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Selection of a rational degree of specialization of Russian companies involved in construction of nuclear power plants in foreign countries

Specialization is one of the forms of social division of labour which is expressed in the concentration of construction companies on performing homogeneous types of work or erecting construction facilities having the same function. Forms of specialization play an important role in the construction process arrangement. Their economic efficiency, which is expressed, first of all, in the increase of labour productivity, rises with the narrowing of the range of works performed and a freer exchange of resources. Four forms of specialization are developing; they are industry-specific, subject or object — focused, technological and sub-industrial ones.
Industry-specific specialization provides for the identification of companies specializing in the construction of certain buildings and structures for certain industries of the national economy. Such specialization exists at the level of ministries.
Subject-focused specialization means the foundation of corporate entities specializing in the construction of buildings and structures having common volumetric and structural modules (for example, construction of nuclear power plants (NPPs), transport infrastructure facilities, etc.). Such form of specialization develops at the level of large construction companies, development companies.
Technological specialization is characterized by the orientation of construction units on performance of certain types of works, that are similar in terms of technology and arrangement, as a result of which a certain stage of construction is completed (for example, construction of the reactor compartment at a NPP, auxiliary reactor buildings, a turbine building, that encompass concreting, finishing, heating installation works, etc.). This form was developed at the level of specialized construction companies, production flows, and construction sites.
Detailed specialization is the breakdown of the overall construction process into a number of specific processes and concentration of work performance in separate units (for example, production of building structures at reinforced concrete plants; manufacturing of assembly parts at the sites of construction companies; installation of building structures, brick and masonry on assembly sites) which ultimately contributes to the transformation of a construction site in the assembly area. Detailed specialization develops at the level of specialized units, teams and gangs.
Keywords: *technological specialization, degree of specialization, NPP project management, Rosatom State Corporation, project lifecycle, Akkuyu NPP*

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THE GENERAL PART

During the construction of NPPs technological specialization was frequently applied mechanized excavations, construction and installation work, installation of building structures, performance of sanitary, electrical, finishing, road and other types of construction work, as well as equipment installation. From this point of view, technological specialization is the most effective instrument. At present, the greatest economic effect is obtained by the corporate participants in NPP construction, that use this principle in their operations.

At the same time, the process of specialization can have a number of negative aspects. The greater the degree of specialization, the larger (1) the number of independent corporate participants of construction, (2) the number of units and external relations due to cooperation, which ultimately worsens the quality of project management and economic performance, causes employees to waste time on communication between departments. Therefore, there is a need to determine the rational level and optimal degree of specialization of companies and subdivisions specializing in technologies or subjects.

The level of specialization characterizes the enlargement of homogeneous construction work, performed by excluding homogeneous and technologically related works (or certain types of construction) from the general activities of construction companies and assigning them to separate specialized units. The creation of these large homogeneous work performance units promotes further division of labour, separation of work, and assignment of its performance to newly established specialized companies or units, which means further degrees of specialization. This process is division of aggregated works or types of construction into components. The conditional limit of technological specialization division is the performance by a particular construction company of only one type of work (concreting, finishing, electrical, plumbing work). Assessment of the degree and selection of the rational degree of specialization helps to further increase the efficiency of construction companies and their units.

A NPP project is a set of interrelated activities designed to achieve goals within a given time and budget. A set of interrelated elements and links between them, representing a “tree” of product-oriented components represented by equipment, work, services and information, determine the structure of such a project[1, 2].

In case of implementation of an NPP project, the level of specialization depends on the project participants, degree of their specialization, while the distribution of functions and responsibilities depends on the nature, type, scale and complexity of the project, as well as the phases of its lifecycle.

NPP project functions are clustered depending on management by project objectives; time management, cost management, quality management, risk management, contract management, project participant and personnel management, relationship and information flow management.

NPP project management is the art of leadership and coordination of human, financial and material resources using modern management methods and techniques, organizational forms of production and construction focused on the achievement of project results in terms of the composition and scope of work, cost, time, quality and satisfaction of project participants.

