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Expert conclusion for the Project "Justification and development clean technology for penetrating the subglacial Lake Vostok (Antarctica)"

Submitted by Russian Federation

Expert conclusion for the Project 6.Justification and development of the ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica)"

In 1999, the Ministry of Industry, Science and Technology of the Russian Federation has approved the Project ..Justification and development of the ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica)". The Arctic and Antarctic Research Institute of Roshydromet and the St. Petersburg Mining Institute of the Ministry of Education of Russia were entrusted with undertaking this Project.A compulsory requirement for the work under the agreement was the need of the state ecological expert examination of its following main provisions:

1. Description of technology for penetrating the subglacial Lake Vostok with a justification of its ecological safety.
2. Environmental impact assessment during drilling of borehole *5-0* I and penetrating the subglacial Lake Vostok (Antarctica).
3. Argumentation for the compliance of the materials submitted under the project to the requirements of the international agreements on the Antarctic.
4. Certificates of the compliance and characteristics of the main properties of chemical reagents used for Project implementation.

The work under the Project was completed in 2000 with all materials submitted for the State Ecological Expert Examination whose conclusion was ready on March 15, 2001. , According to the procedure existing in the Russian Federation, this Conclusion was approved on March 26, 200 I.

Thus, the developed technology for penetrating the Subglacial lake was officially permitted for implementation in the framework of the Russian Antarctic Expedition based on the Russian rules and procedures in force. given a large significance of investigating the subglacial Lake Vostok in this country and in the international Antarctic community, the Russian Party considered it necessary to acquaint all Parties to the Antarctic Treaty with these materials in order to obtain comments and proposals to prepare a final version of the Comprehensive Environmental Impact Evaluation according to the CEP requirements.

1. <u>Conclusion of the State Ecological Expert Examination or the Russian Federation</u>

In compliance with the Federal Law .'On ecological expert examination", the Administration of the State Ecological Expert Examination of the Ministry of Natural Resources of the Russian Federation has carried out the state ecological expert examination of the Project ..Justification and development of the ecologically clean technology for penetrating subglacial Lake Vostok (Antarctica)" submitted by the Arctic and Antarctic Research Institute (AARI).

Based on the analysis of the submitted materials, the Expert Commission of the State Ecological Expert Examination noting that the Project aims in general to observe the nature protection requirements and ensure ecological safety, has concluded that the expected environmental impact in the process of penetrating the subglacial Lake Vostok is permissible and that it is necessary during Project implementation and at the detailed design stage to take into account the recommendations and proposals set forth in the Conclusion of the Expert Commission.

2. <u>Brief characterization of the study area and back2round information</u>

The Russian inland Vostok station is located in the plain snow surface of the glacial plateau of East Antarctica (78°28’S, 106°48’E) at an elevation of 3488m above sea level.

Being in the climatic area of Central Antarctica, the Vostok station is characterized by an extremely low air temperature (yearly average of -55.4oC, absolute minimum of -89.2°C and absolute maximum of -13 .6()C), low atmospheric pressure (yearly average of 624.2 mb) and small relative humidity (yearly average of 71 %). The wind regime of the station area is distinguished by weak catabatic winds with a yearly average speed of 5.4 *mls* and rare storm winds with a maximum speed of 32 *mls*. Due to severe temperature conditions there is no snow melting here. Atmospheric precipitation in the form of snow and ice crystals (with accumulation comprising 2.2 *glcm* year) is subjected to drifting snow transport resulting in snow piling up behind the obstacles (buildings). The vicinity of Vostok station presents a flat snow plateau with small gently sloping blown snow heaps up to 20 cm in height.

At the 3310-3370 m depth range, there are some indications of tectonic inconsistency in the strata bedding. At the 3460-3538 m range, layered ice is observed, which is characterized by alternating layers of fine- and coarse-grained ice. The basal ice layer that was detected below a 3538-m mark and traced to the borehole bottom (3623 m) is comprised of giant-grained ice (with ice crystals greater than I m in diameter).

The ice sheet above the lake in the Vostok station area flows southeastward. Beginning from the 3460-3540 m depths and higher the ice strata are entrained into movement whose rate at the glacial surface comprises around 3 m/year .

Using remote sensing methods, a subglacial lake with an area of more than 10 thousands km2 and the water layer depth of up to 700 m was detected at the Antarctic continent in the vicinity of Vostok station. The cross size of the lake is 220x70 km. According to seismic data. the ice thickness above the lake comprises 3700-4200 m. The thickness of bottom sediments underlying the water column comprises probably up to 330 m. As the glacial surface at Vostok corresponds to a height of 3488 m while the ice sheet thickness is estimated as 3750 m, the glacial foot at this location is 262 m below the global ocean level. It is mainly assumed that water in the lake might be fresh, which makes possible the existence of relict life forms there. The supposed age of the lake is more than 500 ka.

Super deep drilling of the ice sheet at the Antarctic inland Vostok station to a depth of 3623 m and study of the extracted ice core have already yielded very important information on the global climatic changes over more than 400 ka with identification of four full climatic cycles. It was possible to reconstruct the change of the gaseous composition of the atmosphere (CQz. Clli) and the dynamics of different aerosol concentrations in the air

medium throughout the entire period under consideration.

Long-term studies in the area of geophysics, glaciology, paleo-climatology and microbiology that were carried out at Vostok over a wide scientific range have also yielded numerous results of unique significance for world science showing an obvious priority of Russian science in developing a number of scientific problems.

