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CHRONICLE

CONTRIBUTION OF PERMAFROST SCIENTISTS TO SAFE OPERATION OF THE YAKUTSK COMBINED HEAT AND POWER PLANT (to the 85th anniversary of the Yakutsk CHPP)

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The role and contribution of P.I. Melnikov, Academician of the USSR Academy of Sciences; N.A. Tsytovich, Corresponding Member of the USSR Academy of Sciences; N.I. Saltykov, Professor, and V.F. Zhukov, Candidate of Technical Sciences, to construction of the Yakutsk Combined Heat and Power Plant are elucidated. These outstanding figures, known for their pioneering researches in different fields of the permafrost science and engineering, were actively and directly involved in the construction project, including the planning and design, foundation analysis, site investigation, foundation construction, and post-construction monitoring. The foundation condition at the plant site, the causes for talik development, and the dynamics of talik distribution since the beginning of the study are discussed. The reasons of the quite stable state of the plant facilities despite the widespread talik occurrence are explained.

Keywords: *Yakutsk Combined Heat and Power Plant, permafrost, talik, ground temperature.*

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INTRODUCTION

Since November 7, 1937, the Yakutsk Central Power Plant (YaCPP) has been providing the city of Yakutsk with electric power and, since 1961, also with heat [*Zavatskaya, Danilevskaya, 2007*]. The plant generates 52 million kW of electric power and 916 thousand Gcal of heat. In 1969, the Yakutsk CPP was renamed into the Yakutsk Combined Heat and Power Plant (YaCHPP) (Fig. 1).

The YaCHPP became the first industrial facility in the Soviet Union built on the principle of using permafrost as foundation, so permafrost researchers were actively involved in all stages of its design, construction, and operation.

The first power plant in Yakutsk appeared in 1914. Its power capacity soon became insufficient for the growing city. In 1931, the Energy Planning Commission (Energoplan) decided to build a heat power plant in Yakutsk. When choosing the site of construction, three options were considered: (1) on the bedrock outcrops in the area of the Kangalass coal deposit, (2) on the northeastern outskirt of Yakutsk, at the Golminka pier, and (3) on the territory of the Spassky Monastery. The first variant assumed the provision of the plant with local coal and the foundations footing in strong bedrock. The advantage of the second variant was the water supply and proximity to the main industrial enterprises, as well as the possibility of coal delivery by barges on the river. The third option was characterized by the absence of topsoil loams on the surface, a low ice content of sandy sediments in the area of the monastery, and good drainage conditions.

Preference was given to the second variant because of the impossibility to provide a large number of aluminum wires necessary for power lines in the first and third variants.

Participation of permafrost scientists in pre-construction survey, design, construction, and monitoring during the first years of the plant operation

The YaCPP project was developed in the construction sector of Teploelektroproekt Institute under the supervision of senior engineer N.V. Arkhipov in 1932. N.A. Tsytovich*, a Soviet scientist

* All information about the activities of N.A. Tsytovich and other prominent scientists was obtained from handwritten reports and archival documents.

Fig. 1. A general view of the Yakutsk CHPP.
Photo by P.S. Zabolotnik, September 5, 2013.

and educator in the field of soil mechanics, geomechanics, and engineering geology, participated in the design of the Yakutsk CPP as a consultant (Fig. 2).

From 1936 to 1956, he worked in the Obruchev Permafrost Institute (Moscow). The Presidium of the Academy of Sciences of the USSR concurrently entrusted him to organize the base of the Academy of

Fig. 2. Nikolai Alexandrovich Tsytovich (1900–1984).

Doctor of Technical Sciences, Professor, Corresponding Member of the USSR Academy of Sciences (1943), Hero of Socialist Labor (1980), winner of the Stalin Prize (1950), three times Commander of the Order of Lenin and the Order of Red Banner of Labor, Honored Worker of Science and Technology of the RSFSR (1969).

Fig. 3. Nikolai Ivanovich Saltykov (1888–1964).

Doctor of Technical Sciences, Professor, Honored Scientist of the Yakut ASSR, Commander of the Order of the Red Star, "Badge of Honor". From 1936 to 1960, he worked at the Obruchev Institute of Permafrost (Moscow). From 1960 to 1964 he worked at the Permafrost Institute of the Siberian Branch of the Academy of Sciences of the USSR (Yakutsk), and headed the Laboratory of Foundations and Ground Constructions.

