CURRENT STATE AND PERSPECTIVES ON THE DEVELOPMENT OF THE RUSSIAN ENRICHMENT INDUSTRY AND ITS IMPACT ON THE WORLD URANIUM MARKET

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Introduction

Exactly thirty years ago in May 1973 the leading enrichment enterprise of the Russian Federation Ministry of Atomic Energy (Minatom), the Ural Electric Chemical Complex (Novouralsk, Sverdlovsk region) shipped for the first time for export products under the first foreign trade contract concluded between the foreign trade company "Techsnabexport" (TENEX) and the French Atomic Energy Commissariat for the provision of uranium enrichment services.

Thus today we have an excellent reason to speak about the Russian approach to the development and implementation of commercial centrifuge technology for isotope separation, the changes in trends of using Russian enrichment capacities throughout our thirty years of work on the world market, and our view of the prospects for development in the enrichment industry that would satisfy the demands of the world uranium market.

Russian approach to development and implementation of centrifuge technology

In 2002 the Russian scientific and engineering community celebrated the 50th anniversary of the adoption of the USSR Government Decree on development of the design of the commercial gas centrifuge for uranium isotope separation. The design bureau of the Leningrad Kirov plant was designated to produce it. The work was preceded by studies performed in 1946-1951 by a team of German specialists headed by Dr. Max Steenbeck and Soviet scientists under the guidance of academician I.K. Kikoin.

The Steenbeck team developed prototypes of 3-m centrifuges consisting of ten short tubes connected by silfons. The rotor bottom rested on a thin steel needle that, in its turn, was mounted on a bearing made of solid alloy with a damper. The rotor's upper end was fixed with a permanent magnet, shaped as an empty cylinder. The designers proposed a mechanical mode for inducing circulation using a brake disk. Fatigue tests of six prototypes lasted over 1,000 hours and confirmed a possibility of isotope separation, despite a failure to solve the technological problem of transferring the gas from one centrifuge to the adjacent ones.

A team of researchers headed by academician I.I. Kikoin succeeded in solving this problem that was crucial to the creation of a commercial cascade of centrifuges by introducing sorting tubes to transfer gas from one centrifuge to another. The designers also proposed the concept of a "rigid" subcritical rotor with molecular compaction.

A thorough study by designers of the advantages and disadvantages of the concept of flexible and rigid subcritical rotors favored a choice of a subcritical rotor of the centrifuge for commercial separation of uranium isotopes. Shortly afterwards the Russian commercial centrifuges of the first generation were made.

On October 10, 1955 the USSR Government passed a decision on the construction of a pilot centrifuge plant. The pilot plant with about 2,500 centrifuges designed by the Leningrad Kirov plant was commissioned on November 2-4, 1957 at the Ural Electrochemical Integrated Plant (Novouralsk, Sverdlovsk region).

The results of the tests and of the run of the pilot plant were the basis to making the next step and moving on to industrial exploitation of the centrifuge separation of uranium isotopes. The relevant decision was adopted on May 5, 1958 at the session of the Scientific and Technological Board of Minatom chaired by academician I.V. Kourchatov.

On August 22, 1960 Minatom approved the design statement prepared by the Leningrad designing institute VNIPIET for the construction of the world's first industrial plant at the Ural Electrochemical Integrated Plant commissioned in three stages during the period from 1962 to 1964.

In accordance with the design, gas centrifuges were arranged in 20 units assemblies with shared collectors for feed and withdrawal of enriched and depleted factions mounted on multi-tier ferroconcrete columns (*Slide 1*). Through engineering communications with locking and regulating devices, power supply and controls, dozens of assembly units were arranged into sections and units making up technological stages of a separation module (cascade). The design solution envisaged a possibility of halting individual sections or units to replace failed centrifuges or modernize the units by replacing the old generation centrifuges with the last generation models without stopping the entire separation module.

