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17 December 1979

USSR Report

RESOURCES

(FOUO 28/79)

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FUELS AND RELATED EQUIPMENT

ELECTRIC POWER AND POWER EQUIPMENT

KEY TRENDS IN IMPROVEMENT OF THE CONSTRUCTION OF NUCLEAR ELECTRIC POWER PLANTS

Moscow ENERGETICHESKOYE STROITEL'STVO in Russian No 9, Sep 79 pp 2-3

[Article by V.I. Borisov and I.L. Sapir, engineers]

[Text] At the present time the development of nuclear power has become a decisive factor influencing the structure of the country's fuel and energy balance. In particular, energy development in the European sector of the USSR is based chiefly on the utilization of nuclear power.

The national economic plan for the 10th Five-Year Plan period calls for the introduction of 13 million to 15 million kW of capacities at nuclear electric power plants. It will increase even more in the next five-year plan period. In the future the annual entry into service of capacities at AES's [nuclear electric power plants] must reach five million to eight million kilowatts.

The complexity of the task facing building and installation organizations of the USSR Minenergo [Ministry of Power and Electrification] is governed by the fact that nuclear electric power plants are two- to 2.5-fold more labor intensive and materials intensive than traditional thermal plants. Specific indicators of work volumes for nuclear electric power plants are given in the table.

Table

Indicators in terms of 1 kW of installed power	AES with VVER-1000 reactor	AES with RBMK-1000 reactor	GRES with K-800-240 turbine
Amount of concrete and ferroconcrete, m^3	0.14	0.25	0.08
Weight of metal building structures (including facing and fittings), kg	23	38	16
Amount of finishing work, m^3	0.7	0.99	0.16
Floor area, m^3	0.85	0.12	0.04
Weight of pipelines with fittings, kg	7.09	11	3

[Table continued on following page]

Table [continued]

Cost of building and installation work, rubles	100-110	120	80
Labor costs, man-days	4.5	5.6	2.1

Accomplishment of the program planned for the creation of vast-scale domestic nuclear power requires the performance of the following key measures for improving the planning, construction and installation of AES equipment:

A changeover to the construction of AES's in keeping with unified and stable projects.

The erection of AES projects made of prefabricated monolithic structures.

The setting up of a building industry base for the purpose of making possible the combined delivery to construction sites of reactor section structures and other special AES structures.

The creation of stable highly skilled construction and installation teams, which will make possible the continuous entry into service (at a one- to two-year interval) of 1-million-kW-capacity power units at each construction site.

The faster-pace construction of well organized housing projects for construction and installation and operating personnel.

In the USSR Minenergo the head organization in the area of the construction of AES's is the Soyuzatomenergostroy All-Union Association, which is made up of building, building-and-installation and housing construction organizations, precast ferroconcrete and metal structure plants, as well as the Atomenergostroyproyekt [expansion unknown] Institute.

For the successful solution of the problems facing nuclear power is required the active combined work of practically all subdivisions of the USSR Minenergo.

For power units whose entry into service is planned in the 11th and 12th five-year plan periods, the Teploelektroproyekt [All Union State Institute for the Planning of Electrical Equipment for Heat Engineering Structures] Institute has developed a unified project meeting the key requirements for continuous and industrial construction. The single-unit arrangement used in the project makes it possible to arrange for continuous construction with a one-year entry into service rate. Plant-fabricated building structures have been unified.

The Atomenergostroyproyekt Institute in conjunction with the Gidromontazh [State All-Union Construction and Installation Trust of Glavgidroenergostroy [Main Administration for the Construction and Installation of Hydroelectric Power Plants in the Central and Southern Regions]] Trust has developed a prefabricated monolithic protective shell with reinforcement made of sheet metal.

The Gidroproyekt [All-Union Planning, Surveying and Scientific Research Institute imeni S.Ya. Zhuk] Institute has developed a project for an AES with an RBMK-1000 reactor, providing for the extensive employment of unified reinforcement panels used for erecting major areas of the AES's reactor section. However, in the process of further planning, in the working drawings executed the number of type sizes of pillars, crossbars, partitions and ceiling slabs has grown excessively.

In addition, in the projects of both of the above-named institutes insufficient attention has been paid to unification of the building structures of utilities services units, sanitation units and a number of other units for ancillary production purposes.

A key trend in the work of Soyuzatomenergostroy has been the creation of specialized construction industry enterprises. The development of series plans for reactor sections, in which provision is made for the employment of plant-fabricated building structures, will make it possible to create fundamentally new building and installation organizations--so-called nuclear power construction combines (AESK's).

The objective of an AESK is to fabricate and deliver to the construction site a complete set of building structures for the reactor section and other special AES structures. Measures for the improvement of the construction of nuclear electric power plants call for the unification within the framework of a single organization--a nuclear power construction combine--of the base plant for the fabrication of special structures and of subdivisions for the installation of these structures. The following are the necessary conditions for the successful operation of an AESK:

Stability of project decisions, in keeping with which each combine must erect an AES in a period of five to six years.

The faster-pace and complete performance of work relating to preparation of the territory and base-level projects in large areas for future development.

The unification in a single organization of the processes of fabricating, outfitting and assembling building structures.

Precise delineation of the territorial zones for the operations of each combine.

The optimal annual output for a single AESK is two power units with a VVER-1000 reactor, or one with an RBMK-1000.

Under conditions of thorough specialization in the performance of building and installation work and the continuous construction of AES's there has been a sharp increase in the need to observe technological discipline in the construction process. The overall coordination of all work in construction and the ensurance of the timely entry into service of capacities should be accomplished by a general contracting organization (territorial trust).

For a changeover to continuous construction it is necessary to develop appropriate planning forms. Here the proper attention must be devoted both to the drawing up of a scientific program and to supervision of its fulfillment. Scientific planning must of necessity be coordinated for each specialized flowline process and must be in strict agreement with the basic technological rules for the construction of an AES. By these rules must be regulated the following: norms for the duration of construction and appropriate financing year by year; standard item and volume graphs for the completion of work for each specialized flowline process; obligatory deadlines for the delivery of key, auxiliary and non-standard equipment, pipelines, cable, etc., the building and installation work technology for all AES structures, and the choice of key gear, rigging and low-level mechanization equipment; norm-setting documents for labor intensiveness, materials intensiveness and the duration of work for individual construction technology units of an AES; and a quality control system for all types of construction and installation work.

As know-how is accumulated and methods of construction and installation are improved these rules will be refined. The issuance and correction of new technological rules is one of the key objectives confronting the Atomenergostroyproyekt Institute. The fulfillment of these rules will make it possible to assign in good time the front line of operations to allied organizations. Enlisted to take part in this work should be, obviously, specialized installation organizations, as well as Energostroytrud [expansion unknown], Teploelektroproyekt, Gidroproyekt and Orgenergostroy [All-Union Institute of the Planning of Electric Power Projects].

A component of these rules should be an optimal system for the mechanization of building and installation work. Experience in building AES's has demonstrated that the BK-1000 and SKR-2200 tower cranes made by plants of Glavenergostroymekhanizatsiya [USSR State Industrial Committee for Power Engineering and Electrification Main Administration for Construction Mechanization] solve the problem of supplying basic installation gear. It is necessary also to speed up the output of SKR-3500 cranes. Experience in the operation of concrete laying complexes at the Chernobyl', the Smolensk AES and a number of others has demonstrated their high efficiency. However, it must be mentioned that the effectiveness of their employment depends to a great extent on the extensive utilization of powerful concrete pumps and automatic concrete mixers. For the purpose of making possible the required pace of construction, it is necessary in the immediate future to expand considerably the output of concrete pumps and spare parts for them, as well as of manipulators designed for increasing the effective area of concrete pumps.

A highly important condition for the stable operation of building and installation teams is precise organization of the supply of materials and equipment. In the Soyuzatomenergostroy Association at the current time a changeover is being made from the supply of materials and equipment according to orders for an AES as a whole to a system of outfitting in terms of construction technology units. This work is being done together with planning organizations. Classifiers have been developed for construction technology units into which AES projects have been divided.

In the immediate future planning organizations must ensure the thorough issuance of planning and estimating documentation for all classifier elements.

One of the most important conditions for ensuring the timely entry into service of capacities at an AES has been, as a rule, the faster-pace construction of residential and public buildings.

A great number of dwelling units and public buildings in settlements of power engineering personnel are being built at the present time out of brick, which considerably increases building costs. At the present time six active large-panel housing construction plants of the USSR Minenergo are making homes according to plans not in keeping with modern technical specifications and the GOST [All-Union State Standard].

Often in the construction of an AES there are not enough structures for large-panel dwelling units and public buildings, as well as carpenter's items, built-in furniture, etc.

The main problem the Soyuzatomenergostroy Association has been hit with at the present time is an insufficiency of building and installation personnel. In connection with this is required systematic and steady work on the part of planning and building-and-installation organizations with regard to reducing labor intensiveness and improving labor productivity.

