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Implementation of NPP–1200 Nuclear Megaprojects Abroad Using Preferential Rules of Flow Construction

The construction of an individual project or a complex is characterized by a number of interrelated factors, which are determined by the technological, volumetric and design characteristics of the construction process, as well as by planning, financial, organizational and technical conditions.
The optimal construction of objects and complexes is based on the organization of all processes in optimal terms, taking into account perfect technology and mechanization with a rational combination of construction, installation and commissioning works, ensuring minimum cost of construction. The optimal variant of construction of nuclear power facilities is selected by comparing a number of variants that differ in the means of mechanization and technology used for certain types of works, duration of construction and assembly works, start and end dates of works, method of construction of facilities, technological sequence of works, degree of combination of construction and assembly and commissioning works, and applied methods of works production.
The experience of design and construction of start-up complexes shows that in the construction of industrial facilities, on-site preparatory and main construction and installation works are performed sequentially. According to the requirements of the norms for the preparatory works, the capital investments are mainly planned to be distributed evenly, which is irrational, as it leads to a decrease in their efficiency and delays the construction period. In the course of preparatory works at the site, the character of the distribution of capital investments by time periods can be different.
As the practice of NPP construction shows, in case of combined sequential execution of preparatory and main construction and installation works at the site, the following options are possible: 1) less intensive accumulation of volumes at the beginning of the preparation; 2) equal distribution of capital investments over the whole preparation (if preparatory and main works are performed sequentially); 3) accelerated accumulation in the middle part and deceleration of this process at the end of the preparation, or more intensive accumulation of volumes at the beginning and deceleration of this process in the middle and at the end of the preparation (if preparatory and main works are combined).
When considering the possible combinations of preparatory and main construction and installation works, it is necessary to take into account the reduction of the total construction period of the nuclear power complex both due to the combination of the preparatory works among themselves and due to their combination with the main works.
Keywords: *NPP–1200 construction flows, on-site preparatory works, critical path, preference rules, installation methods, different options of construction organization*

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PART 1. DETERMINATION OF THE DURATION OF THE MAIN CONSTRUCTION FLOW

The experience of the construction of the NPP–1200 shows that, as a rule, the preparatory, construction and installation works are carried out sequentially at the site. In this case, the critical path of construction of such nuclear power complexes is determined by the sum of the duration of these stages[1] [1, 2]:

$$T = T^d + T^0, \qquad (1)$$

where T^d is the (d) duration of the preparatory works at the site;

T^0 is the duration of the main construction, installation and special works.

Technologically, the possible duration of on-site preparatory works is determined by the following formula:

$$T^d = f\left(t_{ij}, A_{ij}, N_{ij}, S_{ij}, K_j\right), \qquad (2)$$

where t_{ij} is the duration of the i-th critical path work on the j-th facility; A_{ij} is the turnover of the i-th work on the j-th facility; N_{ij} denotes the resources of the i-th work on the j-th facility; S_{ij} — shows the front usage of the i-th work on the j-th facility; K_j is the coefficient of work overlap on the j-th facility.

Since the absolute values of these quantities vary within sufficiently large limits, in order to establish a general pattern we considered the change in β with respect to ΔT^d (β shows the ratio of current costs to the estimated cost of the preparatory work carried out on site).

Processing the data of β in relation to ΔT^d allows to obtain the dependence $\beta = f(\Delta T^d)$:

$$\beta = 1.4907 - 0.0193\Delta T^d + 0.00002(\Delta T^{2d}), \qquad (3)$$

where ΔT^d is the duration of construction and installation works within the time interval from the maximum technologically possible duration of work performance to the minimum one ($\Delta T^d = T^d_{max} - T^d_{min}$) [3].

Determination of the optimal duration of in-situ preparation works by the graphical-analytical method is labour-intensive, so we use the analytical method to solve this problem. The optimal duration of site preparation works includes the construction of