Thus, the design solution adopted forty years ago had an inherent potential for continuous modernization without acute decrease or increase of enrichment capacity while maintaning engineering communications and multi-tier support columns. It allowed minimum capital investments related to commissioning new generations of Russian centrifuges. During forty years of the first industrial plant operation it witnessed three generations of gas centrifuges. The initial enrichment capacity increased about sixfold.

It is common knowledge that enrichment capacity of a gas centrifuge is determined primarily by the peripheral velocity of rotor's tube wall and length of the rotor's working chamber (*Slide 2*):

$$E = \alpha \cdot V^n \cdot L$$

In the extreme case n=4, although in actual life it depends on parameters of the internal gas dynamics of the rotor and tends to n=2 along with a growing peripheral velocity of the rotor.

Obviously, it is more effective to increase the peripheral velocity of the centrifuge rotor rather than its length. For this reason the Russian designers selected the option of creating and improving subcritical centrifuges with multi-tier arrangement in units.

To increase the peripheral velocity of the rotor it is essential to use materials with highly specific characteristics, as well as effective technological processes for their manufacturing. Advance in designing such materials was concomitant with improvement of Russian centrifuges.

In the past ears seven generations of industrial subcritical gas centrifuges were developed and introduced (*Slide 3*). The enrichment capacity of a single centrifuge increased about eight times, while specific expenditures per SWU reduced about six times, at the same time the size of a 20-machine assembly unit remained the same.

Russian scientists and specialists created a unique system of assuring the quality of the initial materials, component parts, manufacturing and operation of gas centrifuges, control of technical condition throughout their service life that ensured an extremely high level of their reliability and extended their service life from 10 years of the first generation centrifuges to 25-30 years of the last generation centrifuges with minimum maintenance of all systems of enrichment modules throughout their service life.

Use of Russian enrichment capacities

Presently there are four enrichment plants are operating centrifuges of the 5th, 6th and 7th generations. Total enrichment capacity over 20 million SWU is distributed as follows (*Slide 4*):

Name of enterprise	*Per cent*
Ural Electrochemical Integrated Plant (UEIP, Novouralsk)	48
Electrochemical Plant (ECP, Zelenogorsk)	29
Siberian Chemical Integrated Plant (SCIP, Seversk)	14
Angarsk Electrolysis Chemical Complex (AECC, Angarsk)	9

In 2002 Russian enrichment capacities were used as follows (*Slide 5*):

- Enriched uranium for Russian made reactors (Russia, CIS, East Europe) - 33%
- Implementation of HEU-LEU program (accumulation of blendstock with a lower content of U-234) - 24 %
- Export contracts (including reenrichment of tails supplied by - 43%

foreign customers)

Radical changes have occurred on the world uranium market in the past thirty years.

Firstly, the number of suppliers has changed. The emergence on the market of "Techsnabexport" (TENEX), a representative of Minatom's enrichment enterprises, was followed by the appearance of Urenco, Eurodif and more recently companies from China and Japan.

Secondly, the trends for using enrichment capacities have changed. Traditional uranium enrichment services were followed in the 980-ties by contracts for the supplies of enriched uranium product (EUP), and in 1990-ties – enrichment of reprocessed uranium, enrichment of previously accumulated tails, and starting from the second half of the 1990-ties within the framework of HEU-LEU program an accumulation of blendstock with a lower content of U-234 used to dilute weapons grade HEU.

Thirdly, following a long stagnation period most countries adopted programs of nuclear energy renaissance and development.

Future prospects

The required development of enrichment capacities is primarily dictated by the prospects of nuclear energy advancement.

Today the share of NPPs in the world electricity generation is about 17%. In 2002 thirty countries of the world operated 438 power reactors with the design output of 353 GWe.