Beginning from the 13(h Soviet Antarctic Expedition (SAE, 1967), specialists of the Chair of Technology and Technique of Drilling Boreholes and of other chairs of the SPbSMI jointly with AARI scientists participated practically in all Soviet and later Russian Antarctic Expeditions (RAE) both in the wintering and seasonal teams. More than 18 thousand meters with a full ice core extraction were drilled in the Antarctic ice sheet (Vostok station, Mirny Observatory and the glaciological Mirny-Vostok-l profile) and well as in the glaciers of Severnaya Zemlya archipelago. Drilling of a deep hole at Vostok station began in the 35th SAE (1990) by a thermal method using TELOA and TB3S types of drills. In the 38th RAE (1993), borehole 50-1 reached a depth of 2755. Due to insufficient funding of the 39th RAE and some technical and organizational problems, the Vostok station was temporarily decommissioned and no drilling activities were undertaken. During the 40th RAE (1995), drilling of borehole 50-1 was resumed from a depth of 2755 by the electrical mechanical drill.

During the season of tIle 43rIJ RAE (1997-)998). the hole has reached a unique ice depth of 3623 m. which is almost 600 m as great as the maximum depths achieved by specialists of EC countries (3032 m and 2953 m) and the USA (3057 m) in drilling boreholes under more favorable conditions of Green)and. Drilling of boreholes by the EC specialists was stopped due to accidents in these depths. To compensate overburden pressure. the EC specialists use a drilling fluid similar to that used by RAE. Its composition includes aviation fuel of JP-8 type as the main component and Freon F-141b as filler. Same fluid is applied for drilling a deep hole at Dome C in Antarctica under the general European Program EPICA. which has achieved a depth of 1450 m by February I, 2001.

The results of drilling hole 50-1 have finally proved the decisive advantages of the technique and technology of deep ice drilling. As compared with other existing coring electrical mechanical drills at a carrying cable (US CRREL. Danish-Swedish ISTUK and Japanese drills), the Russian drill KEMS-112 is distinguished by simplicity of design and reliability of operation.

Studies of deep holes at Vostok and of the continuous ice core extracted from ho)e 5G-I whose age is greater than 500 kyr. have allowed us to obtain important scientific results:

- scientists of Russia (AARJ. Institute of Geography of RAS). France (Laboratory of Environmental Glaciology and Geophysics of the National Research Center) and the USA (University of Miami) based on the ice core isotope and glaciological studies have established for the first time the cyclicity of climate change on Earth and identified four Glacial and Interglacial periods;
- methodology for aseptic microbiological sampling from the ice core was developed and proved at the level of scientific discovery of duration of anabiosis of microorganisms of more than 200 ka (SPSMI jointly with the Institute of Microbiology ofRAS and AARl);
- data on the temperature regime of the glacial cover were obtained for the first time and were used as a basis of mathematical modeling of the heat-mass transfer processes in the glacier;
- vertical zonation and typical features of ice metamorphism by depth were established.

The bases of the theory of thermal and mechanical ice failure and methodology to calculate the technological parameters of drilling were created. The choice of the formula of non-freezing drilling fluid to prevent borehole narrowing due to overburden pressure and increasing natural ice temperature with depth significantly changing its viscous-p1astic properties was substantiated. Principally new semi-autonomous electrical-thermal (jointly with AARI) and electrical-mechanical drill at a carrying cable (TELGA. TB3S and KEMS), complexes of stationary and mobile drilling equipment and systems of the drilling process control and automated operation were developed. Special methods and equipment of a complex of geophysical studies of boreholes under the extreme conditions of polar glaciers were developed and tested.

The anthropogenic impact on the environment in the vicinity of Vostok station occurs from 1957 .To undertake a complex of studies, 14 to 25 people can be accommodated at the base depending on the season. There are 5 diesel-generators 100 kW each. From 1970.5 holes 15-18 cm in diameter and a depth between 500 to 3623 m were drilled. Contamination with domestic wastes in the station area and ice contamination with kerosene near the wellhead is noted. In accordance with the Project. it is envisaged to continue drilling by a 4-people team.

Based on practical and economical considerations (organization and logistics support for drilling a new hole), the AARI and SPSMI propose to use the already existing hole SG-l for accessing Lake Vostok and special technical equipment and technology of its ecologically sate unsealing.

To implement this Project, the Vostok station has the following facilities:

- drilling complex including a drilling house with a rig and a set of ground equipment;
- glaciological laboratory equipped with necessary facilities and instrumentation for the studies of the extracted ice core;
- specially equipped ice core storage space providing its long-term preservation at a constant below zero temperature;
- living and auxiliary premises.

It is planned in the near future to directly penetrate the lake and conduct hydrological, microbiological and geological studies. In accordance with the international and Russian regulating codes. this penetration should be made provided all ecological safety requirements are met.

Information that will be obtained from the analysis of lake water and bottom sediments is valuable not only for characterizing the processes of lake genesis and its present state. It will also allow making more specific the results of remote sensing studies and model calculations and improving thus these methods.

3. <u>Main engineering and technolo2ieal decisions of Lake Vostok access</u>

There are several ways of penetrating Lake Vostok proposed by different countries. However, they are all based on a preliminary drilling of more than three thousand meters of glacial strata. Since at present, the bottom of borehole SG-I is in direct proximity from the water surface of the lake, it seems to be quite logical to use this borehole 3623 m deep. filled with a drilling fluid to penetrate the lake.

In order to meet all ecological requirements at penetrating water of the lake, the Project authors propose to introduce some changes in the drilling methodology.

A more than 30 year experience of work of a team of drilling specialists allowed finding and testing an ecologically clean drilling technology (both in terms of liquidating adverse impacts on the ozone layer of, the atmosphere and from the viewpoint of ice microbiology).