Sciences in Yakutsk. In 1947–1953, he was the first Chairman of the Presidium of the Yakutsk Branch of the Academy of Sciences of the USSR. The calculations of permafrost stability under the YaCPP and the calculations of foundations were based on his work *Lectures on Foundation Calculations under the Permafrost Conditions.*

The thermometric observation and the permafrost-soil survey of the power plant site was carried out by N.I. Saltykov, Candidate of Technical Science (later, Doctor of Technical Science, professor) (Fig. 3). Temperatures were measured with the use of lazy thermometers; the permafrost-soil survey was carried out by means of the description of core samples from boreholes and pit walls.

Central Yakutia is the area with continuous permafrost, the thickness of which varies from 100 to 300 m, and the mean annual temperature at a depth of 20 m ranges from –2 to –4°C [*Balobaev, 1991*].

The first stage of the YaCPP was built on the alluvial terrace, 9–10 m above the low-water level, at a distance of 70 m from the bank ledge of the Lena River's branch.

According to data of N.I. Saltykov, the permafrost thickness was up to 180–200 m, and the mean annual permafrost temperatures at a depth of 15 m ranged from –3 to –5°C at the construction site before the construction [*Tsytovich et al., 1947*].

The site around the main building of the plant and a number of other facilities was composed of the filled layer of uneven-grained sand, 1–4 m thickness; less often, the filled layer consisted of loam with an admixture of gravels, rock debris, and slag. Fine-grained alluvial sands, often with interlayers of medium- and coarse-grained sands were found below. In the upper part of the section, to a depth of 11–15 m, there were also interlayers and lenses of sandy loam, loam, and fine-grained sand, as well as inclusions of

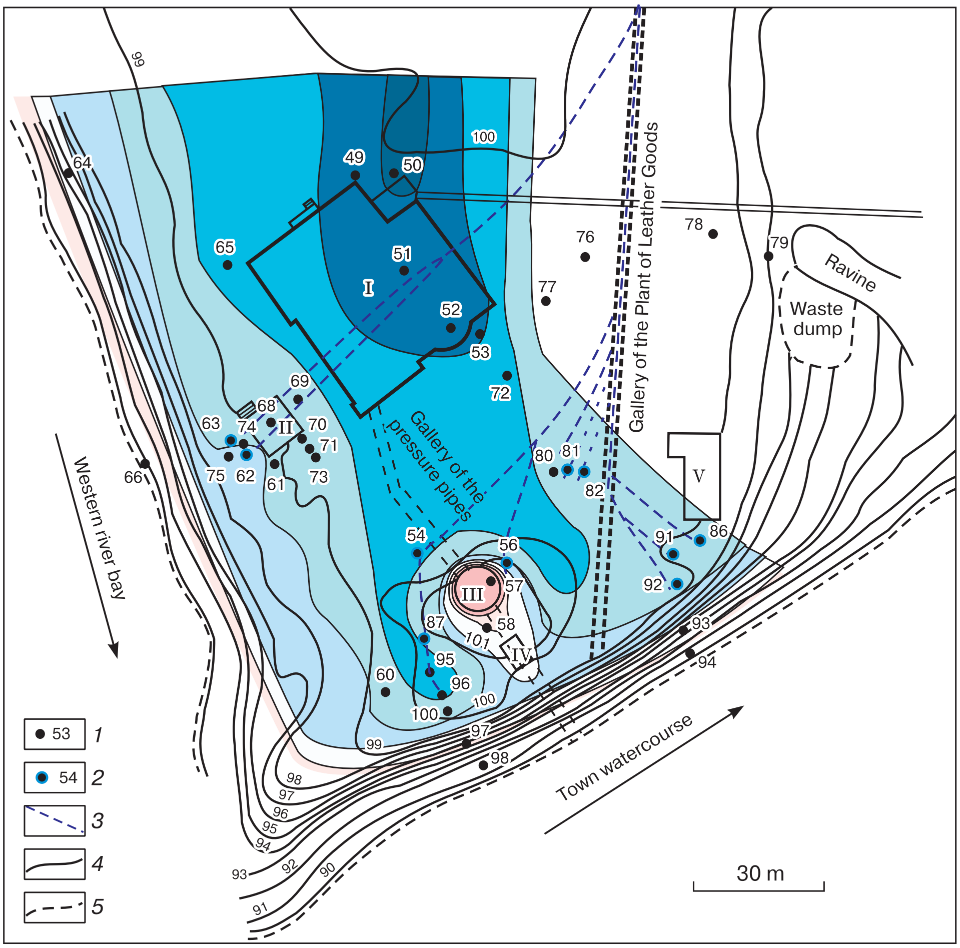

Fig. 4. The temperature field of the Yakutsk CHPP site at a depth of 5 m in 1939.