Development of specialization of construction companies should not be an ultimate goal, but a means ensuring the most exhaustive use of achievements of modern construction science and technology to ensure the best engineering and economic performance of specialized organizations, including higher productivity, lower cost of work, maximum profit, and less time lost [1, 2].

THE MAIN PART: ANALYSIS OF FOREIGN PROJECTS

In the current environment, the concept of international construction or construction in foreign countries as an activity carried out by a construction company(contractor) outside of its own country, has been transformed into a broader concept. Participation in a large-scale international investment and construction project, includes one or more constituents implemented with the participation of foreign companies, such as the performance of construction and installation works, delivery of materials and equipment, provision of design and project management services, as well as fundraising services[3].

Over the past decades, there has been a steady growth in international construction through the implementation of major infrastructure projects in developed and developing economies. According to the forecast, made by PricewaterhouseCoopers, by 2030, the amount of construction products in the world will grow by 85%. Revenues of major international construction companies, such as Actividades de Construccion y Servicios (Spain); HOCHTIEF AG (Germany); China Communications Construction Group Ltd. (China) and others, generated abroad, are estimated at tens of billions of euros[4].

One of the largest Russian corporations ROSATOM implements investment projects abroad (Table 1).

The Russian Federation ranks the first global NPP developer abroad, implementing projects, as it builds power units in Europe, Middle East and North Africa, as well as in the Asia-Pacific region. In the international nuclear power construction market, Russia is represented by the engineering unit of Rosatom State Corporation, which encompasses leading design and engineering companies of the industry: Atomstroyexport JSC, Atomenergoproekt JSC and others.

Implementation of NPP investment and construction projects abroad has a strong potential in terms of increasing the exportation of the nuclear power industry, taking into account the global situation, national competitiveness and current market positions.

The development of the global NPP market represents the evolutionary expansion of nuclear power generation in the countries that have experience in NPP operation and involvement of the "atomic energy club" newcomers. About 50 countries are considering the commissioning of their first NPP. There are about 160

Table 1. Foreign projects of Rosatom, the largest Russian company [3]

Russian project participant	Project country	Major projects	Investment amount, billion US dollars
Rosatom State Corporation	Belarus	Belarusian NPP	12.00
	Finland	NPP Hanhikivi	6.5–7.0
	Hungary	NPP Paksh-2	10.00
	Turkey	NPP AKKUYU	20.00
	Iran	NPP Bushehr	3.5
	China*	Tianwan NPP	1.3
	India*	NPP "Kudankulam"	2.1
	Egypt	NPP El Dabaa	20.00
	Bangladesh	NPP Ruppur	11.00

* Supply of nuclear and turbine island equipment

1 Town Planning Code of the Russian Federation (as amended on April 24, 2020) : Federal Law No. 190-FZ: [adopted by the State Duma on December 22, 2004: approved by the Federation Council on December 24, 2004]. URL: http://docs.cntd.ru/document/901919338

2 Civil Code of the Russian Federation (Part Two) (Articles 454-1109) (as amended on April 28, 2020) (version effective from June 26, 2020) : Federal Law No. 14-FZ: [adopted by the State Duma on December 22, 1995]. URL: http://docs.cntd.ru/document/9027703

3 STO NOSTROY 2.3386-2013. Organization of civil engineering operations. Industrial construction. Reconstruction of buildings and structures: company standard: introduction date March 15, 2013. National Association of Builders. Official edition. Moscow, National Association of Builders, 2015; 109.