The proposed method to access Lake Vostok envisages to use primarily the physical peculiarities of the state of the "ice sheet-subglacial Lake Vostok'. system. The basic fact is that the ice sheet is in the floating state with the pressure at the '.ice-water.' boundary corresponding to the ice column weight (overburden pressure). During ice drilling. the hydrostatic drilling fluid pressure in the borehole compensates the overburden pressure. Decreasing the drilling fluid quantity, it is possible to ensure under compensation of overburden pressure, i.e. create such conditions when the lake water pressure at the given point will be greater than the drilling fluid column pressure.

The Project authors consider that under such conditions. at the hole bottom contacting the lake surface, the drilling fluid will be forced out by lake water upward the borehole to a height corresponding to overburden pressure under compensation. It is believed that penetration of the used drilling fluid to the lake can be excluded as it is hydrophobic and is much lighter than water. The drill will be extracted from the hole immediately after reaching the surface.

It is obvious that lake water rising up the hole should freeze along the entire penetration length. After its freezing, drilling of the ice portion formed of the subsurface water layers of Lake Vostok is repeated. Ice remaining below, which is formed of lake water, divides the hole bottom and the lake, i.e. prevents their possible contact. Thus, the proposed method will allow lake water samp1ing without a direct incorporation of the drill and measurement and sampling instruments to the lake.

It is planned to realize this method of lake access and its study in several stages applying two types of the drill and two types of the drilling fluid.

The first stage of work envisages additional drilling of around 100 m in boreho1e 50-1 by means of a coring electrical mechanical drill KEMS-132 and a complex of drilling equipment used here before. Given a proven reliability and high efficiency of this equipment, its use appears to be completely safe in terms of ecology. In addition it will allow extraction of approximately a 100 m ice core from the basal layers of the ice sheet containing unique information on the lake evolution.

First, it will be necessary to ensure ecological purity of the lake-drill contact.

For this, prior to the second stage of work, it is proposed to introduce to the bottom portion of the hole a new ecologically clean drilling fluid (neutral in respect of water and microorganisms). It can serve as a peculiar liquid plug about 100 m thick between the top and clean bottom parts of the hole. This buffer layer separating the bottom and the earlier used drilling fluid (aviation kerosene *TC-II* freon 141b mixture) Should have a higher density than the drilling fluid of the main hole but lower than the lake water density.

The aviation kerosene presents a mixture of hydrocarbons of different composition and structure including aromatic ones whose fraction comprises 20-22%. Freon 14 I b presents I, I. I tluoro-dichloro-ethane CH3CFCI2.

At the second stage (drilling of about 30 m of ice until the contact with the lake) it is planned to use a thermal drill with a stepped working body (TBPO-132) due to which a pilot- hole with a diameter 3-4 times as small as the` e drill is also equipped with a pump and the feedback system sensors. The thermal drill similar to the electrical-mechanical drill being in the hole is suspended at a carrying cable. The rate of running the last 30 m of ice to a contact with the lake is to be up to 3 m/hour.

Upon reaching the lake surface, the solid ice support under the bottom surface of the pilot-chisel will disappear to which a contact sensor will respond. The sensor signal will switch a packer that serves for isolating the near-bottom section of the hole from the rest of its volume. Simultaneously, drilling will be stopped while the readings of sensors will allow an evaluation of the hydrostatic pressure difference in the hole and in the lake.

When the pilot-hole bottom reaches the lake surface. three variants of the ratio of fluid column pressure near bottom Pf and water pressure in the lake PI are possible: I) Pr < PI; 2) Pr = PI: 3) Pr > PI, with the first variant being the most expected and the second and third variants as unlikely.

At Pr < PI. lake water will rise in the hole to a height h. corresponding to the pressure difference in the lake and the hole L\p = Pr -PI. At thermal drilling. the working body should be in a constant contact with the bottom surface under the action of the force equal to part of the drill weight. Thus, direct water penetration from the lake to the hole is impossible. It can rise to the hole if the drill is raised above the bottom by a carrying cable or by the force that can occur at the moment of contact with the lake surface due 10 pressure difference if it is greater than the force pressing the drill to the bottom (the drill weight with deduction of the Archimedean buoyancy force).

At Pf = PI, the lake water will rise to the hole at the drill raise with decreasing hydrostatic pressure of the drilling fluid, that is. the cable volume retrieved from the hole will be substituted by lake water.

At Pr > PI, which is practically unlikely, at the pilot thermal chisel contacting the lake

surface, the force Po will begin acting on the drill pressing it to the ring bottom of the hole. At disconnecting the power supply, the ring bit will be pressed against the bottom shoulder of the hole isolating it from the lake.
It will be further necessary to pump part of the fluid from the hole decreasing its level to such a value as to ensure inequality Pf < PI. The situation will be reduced to the first variant and the retrieval of the drill from the hole will begin.
Thus, the thermal drill will perform a valve function ensuring the ecological safety of penetrating the lake disconnecting it and the hole at the moment of contact between the pilot thermal chisel and the lake surface.

To drill the last 30 m of ice up to its contact with the lake, a thermal drill will be used without its detachment from the bottom. At ice being melt by the drill, the drill and the cable will be naturally cleaned from the drilling fluid by melt water whose column forms one more buffer layer below the organic-silicon fluid (polydimethylsiloxane).