The color designates the mean annual temperature of the soils. I – main building, II – diesel station, III – pumping station, IV – well, V – garage; *1* – boreholes, *2* – boreholes with mineralized water, *3* – paths of mineralized water, *4* – contour lines and height levels, *5* – water surface level.

plant detritus. On the basis of the survey conducted in 1938–1939, N.I. Saltykov prepared a map of the soil temperature distribution at a depth of 5 m for the territory of the YaCPP (Fig. 4).

The construction of the YaCPP began in 1932. The project involved the installation of foundations on the permafrost with special measures to prevent its thawing. During the first three years, the construction was managed by V.F. Zhukov, a graduate of the Moscow Institute of Transport Engineers, one of the founders of the method of pre-construction thawing and compaction of soils, Candidate of Technical Sciences (Fig. 5). He was assigned as a chief engineer and supervised the preparation of the foundation pit, the footing of concrete slabs and larch timbers, as well as the footing and installation of foundation supports.

The frozen state of soils was retained by installing the building on columns with shoes. A cross-ventilated 1.2–1.8-m-high basement was left between the ground surface and the building to protect the foundation soil from deep thawing under the internal heat of the building, as well as to accumulate cold in them in winter time (Fig. 6).

The foundations of the first stage of the YaCHPP were freestanding reinforced concrete columns with shoes. Depending on the load, the columns had a cross-section from 30 × 30 cm to 80 × 80 cm, and the

Fig. 5. Vladimir Fedorovich Zhukov (1906–1996).

Candidate of Technical Sciences. From 1940 to 1964, he worked at the Obruchev Institute of Permafrost (Moscow). In 1956–1958, he was Deputy Director of the Institute. From 1965 he worked at the Gersevanov Research Institute of Bases and Underground Structures, Gosstroi of the USSR.

Fig. 6. The cross ventilated basement under the main building of the Yakutsk CHPP.

Photo of S.I. Zabolotnik, November 5, 2009.

shoes had a cross-section from 130 × 130 cm to 317 × 317 cm. The foundations were installed at a depth of 4.5 m from the site surface on a deck consisting of two rows of 20 × 20 cm larch timbers laid crosswise. The foundations for the turbine generators were made of 1-m-thick concrete slabs.

The pits were prepared and the foundation columns and slabs were installed and backfilled with soil in winter time. Uncovered deposits were frozen through simultaneously. The pits were backfilled with frozen soil in 20–25 cm layers; the soil was taken from dumps. Hollows between lumps of the frozen soil were filled with dry sand, and the mass, formed afterwards, was rammed. The space directly around the columns was filled with gravelly sand soil.

In the absence of practical experience at that time, the principle of the construction with retaining permafrost at the base of the large structure with significant heat generation, such as the YaCHPP, required continuous monitoring of the state of permafrost in the foundation and of the building itself. P.I. Melnikov, the head of the permafrost research station, Candidate of Geological-Mineralogical Sciences (later an academician) undertook this work (Fig. 7).

Fig. 7. Pavel Ivanovich Melnikov (1908–1994).

Doctor of Geological and Mineralogical Sciences, Professor, Academician of the USSR Academy of Sciences, Hero of Socialist Labor (1984), Honored Worker of Science and Technology of the RSFSR, twice Commander of the Order of Lenin and the Order of the Red Banner of Labor. From 1941, he was head of the Yakutsk Permafrost Research Station, which in 1956 became the Northeastern Branch of the Obruchev Institute of Permafrost, Academy of Sciences of the USSR. From 1960 to 1988, he headed the Permafrost Institute of the Siberian Branch of the Academy of Sciences of the USSR. He was President (1983–1988) and Vice-President (1988–1994) of the International Permafrost Association. In 1995, his name was given to the Permafrost Institute, Siberian Branch of the Russian Academy of Sciences.