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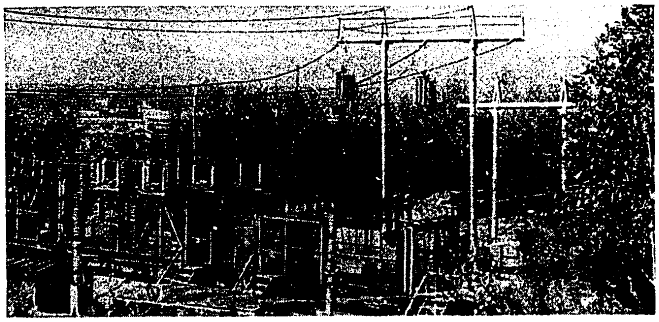
ELECTRIC POWER AND POWER EQUIPMENT

BAYKAL-AMUR MAINLINE ELECTRIFICATION PROGRESS REPORTED

Moscow ENERGETICHESKOYE STROITEL'STVO in Russian No 9, Sep 79 pp 78-79

[Article by A.A. Tamamshev, engineer: "The Baykal-Amur Mainline"]

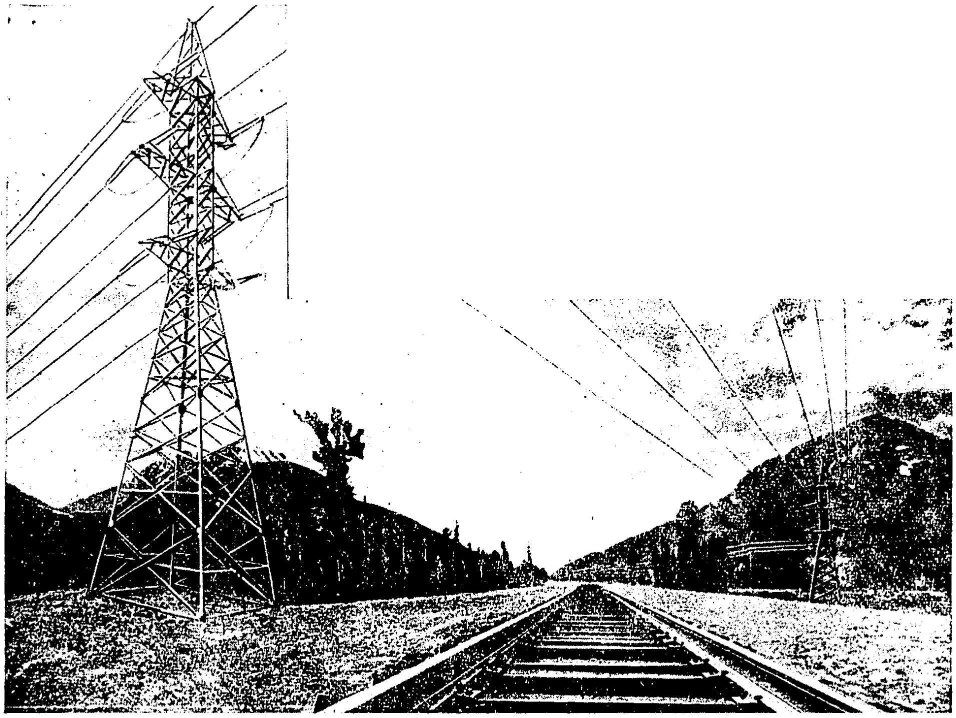
[Text] The BAM. This brief but pregnant word has become close to millions of Soviets. And it is no wonder: The Baykal-Amur Mainline is being built by the entire country.



220 kV Severobaykal'sk Substation

In terms of the extent of its route, the amount of building and installation and other kinds of work, the multitude and complexity of engineering structures and the advanced mechanization equipment employed, the BAM knows no equals in the world. But the BAM, of course, is not only a new cross-country railway line. It is also new towns and settlements, future plants and enterprises. It is also great energy, calling for utilization of the water resources of the Vilyuy, Zeya, Selemdzha and Bureya rivers, as well as of deposits of Neryungri coal.

Construction of the mainline has required an ever increasing consumption of electric power. The major consumers of electric power are Severobaykal'sk, Tynda, Tygda and other worker's settlements, as well as the Baykal'skiy and Severo-Muyskiy tunnels--many hundreds of kilometers remote from powerful sources (the Ust'-Ilimskiy and Zeyskiy GES's and the Neryungri GRES). Therefore, the country's power engineers and, in particular, its electric power network workers, are confronted with great and difficult problems: For supplying with electricity a railway mainline which extends 3140 km from west to east it is necessary to construct 7190 km of electrotransmission lines and to put into service 1.5 million kW·A of transformer capacities at electrical substations.



Crossover of One 220 kV Overhead Line Over the BAM

Electric power network construction in the area of the BAM has its own features, determined primarily by the severe natural climate and complex geological conditions, the lack of materials and equipment centers and continuously operating transportation arteries, as well as by the lack of sufficient experience in designing and constructing VL's [overhead lines] and substations in this region. The high annual temperature differentials (about 80°C) and the severe soil conditions complicate the performance of operations and impose special requirements on the operation of machinery and gear. The diversity of soil--from permafrost to rocky (even along the route of a single electrotransmission line)--results in the need to use in plans different foundation designs, which interferes with a unified technology for carrying out building and installation work. Such specifications for building structures as a drastic reduction in their weight because of complicated transportation conditions, a high degree of prefabrication for the purpose of reducing labor costs at stations, and technological feasibility with allowance for the possibility of using helicopters have acquired a special meaning in the area of the BAM.

It has not yet been possible to solve all problems. But in spite of the difficulties, the teams of planners of the Siberian, Tomsk, Far Eastern and Northwest divisions and of the Irkutsk OKP [okrug committee on transportation] of the Energoset'proyekt [All-Union State Planning, Surveying and Scientific Research Institute of Power Systems and Electric Power Networks] Institute and of builders of the Vostoksibelektroset'stroy and Dal'elektroset'stroy Trusts have done everything possible to fulfill the quotas for supplying the BAM with electricity. Here are some figures: In 1977 were put into service 500 km of 220 kV VL's and 201,000 kv·A of transformer capacities at substations and 16.3 million rubles were utilized; in 1978, 513 km of 220 kV VL's and 50,000 kV·A of transformer capacities, but in more remote and nearly inaccessible regions of the BAM, and 19.7 rubles were utilized. During these years the inexpensive electric power from the Ust'-Ilimskiy GES arrived at the Baykal'skiy Tunnel and in Severobaykal'sk through a 600 km electrotransmission line, and the central section of the BAM and Tynda received power from the Zeyskiy GES.

In the current year it is necessary to fulfill even more strenuous quotas: to put into service more than 800 km of 220 kV VL's and to master more than 26 million rubles of construction and installation work. And in the way that planners and builders are working today is felt the know-how gained from previous years. The technical decisions adopted earlier have been improved; in particular, the metal content of supports for 220 kV VL's has been reduced, a more advanced crossarm design has been developed, providing for suspension of a cable for high-frequency communications channels, and less materials intensive foundations have been introduced. Ever more extensive use is being made of advanced methods of performing work, taking into account the specific features of the area of construction. For example, whereas previously helicopters were used only for delivering freight, now installation work is being performed by means of them, which has made it possible to shorten considerably the duration of construction and to reduce labor costs.

The brigade contract has been introduced universally. Now more than 52 percent of all brigades are working according to this advanced method. The winner of the socialist competition for results of the second quarter of 1979 was the collective of mechanized column No 30 of the Vostoksibelektroset'stroy Trust.

In shock-work fashion are laboring the brigades of communist labor of comrades N.P. Selivanchuk and V.S. Golubev.

"At the present time the key attention of builders has been directed toward furnishing with electric power the Severo-Muyskiy Tunnel now under construction," reports N.K. Petrov, manager of the Vostoksibelektroset'stroy Trust. "For this purpose, in keeping with the socialist obligations assumed, it is necessary to put into service ahead of schedule a 300 km 220 kV VL from Severobaykal'sk to the Severo-Muyskiy Tunnel. Working successfully on construction of this electrotransmission line are the collectives of mechanized columns No 104, 30 and 41 of our trust. Already 605 foundations and 490 supports have been installed and wiring is being installed all over. Another important problem is to complete successfully the construction of a 220 kV VL from Tynda to Neryungri 180 km in length and to furnish with inexpensive electric power from the Zeyskiy GES the Tynda-Berkakit Main Rail Line, and to mine Neryungri coal. Mechanized column No 106 is coping successfully with this problem."

There is no doubt that the quotas for 1979 and for the entire five-year plan period as a whole, for supplying the BAM with electricity, will be fulfilled successfully.

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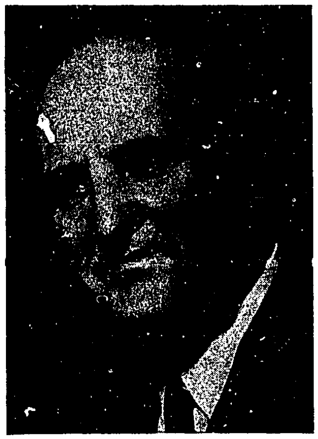
ELECTRIC POWER AND POWER EQUIPMENT

ALEKSEY SERGEYEVICH GORSHKOV HITS AGE 75

Moscow TEPLOENERGETIKA in Russian No 9, 1979 p 75

[Article: "Aleksey Sergeyevich Gorshkov (On the Occasion of His 75th Birthday)"]

[Text] Professor Aleksey Sergeyevich Gorshkov, doctor of technical sciences, turned 75 years old on 22 August 1979.



After finishing Leningrad Polytechnic Institute imeni M. I. Kalinin in 1930, A. S. Gorshkov worked in the Leningrad power system. During World War II he headed the staff of the troubleshooting and production research organization Lenenergo (now "Energoladka").

In 1943 he was appointed deputy chief of the Technical Division of the People's Commissariat of Electric Power Stations, USSR.

A. S. Gorshkov was director of the All-Union Scientific Research Heat Engineering Institute imeni F. E. Dzerzhinskiy from 1948 to 1967. During that time the institute was enriched with many scientific and engineering personnel; an up-to-date experimental base was established in Moscow and an affiliate of the institute in Chelyabinsk. Ties with industry were strengthened, promoting scientific and technical progress in the production and assimilation of heavy power equipment with elevated and supercritical steam parameters. Work was done to further develop central heating, to introduce the first gas turbine and nuclear power istallations, to develop and apply improved facilities for complex automation of power equipment, to master the efficient utilization of various fuels etc.

A. S. Gorshkov is currently working in the institute as the scientific supervisor of comprehensive studies and design work on a heavy, highly economical power unit with elevated supercritical steam parameters.