1 Rosatom Group Capital Construction Project Management System. URL: https://atomsro.ru/wp-content/uploads/file/0PORTAL/AtomStroyStandart-2014/Vasilev_SUP_conf.pdf

temporary infrastructure according to the construction plan (site structures, dewatering, dams, etc.), which can be determined using the first derivative β of the possible duration of works ΔT^d equal to zero:

$$\frac{d\beta}{d\Delta T^d} + 0.0004\Delta T^d - 0.0193 = 0. \quad (4)$$

Having carried out the necessary transformations, we obtain the formulas for determining the optimum duration of the preparatory works on site:

$$T_0^d = T_{\min}^d + 0.482\left(T_{\max}^d - T_{\min}^d\right); \quad (5)$$

$$T_0^d = 0.482_{\max}^d + 0.518_{\min}^d. \quad (6)$$

The established dependency (3) allows, given the estimated cost of preparatory works on site S^d, to determine the reduced cost for each option of their performance in the interval of possible duration according to the formula:

$$3_i^d = S^d\left[1.4907 - 0.0193\Delta T^d + 0.00002(\Delta T^d)^2\right]. \quad (7)$$

The maximum and minimum possible duration of on-site preparatory works is determined on the basis of a typical organizational and technological model. When determining $T_{\max}^d$ of sequential execution of on-site preparatory works, the minimum number of resources to be provided for the scope of the works and the minimum number of shifts of their performance shall be assumed, and when determining $T_{\min}^d$, the maximum number of resources to be provided for the scope of the works and the maximum number of shifts of their performance shall be assumed.

The final duration of the preparatory works at the site is determined after the creation of a specific model of their performance, taking into account the resources used according to the chosen option and all the technological and organizational links established by the typical organizational and technological model [4].

For a nuclear megaproject it is important to determine the most expedient solutions for the construction of the NPP as a whole rather than for separate sets of works or facilities during the construction of power stations. Therefore, it is necessary to take into account the influence of changes in the duration of on-site preparatory works on the duration and cost of construction of the nuclear power complex as a whole[2].

The change in the duration of the preparatory works leads to a change in the total duration of the cost of construction of the nuclear power plant. The total effect (loss) depending on the change in the duration of the construction of the nuclear power plant as a whole is determined by the following formula:

$$E = \Delta C^d + \Delta S^d + \Delta F^d + \Delta F_{ch}^d + L_p^d + L_m, \quad (8)$$

where ΔC^d, ΔS^d, ΔF^d, ΔF_{ch}^d shows the (*ch*) changes in costs depending on the period of construction of the nuclear power plant, the (*d*) duration of the period of capital investment diversion of the active part of the fixed assets, and the period of fixed assets utilization; L_p^d is the effect (loss) due to the (*p*) production of additional products, determined by the formula:

$$L_p^d = \frac{E_n K(T_i - T_{en})}{12(1 + E_{np})^{T_o}}, \quad (9)$$

where E_n is the discount factor, which is determined taking into account risk factors (using the example of Akkuyu NPP–1200, risk-free rate (8.25 %), legal risks (2 %), background risks 2.2 %, economic risks 2.2 %, technical risks 3.2 %, total 17.65); K is the capital investment in the construction of the nuclear power megaproject; T_i, T_{en} is the critical path of the construction of the (*n*) nuclear power megaproject according to the reference and comparable options, respectively; T_o is the duration of the capacity development of the project; L_m is the economic effect of shortening the construction period of the nuclear megaproject due to the change in the sum of moral wear and tear during the design and construction period, which can be determined as follows:

$$L_m = C\,(T_o^{\tau} - T_o^{i\tau}), \quad (10)$$

where c is the coefficient of initial wear (management, *m*) of the design solutions; T_o^{τ}, $T_o^{i\tau}$ are the planned and actual construction times of the power plant respectively; τ is the indicator of the degree of increasing obsolescence.

The construction density coefficient of the nuclear power megaproject is determined by the ratio of the total area of the plant, the areas occupied by common facilities, auxiliary structures, workshops and utilities to the total area allocated to the nuclear power center. The area occupied by utilities is determined by their length and the standard width of the right of way using the formula:

$$K_u = \frac{T_{pl} + T_{com} + T_c}{N_{npp}} \le 0.57 \text{ (according to the Code of Rules)}, \quad (11)$$

where K_u is the area utilization coefficient; T_{pl} is the area of the plant (*pl*); T_{com} is the area of common structures, auxiliary facilities, workshops and waste areas; T_c is the area of communications; N_{npp} is the total area of the nuclear power station determined by the master plan.

The beginning of the main works on the construction of the first of the considered facilities of the nuclear power megaproject is determined by the formula:

$$t_1^d = t_1^d + t_{II-1}^d, \quad (12)$$

where t_1^d is the total duration of the first group of the preparatory works; t_{II-1}^d is the duration of the second group of preparatory works at the first unit of the complex.