In the first decades, P.I. Melnikov constantly monitored the temperature condition of permafrost at the YaCPP foundations and the structure itself and measured the temperatures in boreholes with lazy thermometers. He found that 10 years after the foundations were footed, the soil temperature at a depth of 5 m varied from –3.2 to –3.6°C despite the beginning of water leakages, and the thickness of the seasonally thawing layer decreased by 0.8 m and did not exceed 1 m [*Tsytovich et al., 1947*].

In the following decades, no special problems were revealed in the operation of the YaCHPP constructions, so permafrost scientists did not study its territory repeatedly. At the same time, the city of Yakutsk was growing, and it needed more and more heat and electricity. To provide this, the buildings of the power plant were repeatedly expanded and reconstructed; the entire complex was maintained according to the modern requirements. In 1978, the building of hot water boilers was constructed; in 1989, the extension for KVGM-100 boilers was added to it. All new buildings were constructed according to the first principle of construction – retaining base soils in the perennially frozen state.

Problems in the operation of the YaCHPP and the current state of base soils

Due to the construction of the complex of new structures, it was necessary to control the state of base soils of the foundations and bearing structures of the buildings themselves. Therefore, the Permafrost Institute restarted the studies on the territory of the YaCHPP. Since 1982, the studies have been conducted by S.I. Zabolotnik; since 2005, also by P.S. Zabolotnik. From 1986 to 2015, these works were carried out intermittently. From 2016 to the present time, the research has been carried out continuously. Soil temperatures have been quarterly measured in more than 90 boreholes and vertical movements of the foundations and technological equipment have been monitored during the spring and autumn seasons.

During the long-term operation of the power plant, the problems concerning stability of the structures arose due to partial thawing of the permafrost underneath them. They were generally caused by leaking heated industrial waters from drainage pipes, sewage system, and other utilities directly into the base soils.

To freeze soils beneath the main building near the part of its wall, where the circulating pump station (CPS) is located, six multi-tube seasonally cooling devices (SCDs) of the S.I. Gapeev system were installed and put into operation in 1967. Each one had a capacity of 500 liters of kerosene. In 1973, 17 more devices of the same type were installed on three sides of this building. The SCDs were installed at a distance of 1.7–3.5 meters from the walls of the building; the space between them varied from 2.9–3.1 m to 5–7 m (Fig. 8). According to the report of the Sibtech-Energo Company, the installed SDSs at the Yakutsk CHPP lowered the soil temperature at a depth of 6 m from positive values to –3°C during two winters. The author of the invention said: "Applying... of multi-tube automatically operating cooling devices allowed... to restore the frozen base and reinforce it under the deforming buildings of the Yakutsk CHPP" [*Gapeev, 1983, p. 54*].

The operation of SCDs did enhance the permafrost regime of soils in their immediate vicinity. However, it was not possible to obtain the full expected effect of freezing the foundation bases. One of the main reasons is that SCDs were installed at a rather large distance both from the building walls and from one another. On the basis of numerous experimental data, L.N. Khrustalev, O.M. Yanchenko, and L.A. Naumova [*1983*] have concluded that, "depending on climatic and permafrost conditions, it is possible to achieve the soil freezing in a radius from 1 m (Krasnoyarsk) to 2.5 m (Vorkuta)" (*p. 5*). Similar data on the soil freezing radius with the use of SCDs for one winter season were reported by other researchers [*Alexandrov, 1983; Mirenburg, Fedoseev, 1983*]. There was little chance of freezing the talik under the build-

