is direct supply of nuclear fuel from the producer to the consumer. The alternative is for each individual country that plans to build a nuclear energy industry to make fuel for its NPPs at its own facilities. The necessary ingredients can be produced locally or imported. It is also possible — although this has yet to be implemented — to create regional centers that will make fuel for specific types of reactors. At this time, the key suppliers of uranium do not have the enrichment capacity or fuel manufacturing technology, but they would be glad for an opportunity to participate more actively in such cooperation. Of course, all the relevant factors must be taken into account when technology transfer is involved, including nuclear nonproliferation.

Kazakhstan has large reserves of natural uranium, and it believes that its mission is to offer guaranteed supplies of uranium to every country that pursues peaceful nuclear energy development. In addition, Kazakhstan has preserved and improved technologies for making individual nuclear fuel components, and it hopes to become involved in every stage of the nuclear fuel cycle at some point in the future. That gives the nuclear newcomer states a choice of fuel suppliers. In addition to natural uranium supplies, Kazakhstan currently offers the service of returning uranium back to the nuclear fuel cycle by processing materials that contain uranium and making nuclear fuel components out of them. In partnership with *AREVA*, *Kazatomprom* supplies nuclear fuel components to the Chinese market. An agreement has been reached to produce fuel in Kazakhstan for French-designed reactors operated by *China General Nuclear Power Corporation* (*CGNPC*). This represents an emerging new trend whereby it becomes standard practice for operators to have more than one nuclear fuel supplier; this is a guarantee of reliable fuel supplies. Finally, *Kazatomprom* also plans to enter the uranium conversion market.

HATRON: A sustainable and reliable nuclear energy industry must be based on social responsibility, environmental friendliness, and economic viability. To achieve these goals, the nuclear industry must fulfill the following conditions: ensure safety, security, and local development; minimize the environmental impact; and be economically viable and competitive. France's nuclear industry is the country's third-largest industry. Every possible effort is being made to ensure the safety of the industry's employees. The French nuclear companies are subject to inspections not only by the national authorities but also Euratom, which makes their work even more transparent.

To build a sustainable nuclear energy industry, it is important to minimize the amount of nuclear waste. In this context, the best solution is a complete nuclear fuel cycle, which creates a secondary fuel market and saves natural resources, and thereby creating a stockpile of material for the nuclear power plants of the future. Besides, this is a question of a country's independence from external suppliers. France reprocesses spent nuclear fuel; the plutonium extracted by means of reprocessing is used to make MOX fuel, while uranium is enriched to the required level and also used to make fresh fuel. Making fresh nuclear fuel material by means of reprocessing spent fuel is more costly than simply using natural uranium — but by pursuing that path, France makes a contribution to long-term and sustainable development.

CLARK: The same quantity of enriched uranium can be obtained from various quantities of natural uranium by means of increasing or decreasing the amount of separative work units (SWU) spent on enrichment. Depleted uranium (the so-called "tails") will have different residual amounts of U^{235}. That gives the enrichment process a lot of flexibility. As the price of natural uranium or SWU fluctuates, the balance of the resources used in the enrichment process will also change to ensure the lowest possible price of the resulting product. Another thing to remember is that the financial interests of enrichment companies may differ from the interests of the buyers of enriched uranium.

Russia has the world's largest enrichment capacity; it is followed by *URENCO*, *AREVA*, and Chinese companies (which are growing fast and planning to win large shares of the US and EU markets). These are the main players on the market. Because of flagging demand, the companies that pursued the laser enrichment technology — which is the main competitor of the centrifuge technology — have put their research on hold. According to estimates by Trade Tech Energy, the excessive supply of enrichment capacity on the market will persist until 2025. Nevertheless, it can be assumed that thanks to the aforementioned flexibility, a balance will be found.

DOLGOV: Nuclear fuel must meet the customer's requirements, especially in terms of safety, reliability, performance, and competitive pricing. Performance can be improved through longer fuel life, higher power output, or higher burn-up fraction. Costs can be reduced by upgrading fuel technology and standardizing fuel design.

