KARACHAY LAKE IS THE STORAGE OF THE RADIOACTIVE WASTES UNDER OPEN SKY

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ABSTRACT

Lake Karachay is situated at "Mayak" PA site. From October 1951 the lake was used as a storage of technological radioactive waste to stop the waste discharge into the Techa River. At present time the reservoir contains about 120 mln Ci of radionuclides. Lake Karachay presents a serious ecological problem being source of the contamination of the air, grounds and underground water. In this work a review of available sources dealing with Karachay's problem is made. Present and past approaches to this problem are shown.

INTRODUCTION

Production association “Mayak” is situated in the north part of Chelyabinsk region, near towns Kyshtym and Kasli (Fig. 1). “Mayak” was founded at the end of 40-s to produce plutonium and convert the nuclear materials for creating the parity in the field of the nuclear weapons. Activity of PA “Mayak” (before 60-s) was a source of radioactive contamination of the Ural region and, in the first place, of the norther part of Chelyabinsk region. Imperfection of nuclear technology at that time, lack of knowledge about behavior of radioactive substances in the environment and lack of dependable methods of handling with such substances were main causes of that radioactive pollution.

Lake Karachay is a closed reservoir, situated directly in the PA “Mayak” site, in central part of the water-parting area of Lakes Ulagach, Tatysh, Malaya Nanoga, Kyzyltash, and sources of the Mishelyak and Techa River (Fig. 2). Since October 1951, PA “Mayak” began to use Lake Karachay for the storage of radioactive wastes, in order to stop the waste discharge into the Techa River. This step was made because there were not enough containers for storage of big amounts of the radioactive wastes. Today Karachay is used for discharge of liquid middle radioactive wastes from radiochemical and radioisotope productions of PA “Mayak”.

Totally about 500 millions Ci of beta-radioactive nuclides were put into Karachay during all period of its exploitation. Today Karachay contains approximately 120 millions Ci of radionuclides [2], among them about 40% $^{90}$Sr+$^{90}$Y and 60% $^{137}$Cs. Radionuclides are distributed as follows: 7% in water, 41% in loams of the bed and 52%...

FIGURE 1. Situation of the PA “Mayak” and lake Karachay on the map of Chelyabinsk region
in mobile bottom sediments [1]. So, the main part of activity, accumulated in Karachay, is concentrated in mobile bottom sediments, where specific activities of $^{90}$Sr and $^{137}$Cs are as large as 1-2 Ci/kg. There is an equilibrium between radionuclides which are distributed in water and in bottom sediments. Thus, despite the radionuclide discharge into Karachay has reduced, total radioactivity of water is almost the same. The main radionuclides in water also are $^{90}$Sr and $^{137}$Cs. Content of alpha-emitting nuclides in water (such as Pu, Am, Np, Cm) is about 3-4 order of magnitude less than that of $^{90}$Sr.

**FIGURE 2.** Karachay Lake. View from the west. Summer, 1992

In order to clearly see the danger, emanating from Karachay, let’s look into the past. It’s enough to mention only one fact.

In spring 1967, during the period April, 10 – May, 15, big radioactive pollution of the territory adjoining the PA “Mayak” site occurred. This resulted from snowless winter, early and dry spring with catchy wind, which led to the exposure of lakebed. Total spread of radioactivity was about 600 Ci. Radionuclide compound of fall-out was as follows: 48% $^{137}$Cs, 34% $^{90}$Sr+$^{90}$Y and 18% $^{144}$Ce+$^{144}$Pr.

It should be noted, that the majority of radioactive pollution precipitated near Karachay Lake, within the bounds of the PA “Mayak”. Here density of contamination was 0.1 Ci/km$^2$ of $^{90}$Sr and 0.3 Ci/km$^2$ of $^{137}$Cs. The area of polluted territory (in this limits of density) was about 1800 km$^2$, distance of the radionuclide transfer amounted 50-75 km from “Mayak” (Fig. 3).

Because of this incident, new measures were taken to prevent future accidents. They covered part of Karachay, made some recultivation of the polluted area, put in force strict control of the water level in the lake. Nevertheless, spread of the radioactive aerosols from Karachay surface still take place. In the case of some catastrophe accidents (such as storm or tornado) Karachay can become a large-scale source of radioactive pollution of the environment.

Speaking of Karachay problems, it’s important to note the role of the public informing in this question. People’s apprehension, being adequate, permits to prevent social stress. It lets specialists solve Karachay problems without any haste and pressing.