4 NPP construction abroad. URL: tations_projects/perspektivy-sooruzheniya-rossiyskikh-aes-za-rubezhom

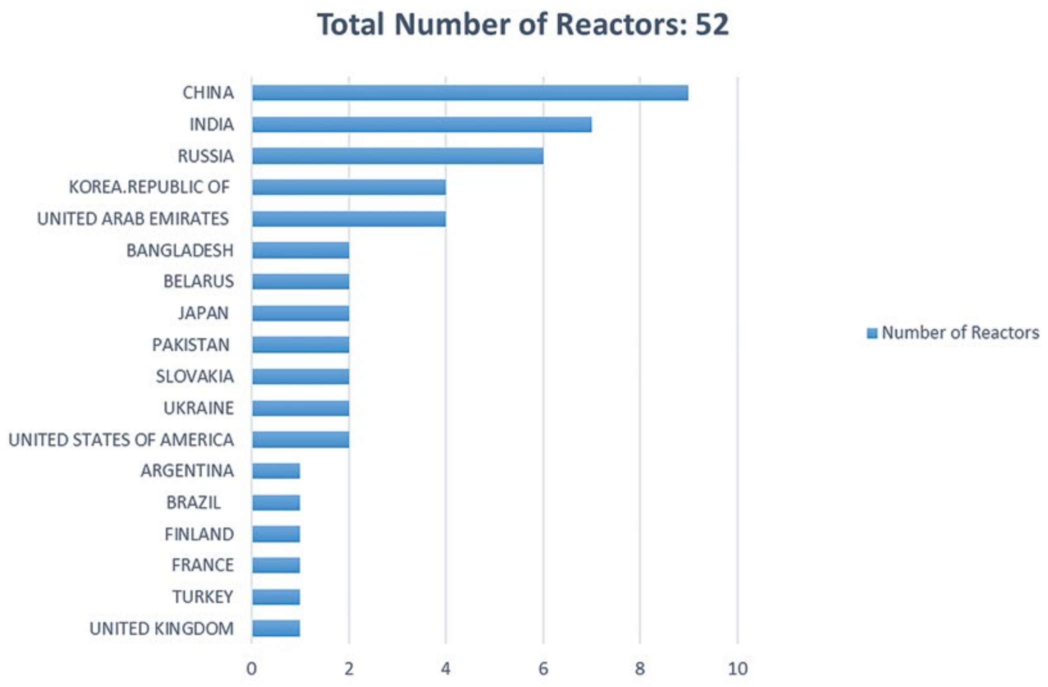

Fig. 1. Number of reactors under construction in 2019

new NPP units in the world that pass through various stages of project planning [4].

The Engineering Division of Rosatom State Corporation, headed by ASE IC JSC, has strong competencies in the management of construction of complex engineering facilities. At present, this Engineering Division specializes primarily in the construction of high-capacity NPPs in the Russian and international markets. At the moment, the Engineering Division of ROSATOM is the global nuclear engineering leader, and its share of the global NPP construction market is, at least 30%. It is active in Europe, Middle East, Asia, North Africa, Asia, and the Pacific region [5].

The Russian projects include Novovoronezh NPP-2, Rostov NPP, Kursk NPP-2, Leningrad NPP-2. About 80% of revenues, obtained by the Engineering Division, are generated by foreign projects.

The project customers are countries seeking to diversify the sources of energy and obtain cheap electricity.

Besides the construction of high-capacity NPPs, the Engineering Division of ROSATOM provides project management services, design, equipment supply [6–8].

One of strategic goals of Rosatom State Corporation is to increase the share of construction of high-capacity nuclear power plants in international markets, and the prerequisite is the unconditional performance by the Engineering Division of its contracts within the preset parameters. Compliance with NPP construction deadlines and costs, both in terms of current and future projects, is an absolute priority for the company. Achievement of this goal is ensured by:

- continually improving operational and project management processes;
- application of effective digital tools and information systems throughout the lifecycle of the project, — from pre-contract works to NPP commissioning;
- quality improvement at each stage of NPP construction;
- development of the key staff.

In addition, among the strategic objectives of the Engineering Division, as well as of ROSATOM as a whole, is the reduction of production costs and timing of NPP construction processes. The company's task is:

- to deliver NPP projects that are competitive in terms of the cost per kW of installed capacity and LCOE;
- to design and implement NPP construction projects within pre-set cost parameters [9–11].

CONSTRUCTION ARRANGEMENTS: THE CASE OF THE AKKUYU NPP PROJECT

AKKUYU NÜKLEER ANONİM ŞİRKETİ, part of ROSATOM, will build NPP AKKUYU (Akkuyu) in Mersin province.