Three generations of fuel have been developed for VVER-440 reactors, which are in operation at the *Paks* NPP in Hungary and the *Dukovany* NPP in the Czech Republic, among other places. Third-generation fuel has also been developed for VVER-1000 reactors; in fact, it is already in use. The fuel for VVER-1000 reactors can work in the daily maneuvering mode. This was confirmed during trials in 2006 and 2015. The operator can therefore increase or decrease the reactor's output depending on the grid's demand. The objectives now being pursued by nuclear fuel developers include increasing the reactor output to 107 per cent.

DAPEI: Most of the electricity in France is generated by the nuclear power plants; this is why the security of the fuel supply is a key issue for us. It is critically important to manage each step of the fuel cycle and to define a front-end procurement strategy—that is, uranium supply, enrichment, and commercial services.

Since the beginning of the French nuclear program, leading actors of the national nuclear industry, *CEA*, *EDF*, and *Cogema,* have forged a strong partnership with *Tenex* to ensure the security of fuel supply. We clearly have strong ties with *AREVA*, which is today our main partner. However, since the beginning of the French nuclear program in the early 1970s, *Tenex* has provided the French nuclear fleet with enriched uranium. This is a very important point for us. It is a long partnership, which proved to be decisive at the beginning of the French nuclear program. While *Georges Besse* I, the first French enrichment plant, was under construction in the 1970s, *Tenex* was able to supply, along with the US enrichers, our first fleet of plants. At the beginning, the contracts were signed between *CEA* and *Tenex*. When *Cogema*, *AREVA*'s ancestor, was created, a new contract was concluded between *Cogema* and *Tenex*. Since mid-2005, *EDF* has established a direct relationship with *Tenex* through long-time contracts.

During all these years, *EDF* was particularly appreciative of *Tenex* as a partner. I would like to underline that there was not a single case of the low quality or delay in *Tenex* deliveries during all these years, which is of utmost importance in regards to the high level of expectation from our nuclear plants. I would also like to mention the high level of technology of *Tenex*, which meets the highest French environmental standards, and its high level of reliability. We are lucky to have *Tenex* to support our activities and competitiveness. This is a success story, and we wish this strong partnership to continue.

ANUFRIYEV: I would like to tell you about our experience of using nuclear fuel as part of implementing a program of increasing electricity generation. All the previous speakers focused on the initial and final stages of the nuclear fuel cycle. In my report, I will speak about the intermediate stage, i.e. burning nuclear fuel in a reactor.

The main task that has been set before us by the *Rosatom* corporation is to increase electricity generation in the existing VVER-type nuclear power reactors without any detriment to safety. *Rosenergoatom* currently operates 18 VVER-type reactors. We have three separate projects in this area. One is to increase the power output of the VVER-1000 model first to 104 per cent, and then at some point to 107 per cent, while at the same time implementing an 18-month fuel cycle. The second project is to increase the output of the VVER-440 model to 107 per cent and to implement a 6-year fuel cycle. The third and final project is to implement an 18-month fuel cycle for the VVER-1200 (AES-2006) reactors. The design of the latter model was finalized in 2007, and back at the time, we were not aiming for an 18-month fuel cycle. There was little ongoing R&D in that area, so the design was based on a 4-year fuel cycle.

In order to ensure the required length of the fuel campaign, we approached the *TVEL* company. A new design of fuel assemblies was developed, and the uranium load was increased by means of enlarging the fuel stack and introducing fuel elements with a higher uranium content. All the necessary procedures were also performed to demonstrate the safety of the modified fuel cycle and of operating the equipment on a fuel cycle longer than 12-months. That included demonstrating the safety of the proposed length of the fuel cycle between scheduled maintenance periods, upgrading the hardware, and conducting a probability analysis for safety. Even though we have already transitioned to using two main fuel types, we are also continuing trial operation of several new fuel types.

Working in cooperation with *TVEL*, we have developed a program of fuel improvement. Twelve TVSA-12 fuel assemblies are now in operation on a trial basis until 2016; these will be supplied to nuclear power plants in Ukraine and Bulgaria.