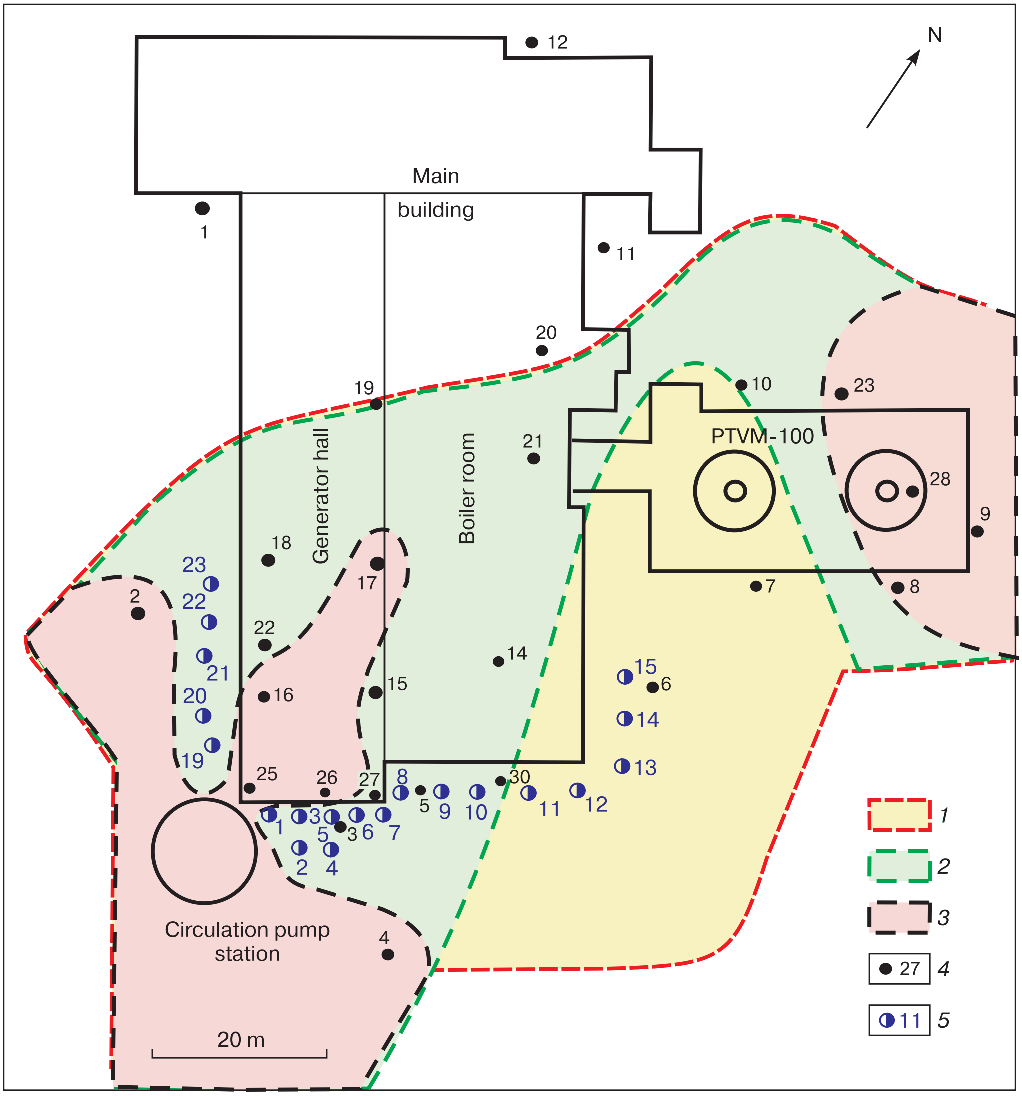

Fig. 8. Changes in the talik boundaries at the Yakutsk CHPP site from 1976 to 1986 [*Zabolotnik, Zabolotnik, 2016*].

Talik boundaries according to data of (*1*) Yakutsk Branch of the Krasnoyarsk Trust of Engineering Construction Surveys (KrasTECS), 1976; (*2*) Novosibirsk Sibtech-Energo Production Company, 1978; (*3*) Permafrost Institute, Siberian Branch of the Russian Academy of Sciences, 1986; (*4*) borehole and its number; (*5*) SCD and its number.

ing, because most of SCDs were away from its walls and beyond the radius of their action.

During further research on the territory of the YaCHPP, the authors found that the talik under the main building was not completely frozen. Measurements of the soil temperature with thermoresistors in boreholes nos. 3, 5, and 30 in the immediate vicinity of the main building (about 1 m), showed that, from October 1982 to February 1986, the soil temperature at depths of 5–14 m varied from –0.5 to –6.9°C. Nevertheless, the talik was retained directly under the southern corner of the main building, around which SCDs were installed on the outer side (Fig. 8), and the soil temperature varied from –0.4 to +1.8°C at a depth of 4 m from May 1985 to April 1986.