May 12, 2010, an agreement was signed between the Government of the Russian Federation and the Government of the Republic of Turkey about the cooperation in the construction and operation of a nuclear power plant at the Akkuyu site in the Republic of Turkey.

On April 14, 2015, the "first stone" was laid at the site of the future construction of the NPP Akkuyu hydraulic engineering facilities.

On April 02, 2018, Turkish Atomic Energy Agency issued a License for the construction of NPP Akkuyu Unit 1.

On April 03, 2018, the Akkuyu NPP construction commencement ceremony was held with the participation of President of the Republic of Turkey Recep Erdogan and President of the Russian Federation Vladimir Putin.

NPP Akkuyu is the first project in the history of the nuclear industry implemented according to the BOO (Build – Own – Operate) model. According to the BOO model, the NPP supplier acts as an investor and co-owner of the future NPP. The company (Akkuyu Nuklear), supplying the technology, stays in the project throughout its lifecycle, providing financing, construction and operation technologies, training local personnel, developing industry-specific

Fig. 2. NPP Akkuyu construction site, Turkey, 2022

competencies of local specialists, participating in risk and responsibility sharing in terms of the sustainable development of the project and its commercial success.

The total cost of the investment project will be ~$ 20 billion, which includes the upfront costs of NPP construction, financing and waste management. This is the largest foreign investment in the Republic of Turkey.

NPP Akkuyu is based on a project similar to the NvNPP-2 reference project in Novovoronezh, Russia. NvARS-2 is currently operating at 100% full capacity. "Lessons learned" from NvNPP-2 help to design and construct a nuclear power plant in Mersin province. The industry practice of working with "lessons learned" is applied in the design and construction of NPP in Russia and abroad to avoid the same mistakes and inconsistencies in the present.

Akkuyu Nüklear Anonim Şirketi is the customer, the applicant for the necessary licenses, and the future operator of NPP. The key project contractor is TİTAN 2 IC İÇTAŞ İNŞAAT ANONİM ŞİRKETİ, which, in turn, enters into contracts with subcontractors, designers and suppliers. Some of them are CONCERN TITAN-2 JSC, Atomenergoproekt JSC, Atomenergomash JSC, and OKB GIDROPRESS.

TİTAN 2 IC İÇTAŞ İNŞAAT ANONİM ŞİRKETİ, is the key contractor for the construction of the plant; this company is responsible for site preparation, construction and installation works, development of working documentation and supply of all necessary materials and equipment (excluding long lead items) for all nuclear and turbine island facilities, the power generation complex and all ancillary facilities, as well as construction of buildings and roads, laying utility and engineering networks, design and supply of control and measuring equipment, landscaping and landscape design.

The Akkuyu construction site will include infrastructure and temporary buildings and facilities at a cost of ~ 800 million dollars.

As of September 2022, about 20,000 people were working on the construction site every day. More than 400 companies are involved in the project, about 80% of them are Turkish companies.

The nuclear power plant consists of a complex of general station buildings and structures, nuclear and turbine island buildings, including the reactor building, the turbine building, the emergency control room building, fresh and used nuclear fuel storage buildings. 260 buildings and structures (including tunnels and overpasses) must be constructed and commissioned as part of the first power unit of the plant. The plant will have 3,900 operating employees.

THE RESEARCH PART

For the purpose of construction of a large power generation complex, evaluation of the optimal level and degree of specialization was conducted using the case of NPP Bushehr. NPP Bushehr is constructed by the general contractor and about 30 subcontractors. The performance of three construction companies was analyzed. Akkuyu performed monolithic concrete pouring.

In these companies, the level of specialization L_S has almost reached its limit value over the last 8 years; it is 92–96% on average. In this regard, the planning of a further increase of L_S involves certain difficulties. For a more objective assessment of the level of specialization, it is advisable to use the indicator "degree of technological specialization" D_{ST}, characterizing the share of the main types of work in their total amount, if performed by the in-house personnel. The value of D_{ST} can be calculated using the formula:

$$D_{ST} = 0.01\sqrt{\sum_{i=1}^{n}\left(Q-\bar{Q}\right)^2}, \quad (1)$$

where n is the number of i-x processes of the main types; Q is the specific weight of the i-th process in the total amount of work in value terms; $\bar{Q}$ is the arithmetic mean value of specific weights of all processes.