As for the results, according to 2013 data from the *Balakovo* NPP, we had a very respectable output of almost 33.7 billion kWh by all four reactors. The installed capacity utilization ratio was 96.2 per cent, and the availability ratio was almost 96.7 per cent. These figures demonstrate that increasing the power output and transitioning to the 18-month cycle has not had any negative impact on operational figures, reliability, or sustainability. We have also performed a technical and economic feasibility study compared to a 12-month cycle. According to that comparison, using the 18-month cycle generates an additional profit of about 5.2 billion roubles.

Let me also say a few words about another promising project. Our company has approved a program of increasing the thermal output of the No 4 reactor at the *Balakovo* NPP to 107 per cent. This builds on the previous project of increasing the reactor's output to 104 per cent using a similar process with several stages. It includes a feasibility study, the actual upgrade, operation in a trial mode, and finally commercial operation. Before taking this decision, the company performed R&D that demonstrated the feasibility of achieving 107 per cent.

Finally, let me say that the objectives set before *Rosenergoatom* have been met. We have completed a transition to 104 per cent power output at all our VVER-1000 reactors, except for the No 1 reactor at the Kalininskaya NPP; ditto for the development and implementation of 18-month cycles using bi-fuel assemblies. Analysis of the actual technical and economic indicators has confirmed that the upgrade has yielded the desired effect. One of the problems that has yet to be resolved, however, is the removal of spent nuclear fuel.

NEWTON: I would like to add a few words about the effects of this program on demand for uranium. The transition to an 18-month fuel cycle somewhat increases the consumption of natural uranium, but the increase in the amount of waste is outweighed by the savings achieved by reducing the amount of the fuel being loaded, and by increasing the number of days in a year during which the power plant produces electricity. The purpose of the program is to increase the power output, and the greater the output, the greater the demand for fuel.

HAVLÍČEK: *ČEZ group* is an international utility with a strong position in Central and Eastern Europe. The biggest share of our power generation is in Northern Bohemia, and the most important *working horses* in our fleet are the nuclear power plants. Nuclear power plants *Dukovany* and *Temelin* were substantially upgraded and now they are generating almost 50% of our output. What is even more important, this output is very profitable. Currently the electricity prices are very low in the Czech Republic and Central Europe, so for us it is important that thanks to the low fuel costs, those power plants are still very efficient. This could not have been achieved without excellent fuel performance, so we are eager to maintain this vital cooperation with the supplier in the long term.

Dukovany NPP was put in operation in 1955; this year we completed 70 years of operation, and for us it is a very important moment. In the Czech Republic, we have to renew our license every ten years; in 2015, we have to apply for license for the next ten years. Historically all fuel for this power plant has been delivered by the Russian propagator. The current fuel contract covers all of the expected operational lifespan of the plant. However, we hope that we will be able to prolong the operation time even further.

The *Temelin* NPP was launched in the year 2000. The plant is operated in 12-month cycles. We have studied the possibility of moving it to 18-month cycles, but in the Czech Republic, we have the highest electricity prices from January to March and from October to December. It would be very difficult to arrange all fuel outages to be out of this period. As a result, we decided to keep the 12-month cycles. At the beginning, *Temelin* used the Westinghouse Vantage 6 fuel. There were some modifications to the design to dissolve operational issues. In 2006 a Russian company, *TVEL* was selected as a supplier for the next decade, with the TVSA design of the fuel. This design was successfully licensed in the Czech Republic, and since 2010, we are operating TVSA fuel in our reactors.

Regarding our front-end strategy, that is, the procurement of nuclear materials, we try to maintain a portfolio of contracts for uranium procurement, conversion and enrichment services with individual primary suppliers or traders. We prefer to have some diversity and flexibility, not to be forced to buy in the market when the situation is not favorable for us. We are also a member of the EU, which means that if we sign a supply contract for nuclear materials, it must be co-signed by Euratom Supply Agency. Currently we have two fuel contracts, one for NPP *Dukovany* and one for NPP *Temelin*. Under the *Dukovany* fuel contract, either we deliver our own fuel concentrate, which is then converted, enriched, and fabricated into fuel in the Russian Federation, or we buy the fuel as a package. In case of NPP *Temelin,* a substantial part of the enriched uranium comes from the Czech Republic; it is fabricated into fuel, and only a small portion of enriched uranium product is delivered directly by the fabricator.