As responsible editor of IZVESTIYA VTI, member of the editorial board of TEPLOENERGETIKA, and a member of the editorial council of Energiya publishing house, A. S. Gorshkov is actively promoting the dissemination of advanced knowledge and the communication of the operating experience of the leading power stations to broad groups of electric power workers.

He has published a number of works, including the book "Tekhniko-ekonomicheskiye pokazateli teplovykh elektrostantsiy" [Technical Economic Indexes of Thermal Power Stations]. His methodological guides for determining the economic effectiveness of measures to improve thermal power installations and hist texts for upgrading electric power workers' qualifications are used extensively in the power systems.

A. S. Gorshkov has headed a chair in the Power Engineering Academy and is currently teaching at the All-Union Institute for Improvement of the Qualifications of Leading Workers and Specialists of the USSR Ministry of Power and Electrification.

He is a member of the scientific and scientific-technical councils of the USSR Ministry of Power and Electrification, the All-Union Scientific Research Heat Engineering Institute imeni Dzerzhinskiy and the Power Engineering Institute imeni Krzhizhanovskiy.

Aleksey Sergeyevich is an honored member of the Scientific and Technical Society of Power Engineering and the Electrical Equipment Industry. The All-Union Council of Scientific and Technical Societies awarded him the title of honored worker of the Scientific and Technical Society. He is an active participant in the Council of Senior Electric Power Workers.

Being for several years head of the Soviet component in the scientific and technical operations section of the CEMA Permanent Commission on Electric Power, A. S. Gorshkov has made a substantial contribution to the development of international scientific and technical cooperation.

A. S. Gorshkov's work has been recognized with high government awards: the Red Banner of Labor, two "Badge of Honor" awards, and medals.

Greeting Aleksey Sergeyevich Gorshkov on this glorious anniversary, we wish him good health and continued success in his fruitful scientific endeavors.

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ELECTRIC POWER AND POWER EQUIPMENT

THERMIONIC TOPPING OF ELECTRIC POWER STATIONS

Moscow TEPLOENERGETIKA in Russian No 9, 1979 pp 2-7

[Article by V. I. Dobrokhotov, D. V. Karetnikov and R. N. Maraginskiy, candidates of technical sciences]

[Text] An important scientific and technical problem in the thermal power field is improving the efficiency with which the thermal energy derived from burning fossil fuels is used. At modern thermal power stations with unit capacities of 300, 500 and 800 MW, the rated net efficiency is 38-39%. Calculations show that the maximum efficiency, with primary and secondary steam temperatures at a level of 540-560°C, can be brought up to 41-42%. Further improvement of the efficiency of the steam turbine cycle can be achieved only by raising superheated steam temperature; this requires new grades of steel for the power equipment and it becomes necessary to employ two-stage superheating, which complicates power station fuel arrangements. The solution to this problem should come from the scientific research and technical-economic comparisons which organizations of the USSR Ministry of Power and Electrification and the Ministry of Power Machine Building are engaged in.

Another way to increase the efficiency of fossil fuel utilization at thermal power stations is development of efforts in the field of steam and gas cycles and direct conversion of thermal energy into electrical energy. The combination of direct-conversion devices with steam turbine units lets us anticipate improvement of full-cycle efficiency to 50-55% with MHD generators, and to 45-50% with thermionic topping.

In the text which follows we examine some alternative procedures of thermionic topping of the steam turbine cycle of thermal power stations.

The ultimate stage of the combined cycle, in this instance, employs thermionic converters--stationary devices for the direct conversion of thermal energy to electricity. The temperature gradient which "runs" the converter exists between the temperature in the combustion chamber and the maximum temperature of the basic cycle. In this case, the efficiency of the power plant functioning in the combined-cycle mode is expressed by the formula (Figure 1)

$$\eta=\eta_{\text{п}}+\eta_{\text{т}}(1-\eta_{\text{п}}),$$

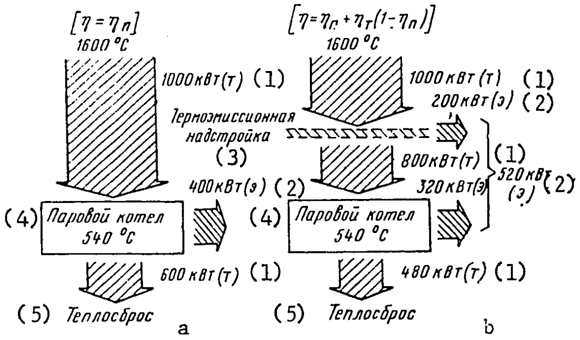

Figure 1. Energy balance of a conventional power station untopped (a) and topped (b). Key: 1. kW (thermal); 2. kW (electrical); 3. thermionic topping; 4. steam boiler; 5. heat discharge

where η_n is the steam power cycle efficiency (it is assumed that, in combined-cycle operation, the whole plant is functioning); η_T is efficiency of the thermionic emission cycle. If, for instance, $\eta_n = 0.4$ and $\eta_T = 0.2$, then $\eta = 0.52$, so that the efficiency increment proves to be considerable. The possibility of using thermionic converters was examined earlier [1], but just in the last few years has the possibility approached the threshold of practical realization [2-4] thanks to progress in thermionic converter development. In the United States, the efforts on topping comprise the basis for a national program of work on thermionic converters. The Stone-Webster and Foster-Wheeler industrial power engineering concerns, together with the "Thermoelectron" and "Razor" research firms, with federal financial support and the participation of more than 10 other organizations, are engaged in planning, design and research studies on experimental plants with toppings. These studies are pointing up not only the possibility of the practical realization of thermionic topping, but its potential economic expediency as well.

Thermionic Converters

A thermionic converter (Figure 2) consists of two closely spaced electrodes --an emitter and a collector--with the space between them evacuated or filled with cesium plasma. The emitter is heated to a temperature at which there is significant thermionic emission. The electrons going from the emitter to the collector, which is considerably cooler than the emitter, build up a negative charge on the collector. When the collector is connected to the emitter across a load, a circuit is formed through which current flows.

The physical processes in thermionic converters have been described [5-7].

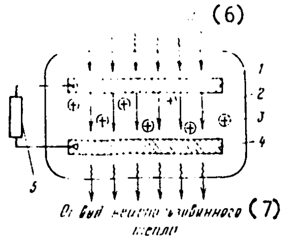

Figure 2. Diagram of a thermionic converter. Key: 1. emitter 1300°C; 2. flow of electrons; 3. cesium ions; 4. collector 550°C; 5. load; 6. heat supply; 7. discharge of unused heat

From the thermodynamic standpoint, the thermionic converter is a heat engine whose operation basically approximates the Carnot cycle. The cycle is not ideal due to irreversible losses in the transport of electrons across the gap and non-optimal conditions of their condensation on the collector. The electron gas, evaporating from the emitter, negotiates the potential field of the interelectrode space, giving up to the field a part of its kinetic energy, and is condensed on the collector. The cycle is completed by the passage of the electrons across the electrical load.

The working temperature of the converter is governed by requirements as to capacity, service life and reliability. If we assume a reasonable--from the standpoint of practical employment--value for the converter's specific capacity, then the working temperature depends on the level of progress in thermionic conversion. Several years ago the working temperature of a thermionic converter at a power level of 3-5 W/cm^2 was about 1600°C. Now, thanks to the use of more improved electrode pairs, it can be reduced to about 1300°C. And further reduction is possible in the future. With the use of more perfect electrodes the converter's internal losses drop (which enables temperature reduction); hence, with the same output the converter's efficiency goes up. The efficiency also rises as a result of reduction of heat losses to radiation from emitter to collector, proportional to the fourth power of the temperature. The results from mathematical analysis [3, 8, 9] provide the basis for this appraisal and are shown in Figure 3. The system employed is an arc system common to most modern thermionic converters and the prospective system is understood to be one in which electron energy transport losses have been successfully eliminated. The curve segments forming an unbroken line have already been experimentally substantiated. Maximum anticipated efficiency amounts to over 35%.

The heat flow through the converter is carried by radiation and by the electrons. The unused heat (i.e., that not converted to electricity) is discharged at the collector. The optimum collector temperature is governed by the collector material and the converter system and lies in the range of 450-600°C.

In practice, the density of the current (current per unit of heat-absorbing surface) passing through the converter depends on the emission capacity of the emitter (i.e., temperature and output performance) and on the internal resistance of the converter's structural elements. The value lies in the

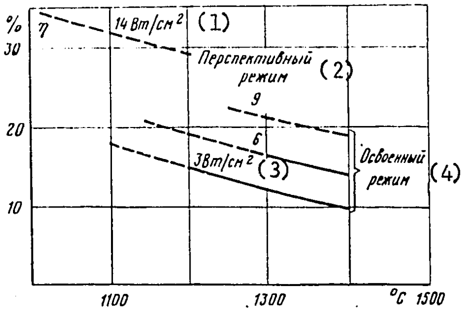

Figure 3. Relationship of calculated efficiency of a thermionic converter functioning with minimum losses to the working temperature for various levels of specific power (the curve segments forming an unbroken line have been experimentally substantiated).
Key: 1. 14 W/cm^2; 2. prospective system; 3. 3 W/cm^2; 4. employed system

8-15 A/cm^2 range. The voltage at the converter output is determined by the contact potential difference of the electrodes less internal losses during the flow of the electron current, and it amounts to 0.5-1 V (to increase the output voltage, in practice, individual thermionic elements are combined in a bank). The specific power of modern thermionic converters is 4-8 W/cm^2. It must be noted that the nominal "electric yield" of present-day steam boilers (i.e., the electric power generated in the steam turbine cycle per unit of heat absorbing surface of the unit) amounts to 8-15 W/cm^2.