Constant heat emissions from CPS (buried more than 10 m) and semi-buried pipelines, as well as the repeated hot water leaks significantly prevented the freezing of the talik in this location. A heated room of the plant is a constant source of high-power heat. Prolonged heat radiation from it has caused thawing of soils around it to a considerable depth. In July 2005, during drilling of borehole 31 located in close proximity to CPS, it was revealed that the soils had thawed to a depth of 23 m, and the talik zone around it extended at least 25 m and captured the southern corner of the main building [*Zabolotnik, Zabolotnik, 2016*].

Over almost 85 years of operation of the entire complex of buildings and structures, the state of soils has changed significantly, which led to the development of talik zones of 19–25 m in thickness with positive temperatures up to +7°C or more, both at the foundation bases and in the adjoining areas. Owing to the additional measures, the talik zones were significantly reduced; nevertheless, they remained in the

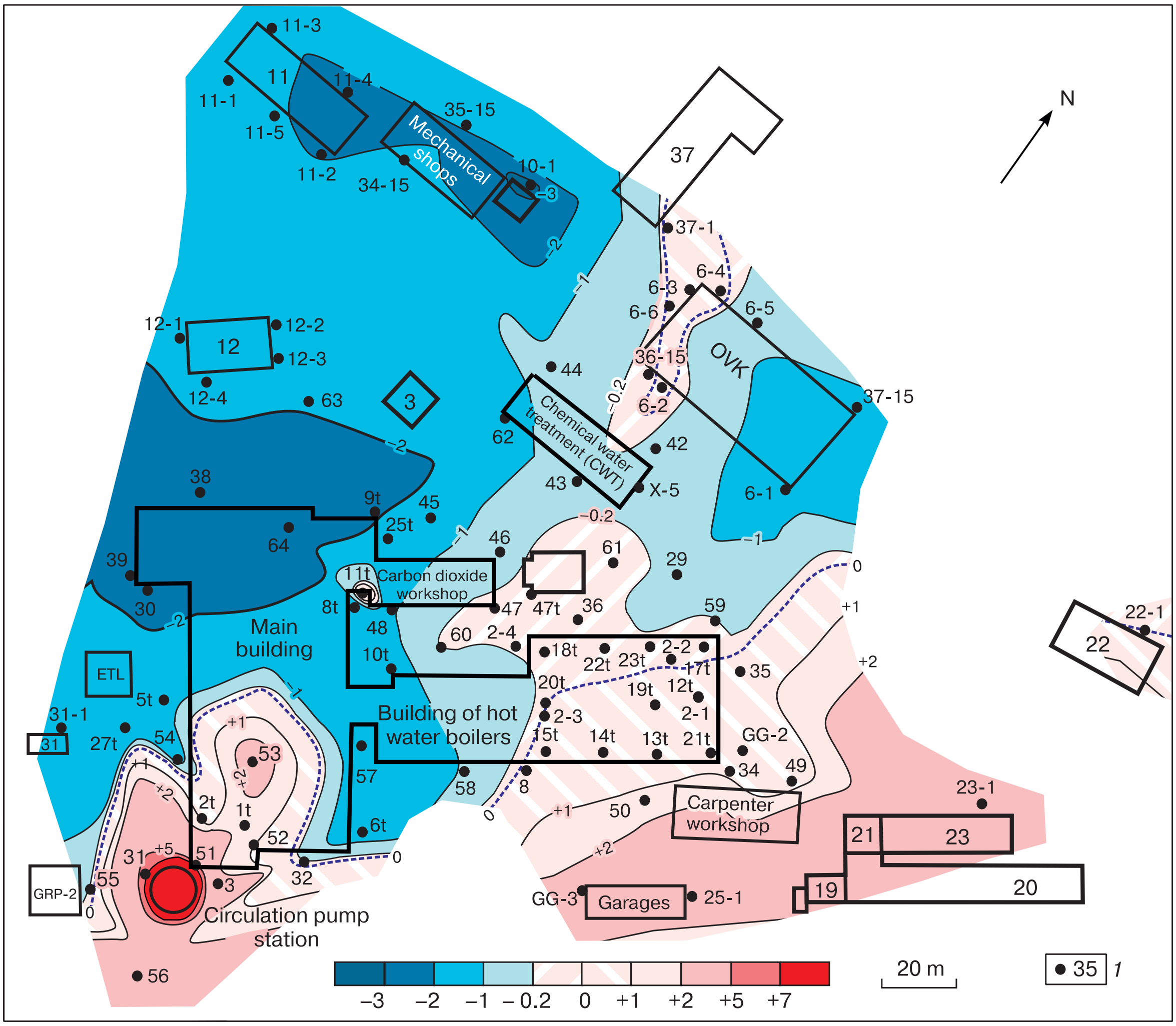

Fig. 9. Soil temperature at a depth of 10 m in November 2020.

CAC – combined auxiliary complex, ETL – electro-technical laboratory, 3 – GRP, 10 – gatehouse of the Yakutsk CHPP, 11 – office of the Yakutsk CHPP, 12 – PTO and medical station, 20 – greenhouse, 19 – control room, 21 – room for personnel, 22 – storehouse no. 1, 23 – storehouse no. 2, 31 – pumping equipment repair zone, 37 – operative dispatching service; *1* – borehole and its number.

same places and were formed under the newly built structures (Fig. 9).