After reaching: the Lake Vostok surface (end of the second stage), the operation in borehole SG-l will be stopped for the period of freezing of lake water introduced to the hole. Then, part of ice formed from lake water will be sampled by a coring electrical mechanical drill KEMS-132. Core retrieval will be performed observing all precautions for preserving the biological purity of the inner portion of this core by means of the method that has already been developed by designers, repeatedly used and that has proved its reliability. The remaining ice will not be drilled ensuring complete isolation of borehole SG-I from the lake surface.

To counteract the overburden pressure. the hole drilled will be filled with a non- freezing fluid consisting of aviation kerosene TC-1 mixed with filler -Freon 141 b in the volumetric proportion of S: I.

Polydimethylsiloxane in the pure form is a low toxic biologically inert substance, and its possible contact with water should not influence the biota state if it is present in the lake.

Obviously. the most valuable material for future microbiological and other studies will be the lower section of the accreted ice column, which is most free from alien admixtures entrapped by the water flow rushing to the hole from the lake.

It is noted in Section 7 of the Project "Scenario of possible emergencies in the process of borehole drilling" that "in the event of unplanned drill exit to the lake, an insignificant drilling fluid quantity and alien micro-biota with it can penetrate the lake. However, with water rising to the hole, all this will be entrained by the water flow back to the hole".
In respect of a possible ecological danger of exposure of the relict Lake Vostok to the current life on Earth, the following is noted.

First, lake water samples collected as an ice core will be in the hands and under control of competent investigators.

Second, according to calculated data, a prolonged connection of the lake surface with the hole will be fully excluded due to an ice plug at the borehole bottom.

Third, and the main, according to current understanding, human pathogens appeared on Earth with appearance of warn-blooded animals and man. And we deal with the material that had been isolated from current civilization long before it appeared.

It is also known that the preliminary microbiological studies of the accretion ice layer formed of water of the subglacial Lake Vostok, have not revealed any unusual forms of microorganisms except for the long known to microbiologists saprophyte forms frequently observed in the water medium.

At present, there are several alternative projects of access to Lake Vostok.

As an example of a principal technological solution of the problem of penetration through an ice shell to the water medium with simultaneous study and minimum contamination, the Project described the USA method of using automated devices. the socalled Cryobot and Hydrobot. It is planned that a Cryobot about 2 m long and 10-20 cm in diameter will be connected with the station on the ice surface by a super-thin cable fulfilling the carrying and communication functions. The Cryobot will pass downward through the ice sheet due to its own weight. With movement, the cable will unwind from the reel inside the Cryobot and remain frozen into the ice behind the device.

According to the design of the us engineers, at the time of passing through ice, the Hydrobot will be accommodated inside the Cryobot. At the time of Cryobot contacting the water layer, the Hydrobot will separate and begin independent studies of the water column transmitting information to the Cryobot by cable. A set of information to be transmitted will probably include visual imagery (images) of the environment, data on its chemistry, insoluble suspended matter, presence of nutrients. etc.

This technical proposal is attractive by the possibility of ensuring high degree of ecological safety during the lake study, however. for its implementation it is necessary to deliver the Cryobot to a maximum possible depth to decrease the distance to the lake surface. which will require drilling a new borehole. Otherwise, it will be necessary to place a reel with a cable 400 m long to the Cryobot. which is quite unreal.

The technology of penetrating Lake Vostok proposed by the AARJ and the SPSMI, differs advantageously from the aforementioned USA technology by its simplicity and reliability, possible control over the entire borehole length and automated operation of the drilling process.

The Expert Commission notes the following in respect of this section. In the framework of the Project of penetrating the subglacial lake, two components of one complex of measures to ensure the ecological safety of drilling operations should be subjected to a careful analysis:

- technological component determined by application of different drilling fluids and use of mechanical and thermal drilling methods;
- engineering components determined by design parameters of the drilling equipment applied.

Technological measures. Before the direct access to the lake, an intermediate buffer fluid layer is created that should decrease a possible lake contamination risk. The main measure of a technological character excluding the possibility of the drilling fluid penetrating the lake is to create in the borehole near-bottom zone the drilling fluid pressure smaller than the water pressure in the lake. This is possible only by ensuring a sufficiently high accuracy of the drilling fluid pressure measurement in the borehole. As estimated by the Project authors, the accuracy of pressure measurements at present is not less than ::to.9 b. To increase this accuracy is the most important reserve in ensuring ecological safety of work. At a high resolution of the instrument used, the accuracy of calculating the overburden pressure under compensation at the borehole bottom is relatively low, which results from the low accuracy of measuring the borehole depth and the drilling fluid level. The Project does not indicate how the moment of ending mechanical drilling and proceeding to thermal drilling will be defined and how the ice layer thickness to the lake surface will be determined and with what accuracy.

Engineering measures. The design parameters of the thermal drill to be used at the second stage of lake access exclude the drill exit to lake water and drilling fluid penetration from the borehole to the lake.

In the opinion of the Expert Commission, at accessing the lake using the proposed method, there are two ways of contaminants penetrating water of the lake:

- Influx of alien substances at water contact with the drill surface (I),
- Influx of such substances to the lake by their diffusion from the borehole through

the ice strata (2).

We shall consider both ways individually.

First way

When the thermal drill is lowered to the borehole before the final drilling stage, the drill should pass through a drilling fluid layer and as a result, its surface will be covered by a thin layer of this fluid.

The presented materials do not indicate at what moment of time the buffer silicon oil will be introduced to the hole -before or after the drill is submerged.

If the drill is submerged to the hole only through a layer of mixed kerosene and filler, the molecules of hydrocarbons comprising kerosene and fluorochloromethane will be absorbed at its surface. At heating the working part of the drill. the absorbed particles will be partly desorbed and transferred to melt water and then to ice. The remaining quantities of absorbed hydrocarbons can enter water from the drill surface.