Very quickly about our back-end strategy: in the Czech Republic, it is based on an open fuel cycle. We store the fuel at the sites of the power plants, and the deep geological repository should be in operation from 2065. We regularly assess the strategy, but without construction of new units, I think, there is no reason to change it.

We remain committed to continue improving efficiency of our fuel and the highest level of fuel safety, and we have to be in compliance with the EU policies. *ČEZ group* remains committed to continue our support for research and development in the nuclear fuel cycle area; we finance a number of local experiments in fuel structure models. We are also active participants in international projects, like Zero Defects, the Halden Reactor Project, and so on.

LEBEDEV: The *International Uranium Enrichment Center* (*IUEC*) ownership structure has not changed since 2012. We still have four stakeholders, with a 50-per-cent plus one stake owned by Russia, 10 per cent by Ukraine, 10 per cent by Armenia, and 10 per cent by Kazakhstan. Nevertheless, energetic negotiations have been under way all these years, and I have good reasons to expect another two stakeholders to join us by the end of 2016. I would like to recall that the conditions for any country becoming a stakeholder in the IUEC are as follows. First, the country must comply with its obligations under the international nuclear nonproliferation regime. Second, it must be developing a nuclear energy industry (i.e. it must require, either at this time or in the future, a certain amount of nuclear fuel that will be supplied by the *IUEC*). Third, it must be a member of the IAEA. And fourth, the enriched uranium made by the *IUEC* and exported from Russia must be used for the importer country's own nuclear energy needs. One final thing: we prioritize countries that do not have any national enrichment capacity, and have no plans for building such capacity; this is our contribution to the nonproliferation program.

We started off with a small contract with Ukraine in 2012, and we believe that this is a very important contract; it is being successfully fulfilled. The arrangement under the contract

is as follows: we receive natural uranium from Ukraine and pay for it. We then enrich the uranium. Usually we do it at Angarsk, at our Angarsk enrichment facility. We then ship the enriched uranium to *TVEL*, where it is used to make fuel assemblies. These assemblies are supplied to Ukrainian nuclear power plants. The overall value of the contract is over 25 million dollars over four years. For our small center, which employs only 14 people, this is a lot of money. The amount of enrichment services we export is 240,000 separative work units (SWU), which is equivalent to two fuel loads for a 1,000 MW reactor. Despite the complicated relations between our two countries, we successfully fulfilled our contractual obligations last year, and I am sure that we will do the same this year. The framework agreement with Ukraine covers a period until 2017; I hope that it will be extended.

Let me now say a few words about our assured stockpile. This, after all, is our main reason for being. That stockpile consists of over 132 metric tons of LEU in the form of uranium hexafluoride enriched to 2 — 4.95 percent. Russia pays for its accumulation and maintenance. A total of about 300 million dollars in today's currency has already been spent. The assured stockpile is kept at an IUEC facility that has been placed under IAEA safeguards. Incidentally, we place non-commercial material for Ukraine under IAEA safeguards as well, so when IAEA personnel visits to inspect our material from the assured stockpile, they also inspect the commercial material that is destined for Ukraine. Essentially, we kill two birds with one stone. I would also like to recall that this is the only facility in Russia to have been placed under comprehensive IAEA safeguards.

Russia wholeheartedly supported the IAEA initiative to set up a nuclear fuel bank in Kazakhstan. In 2011, our Permanent Mission to International Organizations in Vienna submitted a *note verbale* in which we offered *IUEC* cooperation in establishing the fuel bank in Kazakhstan. We were invited to participate in the Russia-IAEA expert group, and we will be directly involved in the transit of material because the material for the fuel bank will almost certainly be shipped via Russian territory. The IAEA will soon hold a tender for supplying the material, and we will take part in that tender, together with other Russian organizations. Regardless of who wins the contract, if the site in Kazakhstan is not yet ready to store the material, we are ready to provide our services and place it under safeguards, i.e. to store the IAEA-owned material at our Angarsk site.