The beginning of the 21^{st} century is marked by a change of attitude towards nuclear energy. Alongside the countries of the Asian Pacific region (Japan, China, Taiwan, Republic of Korea, India and Pakistan) that in the early 1990-ties announced their programs for accelerated development of nuclear energy, an intention to build up nuclear power capacities were announced by such European countries as France, Finland and Czech Republic. The Italian scientific community increasingly supports the idea of switch back to nuclear energy. Appeals to hold debates on construction of new NPPs are voiced in Spain. Despite previous statements on inexpediency of nuclear energy development, the UK Government headed by A. Blair presently accepts such possibility. The US National Energy Policy adopted by G. Bush Administration is favorable to nuclear energy. The Government of Brazil adopted a decision on the construction of the third reactor.

According to the Strategy of Nuclear Power Development in Russia in the first half of the 21^{st} century endorsed by the Russian Government in 2000, total NPPs capacity will increase 1.5 times by 2010 and minimum twofold by 2020.

The process of obtaining licenses for extended operation of previously shut down units has intensified in most countries with developed nuclear energy. A total of 35 reactor units are under construction.

Following two years of discussions the International Forum on fourth generation reactors (GIF) held on September 20, 2002 in Tokyo (Japan) selected six prospective reactor technologies to meet the following requirements: stability, cost saving, safety and reliability, and also safeguarding non-proliferation and physical protection. Five of the six selected reactor types have a closed nuclear fuel cycle. Four of them are fast breeding reactors, one epithermal and one thermal neutron reactor similar to modern NPPs. The R&D on these reactors will continue on an international scale. Their commissioning is estimated within the period from 2020 to 2030. Apart from approving selected concepts of generation IV reactors the GIF forum supported several advanced thermal neutron reactors expected to be built by 2015.

Therefore one could expect that NPPs capacity will increase at least 40 GWe (net) by 2020 and will be determined primarily by using thermal neutron reactors.

How the enrichment industry will respond to nuclear renaissance?

Following a long period of search for the most cost-saving, reliable and environmentally safe commercial method for uranium isotope separation, all manufacturers and suppliers supported the centrifuge technology. The process of replacing gas diffusion by centrifuge technology is underway. One of the world's largest gas diffusion plants in Portsmouth, Ohio was shut down. Despite a substantial share of installed gas diffusion capacity (~ 40%) it is quite obvious that these capacities (~19 million SWU, Eurodif and Paducah) will be shut down by 2020.

One could expect that reprocessing Russian and US weapons-grade HEU will be completed by that time yielding the equivalent of ~ 7 million SWU per year available on the market in the form of energy LEU.

To meet the demands of growing NPPs capacities additional ~ 5 million SWU will be required by 2020.

Thus to ensure stable operation of nuclear energy by the year 2020 the world enrichment industry should be capabl e of launching in operation ~ 30 million SWU of centrifuge enrichment capacity without taking into account replacement of the exhausted capacities.

USEC has recently announced the DOE approved plans to launch into operation a centrifuge plant with the output of ~ 1 million SWU by 2010 to reach ~ 3.5 million SWU in 2011-2012.

The Louisiana Energy Services-2 (LES-2) consortium plans construction in the USA of a centrifuge plant using Urenco technology with the output reaching ~ 3 million SWU by 2010.

AREVA and Urenco have signed a memorandum of intention on cooperation and establishment of a joint venture using centrifuge technology to replace Eurodif gas diffusion plant in Tricasten (France).

The Russian enrichment industry has accumulated a vast experience in development and introduction of gas centrifuges. It possesses the world's largest, and hopefully, most cost-saving operational centrifuge capacities. The industry has successfully overcome the difficulties encountered in the last 15 years, namely:

- Complete termination of weapons-grade uranium production in 1988;
- Reduction of raw uranium sources as a result of the USSR collapse;
- Introduction of limitations (and virtually embargo) for enriched uranium supplies to the USA;
- Limitation of enrichment services procurement by the EU member-states (not exceeding 20% of portfolio);
- Replacement of currently produced enriched uranium by LEU from the blended down weapons-grade HEU (HEU-LEU program).

