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On the choice of technology for a new uranium enrichment plant

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HIGHLIGHTS

- Countries developing nuclear power may desire to own the uranium enrichment plant.
- In the world there is a choice of two potential suppliers of separation technology.
- The method for initial evaluation of some costs for enrichment plant is suggested.
- These costs depend mainly on the same individual characteristics of a centrifuge.
- One of the two considered technologies is shown to have certain advantages.

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ABSTRACT

The question of the choice of technology for a new gas centrifuge uranium enrichment plant is considered and the major factors affecting the cost of construction and operation of such a venture are investigated. Using the method of "essential differences account" (EDA) these factors are compared for two hypothetical plants of equal capacity, using technology provided currently in the uranium enrichment market: the Russian and the West European. The analysis is performed of two parameters that affect the choice of separation technology: 1) the cost of the plant installed capacity, reflecting the capital cost of its construction, and 2) the financial loss due to failure probability of centrifuges in operation, affecting the plant operating costs. It is shown that the main differences in construction costs depend on the characteristics of the gas centrifuge (GC) used. It is also shown that the costs associated with the failed centrifuges replacement are mainly determined by the individual characteristics of centrifuges. The estimates made on the basis of available information show a clear advantage of one of the two considered technological platforms.

1. Introduction

The Chernobyl accident in 1986 seriously slowed the rapid development of nuclear energy that was taking place in the world in the second half of the 20th century. The negative impression left by the disaster in the minds of people, gradually receded into the past, and was replaced at the beginning of the new century by the revival of interest, especially in countries with rapidly growing economies, in the possible solution of their energy problems with the help of atomic power. This shift in global public opinion was reflected in the form of general expectations of the "nuclear renaissance". Different countries have begun to implement projects related to the construction of nuclear power plants and to nuclear fuel necessary for them. The development of new generations of nuclear reactors advanced, construction of new uranium enrichment plants started, a new class of "juniors" in the uranium mining industry had emerged. These positive processes and mood, which lasted about one and a half decades, quickly damped out as a result of the new strike produced by a combined effect of Fukushima disaster and the global economic crisis. Renaissance gave way to stagnation, and in some countries, such as Germany, to a complete pull back. Although these events have again strongly inhibited the global nuclear industry, but they have not led to a universal replacement of growth by reduction, which would mean the imminent disappearance of the nuclear power, the cherished hope of its long-standing opponents. We believe that this fact clearly indicates the objective demand of nuclear energy on the part of humanity.

Today, as it follows from all historical processes logic, the global economic system is at the beginning of a new wave of its activity revival, energy needs growth and, as an inevitable consequence, a large-scale development of nuclear power. Also, based on the current level of nuclear industry technological safety, it can be considered a near-zero probability that the nuclear energy revival process, which already covered a considerable number of countries,

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could again be suddenly interrupted due to any incident or accident.

As a result of this revival, or the beginning of a "new nuclear renaissance", there will inevitably increase needs for nuclear fuel production, and, in particular, for the enrichment of natural uranium. Some countries, among the "newcomers" who are going to participate in the revival of nuclear energy activities can focus their efforts on the way to create their own elements of industrial nuclear fuel cycle. Those responsible for creating nuclear energy strategy in any country will be concerned about the future security of supply of their stations with all the components of the nuclear fuel cycle, from natural uranium to management of spent fuel. Some of those components obviously may not be achieved with the country's available resources, for example, in the absence of native uranium deposits; but some may seem economically attractive as national enterprises. In particular, this may refer to the provision of uranium enrichment services.

Of course, to develop own enrichment industry needs to take into account the limitations imposed by the international non-proliferation regime. At the same time, for the countries that demonstrate their commitment to the NPT[1] and provide full transparency of their nuclear activities, there are no formal barriers to legitimate the creation of their own industry to enrich uranium – for the purposes of meeting the needs of their own nuclear power plants, and for the possible supply of enrichment services to the world market (Treaty on the Non-Proliferation of Nuclear Weapons, 1970). It seems very likely that in the coming years among the fastest growing countries of the "third" world will be such that, while remaining non-nuclear states[2], would wish to have on their territory a uranium enrichment capacity enabling the achievement of these goals. The acquisition of such facilities for them will be most reasonably by way of purchase of the enterprise "turnkey" at the technology owner or participation with him in a joint project. A historical example of the first option was building by Rosatom a gas centrifuge plant (GCP) in China (Vsluh, 2008), the second scheme was initially followed by Urenco when it started to create the company Louisiana Energy Services (LES) in the United States.