If the drill after a kerosene layer passes through a 100 m of PMS. it will be practically cleaned of kerosene that is soluble in polyorganosiloxanes and will be covered by polydimethylsiloxane. In this case, the presence of polydimethylsiloxane molecules at the bottom (contact) pilot-chisel surface at its contact with water is quite possible. However, the edge angle of wetting the surface covered with polydimethylsiloxane is practically equal to 90 and due to its hydrophoby, this substance in not soluble in water. When in water. it tends to form droplets at its surface or films at very small quantities. If this film forms at lake access, which is unlikely, its main portion will go to the borehole at lake water incorporation. A possible remainder of PMS in water will be extremely small by mass at a level of milligrams or even its fractions. It should also be taken into account that polydimethylsiloxane is known as a non-toxic substance inert to biological objects. PMS does not react with water and dissolved salts of natural origin. This substance destroys in the water medium under the action of alkali and in the atmosphere at heating to the temperatures higher than 250oC. In the first case, a silicate anion and methanol and in the second, silica, carbonic acid and water are formed as the destruction products.

The materials submitted for expert examination do not inform how tightly the drill closes the lower exit from the hole and whether liquids will seep between the hole walls and the drill. If a leak of polydimethylsiloxane to the lake occurs, it will be of a lesser hann compared to kerosene whose composition includes aromatic hydrocarbons and other toxic substances.

Second way

It is known that oil and oil products are quite well absorbed by sea ice spreading in it. The oil migration rate in the ice strata was determined by the Canadian-US Expedition to the Beaufort Sea (1974) as 40 mm a day. During the experiments in Lake Ladoga (1978) undertaken by AAR1, the rate comprised 50 mm a day.

It was experimentally determined at the "North Pole-22" station that oil and oil product movement in arctic ice occurs both vertically and horizontally with the oil spreading rate in ice depending on the ice structure and composition. oil and oil product density and on solar radiation temperature and intensity .In the summertime. the rate increased to 80 mm a day decreasing to 20 mm in winter. In multiyear ice, permeated with a large number of pores and capillaries, a rate of 490 mm a day was noted.

Obviously, such migration can also occur under the conditions of Antarctica at the contact of the drilling fluid with the ice walls of the borehole. The specific conditions of Antarctica should also influence this process, however. migration of hydrocarbons comprising kerosene to ice also occurs here.

If we take as a basis. the hydrocarbon spreading rate of 10 mm a day. that is half as large as the lowest rate observed under the Arctic conditions, then for a period of more than 2 years (1999-2000), during which borehole SG-I is preserved filled with kerosene, the front of oil products could advance to all sides from the borehole and downward towards the lake over 7-8 m. One should take into account at this that at low Antarctic temperatures. the evaporation of hydrocarbons that have reached the ice surface in the course of migration is slow and the ice massif self-purification will occur many decades or probably centuries later. However, contamination of the Antarctic ice with kerosene from the existing borehole has already occurred and this is a real fact.

Migration of polydimethylsiloxane oil in ice has not been studied up to now. It can be assumed that it occurs much slower compared to hydrocarbons as the molecules of organic- silicon oligomer are much larger and less mobile than the molecules of hydrocarbons contained in kerosene. The situation is however, complicated by the fact that organosiloxanes are well soluble in hydrocarbons and hence both layers -kerosene with filler and organosiloxane are early or later will solve in each other and become one phase.

If the ice isthmus between the lake and the drilling fluid are preserved for a long time in the borehole, there will be a threat of contamination of the lake complex by hydrocarbons or polydimethylsiloxane through the ice of the borehole walls.

The project does not present the calculations of the heat balance change of the melt water column forming in the process of drilling with a height of around 30 m. We cannot exclude melt water accretion on the ice walls of the borehole at a below zero temperature and full water crystallization in the area of upper horizons until the drill reaches the ice boundary with the lake. If this takes place, then the work can be significantly complicated.

At thermal drill operation, there will be simultaneously a gradual cleaning of the drill and the carrying cable from the drilling fluids by melt water whose column will create an additional buffer layer below the organic silicon fluid.

It is envisaged that the thermal drill will perform a valve function ensuring the ecological safety of penetrating the lake.

Upon reaching the lake surface, it is proposed to create the conditions for lake water incorporation to the hole after which drilling opemtions are stopped until a complete lake water freezing in the borehole. Then, ice sampling from lake water by the electromechanical drill KEMS-132 will be carried out. It is unclear in what way melt water will be separated from lake water during the study. Part of ice near the boundary with the lake will not be drilled in order to ensure isolation of the borehole from the lake and to prevent possible adverse environmental consequences. This fact is a very important moment in the studies planned and one should keep to this variant.

In respect of using Freon 141 b, the Project "characterizes this substance as practically non-impacting the Earth's ozone layer". This is incorrect. Freon 141b is a hydrochlorofluorocarbon CH3CFCI2- The adopted name of this substance in the Vienna Convention (1985) and Montreal Protocol (1987) is HCFC-141b with ozone destroying capability of 0.11 (for comparison, CFC-ll has an ozone destroying capability of 1.0). HCFC-141b is placed among the regulated substances with a 35% decrease of its consumption by January 1, 2004, 65% by January 1, 2010 and 100% by January 1, 2030. However. the appeals for undertaking adequate measures to restrict the use of HCFCs are made increasingly more frequent lately at the international meetings on ozone destroying substances. Since the system considered under the framework of the submitted Project is closed, the emission of Freon 141 to the atmosphere appears to be extremely insignificant.