Around CPS and under the southern corner of the main building, the talik remains to this day, but with lower temperatures. The foundations under the rest of the main building rested on frozen soils until 2014. However, due to subsequent water leaks, the soils thawed dramatically; in November 2021, their temperature rose to +8.5°C, and the talik occupied almost the entire southern part of the main building.

The second deep talik was formed under the eastern part of the first stage of the building of hot-water boilers (BHB-1). In 1986, its thickness was 24.5 m in the immediate vicinity of the eastern end of BHB-1 (Fig. 8). In 1989, the new building (BHB-2) with KVGM-100 boilers was added to BHB-1; it was a little larger in size than the previous one. Although the pit was frozen in winter before construction of the new building, the talik has been preserved up to this day. It is located in a larger part of BHB-2 and extends far beyond it. During the recent years, soils have been gradually freezing from the top to a depth of more than 4 m. By now, thawed soils have remained under the seasonal freezing layer only under the southeastern part of the building (Fig. 10). At the same time, at a depth of 10 m, the talik zone is retained under almost half of BHB and has spread far beyond its limits (Fig. 9).

CONCLUSIONS

The results of the studies at the YaCHPP site demonstrate that the main cause of the talik formation under the buildings and adjacent areas are leaks of hot and aggressive waters. They were almost annually recorded by the authors, when measuring the temperatures under various parts of the structures.

Considering the geocryological setting in the entire site of the YaCHPP, it should be noted that the base soils of some structures are thawed. According to P.I. Melnikov, ten years after the YaCPP was put in