The highly efficient Russian centrifuge technology allows the increase of the rate of U-235 extraction from natural uranium from 58% (U-235 assay in tails 0.3%) to 72-86% (U-235 assay in tails 0.2% and 0.1% respectively), start enrichment of accumulated tails from enrichment plants and the blendstock under HEU-LEU contract with a lower content of U-234 for blending with weapons-grade HEU.

Such use of a considerable part of Russian enrichment capacities will hardly disturb the balance on the commercial SWU market for NPPs which is traditionally calculated on the basis on U-235 contract assay in tails equal ~0.3%. Meanwhile it will enable Minatom to remedy the deficit of the current natural uranium production.

While estimating prospects of enrichment capacities development one should take into account that the transfer to a closed fuel cycle may involve enrichment capacities in the purification of even isotopes U-232, U-234 and U-236 during the reprocessing of spent nuclear fuel from modern NPPs.

The Strategy of Nuclear Power Development in Russia in the first half of the 21st century endorsed by the Russian Government on May 25, 2002 set forth the following tasks for uranium enrichment complex by 2010 (***Slide 6***):

- Provision of enriched uranium for the nuclear development program in the Russian Federation;
- Fulfillment of Russian obligations under HEU-LEU program for weapons-grade uranium dilution to low enriched uranium for NPPs;
- Fulfillment of contract obligations on rendering enrichment services, supplies of low-enriched uranium and reenrichment of tails from foreign customers to match the demands of the world uranium market.

These key problems are resolved through the modernization of the fifth generation centrifuge units that are to be replaced by the seventh generation centrifuges. The enrichment capacity of the modernized units is twice higher compared to practically the same operational expenses of the fifth generation centrifuges before modernization. It means that specific operational expenses of the modernized units are reduced almost twice. We expect that the approved modernization rate will allow increasing Minatom's installed enrichment capacity about 30% in 2010 compared to 2002. The current R&D programs are aimed at developing the next generation centrifuges with the size similar to the 20-machine unit.

Conclusion

There are strong reasons to believe that upon transition to the centrifuge technology, the world enrichment industry will supply the reviving nuclear energy with the necessary volumes of enriched uranium.

We are confident that centrifuge technology has not exhausted its potential for upgrading the effectiveness of enrichment capacities and therefore contribute to competitiveness and further development of nuclear energy.

Thank you.

SLIDES

SLIDE 1.

SLIDE 2.

Enrichment output of gas centrifuges.

Theoretical (maximum) - $E = \alpha \cdot V^4 \cdot L$

Where:

α - is determined by the working gas characteristics and difference of molecular masses of separated isotopes

V – is the peripheral velocity of centrifuge rotor wall

L – is the length of the rotor working chamber

Actual - $E = \alpha \cdot V^n \cdot L$

Where:

$n \approx f(V)$, with the growing V tends $n \rightarrow 2$.

SLIDE 3.

Parameters of improving Russian centrifuges.

- Relative specific expenses
- Centrifuge generation

SLIDE 4.

Distribution of enrichment capacities among the enterprises

- UEHK (Ural Electrochemical Complex)
- EHZ (Electrochemical Plant)
- SHK (Siberian Chemical Complex)
- AEHK (Angarsk Electrolysis Chemical Complex)

SLIDE 5.

Use of Russian enrichment capacities (%)

- Enriched uranium for Russian made reactors (Russia, CIS, East Europe) - 33
- Implementation of HEU-LEU program (accumulation of blendstock with a lower content of U-234) - 24
- Export contracts (including reenrichment of tails supplied by foreign customers) - 43
- TOTAL –100

SLIDE 6.

Main targets of modernization program

- Provision of enriched uranium for the nuclear development program in the Russian Federation;
- Fulfillment of Russian obligations under HEU-LEU program for weapons-grade uranium dilution to low enriched uranium for NPPs;
- Fulfillment of contract obligations on rendering enrichment services, supplies of low-enriched uranium and reenrichment of tails from foreign customers to match the demands of the world uranium market.