Value D_{ST} varies in the range $0 < D_{ST} < 1$, and its rational value depends on several factors: specialization, conditions of activity of specialized subdivisions, work performance arrangements, etc.

Data on changes in the degree of specialization broken down by the years of construction are shown in Table 2.

Table 2. Degree of specialization

The company	2015	2016	2017	2018	2019	2020
Bel NPP	0.44	0.502	0.503	0.526	0.568	0.810
Akkuyu NPP	0.72	0.84	0.87	0.90	0.92	0.95
Busher NPP	0.48	0.606	0.74	0.75	0.82	0.84

Analysis of the main engineering and economic indicators of industrial and economic activities of the companies in question for the same period shows that all three companies exceeded the annual targets for the amount of construction and assembly work, production, cost and profit. At the same time, monthly graphs of the actually performed construction and assembly work shows that the basic principles of construction, such as uniformity and rhythm, were violated in these companies. Hence, during the last months of a quarter, a six months' period and a year, the amount of work performed was 1.5–2 times higher than the annual average. Given that the number of teams in construction units remained the same, such facts indicate the presence of significant untapped reserves for the further improvement of the arrangement of the NPP construction process.

Practice shows that the availability of reserves is caused by time losses at the "junctions" between the main types of work due to complicated cooperation links. External time losses are caused by untimely provision of work front, design and estimate documentation, equipment; internal losses are caused by untimely delivery of materials, failure to provide vehicles and mechanisms, violations of the labour discipline.

Time losses (Table 3) are equal to the annual under-performance of construction and assembly works by almost 100 millio.rubles.

Numerous possible options for the development of engineering specialization within a conditionally closed system (which is a set of construction companies engaged in the construction of NPP) and the need to choose the most optimal boundary values of D_{ST} at which the best engineering and economic indicators are achieved) require a substantiated approach to the problem under consideration. The impact of various factors on the degree of engineering specialization can be simulated using the economic statistical method, or identification of correlation relationships between the degree of engineering specialization of construction units and criterial indicators of their activities in a past period.

Such indicators are usually taken as the cost of building and assembly jobs, labour productivity or a set of indicators (cost price and profitability, labour productivity and profitability level, etc.). Indeed, a degree of engineering specialization contributes to the growth of labour productivity and reduction in the cost of works. However, along with positive results there are undesirable consequences of specialization, in particular, higher losses of time and resources at the "junctions" between the main types of work (or engineering operations) due to the higher complexity of cooperation links and lower reliability of construction management. Therefore, there is a need to consider the influence of D_{ST} not only on labour productivity B and level of profitability P, but also on time losses TL at the "junctions" between the main types of work performed by various construction organizations (departments).

The studies, conducted in other branches of construction, indicate that the relationship between the performance of construction units and D_{ST} is approximated by the parabolic dependence (a second-order parabola):

$$\left.\begin{aligned} B &= a_1 + B_1 D_{ST} + C_1 D_S m^2; \\ C &= a_2 + B_2 D_{ST} + C_2 D_S m^2; \\ TL &= a_3 + B_3 D_{ST} + C_3 D_S m^2. \end{aligned}\right\} \quad (2)$$

The nature of these dependences allows to identify a certain zone of rational boundary values in which at the highest labour productivity, relatively low $B_{TS.rat}$ cost of works and losses of time are possible.

The problem of determining the rational degree of engineering specialization can be solved graphically (Fig. 4, 5).