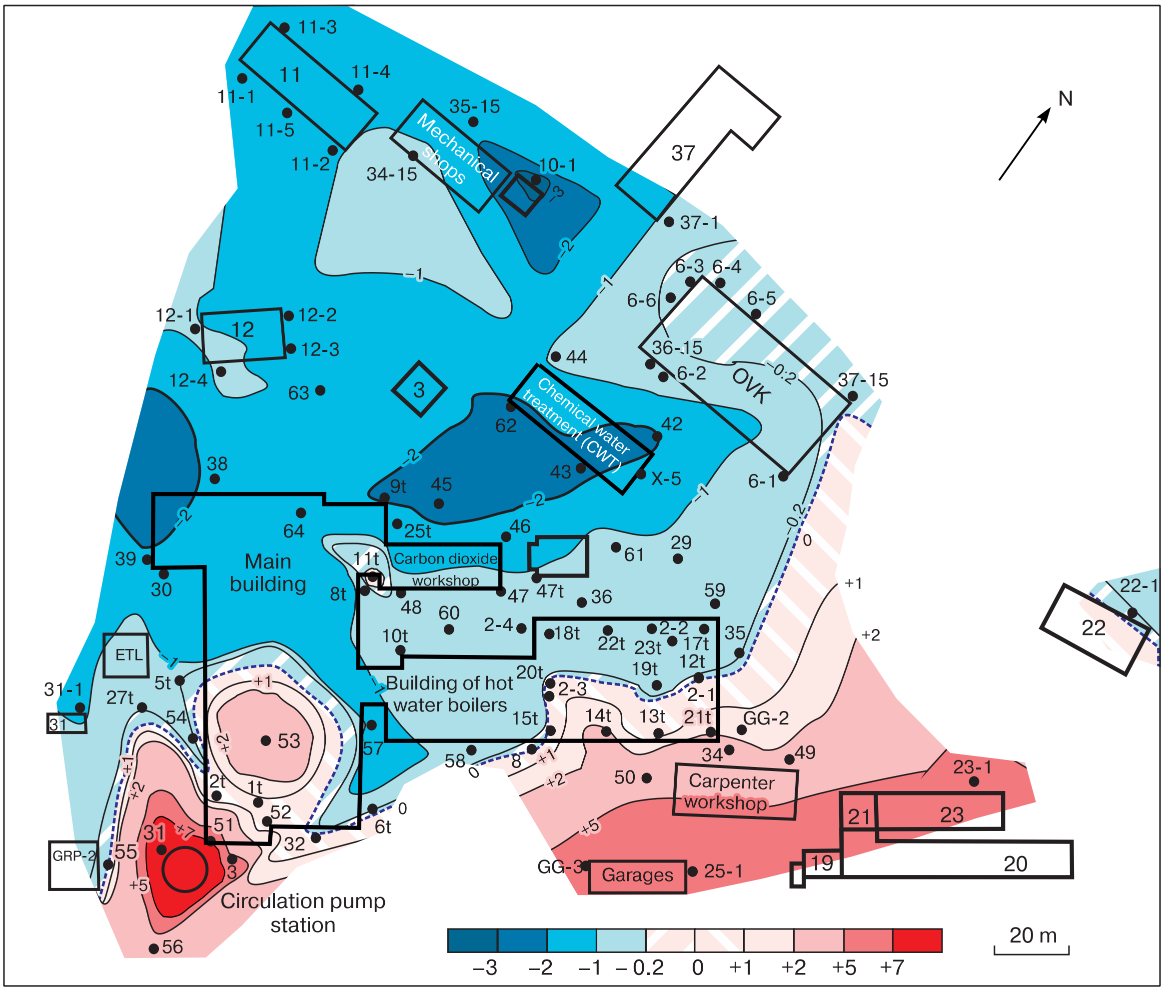

Fig. 10. The temperature field at a depth of 4 m in November 2020.

See legend to Fig. 9.

operation, the soil temperature varied from –3.2 to –3.6°C at a depth of 5 m [*Tsytovich et al., 1947*]. At present, at a depth of 4 m (close to the depth of the foundation footing) it varies from –0.2 to –2.0°C under most buildings and from –2.0 to –3.0°C only in small areas (Fig. 10). A similar picture is observed at a depth of 10 m, where the soil temperature below –2°C is established only under the western corner of the main building, on the part of the territory adjacent to it from the northwest, under the CPS mechanical workshops and some administrative buildings (Fig. 9).

Long-term studies on the territory of the YaCHPP showed that, for almost 85 years of the operation of buildings and structures, the temperature regime of soils has changed significantly. In some places, taliks were formed to a depth of 25 m; the mean annual soil temperature in them was up to 12–13°C. However, the state of the whole set of structures remains quite stable. This occurs because the sufficiently large factor of safety in the design of the buildings. Loamy and sandy-loamy soils in their bases were replaced with non-heaving and non-subsiding (upon thawing) sandy substrates; the foundations for boilers and turbine generators were made of solid concrete slabs of about 60 m^2 in area and 1 m thick.

Owing to the authors' regular studies of the permafrost state at the YaCHPP, the plant management is able to apply the proactive measures to prevent the development of negative consequences. Timely obtained data allow us to urgently eliminate water leaks from utilities, clear ice accumulations, create drainage ditches in order to remove water from ventilated basements, and to repair and reinforce the corroded and destructed bearing structures, etc.

All this makes it possible to provide the stability of the combined heat and power plant up to the present time. As a result, the condition of the entire complex of structures remains fully suitable for further operation, although some of them have been partially located on thawed soils for many years.

Recently, due to natural cold and in the absence of water leakage, gradual restoration of the temperature regime of the base soils of the buildings and in the adjacent areas has been observed. However, it is a very slow process, which will take many, many years to fully restore the frozen state of the soils.

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