The time of the combination of preparatory and main construction works of the NPP is determined by the formula:

$$\Delta t_c = T^d - t_1^d = T^d - t_1^d - t_{II-1}^d. \quad (13)$$

The coefficient of the combination of preparatory and main works during the construction of the nuclear power station can be determined by the formula [5]:

$$K_c = \frac{\Delta t_c}{T^d}. \quad (14)$$

PART 2. DETERMINATION OF THE EFFECTIVE DURATION OF PREPARATORY WORKS

On the basis of the data on the scope of preparatory works at the site, peculiarities of the construction site, resources available in the power generating enterprise, volumetric, design and structural solutions of the nuclear power complex, as well as a typical model

2 Kulapin A.I. Energy strategy of Russia until 2035 (Ministry of Energy of Russia). Scientific and practical conference “Project direction «Breakthrough»” : materials. 2016. Pp. 1–10. URL: http://www.innov-rosatom.ru/files/articles/c4bcf5b1329916e8f5b2b339cd2db098.pdf (Last accessed December 1, 2016).

of the organization of work production, an extended organizational and technological model of their performance has been developed.

In order to choose an effective duration of preparatory works at the site, it is recommended to use the method of subdivision into subtasks. The process of determination includes the following steps:

- determination of initial data;
- determination of the search area for the optimal option in terms of duration;
- calculation of options within the search area and selection of the optimal option of performance of on-site preparatory works;
- calculation of a rational combination of site preparation, main construction and installation works;
- calculation of the duration and cost of construction of the nuclear power plant taking into account the selected option.

The search area for the optimum duration of field preparation is determined as follows. The time interval from $T^d_{\min}$ to $T^d_{\max}$ is divided into smaller intervals and then for each of them the costs are calculated taking into account the time factor.

Based on the data obtained at this stage of calculation, the search area (interval) for the most effective duration is determined[1].

In addition to the proposed methodology, it is recommended to use the established dependency (6), which makes it possible to obtain an unambiguous solution for determining the optimal option in terms of duration.

The next step is to specify the duration and discounted cost for each of the options within the established range. The options that fall within the range of the most effective in terms of duration will be considered in more detail, since the duration of the scope of preparatory works on site depends on the resources allocated, the intensity and sequence of individual works, the degree of their combination, and technological and organizational constraints.

For each of the considered options we consider a set of various construction machinery for performance of preparatory works on the site; on the basis of specific reduced costs of performance of a unit of works by one or another machine we establish types and makes of equipment providing performance of works in each interval of the search area.

In the first case, when choosing the type of mechanization options for each type of work, the equipment with the lowest specific costs per unit volume are used. The formation of sets of machines is made from the existing fleet, and the selection is made on the basis of actual (minimum) costs.

On the basis of the calculations, the specific duration and minimum costs for each of the options in the search area are determined. The option with the lowest cost is assumed to be the most effective in terms of duration [6].

In order to determine the value of the overlapping works, the preparatory works on site are divided into groups, and the works of the second group are performed in the order of the construction of the facilities. The works of the second group are carried out first in order to start the main construction and installation works as soon as possible and to maximize their overlap with the preparatory works. It will allow combining the critical path of preparatory works on site, main construction and installation works without attracting additional resources in order to reduce the overall construction period of the NPP complex.

The on-site preparatory works according to the most effective variant in terms of duration, taking into account the combination of works, will reduce the total construction period by the value ΔT, which is determined by the formula [7]:

$$\Delta T = \Delta t_c + \Delta t_o, \tag{15}$$

where Δt_c is the reduction in construction time on the critical path due to the combination of preparatory, construction and installation works at the site; Δt_o is the reduction in the duration of on-site preparatory works under the calculated option compared to the given option:

$$\Delta t_o = T^d_e - T^d_{pr}. \tag{16}$$

The order of construction of NPP facilities and groups of structures is determined according to the (*pr*) preference rules, which determine the order of execution of on-site preparatory works.

Due to the fact that for the economy of the country it is important to determine efficient solutions not only for individual work packages and facilities, but for the construction of power stations as a whole, it is necessary to take into account the impact of the selected efficient option for the performance of the site preparation works on the total duration and cost of the construction of the nuclear power complex.

The most effective option determined in this way will ensure reduction of the total duration and cost of construction of the NPP [8].

The experience of development and implementation of effective options shows that the proposed methodology makes it possible to select the most effective variant of performance of on-site preparatory works in each specific case, providing the optimal duration of their performance, as well as combined implementation with the main construction and installation works, which allows to reduce the cost of their performance up to 3 % (according to the actual data of Akkuyu NPP–1200, Turkey) [9, 10].