The hermetic sealing of the borehole with a thermal drill acting as a valve is not sufficiently justified.

There is no calculation of the heat sink rate and the drill capacity providing sufficient ground to think that water will not freeze ('... the melt water column -a buffer role").

A great deal of attention in the Project is given to describing the drilling fluid, its components. methods of delivery and storage and its properties. Unfortunately. there are no data on bactericide and bacteriostatic features of these liquids and a possible presence of the cells of macroorganisms in them. From experience of multiyear microbiological studies of the ice core segments from borehole SG-I. it is known that neither kerosene that has quite a large penetrating ability nor the microbial cells that are probably contained in an insignificant quantity in the drilling fluids penetrate the central ice core segments. Therefore. the presence of the drilling fluid in the borehole did not influence the results of microbiological studies of the ice core middle as shown by direct experimental studies. However. at a possible penetration of the drilling fluid to the lake, the cells of microorganisms it contains can get to the lake.

The Expert Commission has some comments on the contents of the documents under consideration, not directly connected with the ecological purity of the proposed technology. All of them refer to an incorrect use of chemical terms and formulas.

To increase the reliability and effectiveness of the methods to protect the subglacial lake from contamination, the expert commission has some recommendations.

4. Recommendations and proposals

To ensure a guaranteed ecological purity of Project implementation, it is desirable to make a preliminary checking of the developed technologies and drilling equipment before penetrating Lake Vostok under the field conditions to exclude possible failures. In the opinion of the Expert Commission, detailed consideration of the drill design and careful field trials before its application in the deep borehole are necessary .

1. It is desirable to conduct the preliminary studies specifying the parameters, processes and design features of the drill.

2. The same can be said about drilling the last 30 m as here. the cable with a drill will entrain part of the buffer fluid downward. Therefore, when operator senses that the drill approaches the moment of penetrating the lake, it will be probably necessary to stop drilling to give the buffer particles time to surface. The figure of 30 m requires additional justification.

3. In order to prepare the detailed documentation, the Expert Commission considers it necessary to:

- increase the accuracy of determining the pressure difference between the drilling fluid in the borehole and the ice massif overburden pressure;
- specify the method of determining the moment of transition to drilling by a thermal drill;
- specify the methodology of determining the ice layer thickness between the hole bottom and ice surface;
- work out in detail the drill design and make careful field tests before using in the deep borehole;
- specify the method of separating melt water from lake water during the operation and the heat sink rate and the thermal drill capacity~
- check experimentally whether there is a leakage of the drilling fluid and polydimethylsiloxane oil between the walls of the hole and the drill body. If it takes place, it should be eliminated by improving the drill design or in some other way;
- take into account the diffuse spreading of hydrocarbons in Antarctic ice and calculate on this basis the safe thickness of the ice plug in the hole and the ultimate permissible time of kerosene stay in the ice hole;

- develop and test the methods preventing or restricting dissolving of kerosene and polydimethylsiloxane oil in each other and use the most optimal solution for accessing the lake;
- envisage a possibility of breaking the monolithic character of the ice strata at the boundary with water.

5. In the opinion of the Expert Commission, at all stages of handling the drilling fluid, it is necessary if possible to ensure the purity of this fluid. It is noted in the Project that "liquid flowing from the cable and the drill at the recovery from the borehole is gathered in trays from which it goes again to the borehole". During this procedure, the maximum cleanliness of the trays and other materials contacting the flowing fluid to be repeatedly poured to the hole should be observed.

6. An analysis of all possible cases that might result in emergency with serious environmental implications primarily for the lake and the air medium should be presented in the detailed documentation.

7. It is necessary to envisage and eliminate a possible contamination of the butter layer, as to fill 100 m, 10 runs of the drill (descent and recovery) will be necessary, each of them resulting in the drilling fluid penetrating the buffer layer medium. Therefore, a more careful analysis of this mechanism is required. It can be performed theoretically (using, for example, the "boot effect" method) at the laboratory or under the field conditions.

8. During the work, the bactericide and bacteriological characteristics of the drilling fluids should be taken into account.

5. <u>Environmental protection during Project implementation</u>

The technical solutions of penetrating the lake considered in the Project were primarily assessed in terms of preventing the contamination of the relict lake.

The Program of investigating the subglacial Lake Vostok (its origin, regime hydrochemistry and possibilities and conditions of existence of hydrobionts in its water and their composition) envisages in addition to remote sensing geophysical surveys to use mathematical and physical models. It is also planned to directly penetrate lake water and conduct in situ studies. It is supposed that the lake access will be short-tern1.

An obligatory term for accessing the lake is a guarantee of cleanliness of technical equipment and technological operations, which should protect this unique natural object from chemical or biological contaminants.

An important problem of drilling operations at Vostok in order to investigate the subglacial lake is to minimize the adverse environmental impact. This impact can be subdivided into 2 categories -direct and indirect.

The first category includes waste accumulation near the hole, use of mixed drilling fluid~ deepening of borehole; ice structure change in the hole, unsealing the relict lake without penetrating it and an insignificant disturbance of the lake regime by an insignificant ingress of 1.5 mJ of water to the hole. The second category covers the risk of unplanned environmental impact; a possible loss of the drilling equipment in the lake and penetration of the drilling fluid to the lake.

The Expert Commission notes that all aforementioned aspects of possible environmental impact were considered in sufficient detail.