At the present time, engineering development of thermionic converters for a temperature range of 1500-1600°C is at the stage of consummation. A service life of about 5 years has been attained in laboratory tests of individual elements. Thermionic energy set-ups in which various heat sources were employed--concentrated solar energy, decay of radioactive isotopes, nuclear fission reaction (nuclear reactors)--have been tested and have functioned successfully for a period of several thousand hours. The total information file of test results has now surpassed 10^7 element-hours.

Thermionic converter development, resulting in a gradual lowering of the working temperature an average of 40-50°C each year, has reached a stage which enables a transition to new ground. Heretofore, the basic materials for the high temperature (emitter) part of a thermionic converter were high-melting metals (tungsten, molybdenum, niobium) and their alloys, which had to be carefully shielded from contact with air by keeping them, for example, under vacuum. Now there are technical decisions moving toward the development of thermionic converters with an emitter working temperature of about 1300°C, which is the upper limit for low-alloy chrome alloys. These alloys are plentiful, much cheaper than the high-melting metals and, in particular, they are able to function in air or in a chemically active environment

[4, 10, 11]. In connection with this development there emerges the opportunity to utilize thermionic converters for the experimental topping of modern thermal power stations. For such industrial utilization, however, there must be either some additional increment to the heat resistance of the converters' structural units (for example, some cermets, carbides and sitalls are more heat resistant and can be used as protective coatings), or further improvement of the converter. Given the current rate of scientific and technical development in this field, it will take a few more years to provide the opportunity for industrial realization of thermionic converters. This time can be used to advantage to experiment with topping.

So we can figure that the thermionic converter, in essence, has arrived, and can, practically, in the very near future, be regarded as an untonomous power generating element which, when heated to 1300°C, produces 4-5 W of power for every square centimeter of emitter surface and forms at output a thermal flux of 15-20 W/cm^2 at a temperature of 500-650°C.

Thermionic Topping

The thermodynamic cycle of a combination of thermionic topping and a basic Rankine steam power cycle in Ts coordinates is shown in Figure 4 [3, 10]. The upper temperature of the thermionic cycle (temperature of thermionic converter emitters) depends on durability required of the materials for operation in a combustion chamber and on thermionic conversion efficiency. The limit value, as noted above, is about 1300°C, but its variation over the cycle for classical steam boiler operation reflects the flame temperature distribution throughout the height of the combustion chamber. In order to provide for high efficiency of the majority of thermionic converters going into topping and for their structural uniformity, it is advisable, obviously, to ensure a balanced temperature field throughout the height of the combustion chamber and, at the same time, to limit the peak flame temperature so as to lessen the formation of nitrogen oxides. The lower temperature of the thermionic cycle is governed by the optimum temperature of the converter's collector, with the proviso that it remains higher than the temperature of the pertinent parts of the basic cycle by a value at least that of the temperature head requisite for heat transfer. Thus, for example, in a shielded zone it is possible to use converters with a relatively low optimum temperature (350-400°C) whereas, in a superheater zone, converters with optimum collector temperature over 550°C should be employed. Under these conditions the basic and topping cycles have no effect on each other.

The true efficiency of stations with thermionic topping differs somewhat from that determined by the formula given earlier. A more exact expression for the efficiency is:

$$\eta=\eta_{\text{п}}+f_k\eta_{\text{т}}(1-\eta_{\text{п}}),$$

where k is a coefficient accounting for unavoidable losses in series connection of single thermionic converters as well as heat losses with respect to topping structural elements (k≈0.8 according to accepted estimates); f is a coefficient accounting for enthalpy used in combined cycle functioning.

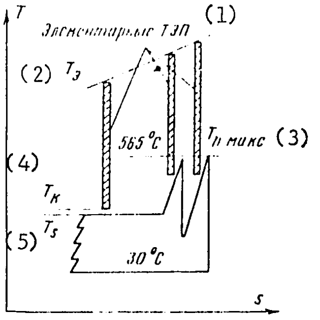

Figure 4. Thermodynamic scheme of a combined cycle in Ts coordinates.
Key:
1. elementary thermionic converters
2. emitter temperature
3. maximum steam temperature
4. collector temperature
5. saturation temperature

To raise it, it is advisable to cover as much as possible of the combustion chamber surface with thermionic elements and, evidently, to use high temperature air heaters as well. On the whole, from engineering calculations of several versions of topped stations, taking into account internal needs and other unavoidable losses, it follows, approximately, that $\eta=\eta_п+(0{,}4\div0{,}5)\eta_т$. Therefore, with the employment of modern thermionic converters a station's efficiency can be increased 6-9% and, prospectively, 12-15%. These figures are significant enough for the idea of thermionic topping to require careful examination.

An important property of thermionic converters is the possibility of putting together a power plant made up of a considerable number of individual converters or groups of converters, i.e., modularity. This enables us to have: thermionic power plant output parameters almost totally independent of the scale factor; increased plant reliability in the case of matrix (series-parallel) switching of individual elements (according to estimates, malfunctioning of even up to 25% of all elements due to internal shorts or circuit interruptions won't lead to a total outage); substantial economy in the process of plant development.

Additional positive features of the thermionic converter may emerge if wholly autonomous (as with galvanic cells) individual converters are used. This will provide: opportunity to distribute converters in groups with each group adjusted for optimum operation in accord with local parameters of heat flow in the zone where the group is situated; repair work by way of replacing single modules or groups of converters; opportunity to use proven technology of industrial mass production.

The difficulties in using the thermionic method relate mainly to the low output voltage of the single converter and comparatively low density of energy generation, resulting in the notable volume of metal used in a thermionic plant, and also to the known difficulties in inverting the low-voltage dc to standard-parameter ac.

But the use of thermionic converters for topping will yield certain advantages.

1. The thermionic thermodynamic cycle has no effect on the basic Rankine cycle. The working temperatures and the heat fluxes of thermionic converters and in the combustion chamber of steam boilers almost exactly coincide. Hence, the standard steam power, energy-producing and other equipment of ordinary stations can be used practically without modification for the basic cycle. Under certain conditions the question may also be raised in the future about the use of topping to raise the efficiency of existing stations in the case of radical reconstruction or the extensive replacement of just steam boilers.

One particular difficulty in producing steam boilers with topping is the need for maximum equalization of the heat-generating field around the walls of the chamber where the thermionic modules are located. As thermionic con-converters are improved the requirement for uniformity of heat generation will steadily diminish.

2. The processes of the combustion of fuel and conversion of heat to electricity are spatially separated.

Thermionic topping can be employed with any type of fuel, including some grades of coal, which would contribute to solving one of the cardinal problems of modern thermal power engineering--upgrading the efficiency of solid fuel utilization.

3. Thermionic converter elements do not bear substantial mechanical loads, so it is primarily the requirement for heat resistance that is imposed on the modules' materials and parts. This simplifies the structural materials aspect of topping.

4. The electrical efficiency of the topping remains almost constant under load variations in the range of 20% to 100% [11-12].

5. *Since it is in essence an electronic device*, the thermionic converter's response to sharp surges in electrical load is practically inertialess.

6. The use of thermionic topping enhances the ecological situation in the station locale. An increase of 10% in station efficiency leads to a reduction of some 20% in atmospheric discharges and 25-30% in thermal contamination.

We will note, finally, that thermionic converters may in the future find use as an intermediate component between MHD topping and the steam power basic cycle, and also as topping in combination with high-temperature nuclear reactors.

Topping Arrangements

The link between the processes which take place in the boiler's steam and water loop and the thermionic converters is the heat led off from the converter collectors. If the thermionic modules are built into the combustion chamber and are in direct contact with the combustion gases (so-called version with built-in topping), the heat may then be removed from the collectors by one of two methods--by direct connection of the collectors with the steam and water loop or by means of an intermediate heat exchanger. A diagram of a steam boiler of the former type is presented in Figure 5. Thermionic modules are placed on the walls of the combustion chamber and in the zone of the radiative steam superheater. Transfer of heat from the modules to the shielded heating surfaces of the boiler occurs via direct heat contact. This is characteristic of a topping system developed in the United States by the "Thermoelectron Corporation" [11,13].

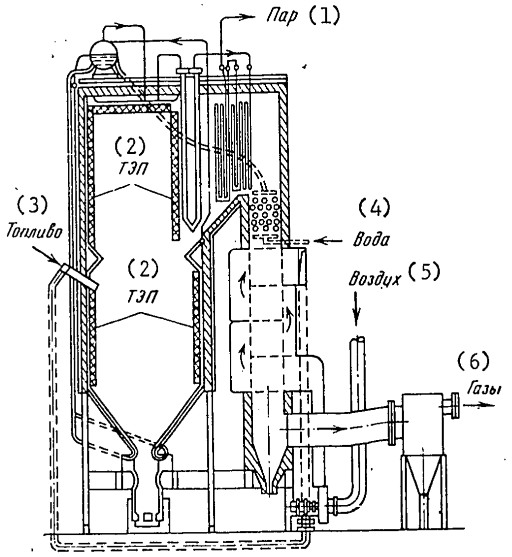

Figure 5. Diagram of a steam boiler with built-in topping (the zones for placement of thermionic modules are cross hatched). Key: 1. steam; 2. thermionic converters; 3. fuel; 4. water; 5. air; 6. gases

In another version, the heat in the topping is transferred from the modules to the boiler surfaces not by direct contact but via heated air specially blown between the modules and the boiler's heating surfaces. The construc- of the unique thermionic converter for this version is shown in Figure 6.

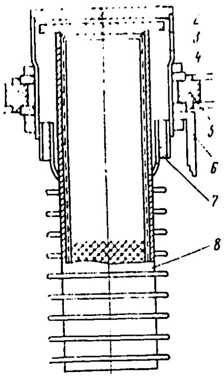

Figure 6. Diagram of a built-in type thermionic topping element with an auxiliary heat exchanger. Key: 1. housing; 2. emitter; 3. collector; 4. cesium space; 5. assembly collar; 6. current tap; 7. insulator; 8. heat pipe

Each converter is equipped with a finned collector heat pipe for effective heat removal by the air flow. A schematic diagram of this type of topped station is shown in Figure 7, which also includes the temperature values calculated for significant areas [11].