PART 3. MODELLING THE PROCESS OF FLOW CONSTRUCTION

At present, deterministic organizational and technological models do not take into account the probabilistic nature of production. In these models, none of the activities of the nuclear power plant depends on other activities, and there is a set of unrelated activities, for each of which start and end dates are set.

Flow charts (cyclograms, or multiple activity charts) are constructed on a plane in a two-dimensional "work – time" coordinate system. The cyclogram describes the interrelationship of works, but in case of deviation from the planned duration of construction of large-scale complex investment and construction megaprojects, the chart should be recalculated and updated, as in these cases the assumed flow of works changes. The multiple activity chart is used when planning the construction of relatively simple standard buildings and complexes (mainly in housing construction) and linearly extended structures.

Matrix organizational-technological models of NPP–1200 in-line construction allow to present in a relatively simple analytical form the complex of operations performed by the in-line method.

When modelling construction processes, network models describing the relationships between works are widely used. However, only one type of relationship between dependent works is used, reflecting their complete priority, whereas in real processes there are much more complex relationships between dependent works. This leads to a distortion of the real work organization and technology when describing processes. To avoid distortion, special constraints need to be imposed to account for these relationships. Network models cannot reflect the requirement of continuity of one or more activities because they reflect the simultaneous organization and execution of activities and require revisions of the network configuration for minor changes. These drawbacks have led to the improvement of network models through the development of various modifications, including aggregated organizational and technological models.

PART 4. SELECTION OF THE OPTIMALITY CRITERION VARIANTS

The choice of the optimality criterion for each particular problem should meet the requirements of the applied analytical apparatus and satisfy the practical needs. When solving the needs of construction planning and implementation, the following factors are considered as optimality criterion or given duration: minimum or given duration of construction, minimum labour intensity and cost of works; minimum costs taking into account the time factor, i.e. taking into account the effect (loss) resulting from changes in the duration of construction; maximum profit and planned profit; minimum current costs and the difference between the current costs and revenues received from the operation of the commissioned facilities by the time of full completion of the construction works, etc.

The choice of one or another criterion depends on the level of the task under consideration, its nature and the construction conditions. The most general criterion, which allows to determine the economic efficiency of the decisions taken, is “the minimum labour intensity taking into account the time factor”, as it takes into account the influence of the time factor in the sphere of construction and operation of the NPP–1200.

The criterion of minimum labour intensity is preferable for a number of specific tasks of construction (distribution of the existing fleet of machines, selection of techniques and options for mechanization of construction processes, etc.), but its application causes certain difficulties connected with taking into account the transfer of past labour (contained in machines, materials, products, etc.), the possibility of comparing the tasks of labour, workers of different qualification, etc. The most flexible criterion is the minimum cost of production. However, its application for workers of different qualifications is controversial. It can be applied provided that the duration of construction is respected in the conditions of comparability of variants, and the duration itself (T) is reflected in the value of production costs. The criterion of the minimum actual cost, which takes into account the construction base, is a more general indicator, which, together with the construction cost and the efficiency of the use of the means of production, is a more general indicator that can be applied in solving higher-level problems that also have the duration of construction as a constraint. In this case, as in the previous one, there is no need to take into account the effect of the time factor, which greatly simplifies the task of finding the optimal variant. The optimality criteria of maximum planned profit and minimum costs make it possible to take into account the value of fixed assets and investments. Calculations according to the criterion of maximum planned profit allow us to determine not only the maximum production of construction products, but also the maximum volume of construction products obtained by applying the most economically favorable production solutions, taking into account capital investments in production [10].

In addition to the above optimality indicators, the general profitability of an energy generating company is applied, which allows maximizing profit while minimizing the cost of obtaining it. Three variants of the optimality criterion have been established: the ratio of profit to construction costs, profit to the fixed assets and profit to all production assets (fixed and current assets). Experimental calculations on all three variants have shown that the greatest efficiency in optimizing the operation of power generating companies is achieved by the criterion of profitability, i.e. the ratio of profit to all production assets.

When solving small specific economic and mathematical problems and in many economic calculations, various optimality criteria are used mainly in natural form.

The objective of the problem should be a function of the set constraints and levels of active actions.