One final thing: experts of the Angarsk complex, in cooperation with our own specialists, have developed a unique material control and accounting system. That system stores and automatically processes a very large amount of data. It can automatically compile reports for the standard national control and accounting systems as well as IAEA-standard reports for the facilities that have been placed under comprehensive safeguards. The system has layers of data protection and a built-in error diagnostics program. Our Belarusian colleagues expressed their interest after Russia and Belarus signed an agreement in March 2011 on building the first nuclear power plant in Belarus. Earlier this year Belarus asked the *IUEC* for information and consultation assistance concerning nuclear material accounting and control at the Belarusian NPP.

TOVSTENKO: First, let me say a few words about the state of the market. There are two key trends here. First, over the past year, market players have become more confident about the outlook on the global nuclear energy industry. Of course, it is important for the suppliers of nuclear fuel cycle products and services to have not only a good long-term outlook, but a medium and short-term outlook as well. In that regard, everyone is now watching Japan, where the first several reactors are being re-launched. I hope that when we meet again in a year's time, this trend will have gained momentum. Second, in the

most important segment of the nuclear fuel cycle, i.e. enrichment, the industry has completed a renewal of technology and transition to gas-centrifuge enrichment technology. The technological level of all the market players is now more or less the same. Another important development is the expiration of the HEU-LEU contract, which had been a key market factor for over two decades.

In these new market conditions the suppliers that want to be successful must find new ways of boosting their competitiveness. *TENEX*, which relies on the vast expertise and capability of Russian industry, seeks to gain an advantage in the form of integrated solutions. We believe that package contracts for nuclear fuel cycle products and services offer several substantial benefits, especially for companies from the nuclear newcomer countries. When an energy company buys enriched uranium (which is the product of three technological phases of the nuclear fuel cycle), it thereby secures several benefits, such as optimization of the logistics, no need to allocate money for the acquisition of material, and a better supply system. The ultimate form of the integrated solutions concept in the nuclear fuel cycle is one that brings together the output of the early and final phases of the fuel cycle. In that case, the energy company is able to resolve various important problems related to reliability of supply, enrichment of spent fuel, and the fuel's inclusion in the reprocessed uranium cycle.

TENEX works to reflect of all the aforementioned market trends in its strategy. That strategy is based on further development of our traditional core business as well as new projects and programs structured in the framework of two key areas: integrated solutions and development of our marketing and distribution infrastructure.

As part of the effort to improve our sales infrastructure, we are working to reduce the terms of delivery and to further improve logistics and transport, which is one of the elements of our integrated solutions for the early phases of the nuclear fuel cycle. Let me give you one example. As recently as 10 years ago most of our exports were shipped via St. Petersburg on FOB (*free on board*) terms. Now almost 100 per cent of the shipments are made on DDU (*delivered, duty unpaid*) / DDP (*delivered duty paid*) terms.

I would also like to mention the project to set up a transport corridor for uranium products via the Russian Far East. We have already made several shipments on a trial basis to Japan and South Korea via that corridor. In fact, we have started to use that route on a regular basis. It reduces shipment times from 2–3 months to 2–3 weeks, which is very important for our customers in Asia.

Speaking of integrated solutions that we offer to our customers, *TENEX* has gradually transformed itself from a supplier of SWU for uranium enrichment into a company that offers the enrichment process, enriched uranium, and related services. It is important to note that *TENEX* has a good record in offering foreign customers enrichment services for reprocessed uranium; this is one of the areas we currently pursue.

We are also using the capability and expertise of the Russian industry to explore new technological solutions, including REMIX technology. It enables us to use all of the unseparated mixture of uranium and plutonium extracted from spent nuclear fuel in order to make fresh fuel for our customers with only a small addition of uranium. This is our attempt to fulfill the dream of every NPP operator: to buy fuel, burn it, return spent fuel for reprocessing to the supplier, and then once again receive fresh fuel for their reactors.