The graph (Fig. 4) shows dependences between the cost-effectiveness of labour productivity, time losses and the degree of engineering specialization at Bel. NPP, UEM and DAEM companies. As the analysis shows, the degree of engineering specialization of each company depends on the number of items of work performed, the number of employees, as well as the characteristics of the so-called range of each company. The range is understood as the zone of optimal values of the functions characterizing loss of time, labour productivity and profitability level within the boundary

Table 3. Time losses during the construction of nuclear power plants from 2015–2020

Year of construction	Labour productivity, thousand rubles/year			Profitability level, %			Time loss, %		
	Bel NPP	Akkuyu	Busher NPP	Bel NPP	Akkuyu	Busher NPP	Bel NPP	Akkuyu	Busher NPP
2015	11.9	16	10.3	26.1	12	7.4	3.7	4.1	9
2016	13.3	21.4	11.7	27.2	14.8	8.6	3.7	3.9	8.7
2017	15.3	22	14.7	27.7	15	8.2	3.6	3.7	9.1
2018	15.6	23.1	16.8	20.6	15.5	7.5	3.1	3.9	10.4
2019	15.4	19.6	13.9	20.1	15.4	7.1	4.3	4.1	10.8
2020	15.9	23.2	16.5	20	15.1	7	4.9	4.2	10.8

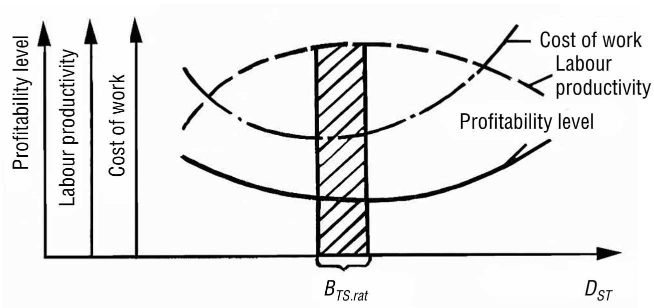

Fig. 3. Dependence of labour productivity B, cost of works C and loss of time TL on degree of engineering specialization DST

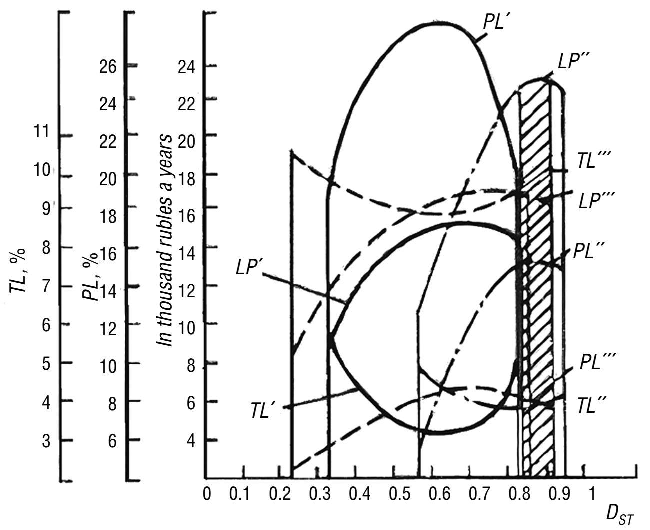

Fig. 4. Dependence of labour productivity B, profitability level P and time loss TL on degree of engineering specialization D_{ST}: — for Bel. NPP; —•—•— for Akkuyu; — — — — for Busher NPP

values of D_{ST}. This zone is also a rational zone for the number of types of work performed by the construction company. For example, for Busher, zone D_{ST} is rational (0.85–0.93).

The results of the analysis have revealed the following regularity: some rational degree of specialization corresponds to the most effective engineering and economic characteristics of the building

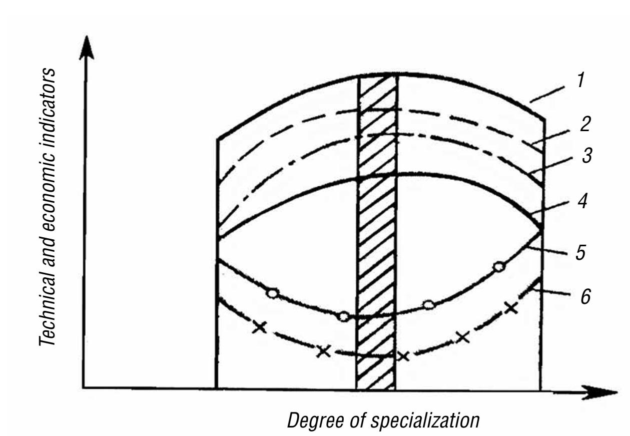

Fig. 5. The regularity of bifurcation, used to analyze the activity of construction companies: 1 — productivity (output); 2 — economic effect; 3 — profit; 4 — profitability; 5 — cost price; 6 — time loss

unit. This general law was called “the law of bifurcation”. This regularity can be used to analyze the activity of building companies (Fig. 5), as it demonstrates a strong correlation between engineering and economic indices with the optimum degree of specialization. Those indices, which do not depend on D_{ST}, although they show secondary factors, do not follow this regularity.