The aforementioned types of impact will obviously produce some specific environmental influence in the vicinity of Vostok station. This specifically concerns the ice structure change at additional drilling of 130 m of borehole 5G-l ~ presence in the hole of the special composition of the drilling fluid -aviation kerosene TC-1, Freon 141-b and organic- silicon fluid~ exposure of the subglacial lake and studies at the ice sheet surface. Continuation of drilling borehole 50-1 by a team of 4 people cannot make serious additional environmental changes. An assessment of the scale of the environmental impact given the efforts to prevent and mitigate this impact shows that in the opinion of the developers, this impact will be quite restricted and will not lead to any significant environmental changes.

The materials submitted by the AARI present a description and evaluation of the environmental impact during drilling of borehole SO-l and penetration to the subglacial Lake Vostok and measures to minimize this impact.

In accordance with Project calculations, no serious changes in the lake regime and the ambient conditions are expected.

In the opinion of the Expert Commission. the Section "Evaluation of Environmental impact of drilling borehole SO-l and penetrating the subglacial Lake Vostok'. mainly takes into account all requirements for protection of the specific natural environment at the Vostok station as recorded in the international agreements.

However, the Expert Commission has several recommendations that will allow making the protection of such a unique natural body as the subglacial lake more efficient.

5.1. Recommendations and proposals

1. The major recommendation in respect of environmental protection in the area of work planned is primarily the control for using a reliable ecologically clean and in situ tested technology for accessing Lake Vostok.

2. In the opinion of the Expert Commission. there should be a reference to Article 8 of the Protocol on Environmental Protection to the Antarctic Treaty in the EIA Section and in compliance with this Article. a definition of the impact of future activity (drilling and penetration) as:

a) less than a minor or transitory impact.

b) equal to a minor or transitory impact; or

c) more than a minor or transitory impact.

According to the Madrid Protocol. Criteria b) and c) require a Comprehensive Environmental .Evaluation in strict compliance with Article 3 (Annex 1 to the Protocol) with detailed answers on all sub-paragraphs.

There are such materials (answers) in the Project. It should be precisely stated whether the .'evaluation" perfom1ed refers to category (b) or (c).

3. The detailed design stage should envisage creation of a comprehensive ecological monitoring program.

6. General assessment or the submitted materials

1. The Expert Commission assesses positively in general the Project " Justification and development of the ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica).. submitted for consideration.

In general, the Project is characterized by using sufficiently efficient measures of protecting water of the subglacial Lake Vostok from external contamination. It identifies to a sufficient extent the ecologically dangerous factors and analyzes the contamination risks of ice massif and water of Lake Vostok at the different stages of drilling the borehole.

The Project uses high level technology and has an obvious scientific value. Its implementation is necessary .

2. It is noted that the proposed further drilling of borehole SO-l that has already reached a record depth of 3523 m will use tested and efficient technology by means of equipment available at Vostok with its insignificant modernizing, which minimizes the risk of

operation and ensures its sufficiently high reliability. In addition, the studies planned envisage a complex of measures to mitigate the environmental impact.

3. Analysis of engineering and ecological parameters of the proposed operations indicates that they were worked over in detail although some issues require even a more careful consideration.

This is primarily the control and comprehensive environmental monitoring.

4. It is noted that a possible environmental impact does not contradict the main principles recorded in the legislative documents and regulating acts of the Russian Federation, the UN program documents (2nd UN Conference, 1992) and the Protocol on Environmental Protection to the Antarctic Treaty signed in Madrid on October 4, 1991.

5. The work under consideration contains much interesting evidence and original technical solutions and can be in general approved both in terms of science and technology. It uses simple but sufficiently efficient measures to protect purity of water of the subglacial Lake Vostok.

6. The calculations of the Project authors aimed to prevent the drilling fluid penetration to the lake due to the pressure difference appear to be quite convincing. The authors note that the fluid pressure in the borehole will be less than the water pressure in the lake, that is, at the moment of accessing the lake, water will be rising to the hole. According to calculations, this fact can be regulated by changing the pressure in the drilling fluid column in the hole.

7. The Project considers several degrees of protecting the study object due to technology and technical equipment used. which can be considered quite justified.

The Project considers in detail the physical, chemical properties of the fluids used in the process of drilling and penetration to the lake. The choice of hydrophobic and inertial organic-silicon fluid (one of the silicone oils) as a material for a buffer plug at running the last 130 m appears to be quite justified.

Penetration of some significant volumes of the drilling fluid to the lake can be probably excluded. as the fluid is hydrophobic and much lighter than water. The Commission considers that even a local appearance of trace quantities of polydimethylsiloxane cannot produce any significant influence on the lake state either in chemical or biological respect.

It seems that under the conditions of lake access operation and after it is completed, no decomposition of polydimethylsiloxane will occur.

8. The Project proposes a sufficiently reliable, ingenious, effective and original method of solving quite an important and difficult problem based on long-term experience of glaciological drilling studies at Vostok station. This project differs advantageously from some foreign developments on penetrating Lake Vostok by its simple, relatively cheap. reliable and realistic character .

The Project developed by the AARI and SPSMI under the framework of the Program "Comprehensive studies of the oceans and the seas of the Arctic and the Antarctic" '.Justification and development of the ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica)", seems to be most acceptable compared to the other projects and can be assessed in terms of ecological safety as meeting the requirements made.

9. The submitted materials on the development of the ecologically clean technology and assessment of environmental impact during penetration to the subglacial Lake Vostok have been prepared at a high professional level and can be approved taking into account the recommendations and proposals of the Expert Commission.

CONCLUSIONS

1. The Project .'Justification and development of the ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica)" by its scope of work and contents

corresponds in general to the requirements of the legislative acts of the Russian Federation and regulating documents.