PART 5. SELECTION OF RATIONAL METHODS OF INSTALLATION OF NUCLEAR POWER PLANTS

Availability of aggregate resources, limits of technical expediency of saturation of the work front with resources, organizational feasibility of concentration of construction machines, workers, etc. should be taken into account. Limitations ensure the fulfillment of works in a given volume or determine the limits of fulfillment of any conditions.

Closed, open, integrated and combined methods of installation are used in the construction of industrial nuclear power facilities.

The closed method is used in the construction of facilities equipped with technological equipment, the installation of which must be carried out in closed spaces due to technical requirements. This method provides for the installation of process equipment and pipelines after the completion of the building frame of the whole asset or in some of its sections. It allows the installation of technological equipment with operational overhead travelling cranes.

The open method involves the installation of the main process equipment and pipework in open areas. After completing the installation of process equipment on a separate section of the structure or on the entire building as a whole, the installation of building envelopes is carried out. Application of this method allows increasing the number of free accesses to the place of equipment installation, to increase the degree of convenience of installation, as well as to use various devices (winches, masts, etc.) instead of heavy cranes.

The integrated method provides for the execution of work on the arrangement and installation of equipment support structures, installation of at least one of the sections of process equipment and piping to be carried out in parallel with work on the construction of the building.

The combined method is used for projects where some of the equipment is to be installed outdoors and some cannot, due to technical specifications, be installed until after the main construction of the plant has been completed. Equipment to be installed indoors includes compressors, pumps, air separation units, etc. This method can also be used if it is practical to install some of the process equipment using operational overhead travelling cranes. The options available for each of the four methods of building and plant construction can be characterized. Projects with pavilion-type buildings can be constructed using any of the four methods listed. For projects with structures of conventional type, the methods of construction and variants of technological sequence of works execution are basically the same as for pavilion-type facilities [11].

Technological equipment in these buildings is usually installed on monolithic foundations or plinths. The necessity to observe the process pause for the concrete to gain strength does not allow to vary the technological sequence, when the equipment installation and the construction of foundations and plinths are carried out simultaneously.

When designing NPP facilities, an attempt is made to locate most of the heavy and high equipment on open sites, which significantly reduces the cost of the project. Maintenance of this equipment during operation is carried out from platforms (mainly made of metal) attached to the structures of the process equipment. In order to increase the ease of installation during the construction of the facilities, the installation of the heavy and high equipment should be carried out first, followed by the installation of the racking structures and the rest of the technological equipment.

Methods of construction of multi-storey buildings and mixed-type buildings have their own peculiarities, which are determined by the number of floors, location of equipment on the intercommunication floors, height levels, etc. In the case of single-storey buildings, the work is carried out in horizontal direction, and in the case of multi-storey buildings in the horizontal, vertical and diagonal directions.

When assessing the different duration options for building the project, the value of economic effect is determined from the expression:

$$E = E_{oc} + E_{fca} + E_d + E_c, \tag{17}$$

where E_{oc} indicates the economic effect of reducing the relatively constant part of (*oc*) overhead costs; E_{fca} is the economic effect of reducing the period of operation of (*fca*) fixed and current assets; E_d is the effect (loss) of changing the amount of (*d*) diverted capital investments in the construction of the project; E_c is the economic effect of early (*c*) commissioning of the nuclear power complex.

PART 6. SELECTION OF THE MOST RATIONAL OPTION FOR TECHNOLOGY AND ORGANIZATION OF CONSTRUCTION WORKS

During the development of the statement of the construction method a special role is given to the selection of the most rational options of technology and organization of construction works.

The main documents reflecting the planned technology and organization of construction works of linear or power grid facilities and energy-efficient complexes are flowcharts and cyclogram-based models of the construction process.

Existing methods of flow chart development require time-consuming and labour-intensive calculations and consider the works in a disjointed manner; moreover, they do not allow to choose a single optimal solution taking into account the totality of influencing factors. In order to select a solution with the help of available software, it is necessary to formalize the process of developing time schedules for the construction of an industrial nuclear complex in the following way: a certain industrial complex is given, consisting of j (j = 1, 2, n) facilities to be built in the planned period, each of which requires m (x = 1, 2, m) types of work. The task is to provide a schedule of work execution and to determine the technologically justified and economically feasible duration of construction of the nuclear power complex, while ensuring the most uniform alignment of resource consumption by construction companies engaged in NPP construction. To solve this problem, methods of linear and dynamic programming were used, as well as a number of exact methods based on Johnson's algorithm.