The advantages of a system with heat lead-off by direct contact are a lesser temperature drop between the converter collectors and the boiler tubes, and the absence of extra power usage for air input. A shortcoming exists in the difficulties of ensuring sound and stable thermal contacts of the converters and the steam boiler in the case of the unavoidable temperature variations under actual operating conditions.

The heat pipes are heat transfer devices of the sublimation-condensation type designed to carry intense flows of heat with a very small temperature drop--a rapidly developing field of engineering heat physics [14]. Temperatures of up to 600-650°C (range of the collector temperatures of thermionic converters) are regarded as mastered from the engineering standpoint with respect to heat pipes, including conditions involving a hostile environment [15]. There is laboratory experience in the prolonged functioning of heat pipes at even higher temperatures--up to 1500-1600°C--albeit in an inert environment. Progress in this direction is quite remarkable, permitting the hope that the sphere of application of high temperature heat pipes will rapidly expand. For example, a thermionic converter can be equipped with a heat concentrator in the form of an emitter heat pipe. Such converters can be used in those parts of a combustion chamber where the temperature of the gases is high enough but the heat flow is inadequate for effective converter functioning.

In the studies cited, the thermionic elements have been assembled into modules comprising flat plates, each several square meters in size. The modules were arranged into matrix schemes with so many elements in them series connected as to yield an output voltage of 300 V for a module at optimum load. The dc at the converter output was inverted to standard-parameter ac. According to the

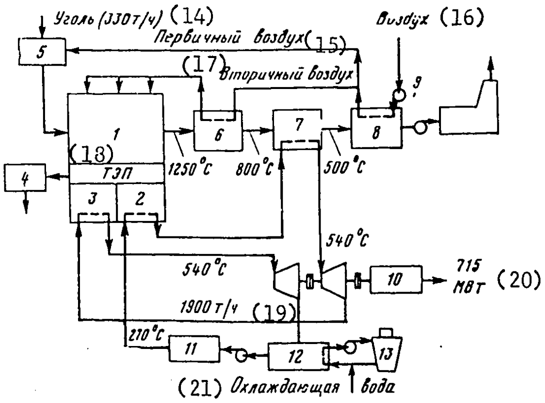

Figure 7. Thermal schematic of a station with built-in topping of the type incorporating an auxiliary heat exchanger. Key: 1. combustion chamber; 2. steam boiler; 3. secondary steam superheater; 4. inverter; 5. fuel preparation; 6. high temperature air preheater; 7. steam superheater; 8. low temperature air preheater; 9. blower; 10. generator; 11. heater; 12. condenser; 13. cooling tower; 14. coal (330 t/hr); 15. primary air; 16. air; 17. secondary air; 18. thermionic converters; 19. 1900 t/hr; 20. 750 MW; 21. cooling water

calculations performed, the thermionic capacity of this station is 330 MW; the overall efficiency is 45.4% in the version with heat removal by air convection and 47.8% with contact removal of heat, at a steam-turbine-cycle efficiency of about 38%. In these calculations, the specific heat supply to topping was taken as 22 W/cm^2, i.e., the same as for ordinary steam boilers (effective $\varepsilon = 0.37$). There is a possibility in the future of approximately doubling the heat supply by improving the combustion process [16]; the station efficiency will thereby go up another 1.5-2%.

A diagram of a steam boiler with external topping [12] is presented in Figure 8. In this case, the steam boiler tube bundles have been replaced by bundles of heat pipes which form the combustion chamber loops. A major part of the heat is taken by the system of heat pipes outside of the combustion chamber where the thermionic converters and steam generating system are located. To lessen the portion of heat that doesn't get used in the combined cycle there is a high temperature air preheater installed at the output of the fire box equipment. By calculations, the efficiency of this plant version may amount to 46.8%, and may be upped to 52% in the future.

A comparison of the versions with built-in topping and external topping shows that advantages of the former are less metal content and less additional

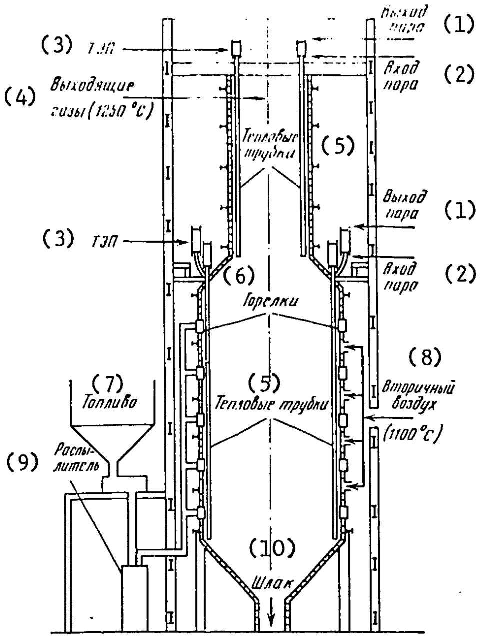

Figure 8. Diagram of a steam boiler with external topping. Key: 1. steam output; 2. steam input; 3. thermionic converters; 4. outgoing gases; 5. heat pipes; 6. burners; 7. fuel; 8. secondary air; 9. pulverizer; 10. cinder

development of nonstandard equipment. However, in the version with built-in topping there may be problems with prevention of slagging of the modules when low grade fuels are used, and penetration of combustion gas light components (primarily hydrogen), at the elevated temperatures, into the working space of the thermionic converters. In the version with built-in [as published] topping, due to the separation between the combustion chamber and the converters by a heat pipe, the solution of these problems is considerably simplified. In this version, too, there is no problem of equalizing flame temepratures around the combustion chamber (the heat pipe, being an isothermal device, averages out temperature over its cross section and conveys the heat flow from the combustion chamber at the averaged temperature).

However, the present lack of engineering experience with high temperature heat pipes with large individual capacity in a combustion-product environment is a serious handicap to realization of the latter version. Economic estimates of the cost of thermionic topping done by specialists in the United

States indicate that, for built-in topping, the cost of the thermionic equipment including overhead and profit amounts to $250/kW of installed topping capacity (in 1976 prices). For external topping the figure is $390/kW. This doesn't include the cost of additional equipment necessary to cover operation of the topping at the plant. Because of the sharp increase in the price of electric power in the United States, a comparison of these data with the cost of an installed kilowatt on an absolute scale is difficult. Comparative estimates indicate that specific capital outlays for topped plants may be just a little higher than for conventional plants, so that as a result of fuel savings the topping will yield considerable economic gain in the final analysis. It is impossible to avoid reviewing the criteria of economic effectiveness when fuel costs are showing an upward trend.

Conclusion

Progress in development of the thermionic method of conversion has reached a level where thermionic converters can function in an ordinary atmosphere or even in an evironment of combustion products from common fossil fuels. The most significant advantage in this case is that thermionic converters can be integrated with the heating surface of steam boilers and used as high temperature topping of the steam turbine cycle of thermal power stations.

The efficiency of the combined cycle may already be around 45%, and as the thermionic converters and steam boilers are improved, it may reach 50-52%. The importance of the matter here discussed, its anticipated major economic impact, and the existence of real scientific and technical stores appear to provide the foundation for going ahead with comprehensive studies using test installations to further improve the thermionic converter and examine possibilities for designing steam boilers under consideration of topping in order to formulate the scientific and technical prerequisites for a sufficiently precise engineering appraisal of the technical and economic prospects in this pursuit and, as a possible consequence, to go ahead and build an experimental thermionic topped steam boiler.

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FUELS AND RELATED EQUIPMENT

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ENVIRONMENT AND DEVELOPMENT OF GAS EXTRACTION IN NORTHERN USSR

Moscow IZVESTIYA AKADEMII NAUK SSSR, SERIYA GEOGRAFICHESKAYA in Russian
No 4, Jul-Aug 79, pp 52-63

[Article by A. V. Yepishev: "The Effect of Geographic Conditions and the Requirements of Environmental Protection on Development of the Gas Industry in the Northern USSR"]

[Text] This article investigates the unique physical and economic geographic conditions and special environmental characteristics of the primary locations of the gas industry in the North, compares their effect on the development of the sector, and proposes ways to take this effect into account in planning development of the gas industry in the most promising regions.

The gas industry is a promising, swiftly developing sector in the Northern USSR. The process of industrial development of gas deposits covers all the new territories; a series of crucial problems of development of the North as a whole is concentrated in them. The regions of gas industry development emerging there are becoming the "testing ground" in which the effectiveness of various key aspects of the strategy for development of the entire zone must be confirmed.

Geography is very important in considering the regional characteristics of development of the North. The geographic approach makes it possible to deepen and supplement the generally accepted methodology of economic planning for development of the sector in the undeveloped regions of the North by studying the effect of the economic geographic position, natural conditions, and environmental demands.

In large part geographic conditions determine differences in the efficiency of development of the gas industry in various regions. Planning practices and the necessity of comparing alternatives for placement of enterprises demand clarification of regional differences in the effect of geographic conditions, a comprehensive assessment of them, and consideration of the policy of developing particular territories in the North. This article attempts to find ways to solve these problems, and this has significantly predetermined this scientific methodological orientation. Of course, such an evaluation must be made first of all for the most important prospective gas industry regions.

The territory where the sector is located in the North includes gas extraction regions, deposits and groups of deposits, and gas pipeline corridors. Overall these regions occupy a considerable part of the North in the European USSR, Western Siberia, and Western Yakutia. At the same time, they typically have differentiation of location within the zone by regions with different geographic conditions. An analysis of the raw materials in different regions of the zone shows that the northern part of Western Siberia is most promising for creation of a gas extraction industry. This region already has extremely large proven gas bearing structures and its gas reserves have the highest density. The Komi ASSR and Yakutia have the geological prerequisites for increasing gas reserves to compensate for deposits now being worked and to increase extraction.