The Project contains the materials on environmental impact assessment with indication of nature protection measures and justification of the ecological permissibility of the activity planned.

2. Based on the examination of Project materials and given the submitted certificates of the correspondence and characteristics of the main properties of chemical reagents applied for Project implementation. the Expert Commission considers that the envisaged environmental impact of the Project in the process of penetrating the subglacial Lake Vostok is permissible and can be adopted as a basis to develop detailed documentation.

3. During Project implementation and at the detailed design stage. it is necessary to take into account the recommendations and proposals set forth in this Conclusion.

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Results of the Russian studies of the subglacial Lake Vostok

During the season of 2000-200 I. Russia continued studies of the subglacial Lake Vostok that have been started on a regular basis in 1995. [n the framework of the activities under the Russian Antarctic Expedition Program. the field studies included ground radar and seismic surveys to investigate the characteristics of the internal lake structure. The laboratory studies aimed at glaciological and microbiological investigation of the ice cores from the low horizons of the deep borehole drilled at Vostok station to a depth of 3623 m.

The radio-echo sounding of the ice sheet strata and the determination of the type of the reflecting surface (water or bedrock) were conducted by a discreet-continuous digital system with a carrier frequency of 60 MHz towed by a caterpillar vehicle. As a result of these studies, the coastline position in the southern area of the lake was obtained. The total length of radio- echo-sounding profiles comprised 1200 km where 58 points of the lake coastline determined by the change of the radiowave passage medium (water column-bedrock) were recorded. The assumed coastline boundary was described in the general plan at the map of the glacial daytime surface tilts. Special high precision work for mapping the coastline was undertaken and its details were specified approximately for one third of the water table of the lake in its southern area. According to the data obtained. the eastern shore of the subglacial Lake Vostok is located in the submeridional direction along 107~ at a distance of more than 70 kID. The southern shore has a complicated configuration characterized by a small inlet and a cape protruding to the take over more than 6 km. The western coast is strongly dissected. In the southwestern area. there is a round-shaped bay entrenched to the land over 6 km. At a distance of about 170 km from Vostok station northward, there is a system of bays and capes. The southernmost of them elongates submeridionally approximately along 104020'E protruding to the lake over a distance of about 15 km at a width of about 7 km. Here. a round- shaped bay is located intruding to the land over a distance of about 20 km. Farther north, there is an L-shaped peninsula with a size of approximately 30x I S km.

The ice sheet thickness above the lake changes from 3700 m in the southern area to 4350 m in the western part. The latter is the largest thickness ever measured by Russian (Soviet) specialists in Antarctica. In the general plan. the glacier thickness increases northward and eastward from the Vostok station. The glacier foot above the take is located in heights between -700 m to -200 m relative to sea level. In the southern area of Lake Vostok there is a lowland plain with depths around -200 m directly adjoining the lake. The character of radar signatures suggests the presence of small water-filled depressions of about 1 x I m in size. The study of the spatial structure of the water column and the bottom sediment layer was continued by means of seismic methods. According to these data. there are two "deepwater'. troughs in the southern lake area with the water layer 600- 700 m thick directly under the Vostok station and up to 1200 m north of the station. The trough situated under the station us characterized by the thickest layer of bottom sediments up to 200-300 m. The northern portion of the lake presents a shallow water area with the layer thickness less than 200 m. Similar decreases are also noted in the layer of bottom sediments where they have a thickness of several tens of meters.

An analysis of the measurements of the ice isotopic composition and electrical conductivity and the size of ice grains and the number of mineral inclusions in the ice core obtained at Vostok allowed a conclusion that the boundary between the glacier ice of atmospheric origin and the frozen at the lower ice base congelation ice formed from subglacial lake water occurs and the frozen at the lower ice base congelation ice formed from subglacial lake water occurs at a depth of3538 m. The study of the crystalline structure of lake ice by means of the x-ray topography method has revealed that this ice is characterized by an almost ideal structure and low density of the crystalline dislocation lattice. The maximum shear ice deformations occur in the 3460-3538 m layer that beds directly above the contact of glacial and lake ice. The calculations made on the basis of ice core data using a model of helium diffusion in ice have shown that the flowing ice sheet erodes to the upper surface of the lake ice layer with a rate of 2-8 mm/year. Thus. assuming the total thickness of the ice growth layer to be 220 m, one can calculate that the period of a full renewal of lake ice in this area comprises approximately 45 kyr.

The microbiological studies of the ice core deep layers were aimed to study the morphological diversity of microorganisms and obtain evidence of a possible preservation of their viability in the glacial strata. The results of these studies have indicated the presence of microorganisms in the lake ice belonging to different taxonomic groups. The numbers of bacteria vary from horizon to horizon reflecting a periodic character of the formation of layers of this zone. The morphological assessment of the detected microorganisms has revealed their significant diversity although slightly less compared to glacial ice. The molecular-biological investigation of microbial communities in the lake ice layer has indicated the absence of cyano-bacteria compared to surface snow specimens and the absence of the known forms of archae-bacteria {three divisions). A clone (DNA) of unknown origin was detected at this that may present a bacteria or archae-bacteria unknown to science. In addition, fungi DNA were found in the lake ice samples.

The obtained results of investigating the subglacial lake indicate a wide range of possible scientific interests in this natural phenomenon. The Russian Federation plans to continue both in-situ {radio-echo-sounding. seismic surveys and probably, drilling of ice with a thickness of not greater than 50 m) and laboratory (glaciology and microbiology) studies in the framework of the Russian Antarctic Expedition activities and at the research institutions of the country .