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PERFORMANCE ESTIMATION IN EXPLOITING THE YUZHNOE URANIUM DEPOSIT BY UNDERGROUND LEACHING

Yu. V. Kul'tin

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The Yuzhnoe deposit lies on the northern flank of the Aldan shield and is the largest uranium deposit in the Russian Federation. Signs of uranium were detected in 1959, and surveys were performed from that time up to 1981 by the Prilenskgeologiya cooperative. During that period, repeated attempts were made to demonstrate the scope for exploitation by underground mine working, but each time the result was negative, so no further studies were conducted after 1981.

I consider that there is real scope for highly profitable exploitation by underground leaching, which is also ecologically cleaner than traditional methods and is favored by natural features.

The Yuzhnoe deposit is associated with a narrow zone of the same name in crushed and sometimes ground granites, gneisses, schists, and other igneous rocks that enclose the ore. The zone has an average thickness of 15 m, a dip angle of 70°, and can be traced along the strike for more than 20 km and to depths of more than 2 km.

The ores are of the aluminosilicate type having elevated contents of sulfide sulfur and carbon dioxide, namely on average 2.5 and 4.5% respectively for the mean values. About 95% of the sulfides is accounted for by pyrite.

The main uranium mineral is brannerite (uranium titanate), in which 2/3 of the total uranium is in the unoxidized quadrivalent form, and 1/3 in the hexavalent form. The ores also contain molybdenum, gold, and silver. There are appreciable amounts of vanadium, titanium, niobium, and certain other elements.

Joint-vein groundwaters occur in the deposit and in the surrounding rocks; the water permeability has been examined from pumping data for 107 hydrogeological boreholes, and also from observations on water inflow to mine workings. These data give the infiltration coefficient for forecasting purposes as 0.05 m/day. The productive zone enclosing the orebodies is much more fractured and therefore more permeable than the surrounding undamaged rock, but the infiltration coefficient has not been determined for it, water absorption by specimens of the ore and pumping data for one of the five parts of the deposit (the Neprokhodimyi part), with a mean infiltration coefficient is 0.145 m/day, and certain other signs of elevated permeability in the productive zone indicate that the infiltration coefficient should be increased above the average for the area by a factor 3-5 and constitute not less than 0.2 m/day. For comparison we note that such a coefficient occurs in the enclosing fractured quartz sandstones at the Königstein deposit in Germany, which was successfully exploited in the 1970s and 1980s by underground leaching without artificial ore crushing [1, 2].

The extraction of uranium from the ores was examined on a large number of samples ground to a grain size of 1 mm. Various leaching schemes and modes were considered involving the use of sulfuric acid and soda solutions, and it was found that the sulfuric acid process had advantages. The uranium recovery is estimated as 90% on the basis of a complete cycle of processing the extracted ores, including radiometric grading, dressing, and hydrometallurgical working. Surveys of the deposit have involved drilling over 2000 boreholes (among them, there were 8 boreholes of depth 1.5-2 km), and underground mine workings of length 52,500 m have been drilled. The boreholes and the mine workings were produced in the main without lining or reinforcement on account of the good rock stability. The rocks are classified as brittle and very brittle, and Protod'yakonov's coefficient is 10-15.

The deposit has been examined in the light of experience with underground leaching of uranium deposits, which showed that two varieties of the method can be employed: block underground leaching for crushed ores and borehole leaching of ores in natural lie. The main obstacles to block underground leaching are the high capital costs, the incomplete utilization of the reserves, the expense of mineworkers' labor, and so on. On the other hand, one should not rule it out completely at the current stage, but one can return to the subject if unsuccessful attempts are made to use borehole underground leaching, which has substantial advantages.

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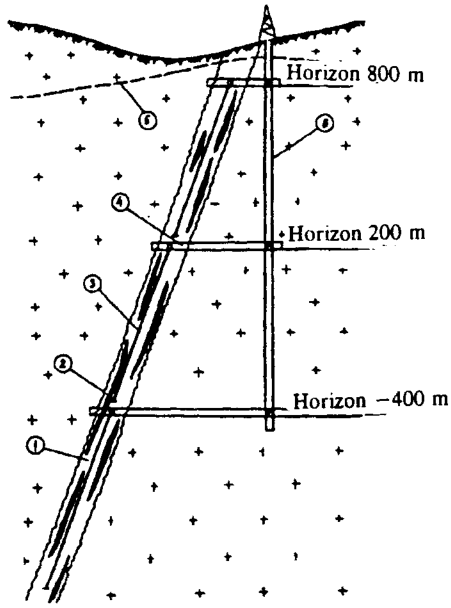

Fig. 1. Underground leaching scheme for steeply dipping orebodies.