**THE KARACHAY PROBLEM AND ITS SOLUTION**

Problem of Karachay includes at least three aspects [1]:
- Full liquidation of the lake to prevent the spread of radionuclides by the wind;

**FIGURE 3.** Area. polluted in 1967 ($^{137}$Cs)
• Restoration of the polluted area near Lake Karachay;
• Localization of the lens of polluted ground water.

Spreading of the radionuclides by the wind

In 1967 a decision about full liquidation of Karachay was accepted. In 1978-1986 they worked out a new technology of covering lake Karachay with rocky ground using empty concrete blocks (blocks like PB-1). This technology enables localizing mobile bottom sediments. This work has been carried on since 1986. The whole work may be divided into three stages [1].

The first stage is covering of north-east part of Karachay and filling partitioned dams. The second stage envisages complete closure of the lake and technical repair of the territory to "green lawn". This will remove any possibility of contamination of the air. This is in progress today. The third stage implies a localization and cleaning of polluted ground and underground water of Karachay Lake.

Partition of Karachay with dams, made in the first stage, made it possible to decrease spread of radioactive aerosols from the open surface and reduce possible negative consequences in case of storm. This was made in 1988-1990. As a result of the work carried out about 60% of mobile bottom sediments were localized. It's around 70% of total amount of radionuclides, accumulated in Karachay's water.

Today work of the second stage is in progress. This resulted in diminishing of the open water surface from 36 hectares (1971) to 8 at the end of 1999.

Water level in Karachay is controlled and regulated (if needed) by feeding with pure water. This permits to prevent exposing of the lake bed and eliminate spread of the radioactive clays. Complete liquidation of the source of spreading of the radioactive aerosols will be achieved only after total closing of Karachay.

It should be noted, that complete closing of Karachay is impossible without putting into operation the plants for conversion of the radioactive wastes. To stop discharging of radioactive wastes into Karachay without stopping PA "Mayak" activity is possible only by solving the problem of recycling and solidifying of liquid wastes of medium activity.

Contamination of the underground water with radionuclides

Lake Karachay contaminates underground water with radionuclides and chemical substances. Due to filtering of solutions from lake to underground, the aureole of polluted water was formed. In mass media this aureole also is known under term of "radioactive lens".

Total quantity of radionuclides, passed from Karachay to underground water for the whole period of activity, is estimated in 900 000 Ci. This equal to about 3.5 millions of cubic meters solution, containing around 1.4·10^6 kg of nitrate-ion. Today the volume of contaminated underground water amounts 5·10^6 m^3.

Concentration of the main radionuclides (like 90Sr, 60Co, 137Cs, 106Ru) in the lens directly under lake is 20-300 times less, than in the lake. But the content of nitrate-ion is 3-5 times more, than in the lake.

The determinants of spreading of the pollution in aquiferous layer are [2]:
• waterparting site of Karachay;
• permanent filtration of technical solution into the lens;
• presence of practically monolithic rocks in depth of 80-100 meters under the lake. This play a role of relative water lock, limiting the vertical migration of the radionuclides;
• heighten density of the polluted water, determining a differentiating of the solution in vertical cut;
• horizontal and vertical anisotropy of filtrating properties of the water containing rocks;
• sorption of radionuclides by the rocks;
• radioactive decay of radionuclides, resulting in self-cleaning of polluted water;
• diluting with pure ground water.

Density of underground water in the aureole is about 1.05 g/cm^3 [2]. The difference in density of polluted and pure water determines diffusion of contamination down. Due to gravitation, technical solutions are put down to upper border of the relative water lock and migrate to the unloading parts at a depth ranging from 40(60) to 100 meters. This is shown in hydrogeochemical cut of Karachay and adjoining territories (Fig. 4).

As it’s mentioned above, Karachay site is waterparting. So, there is a permanent flow of underground water from the lake to different directions according to hydrodynamic structure. Full-water years are an exception. Examples of such years are 1993 and 1994. There annual precipitation was half as much as the mean value for 46 years of observing. This led to the formation south to Karachay, of an area with ground water level being 1-2 meters that of the lake. Thus, underground water flow formed was directed into Karachay and resulted in raising its level. This caused the delay in covering the lake surface in 1993-1994.

Nitrate-ion, 90Sr, 60Co, 106Ru and tritium were selected as indicators for checking up expansion of the pollution. The aureole of polluted underground water around Lake Karachay is circumscribed by value of maximum permissible concentrations (m.p.c.) of nitrate-ion, and values of permissible levels of radioactivity (p.l.r.) of radionuclides mentioned, established by Norms of Radiation Safety (NRS), being in force.

Extension of aureoles of different contaminants is various. It is determined by its physical and chemical properties, concentrations, geological conditions, etc.