The North Tyumen' gas region occupies a leading place in gas extraction at the present and for the future. The deposits discovered there, Medvezh'ye, Urengoy, Yamburg, and Zapolyarnoye, have balance reserves of more than 1 trillion cubic meters of gas. Each of these deposits occupies several thousand square kilometers. Two other extremely large deposits are the Kharasavei and Bovanenkov deposits on the Yamal Peninsula.

The gas pipeline systems in the principal extraction regions of the northern Tyumenskaya Oblast and the Komi ASSR are being formed with due regard for the established geography of gas consumption: the principal gas customers are located in the European part of the country. The principal lines for transporting gas from the North are the following: Vuktyl — Ukhta — Torzhok, Medvezh'ye — Punga — Ukhta — on to Torzhok, Medvezh'ye — Punga — Nizhnyaya Tura — on to the Central Zone, Urengoy — Tyumen' — on to Chelyabinsk, and Yamal — Ukhta.

Evaluation of the Economic Geographic Position of Gas Industry Regions

The economic geographic position of the regions can have a significant effect on development of the gas industry: with the shifts of the sector to the eastern and northern regions of the country this will become more important.

Evaluation of the economic geographic position requires an analysis of current progress in development of the regions and planned changes in the future. The current process of development has the following regional characteristics (see Figure 1, next page). In each region development is carried out along major interregional transportation lines: primarily railroads and the Northern Sea Route in the European and Western Siberian North, and by river and highway in Western Yakutia. The transportation centers of Nar'yan-Mar, Pechora, Ukhta, Urengoy, Surgut, Yakutsk, and Tiksi are developing at the connecting or intersecting points of these main routes, the most favorable geographic locations. New towns are springing up where existing settlements are being expanded to play the role of local development bases for several fields or a region (the cities of Nar'yan-Mar, Usinsk, Ukhta, Nadym, Urengoy, Surgut, Yakutsk, and the field settlements of Vuktyl, Yagel'nyy, and Mastakh) in regions of concentrated development of the sector. Tyumen' and Tomsk

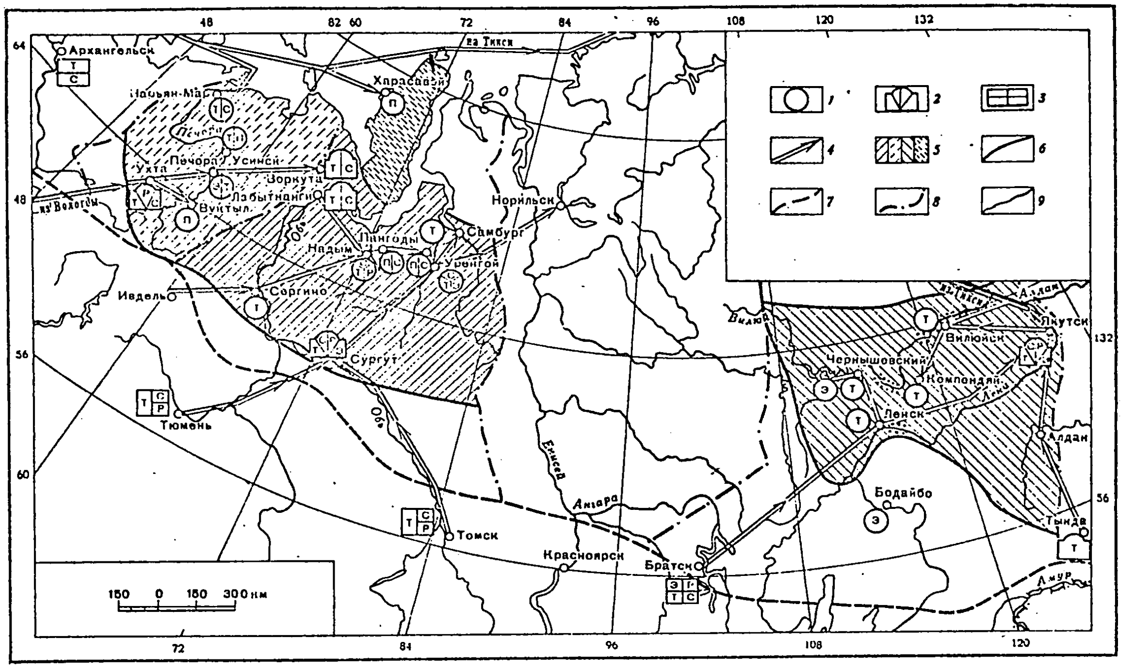

Figure 1. Structure of Development of Territory in the North for Evaluation of the Economic Geographic Position of Gas Industry Regions: Primary bases of development -- (1) local; (2) support; (3) rear support; (4) axes and directions of development; (5) place occupied by gas industry territory with respect to favorability of its economic geographic position; Boundaries -- (6) of gas industry territories; (7) of the southern zone of the North; (8) of the Northern regions; (9) of the zone of water intake for industrial needs; Elements of the infrastructure -- (T) transportation centers; (Э) power bases; (C) construction industry bases; (P) repair bases; (П)field settlements.

act as support bases. The methods used to operate installations of the sector are also linked to differences in territorial development: the tour of duty (watch) method for the entire Yamal region, for certain gas preparation shops at large deposits, and for compressor plants that are far from existing development bases; permanent residence by service personnel at other deposits (in the communities of Pangody and Vuktyl) and for base compressor plants (Nadym, Peregrebnoye, and others).

Location relative to established development bases and main transportation lines allows an assessment of the advantages of the economic geographic position of prospective regions for development of the sector. The economic geographic position is described below on the basis of particular factors and possible methodological approaches to evaluating them are suggested.

Position relative to consumers. This may be evaluated by comparing indexes of the average distance of gas transportation for base years in the immediate and remote future. The average distance together with a whole system of other indexes is now used to evaluate solution alternatives for the development and location of gas transportation systems (Furman et al, 1977). The average length of gas transportation l_{ave} is found dividing the volume of transportation work QL by the volume of gas arriving Q_a

$$l_{ave} = \frac{Q_1L_1 + Q_2L_2 + \dots + Q_nL_n}{Q_a} \text{ км}.$$

The average distance may also be evaluated in cost terms, adopting an arbitrary cost per kilometer of gas pipeline as the unit of measurement. According to our calculations, the average distance in gas transportation in the long run varies in the following ranges: 3,000-3,300 kilometers for Tyumen' gas; 2,100-2,150 kilometers for Northern European gas; from 250-450 kilometers (consumption within the region) to 2,300 kilometers (for transportation to Primorskiy Kray) for Yakut gas.

Because the sector has a high index of materials-intensiveness it is very important to evaluate another factor of the position, remoteness of gas industry regions from the enterprises that supply elements of fixed capital and from support bases. A calculation of the relative remoteness of each region makes it possible to compare their transportation geographic positions. Taking the smallest calculated remoteness value as one, we derive correction coefficients to it for the other regions to reflect the increase in number of days required to deliver freight in comparison with delivery to the standard region.

According to calculations made with due regard for freight storage time at transshipment points, the coefficients of relative remoteness of regions from the nearest plant producing pipe (in the city of Vyksa) compared to the distance for the North of Western Siberia, which is least remote, were as follows: 1.1 for the European North, 1.9 for the Yamal Peninsula, and 1.2-1.3 for Western Yakutia. The relative remoteness may be assessed economically by calculating national economic losses from the "freezing" of the freight during the transportation process (Burkhanov, 1971).

The position of prospective regions relative to regional factors of location. This may be evaluated by comparing the remoteness of prospective gas territories from internal development bases and transportation axes. The manifestation of regional factors of location related to prospects for development of the gas industry is evaluated by experts in the following manner:

1. For the European North and Yamal and Gydanskiy peninsulas — worsening of the position in a northeasterly direction with greater distance from development bases, transportation networks, and reliable sources of water supply;

2. For the remaining gas territories of the Tyumen' North — favorable position related to gravitation to bases and transportation networks, but with a growing scarcity of water resources;

3. For the gas territories of Yakutia — an improvement in the position in a westerly direction related to the emergence of a new economic geographic situation, drawing closer to the Lensk — Mirnyy highway and to consumers in the northern rayons of Irkutskaya Oblast and in connection with favorable conditions for insuring year-round water supply.

The economic geographic position improves significantly with continued development of the "economic framework" of a territory, in particular with construction of Synya — Usinsk and Surgut — Urengoy railroads.

The factor of position relative to other gas industry regions. This should be assessed from the standpoint of receiving an additional economic impact from the possibility of using existing sectorial material-technical facilities or building them for developing regions or regions just opening up.

The impact of this factor is realized most fully when a series of gas extraction regions is connected up in one direction or where regions with different directions of gas transportation are located close to one another. In this respect, the development of the transportation link to Yamal gas is less advantageous than successively connecting up the Medvezh'ye, Urengoy, Yamburg, and Zapolyarnoye deposits. The gas industry regions in Western Siberia have the greatest potential for neighboring and intermediate economic geographic positions.

The possibility of cooperation between the gas industry and other sectors that establish prerequisites for the development of the particular region plays a definite part in improving the economic geographic position of the gas industry. A present-day example of cooperation is the share participation of the Ministry of the Gas Industry and the Ministry of the Petroleum Industry in financing construction of the Surgut — Urengoy section of the Surgut-Kogolymskaya railroad. The greatest impact from cooperation is possible for the North of Western Siberia (excluding the Yamal Peninsula) because of the large scale of construction, whereas the Yamal Peninsula and Western Yakutia have the least potential. To evaluate the economic impact from cooperation with other sectors in the North we suggest relating expenditures for the regional infrastructure for all sectors of specialization planned for the coming 15-20 years proportional to the national economic impact from the production of this output by the sectors in the region with due regard for the time factor (Faustov et al., 1975).*

Thus, an evaluation of extraction areas at the regional level shows that the areas of Western Siberia (without the Yamal Peninsula) have the most favorable economic geographic position and the Yamal Peninsula has the least.