The analysis of the applied methods showed the usefulness of using the modelling method based on preference rules, which is the most commonly used in the development of construction schedules, as well as the random object selection rule and the combination of several preference rules for solving such problems. The choice of preference rules is complicated by insufficient and uncertain information on resources at the stage of construction statement development. Therefore, when evaluating the variant of the schedule developed according to this preference rule, it is necessary to take into account both the reduction of the construction period of the nuclear power plant and the uniform distribution of resources. For this purpose, a dimensionless criterion is used, which is determined by the formula:

$$C = \alpha\frac{T}{T_s} + \beta\frac{P}{n}, \tag{18}$$

where T is the duration of construction of the nuclear complex according to the accepted sequence of construction, taking into account the critical path; T_s is the statutory duration of the NPP construction; P is the number of parallel flows, in which simultaneous types of work are performed continuously at T; n is the total number of facilities in the project; α, β are coefficients taking into account the influence of the NPP construction period and the level of resource consumption. Since the calculation method for determining the numerical values of α and β coefficients is unknown, the method of expert judgment was used for their estimation during the construction of Akkuyu NPP–1200. As a result, the numerical values of α = 1.63 and β = 1.0 were determined. Accordingly, after the necessary transformations, the expression for determining the criterion took the following form:

$$C = 1.63\frac{T}{T_s} + \frac{P}{n}. \tag{19}$$

In order to select the best preference rules according to this criterion, we have developed an algorithm that repeatedly simulates the process of developing a flow chart. The initial data for it are distribution functions of the duration of work types identified on the basis of statistical data taken from the construction method statement.

The developed algorithm provides the following modelling sequence (Fig. 1):

- for each preference rule, a number of facilities in the complex and types of works on them are defined;
- the duration of the types of works on the facilities is calculated by distribution functions using a pseudo-random number generator;
- groups of facilities built in parallel facility sequences are organized according to the analyzed preference rule, taking into account the constraints;
- the total duration of the NPP construction is determined by selecting the longest duration of one of the parallel facility flows;
- the criterion is calculated;
- after a given number of realizations, the distribution of the criterion is determined and its statistical characteristics are calculated;
- selecting the best preference rules by comparing the mathematical expectations.

The best preference rules are: minimum duration of separate types of work, construction of the facility without the first type of work; combination of the equal probability sampling rules and minimum duration of construction of the facility.

Subsequently, each of the four selected preference rules is used to compute and build four variants of the flow chart.

A special algorithm has been developed to solve the task of building a schedule, the computational sequence of which is shown in Fig. 2.

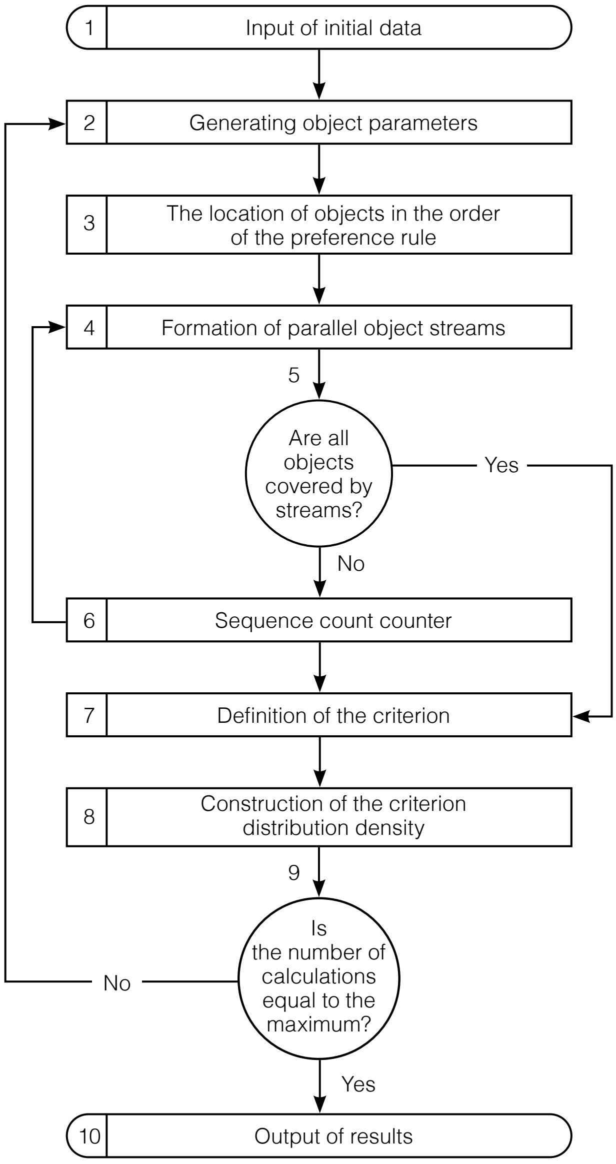

Fig. 1. Algorithm of preference rule selection [12]