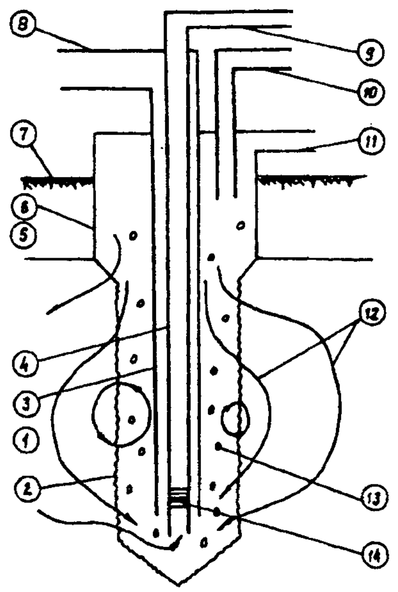

Fig. 2. Scheme for single-borehole orebody leaching by means of a gas-hydrodynamic link between the solution supply and solution removal parts of the borehole.

There are numerous underground leaching borehole systems [2, 3], which have been devised mainly for deposits associated with unconsolidated sedimentites. For rocky deposits, there are systems in which the solutions are supplied through boreholes drilled from the surface and also ones with solutions infiltrating through mineralized jointed granites and extracted by drainage workings drilled from mining horizons. Such systems amount to combined exploitation [2].

The number of borehole systems for exploiting rocky deposits is not known, but much attention is given to the topic. An example is provided by the industrial experiments on borehole underground leaching at the Santa Cruz copper deposit in the USA [4]. We know that preparatory work was done on the project (working boreholes were drilled, hydrogeological research was done, and so on), and the results were evaluated as positive, but there have been no publications on the subsequent implementation of the project and particularly on the results from underground leaching. There are reasons to doubt that the results have been positive, since the project was based on a geotechnological scheme for underground leaching of uranium deposits in unconsolidated beds and did not incorporate the substantial differences of the latter from rocky ones.

TABLE 1. Estimate of Costs in Extracting 1 kg of Uranium by Underground Leaching at Yuzhnoe

Operation	Costs	
	volume	value, dollars
Excavating mine workings, linear meter	$2,25\cdot10^{-4}$	0,203
Drilling geotechnical boreholes, linear meter	$3,3\cdot10^{-3}$	1,155
Preparing and supplying compressed air for oxidizing ores at a pressure of 60 atm, n·m^3	105	2,1
Cost of compressed air for pumping out productive solutions and transporting them for processing, n·m^3	15	0,3
Energy cost for pit drainage in drying spent horizons, kw·h	13,6	0,544
Processing productive solutions and obtaining final product, m^3	3	3
Processing final product and making saleable goods, kg	1	1
Washing and treating wash waters in restorative operations, m^3	1,5	1,2
Restoration operations, checks on the performance of environmental measures, and execution of methods of restoring the deposit and so on, man·months.	0,002	1

The main distinctive features of rocky deposits are the uneven jointing (and correspondingly permeability), the high thickness of the orebodies, the need to use large amounts of oxidizing agent, the, on the whole, low permeability of the enclosing rocks, and veinlet-nodular mineralization and so on. A feature of Yuzhnoe is that the orebodies dip steeply to great depths.

Experience with underground leaching and with engineering facilities [5] indicates that the Yuzhnoe deposit should be exploited in a combined system based on a one-borehole approach. This corresponds to the natural conditions at Yuzhnoe, although it was devised for the Udokan copper deposit [6].

Figure 1 illustrates the combined scheme for the Yuzhnoe deposit, in which we show the productive zone 1, the orebodies 2, the geotechnical boreholes 3, horizontal workings 4 across the strike of the productive zone, the lower boundary of the permafrost 5, and the pit 6. The deposit is divided into three horizons or stages at distances of 600 m apart. The exploitation begins with the top horizon, which is at a height of +800 m. After the productive zone has been reached by the horizontal channel, geotechnical boreholes are drilled at distances of 25 m apart along the dip of the productive zone to a depth of 600 m. After the top level has been exploited and washed free from leaching solutions and drained, preparatory operations are made on the horizon at the level of +200 m, and then the underlying stage is exploited by the same borehole system. When that stage has been exploited, the lowest stage of the deposit is exploited in the same order.