Special Features of Considering Natural Conditions When Building Production Installations of the Sector

When building production facilities in these regions the problem arises of determining the uniqueness and intensity of manifestation of local natural conditions and their regional differences. Because the greatest differentiation of natural conditions occurs on the routes of gas pipelines, the questions of considering and evaluating their effect on the organization and cost of construction are very important.

The conditions of construction of gas pipelines in northern regions differ significantly from conditions in the middle zone (see Figure 2, next page). They determine the seasonality of certain production operations and significantly lengthen the total construction time for installations. The specific importance of particular natural factors in the total impact of natural conditions will vary because of regional differences. Thus, where construction operations are carried on in the open air the air temperature is most important in Yakutia, but on the Yamal Peninsula the combination of air temperature and wind velocity is crucial. When selecting a route in the European North and North of Western Siberia the degree of flooding in the presence of permafrost is most important, while in the mountainous regions of Eastern Siberia and the Northeast the topography is the key consideration.

At the present time the effect of natural conditions is evaluated in consolidated calculations in the preplanning and technical specifications stages by groups of natural factors based on available information about the region. Specifically, the climatic group of factors, which

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* Major interregional expenditures and different ways to spread them among the principal prospective sectors indirectly confirm the proposition expressed in the literature as to the necessity of a differentiated (understated in the initial stage of development of the sector) evaluation of the efficiency of capital investment in regions just being opened up (Agranat, Loginov, 1976; Kirillin, 1974).

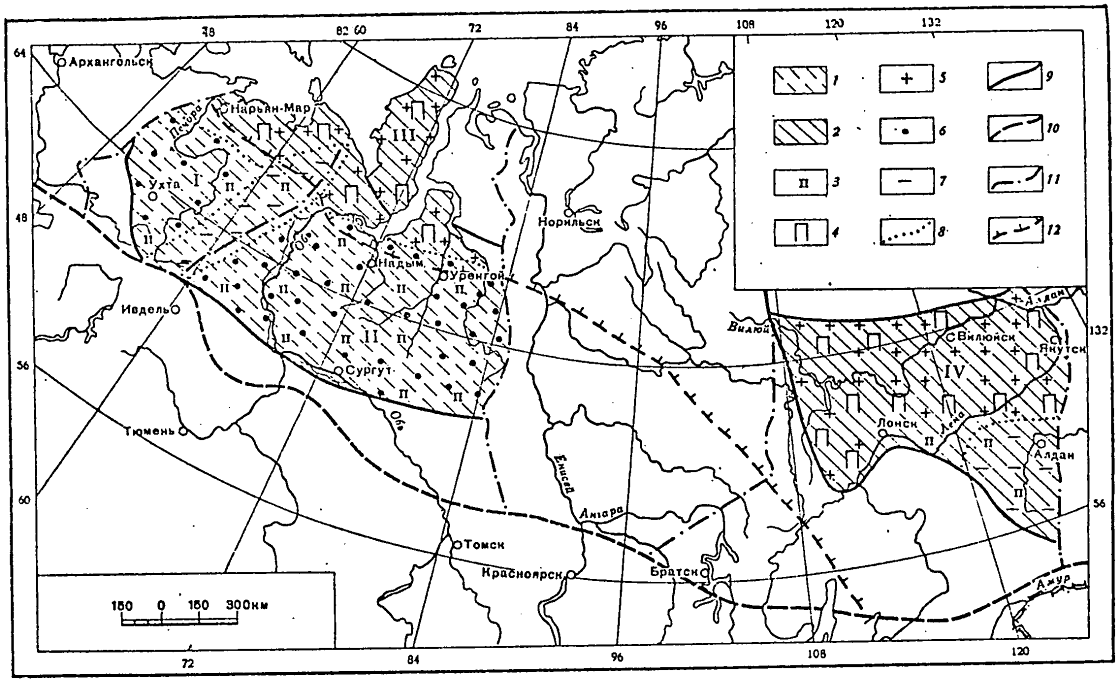

Figure 2. Evaluation of the Impact of Natural Conditions in Connection with Development of Gas Extraction in the North: Territories with different levels of increase in gas pipeline construction costs owing to natural conditions -- (1) 24-30%; (2) 31-39%; Number of days of no-work in open air as percent of days in the year -- (3) 2-10%; (4) 10+%; degree of vulnerability of environment with development of gas industry -- (5) maximum; (6) moderate; (7) minimal; (8) territorial boundaries; (9) boundaries of primary gas industry regions; (10) boundary of southern zone of North; (11) boundaries of Northern regions; (12) boundary of southern line of solid permafrost. Gas regions: I -- European North; II -- Northern Western Siberia; III -- Yamal Peninsula; IV -- Yakutia.

determines the seasonality of jobs and makes work in the open air impossible on some days. However, different criteria are adopted to calculate allowable air temperatures, wind velocity, and precipitation in the form of rain and snow. This is shown graphically in S. A. Rakita's work (1977).

It appears that to standardize the basic criteria that mean a stoppage of work in the open air, we must adopt the permissible values of air temperature (-40 degrees C.) and wind velocity (15 meters/second) that are most widespread in planning practice. A study of long-term observations showed that the greatest frequency of days in the year with temperatures below -40 degrees C. and wind velocity of more than 15 meters/second is observed in the more northern and eastern regions of prospective development. The number of no-work days per year ranges from two to 19 percent depending on regional conditions. These findings make it possible to divide the territory of these regions into a southern part and a northern part, for which the proportion of no-work days ranges from two to 10 percent and more. The latitudinal boundary between these parts runs between the cities of Vorkuta and Pechora in the European North, between the settlements of Tazovskiy and Urengoy in Western Siberia, and between Yakutsk and Chul'man in Yakutia. Regional differences in air temperature and wind velocity are reflected in the organization of gas pipeline construction in different sectors.

Topography, hydrography, and permafrost conditions are evaluated by choosing coefficients of increase in construction costs envisioned in normative documents currently in use: K_r for territorial regions of the country with especially complex construction conditions; K_{tp} for the topographical conditions of a territory. However, the problem is made difficult by the fact that the line must be broken into distinct sectors corresponding to the requirements of definite values of K_r and K_{tp} on the basis of a study of natural conditions. In this case, even in the stage of consolidated calculations and drawing in as much available information as possible, it is necessary to strive for a more detailed breakdown of the route into sectors that reflect the demands of normative coefficients of increased costs.

The analysis made by us of natural conditions along the routes of prospective gas pipelines enabled us to divide each of them into sections using normative coefficients of increase relative to the initial cost of construction. On this basis the full cost of building one kilometer of each section was calculated. A more differentiated approach to evaluating natural conditions along routes makes it possible to determine the cost of building gas pipelines with greater accuracy. At the same time, it becomes possible to make a more reliable quantitative evaluation of the effects of regional difference in natural conditions on the cost of construction in the North. Thus, our analysis showed that the increase in gas pipeline construction costs traceable to natural conditions varied from 24 to 39 percent. In most of the sections evaluated (primarily marshy permafrost ground) this index was 34-39 percent. For sections with thawed ground the increase in cost was less than 30 percent. Thus, the increase in construction costs owing to natural conditions for the more northern parts of the prospective pipeline routes evaluated (marshy areas in the permafrost zone) was about 10 percent greater than for sections to the south. In other words, natural conditions in the North cause a meridional pattern of increasing construction costs.

Geographic Aspects of the Relationship Between the Gas Industry and the Environment

Current scientific literature has suggested a territorially differentiated approach to the problems of using, protecting, and restoring the natural environment in the North (for example, Agarnat, 1976). The essence of the geographic approach is to forecast regional differences in industrial impact on the environment and the vulnerability of the environment, and solving the problem of environmental protection with due regard for these factors. Regional differences in the interaction between the environment and gas industry facilities depend on characteristics of the location of the sector and differences in natural conditions in the regions. It must be considered here that the greatest industrial impact on the environment is created by spread-out extraction installations, while the vulnerability of northern territory is seen most strongly in the construction of linear facilities, that is, pipelines.

The industrial impact that is created results from the consumption (withdrawal) of natural resources and discharge of pollutants. Among the natural resources consumed are water, mineral raw material, and wood for production of building materials, territory taken for development, and the natural gas for the sector's own regional needs. The discharge of industrial pollutants depends on the physico-mechanical composition of the raw material being extracted, by-products of extraction (condensate, petroleum, and layer water), and chemical agents used in gas exploration, extraction, and transportation (methanol, diethyleneglycol, and others).

The volumes of natural resource consumption and discharge of pollutants are determined by the degree of production concentration (they can be calculated by projected norms). Concentration of the gas industry relative to the environment plays a dual role. The lower specific expenditure of water per unit of output and reduction in built-up area are important ways to rationalize the use of nature in northern regions. At the same time, this process involves an intensified impact of the sector on each unit of territory taken for development. The radius of manifestation of industrial impact enlarges here and territorial differentiation is greater: the volume of resources extracted per unit of territory and the content of pollutants will decrease at greater distance from the industrial installation.* However, the cause of pollution of the water and air basins the radius of industrial impact will significantly exceed the territorial distribution of the impact on resources consumed.

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* Thus, an analysis of materials on the development of deposits makes it possible to divide their territory up into zones by intensity of withdrawal of natural resources: intensive (land, water, timber, and

It should be observed that the area drawn into interaction with gas industry installations is much greater than the territory actually occupied by these installations. With greater production concentration this relationship intensifies. According to our calculations the territory now occupied by installations of the sector in the North is about 20,000 square kilometers, so we may consider that the sector is having an impact on an area of hundreds of thousands of square kilometers.