THE FINAL PART

Fig. 4 shows that some indicators (output, profit, profitability, cost of work, loss of time, economic effect) correspond to the best degree of specialization. If we plot the values of engineering and economic indicators on the general graph in the coordinate system, it will show that all the extremums of the functions will be located in the same zone for a certain degree of specialization. Each curve has a zone of the most favourable indicators for a construction unit, in which the output, profit, minimum time losses, etc. are the highest.

The degree of engineering specialization increases with a decrease in the number of types of work assigned to one specialized company, as well as with an increase in the amount of work of one type performed at one site. Hence, dependencies, shown in Fig. 1, make it possible to predict the recommended degree of specialization for construction and installation companies to achieve maximum output, profitability and minimum time losses. This approach makes it possible to improve the engineering and economic performance of NPP construction companies. It is no coincidence that the degree of specialization has increased by 3 times over the last 8 years at the relatively constant level of specialization in the course of NPP Bushehr construction.

The proposed approach to choosing a rational degree of specialization makes it possible for the construction units to plan this indicator for five years, a year, a quarter to assess the economic efficiency of specialization depending on its growth. Among other things, achievement of the best degree of specialization, also depends on the potential of the team, because setting reasonable boundaries D_{ST} is important not only from the economic, but also from the social point of view.

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Выбор рациональной глубины специализации российских компаний, участвующих в строительстве АЭС за рубежом

Специализация — это одна из форм общественного разделения труда, выражающаяся в сосредоточении строительных организаций на выполнение однородных работ или возведение объектов одинакового назначения. Формы специализации играют важную роль в организации производства. Их экономическая эффективность, выражающаяся в первую очередь в повышении производительности труда, возрастает по мере сужения номенклатуры выполняемых работ и обеспечения в рассматриваемом специализированном подразделении более свободного обмена ресурсами. Развиваются четыре формы специализации: отраслевая, предметная (объектная), технологическая и подетальная.

Отраслевая специализация предусматривает выделение организаций, специализирующихся на строительстве определенных зданий и сооружений для отдельных отраслей народного хозяйства. Такая специализация существует на уровне министерства.

Под **предметной специализацией** понимается создание хозяйствующих субъектов, специализирующихся на строительстве зданий и сооружений, имеющих общие объемно-конструктивные модули (например, строительство АЭС, объектов транспортной инфраструктуры и др.). Развивается такая форма специализации на уровне крупных строительных компаний, девелоперских компаний.

Технологическая специализация характеризуется ориентацией строительных подразделений на производство определенных видов работ, объединенных технологией и организацией, в результате выполнения которых завершается определенный этап строительства (например, для АЭС возведение реакторного отделения, вспомогательного здания реактора, здания турбины — бетонные, отделочные, тепломонтажные работы и т.п.). Эта форма получила развитие на уровне специализированных строительных компаний, производственных потоков, участков.

Под **подетальной специализацией** понимается расчленение укрупненного строительного процесса на ряд частных процессов и сосредоточение производства в отдельных подразделениях (например, производство строительных конструкций на заводах железобетонных и металлических конструкций, доборочных деталей — на полигонах строительных компаний; установка строительных конструкций, кирпичная и каменная кладка — на монтажном участке), что в конечном счете способствует превращению строительной площадки в монтажную. Развивается подетальная специализация на уровне специализированных подразделений, бригад, звеньев.

Ключевые слова: *технологическая специализация, глубина специализации, управление проектом АЭС, ГК «Росатом», жизненный цикл проекта, АЭС «Аккую»*

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