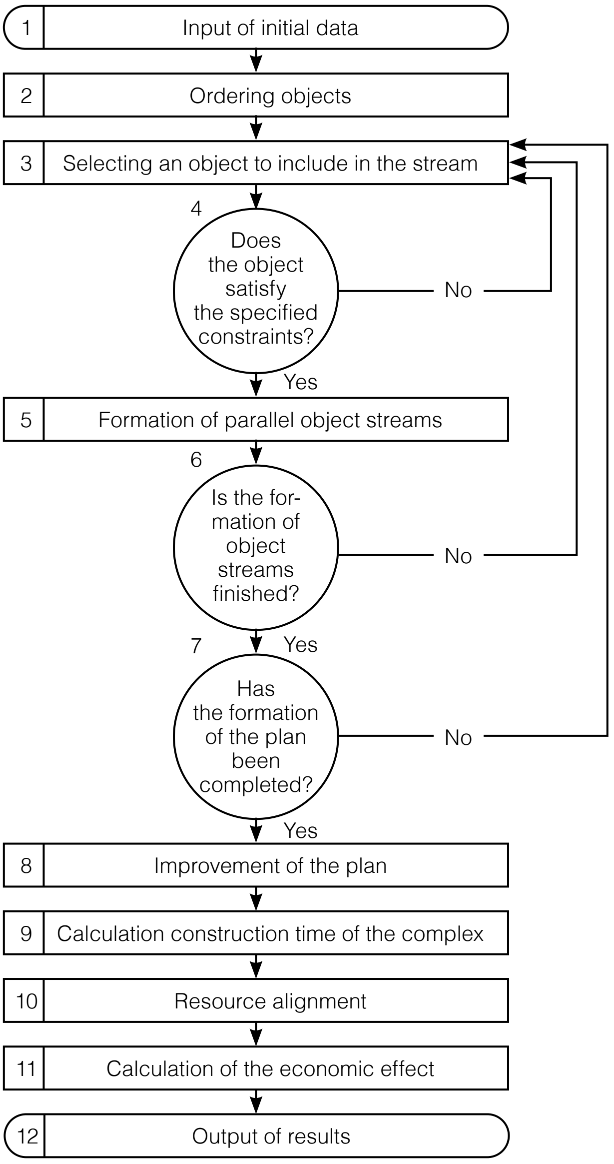

Fig. 2. Algorithm of flow chart calculation

After entering initial data for each of the facilities, they are sorted according to the given preferency rule. The facilities are included in the groups of facilities built according to continuous parallel flows, taking into account the following constraints:

- work on separate specialized and individual flows in the facility stream must be continuous;
- a subsequent individual flow cannot start before the previous one on the same facility is completed;
- the period of implementation of each facility flow, determined by the date of completion of the last individual flow on the last installation, shall not exceed the given prescribed period;
- technological constraints;
- the duration of the construction of facilities should be linked to the terms of delivery of equipment.

The development of an integrated flow is considered complete when each of the installations not covered by it violates the given restrictions when attempting to include it in this flow.

After checking that all the facilities of the given group are covered by the facility flows, the heuristic procedure of plan improvement is applied, which consists in rearranging the installations in parallel facility flows in order to reduce the previously calculated construction time of the group of installations. If there is no reduction, the original plan is adopted. The total duration of construction of the NPP is determined by the maximum duration of implementation of one facility flow out of the number of parallel streams considered.

The best plan with the minimum duration is selected from the plans obtained by applying different preference rules. The resource alignment order for the types of works on the facility is assigned (priority of works). Based on the experience of solving the resource alignment tasks, technically feasible types of works are assigned.

Depending on the priority for each variant of the construction duration, chosen in increments of one week (month) from the interval between the calculated and prescribed construction duration, the earlier start and later finish of all types of works are determined for all facility flows included in the integrated flow that is on the critical path.

In the next step, the installation-specific flows are shifted within their time reserves, with the first installation flow with the maximum construction time being shifted to the rightmost position, followed by the next one with the maximum to the left. The individual installation flows are shifted, taking into account the distribution of resources, so that the smallest sum of squares of the deviations from the average level has the minimum of its maximum consumption.