When choosing the optimal variation for location of the sector in the North, in addition to a determination of the industrial impact on the environment there must be an estimate of the degree of vulnerability of the environment. The two types of data complement one another. The degree of environmental vulnerability is linked to characteristics of natural conditions. With identical conditions of impact on the environment (industrial impact) consequences may differ depending on the concrete natural situation. In other words, natural characteristics may aggravate or mitigate the industrial impact. Environmental vulnerability manifests itself in the North with the following types of impact by the gas industry: pollution of bodies of water and the air; removing the vegetative cover; and impact on the soil or ground. The special characteristics of their vulnerability in the North are reviewed in the scientific literature (PROBLEMY SEVERA 1973, No 18, and others). With respect to the gas industry, the additional complexities of environmental protection related to the greater vulnerability of the Northern environment may be noted.

During drilling work stable drilling platforms without vegetation should be chosen to preserve the heat balance in the top layer of ground. Chemical treatment of the flushing liquid used in drilling and pumping runoff water into special ejection wells are required to prevent contamination of ground and surface water by toxic substances.

Because the rivers of the North have less capability for cleaning themselves, decontamination of industrial runoff is a serious problem at deposits of the Urengoy type, covering large areas. The volume of industrial runoff at a deposit where gas extraction is up to 100 billion cubic meters a year is several thousand meters a day. It has been established that during the exploitation of deposits the mineralization of outflowing layer waters rises significantly, to 16-18 grams/liter (Medvedskiy et al, 1978). Centralized collection of waste water must be set up to prevent the contamination of various sectors. The increased air humidity in the North and lessened self-decontamination potential make it necessary to avoid polluting the air with products of combustion, especially in oil field regions which have significant discharges of by-product gas, for example the middle Ob'. Because it takes many years for a forest to replace itself, there must be higher requirements for preservation of the forest and replacement of the forest in regions of concentrated gas development, in the transitional zone from the tundra to the taiga.

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mineral and hydrocarbon raw materials) -- a few kilometers within the field; moderate (water, timber, mineral raw material) -- dozens of kilometers within the gas extraction region; slight (timber and mineral raw material) -- dozens to hundreds of kilometers.

The vulnerability of the Northern environment is considered most fully in the construction of pipelines. This is done through the construction norms and rules that are worked out. They recommend protective steps and consider accumulated construction know-how as fully as possible. However, unforeseen accidents and fires in gas line and compressor plants, especially those located in forested areas, cause significant harm to the environment.

An evaluation of the characteristics of vulnerability based on topography, hydrography, vegetation, and frozen ground conditions enable us to identify three degrees of environmental vulnerability in order of diminishing value of regions of prospective development (see table below).*

The regions of the European North and North of West Siberia above the Arctic Circle have the greatest (degree I) vulnerability. Degree II corresponds to regions located south of this boundary within the distribution of permafrost. Sections of regions on passes through the Polar Urals and Stanovoy Range belong in the third category of vulnerability. A combined evaluation of the industrial impact on the environment and the degree of its vulnerability in regions of gas industry development shows that the most critical problem of environmental protection in the future will occur in the regions of Western Siberia, and by comparison the problem will be less severe for the European North and Yakutia.

Lessening unfavorable influence on the environment involves reducing the industrial impact (increasing the capacities and improving the operation of decontamination facilities, partial switching of the withdrawal of resources and disposal of production wastes after decontamination to areas more remote from the center of construction development) and seeking to develop less vulnerable territory (primarily sections of river valleys and mountainous sections with large-textured or thawed ground, enclosed bodies of water, and deciduous and conifer forests). In the regions north of the Arctic Circle which have the highest degree of vulnerability the problem of self-support, for example providing local building materials, is much more complex. The demands of environmental protection there may be one of the important factors determining the advisability of importing construction materials (at least in part) from other regions and cutting down on the number of service and auxiliary facilities.

Expenditures for environmental protection measures must also increase in conformity with an increase in the industrial impact on the environment and the degree of its vulnerability. The bulk of all essential expenditures for these purposes is incurred in the initial stage of development of the sector. These expenditures have distinctive features of composition under northern conditions. At spread-out installations (compressor plants and installations for comprehensive preparation of the gas

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* The evaluation was done using classifications of plant vulnerability (Nefedova, V. B., 1976) and frozen grounds ("Spravochnik po Proyektirovaniyu" [Planning Handbook], 1977) developed for the North

Table. Vulnerability of the Northern Environment in Regions of Gas Industry Development (characteristics of vulnerability, ranked by degrees, I-III, according to distinctive features)

A. Topography

- I. Dissected maritime plains with peat bogs with flat and large hummocks
- II. Dissected maritime plains, interfluves.
- III. Mountainous country, river terraces and floodplains.

B. Hydrography

- I. Large rivers flowing to the sea, first and second order tributaries. Territory more than 50 percent flooded.
- II. Large enclosed bodies of water, third and higher order tributaries of large rivers. Territory 25-50 percent flooded.
- III. Small enclosed bodies of water. Territory less than 25 percent flooded.

C. Vegetation

- I. Moss-like tundras.
- II. Dark conifer and deciduous green moss forests.
- III. Brush, deciduous and conifer forests.

D. Frozen ground conditions

- I. Icy, silty loams. Subsidence of more than 40 centimeters/meter when thawed.
- II. Icy sandy loams and sand. Subsidence of 10-40 centimeters/meter when thawed.
- III. Icy large-textured ground or thawed ground. Subsidence less than 10 percent or not present.

at the fields) the chief expenditure heading for environmental protection is building decontamination structures and installations to utilize potential pollutants: methanol, hydrocarbons, and sulphur compounds. These expenditures raise the full cost of projects several percentage points. But from a national economic standpoint they are essential and entirely justified. They will be highest in the permafrost zone because there it is necessary to build engineering structures to prevent the frozen ground from thawing.

In the developed regions of the country the principal expenditures in constructing linear installations, pipelines, are the costs of removing structures and rebuilding roads and bridges. In the North the chief expenditures are for installation of the heat insulation layer in permafrost sectors, making a way for travel along the pipeline, setting up experimental gas pipeline sectors and permafrost stations, and extensions of the route to go around regions with unfavorable natural conditions.

Despite the high demands made on industrial construction with respect to the especially vulnerable environment of the North, in current planning practice expenditures for environmental protection measures in these regions are lower than during the construction of similar facilities in the middle zone of the country. Thus, although three times as much gas is extracted at the Urengoy deposits as at the Orenburg deposit, expenditures for environmental protection measures at Urengoy are projected as several times lower. It is obvious that this represents an underestimation of the heightened vulnerability of the Northern environment. Not all essential expenditures for environmental protection are being considered. Additional economic losses may occur from disruption of the environment as the result of such "half-hearted" decisions.

Careful preliminary study of the vulnerability of the environment and setting up experimental sectors require additional expenditures. However, these steps are necessary because scientific development of the issues of environmental protection must precede intensive development of the sector in the North. For example, it is already time to build experimental sectors in prospective development regions in the main sectors of the pipeline systems: on various frozen ground and on the bottom of Baydarau Bay on the Yamal — Ukhta route; in marshy sectors with permafrost on the Nadym — Salekhard route; in the mountainous sector of the Yakutsk — BAM route.

The geographic point of view makes it especially clear that the generally accepted criterion of optimality, minimum calculated costs, is unacceptable for evaluation of the economic efficiency of capital investment to protect the environment. In view of the heightened vulnerability of the Northern environment, savings of investment capital may lead to losses that exceed the particular savings many times. Furthermore, the geographic approach makes it possible to evaluate the full national economic effect of environmental protection by comparing expenditures for enviornmental protection measures during the development of the sector in the particular region not only with the profit from utilization of industrial waste and savings from accident-free operation of industrial installations, but also with the potential savings from natural resources conserved.

Based on the analysis presented in this article the regions of the North can be ranked by favorability of geographic conditions for development of the gas industry. The North of the European part of the country requires least expenditures owing to the effect of natural conditions. Expenditures for environmental protection are least for Yakutia. At the same time, construction costs for gas pipelines are highest for Yakutia and it is most remote from development bases and main transportation lines. The North of Western Siberia (without the Yamal Peninsula) has the most favorable economic geographic position, but the problem of environmental protection is most complex there because of the large scale of development of the sector. The Yamal Peninsula has the worst conditions.

Conclusions

The problems posed in this article, studying regional differences in the effect of the economic geographic positions, natural conditions, and environmental protection requirements and developing ways to evaluate them and take them into account in long-range planning for development of the gas industry can be solved on the basis of quantitative and qualitative analysis using normative materials and direct calculation, methods employed in long-range sectorial planning, and traditional geographic techniques.

The combinations of factors identified as important for evaluating the economic geographic position of gas industry regions reflect the basic meaning of the economic geographic position of regions in the North. The analysis shows that the position of gas industry regions will improve significantly in the future following economic development of the territory, above all the northern region of Western Siberia.

Natural conditions have the greatest effect during the construction of linear facilities, pipelines. This effect on the route is highly differentiated and significantly increases construction costs and number of days lost when working outdoors. The general trend is for an increase in these problems as one moves further north.

The evaluation of the gas industry's impact on the environment is expressed by a consideration of its vulnerability. The degree of impact depends on the concentration of production and the degree of vulnerability depends on local natural conditions. Three degrees of environmental vulnerability are distinguished. They require different expenditures for environmental protection measures. It is most important in the future to consider the demands of environmental protection during development of the sector in the North of Western Siberia because it will have the greatest industrial impact on an environment characterized by heightened vulnerability.

The regional characteristics of the geographic approach to development of different regions considered above may be used in working out prospects for the development and location of the gas industry in the North.

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