Migration of many contaminants is slows down owing to its sorption by rocks. However, sorption ability
Anions of mineral and organic acids, radionuclides such as $^3$H, $^{106}$Ru, $^{60}$Co freely migrate in form of anions and neutral complexes. Velocity of its migration is practically equals to velocity of the flow. Such radionuclides as $^{90}$Sr, $^{137}$Cs, $^{144}$Ce, $^{95}$Zr, $^{125}$Sb are in forms of cations and composite complexes. Its sorption by rocks is considerable, so its migration is slower than real velocity of the flow.

Spread of the aureole of radionuclide pollution depends on its half-life, unlike the stable components. At the same time some long-lived radionuclides such as uranium (many thousand years), $^{90}$Sr, $^{137}$Cs (about 30 years) and partly $^3$H (about 12 years) spread like stable components. It can form a stable aureole of pollution.

Extension of the aureole is had in eye. Its present state is well monitored. There are a lot of hydrological wells (189 pieces, which were drilled in 1962-1994).

Nowadays the aureoles of every contaminant are relatively stable, it means there is a fluctuation of concentrations around permanent magnitudes. Frontal parts of pollution are not so stable because of small concentrations of contaminants which can vary due to altering dilution, irregular arrival of pollutants into the flow etc.

Average velocity of frontal part of southern aureole is about 0.2 meters per day (73 meters per year), including nitrate-ion and $^{90}$Sr (0.23 meters per day), $^{60}$Co (0.14 meters per day). Average velocity of undiluted solutions, filtering from Karachay is about 0.17 meters per day [2].

So, nitrate-ion has a maximum velocity of spread in the underground water. Therefore the widest area of pollution is circumscribed by m.p.c of nitrate-ion. It amounts 10 km².

But the most ecologically dangerous is $^{90}$Sr because of its comparatively high concentration, toxicity, and long half-life. This radionuclide form a stable aureole, which is almost the same as of nitrate-ion. Other radionuclides form much less aureoles of pollution, it don’t spread over sanitary-protective zone of PA “Mayak”. In the inner parts of aureole concentrations of some chemical substances (Ac$^-$, SO$_4^{2-}$) and radionuclides (U, $^3$H, $^{137}$Cs, $^{106}$Ru, and other) are higher than m.p.c and p.l.r. accordingly.

Accordingly to the latest investigations, frontal southern part of aureole, polluted with $^{90}$Sr, now is closed in Mishelyak river. Heighten concentration of nitrate-ion is fixed in underground water of right bank of the river. However, lately some changes have occurred in spread of frontal part of the aureole southerly. The underground water flow having reached underbed zone of the Mishelyak River, turned to the course of the river (Fig. 5). This resulted from the presence of counter flow of unpolluted groundwater. So, further spread of the radioactive pollution southerly is unlikely occur.

![FIGURE 4. Hydrogeochemical cut](image)

![FIGURE 5. Scheme of the underground pollution](image)
Appreciable spread of the aureole eastward to mouth of the Mishelyak River and degradation of water quality in the river don’t take place.

Unique mathematical model “GEON-3D” based on perennial observation and scientific investigations was created to predict situation, dealing with polluted underground water spread from Karachay Lake. 300-years forecasts, made with the model, exclude any possibility both of polluted underground water of Karachay making appreciable effect on opened hydrographic net of the region and of global ecological catastrophe.

CONCLUSION

Highly qualified specialists deal with Karachay problem. The work is made by specialists of PA “Mayak” in colaboration with scientists of leading Russian scientific and production organization (such as Institute of geology and mineralogy of Russian Academy of science, Institute of geophysics of Ural department of Russian Academy of science and so on). Within the framework of State program of Russian Federation for rehabilitation of the Ural region, a big amount of complex geologic-geophysical and hydrogeological investigations was executed. The program of scientific investigations dealing with Karachay Lake problem is chaired by vice-president of the Russian Academy of science N. P. Laverov.

Mass-media often draws public attention to the lens of radioactive polluted water under Karachay. However it should be marked, that underground problem is too exaggerated. It may be affirmed that there won’t be any extreme situation, dealing with underground water. This is fluently developing and reliably controlled situation.

What is of real danger is opened water surface. Spread of the radioactive aerosols by the wind still take place. Thereto we mustn’t eliminate a possibility of tornado or storm above Karachay (only in this century thirteen tornados were registered at the Ural region). The consequences of this can be much more severe than an accident of 1967 or 1957 [3]. But this problem will be solved in the near future. A new plant for utilization of liquid radioactive wastes is to be put into operation in 2000-2001. So, there will be all conditions for complete closing Karachay Lake.

But even if Lake Karachay disappears forever from the Earth, problems related to it will remain.

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REFERENCES