Figure 2 shows the leaching scheme in the one-borehole method: the orebody 1, the open part of the borehole column 2 in the orebody, the air inlet 3, the solution inlet 4, the barren rock 5, the lined part of the borehole 6, the surface of the Earth (drilling soil) 7, the compressed air pipe 8, the productive solution pipe 9, the pipe supplying the leaching solutions to the borehole 10, the pipe 11 for removing air from the borehole, the flow lines 12 of the solutions in the orebody and borehole, air bubbles 13, and the filter 14 in the solution-raising column.

In the borehole that has been drilled and fitted with pipes and a sealed header as in Fig. 2, leaching begins, for which air is supplied to the borehole through column 3 and leaching solution through pipe 10. Under the conditions at Yuzhnoe, the leaching solution is provided by stratal water, which together with the atmospheric oxygen dissolved in it is converted in the orebody by the oxidation of sulfide minerals to sulfuric acid containing an elevated amount of ferric sulfate, i.e., the solution usually employed for leaching uranium ores.

The sulfide minerals in the ore are sufficient to maintain a sulfuric acid concentration in the solution of 5-10 g/liter throughout the extraction from the ore in a single borehole. The approximate working life is 5-10 years with a liquid:solid ratio of 1.

As the solution is supplied, the productive solution is pumped out at the same rate through column 4, by the use of part of the air from column 3. The air passing through the perforated part of column 14 provides air-lift pumping. Much of the air on the other hand that rises in the space between the walls of the borehole and the tubes 3 separates the leaching solutions from the productive ones, and provides a gas-hydrodynamic barrier between them. Part of the air dissolves in the leaching solution and passes with it into the orebody and oxidizes not only the sulfide minerals but also the ore ones, which converts the quadrivalent uranium to the readily soluble hexavalent form. Another fraction of the air rises to the mouth of the borehole and is discharged into the atmosphere.

The productive solution is passed to a sorption equipment, where the uranium is extracted along with the associated elements in solution, and then passes as leaching solution through the pipe 10 for reuse until the uranium has been extracted completely from the orebody.

This processing system has been used in estimating the cost of extracting 1 kg of uranium in the commercial operation at Yuzhnoe. Table 1 shows that the cost of extracting uranium is 10.5 dollars/kg. The low extraction cost occurs first because of the large volume of ore processed by a single working borehole. In a sedimentary deposit, one has a network of boreholes over a cell size of 50×25 m, and one working borehole encompasses 1250 m^2 of the productive horizon, whereas at Yuzhnoe the area is $600 \times 25 = 15{,}000$ m^2. That area ratio and the other conditions mean that the cost of drilling the working boreholes are less by a factor of 10 than for sedimentary deposits. Also, there is no cost of sulfuric acid, which is the main reagent in the leaching solutions in sedimentary deposits. The basic reagent in the leaching solution instead is atmospheric oxygen, which reduces the cost by about a factor of 3-5 relative to sedimentary deposits.

In spite of the expected high performance, underground leaching should be applied to Yuzhnoe in the traditional three-stage sequence: ore sampling, experimental processing on a representative part of the deposit by underground leaching, and full commercial operation.

The ore sampling is designed to determine the scope for using underground leaching. For this purpose, a relatively small volume of ore is leached where it lies. The sampling is performed without processing the productive solutions, i.e., the useful components are not extracted. The sampling can be conducted in accordance with the scheme in Fig. 2. In this single-borehole scheme, one needs only 1-2 working boreholes and 1-2 observational ones, which are used over a period of 1-3 months at a total cost of 100-200 thousand dollars. The experimental operation of a part is used to formulate the economic basis for full commercial operation. The operations at this stage should pay for themselves. If positive results are obtained from the experiments, one devises an economic basis for the commercial exploitation, and the experimental part is extended to start the deposit exploitation.

Thus, the total duration of the operations in underground leaching does not exceed the periods laid down for sedimentary deposits.

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