Self-development of enrichment technology is obviously not realistic: firstly, from an economic point of view, as a very complex and expensive technological problem, and secondly, due to the fact that despite the absence of formal prohibitions the attempt to start this activity would inevitably cause stiff opposition from the international community as being contrary to the objectives of non-proliferation of sensitive nuclear technologies. Notable examples are available in the modern history: the first consideration is illustrated by the failure of the multi-billion dollar project "American Centrifuge" in the United States (The United States stopped building its centrifugal enrichment plant, 2016), the second – by Iran's nuclear activities, which led to long-term economic and political sanctions.

2. Statement of the problem

The quite probable scenario is as follows. A certain country is planning the construction or already is building, most likely with external assistance, one or more nuclear power plants (NPPs) consisting of 6 to 12 nuclear units and is willing to optimize the management of nuclear fuel. Responsibility for fuel supply lies with the national organization responsible for operation of those nuclear power facilities. It does not matter if this organization is private or public, since due to the specifics of the subject all the issues of supply of nuclear materials will be under the control of the state anyway. Therefore, for the sake of brevity, bearing in mind the stakeholders in general, we shall speak simply of "customer" or "country."

Thus, this country wants for its nuclear power plants to have its own source of supply of enriched uranium, and more specifically, enrichment services. We are considering here this particular demand alone, suggesting that, in accordance with general practice, other components of the fuel cycle – natural uranium, conversion and fuel fabrication – could be purchased on the market. As for the amount needed for the purchase of enrichment services in the market this can vary from 1/3 to half the cost of the finished fuel.

The output of a gas centrifuge separation plant is the service of natural uranium enrichment by fissile isotope U-235, as measured in separative work units – SWU[3]. SWU is a market commodity, the price of which is quoted in the uranium market and is published regularly by specialized companies, such as Trade Tech and Ux. Over the years, supply and demand for the SWU in this market are basically balanced, although in recent years the price of SWU tend to decrease. Based on the typical characteristics of modern nuclear reactors, one unit of 1000 MWt consumes, after initial core loading, in the average about 0.15 million SWU per year. At current market prices this is of the order of $12 million (World Nuclear Association, 2017).

According to approximate economic evaluation to own enrichment plant compared to purchasing the separation work in the world market becomes profitable if the plant service is in demand by nuclear power plants with a total capacity of about 10–12 GW, that is by 10 to 12 typical nuclear power units. Then the annual production of the enrichment plant intended for local consumption must be 1.5–2 million SWU. This evaluation is qualitatively shown in the diagram taken from Grigorev (2014), see Fig. 1. There the costs of purchase of enrichment in the market (in blue color) grow in time with the NPP units commissioning. For comparison in red color is presented the curve of distribution in time of the expected costs associated with a centrifuge enrichment plant construction and its operations for SWU production at the rate of about 3 million SWU per year. It is shown that the cost of market SWU supply remains lower than GCP costs for cases with one (a) and six (b) nuclear reactors in operation, while for the number of units above ten (c) the supply by own plant becomes more economic. Choice of an appropriate moment for home GCP construction and commissioning would allow starting NPPs supply by domestic enrichment just when the generating capacity reaches the economic volume of 10GW. Although this illustration lacks rigor, since the correct analysis requires having a financial-economic model of the whole complex of NPP plus GCP (also see Section 4 below), it shows the basic rationale for having the enrichment capacity together with the nuclear generating capacity.

If the country intends to expand its national atomic energy program, its generating capacity may reach 10 GW quickly enough. The enrichment plant economics will break even with guarantee if its capacity is no less than 3 million SWU per year.

What will happen if the plant is built, but the pace of construction of nuclear power plants in the country slowed down? According to the World Nuclear Association today about 20 countries in the world have a solid nuclear energy development plans (World Nuclear Association, 2015). All forecasts of enrichment services in the world market say that the demand will not be reduced for at least 50 next years, even in the case if over some time a large-scale implementation of a closed fuel cycle on the basis of fast

[1] Non Proliferation Treaty (Treaty on the Non-Proliferation of Nuclear Weapons, 1970).

[2] i.e. non-nuclear-weapon states. According to the NPT wording of the «nuclear state», it is the state, which has manufactured and exploded a nuclear explosive device prior to January 1, 1967. There are five countries: USA, USSR, UK, France and China.

[3] Because of SWU physical dimension the unit is sometimes denoted as kgSWU; also 1 ton SWU may be used instead of 1000 SWU.