If the order of alignment of work types is not specified, the diagram of resource consumption is smoothed for each of the resources and ends with the compilation of the overall schedule of resource distribution for each duration option, taking into account the priorities, after which the best option is selected.

PART 7. CONCLUSION

Resource alignment ends with a summary schedule of resource allocation for each duration option from the interval between the estimated and prescribed durations, after which the best option is selected on the basis of economic evaluation (minimum labour intensity). The above methodology has been to calculate the construction schedule of the nuclear power complex of Akkuyu NPP–1200, Turkey. The estimated cost of construction and installation works on buildings and structures of this complex was X millio.rubles, with the prescribed construction period of 60 months (actual not less than 39 months), including the preparatory period and works on testing and adjustment of equipment up to 12 months, but not less than three months. This industrial nuclear power complex consists of 33 facilities (buildings of the main production, storage, auxiliary, administrative, and utility facilities).

As a result of the calculations performed in the software package, an option of the schedule was selected, characterized by the indicators given in Table.

Determination of the intensity of work of the construction system taking into account the operational readiness factor

Phases of the investment cycle	Stages of the investment cycle	Planning period	Loss of time	Readiness factor	Planned intensity (man – days)	Actual intensity (man – days)
Pre-investment	Conclusion of an inter-governmental agreement	4	2.5	0.62	2,747.00	2,747.00
Investment	Design and estimate documentation	7	2.5	0.74	2,747.00	2,024.11
	Construction and installation work	6.25	2.8	0.69	3,652.00	2,522.1
	Technological work	5.6	3	0.65	1,422.00	925.95
	Commissioning works	1.5	0.2	0.88	562.00	495.88
Exploitation	Operating permit	1	0.2	0.83	563.00	469.17

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Реализация энергоатомных мегапроектов АЭС–1200 за рубежом с использованием правил предпочтения при поточном строительстве

Строительство отдельного объекта или комплекса характеризуется множеством взаимосвязанных факторов, которые определяются конструктивно-технологическими и объемно-планировочными характеристиками, а также планово-финансовыми и организационно-техническими условиями.

Оптимальное возведение объектов и комплексов — это организация их строительства в оптимальные сроки с учетом совершенной технологии и механизации при наиболее рациональной степени совмещения строительных, монтажных и пусконаладочных работ, обеспечивающих минимальные издержки по строительству. Оптимальный вариант строительства объектов пускового энергоатомного комплекса выбирается путем сопоставления множества вариантов, которые различаются: применяемыми средствами механизации и технологией производства отдельных видов работ; продолжительностью выполнения строительно-монтажных работ; сроками начала и окончания работ; методом возведения объектов; технологической последовательностью выполнения работ; степенью совмещения строительных, монтажных и пусконаладочных работ; применяемыми методами производства работ.

Опыт проектирования и строительства пусковых комплексов показывает, что при строительстве промышленных объектов внутриплощадочные подготовительные и основные строительно-монтажные работы выполняются последовательно. Согласно требованиям норм на выполнение подготовительных работ планируется в основном равномерное распределение капитальных вложений, что нерационально, поскольку приводит к снижению их эффективности и затягиванию сроков строительства.

В процессе выполнения внутриплощадочных подготовительных работ характер распределения капитальных вложений по периодам времени может быть различным.

Как показывает практика строительства АЭС, при совмещенном последовательном выполнении внутриплощадочных подготовительных и основных строительно-монтажных работ могут быть варианты: 1) менее интенсивное нарастание объемов в начале подготовки; 2) равномерное распределение капитальных вложений на протяжении всей подготовки (при последовательном выполнении подготовительных и основных работ); 3) ускоренное нарастание в средней части и замедление этого процесса в окончании подготовки или более интенсивное нарастание объемов в начале и замедление этого процесса в середине и в конце подготовки (при совмещении подготовительных и основных работ).

При рассмотрении возможных совмещений подготовительных и основных строительно-монтажных работ следует учитывать сокращение общей продолжительности строительства пускового энергоатомного комплекса как за счет совмещения внутриплощадочных подготовительных работ между собой, так и за счет совмещения с их основными работами.

Ключевые слова: *потоки строительства АЭС–1200, внутриплощадочные подготовительные работы, критический путь, правила предпочтения, методы монтажа, различные варианты организации строительства*

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