THE RESULTS OF LABORATORY AND FIELD IN SITU LEACHING TESTS AT THE NYOTA URANIUM DEPOSIT (UNITED REPUBLIC OF TANZANIA)

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1. INTRODUCTION

The Nyota uranium deposit is located in the southern part of the United Republic of Tanzania (Tanzania). The geological setting of the deposit and its hydrogeological properties suggest that part of the resource could, potentially, be amenable to in situ leaching (ISL). In 2015–2016, the Uranium One Group conducted a range of studies to evaluate the possibility of ISL mining of the deposit. The studies consisted of laboratory core leaching, hydrogeological pumping tests and a field ISL test, carried out without processing of pregnant solutions. The ISL test aimed at determining the main ISL process parameters which are used for calculation of ISL mining parameters. The main ISL parameters are: uranium recovery, average uranium content in pregnant solutions, specific lixiviant consumption and the liquid:solid ratio.

2. DESCRIPTION

The Nyota uranium deposit, which forms a part of the Mkuju River Project, is located in southern Tanzania, some 470-km south-west of Dar es Salaam. The deposit is associated with a series of Lower Triassic continental sediments of the Karoo Supergroup, which are represented by poorly lithified gravels, sandstones and siltstones. There are three basic mineral forms that represent uranium mineralization: meta-autunite, meta-uranocircite and phosphuranylite. The minerals form a dense interspersed yellowish-green colour in the mica–hydrogoethite cement and on the surface of detrital grains. Ore hosting rocks are of low CO₂ content are therefore considered as being non-calcareous.

Orebodies are defined using a 0.01% uranium cut-off grade. Within the orebodies, ore grade varies from >0.01% to 1.8% U. Within the central part of the deposit, orebodies are detected at shallow depths ranging from the surface down to depths of 60–70 m. Within the northern part of the deposit, uranium mineralization has been detected at a depth of 150–170 m. Groundwater depths range from 1–2 m within river valleys to 40–50 m at watersheds. Consequently, uranium mineralization is located partly above groundwater level and partly below. The ore hosting aquifer is unconfined and has neither overlying nor underlying regional aquitards.
On the 31.12.2016, proven and probable reserves of the Nyota deposit were estimated at 25,900 tU and measured and indicated resources were estimated at about 48,000 tU [1]. The existing development plan of the deposit provides for conventional open pit mining with hydrometallurgical processing of ore. Owing to the recent decline in the uranium market, Uranium One Group is considering other mining possibilities in addition to the open pit mining method. The geological and hydrogeological setting of the deposit suggested the potential for uranium mining by the in-situ leach method. In 2015–2016, Uranium One Group conducted research to evaluate the amenability of the uranium mineralization for ISL mining. The studies consisted of laboratory core leaching tests, hydrogeological tests and an ISL field test.

Laboratory tests were conducted on core samples obtained during the drilling campaign of 2015. The borehole location provided core sampling in the central, the north-eastern and the southern parts of the deposit. Core samples were crushed to the size of sand grains (0.5–1.5 mm) and averaged.

Laboratory leach tests were conducted in two modes: static and dynamic. The main objectives of static leaching were to determine the amenability of uranium to dissolve in the leaching solutions; to select an appropriate composition for the leaching solution and to determine a degree of homogeneity of the samples in terms of leaching. In static tests, 10 g samples were leached in flasks at a constant liquid:solid ratio of 10. On the basis of the results of preliminary leaching tests, a sufficient test duration was defined as 24 h. A series of preliminary tests also revealed sulphuric acid to be the most efficient lixiviant. Therefore, further static tests were all carried out using solutions with sulphuric acid in concentrations of 5, 10 and 20 g/L. The static tests numbered 222 (71, 73 and 78 respectively). The test results showed that: (a) uranium mineralization is easy to leach, (b) all the samples are of the same type in terms of leachability and (c) uranium recovery for the entire sample batch is independent of uranium head grade and equals 100%.

In dynamic tests, filtration of leaching solutions through the core material was modelled. For this purpose, leach solutions were pushed upwards through the column loaded with 200 g core samples. Pregnant solutions were collected as samples of equal volume (25 mL) from the overflow and then analysed for uranium content, acid concentration and pH. Tests duration varied from 3 to 26 h. The results of the dynamic leaching tests were: uranium recovery 85–99%, average uranium content in pregnant solutions 69–1270 mg/L, sulphuric acid specific consumption 4–60 kg/kgU and a liquid:solid ratio of 1–4. These results are considered positive.

Hydrogeological studies consisted of single and cluster pumping tests which were conducted in hydrogeological wells drilled in 2015. The pumping tests were conducted in line with the ordinary technique, i.e. pumping at a constant discharge rate and monitoring at groundwater levels at the draw-down stage and recovery stage after pumping had stopped. Considering the possibility of deposit development by both open pit and in situ leaching, studies were conducted to evaluate hydrogeological properties of the upper part of uranium hosting aquifer. For that purpose, well screens were installed in hydrogeological wells at a depth interval of 6–83 m. Estimation of hydrogeological properties showed that uranium mineralization is distributed within the aquifer represented by sandstones of non-uniform permeability. Hydraulic conductivity of the sandstones determined in cluster pumping tests is 25–63 m²/d, suggesting that the aquifer is permeable in general.

The results of hydrogeological and laboratory leaching tests show that uranium mineralization is located in permeable sediments and can be dissolved by sulphuric acid solutions. These results made it possible to pass on to the implementation of an ISL field test.

ISL field testing was executed using the two-spot scheme, which was invented in the Russian Federation [2]. There are only two operating wells: the injection and the recovery ones. The flowrate of the recovery well should be greater than that of the injection well, and the ratio of these flowrates should be maintained constant throughout the test as this maintains the hydrodynamic isolation of the geological medium involved.
in the ISL test. This ensures movement of the solutions from the injection to the recovery well and only within the sampling volume. The planar area of the sampling volume can be calculated using a formula, with the distance between the injection and the recovery wells and the ratio of their flowrates indicated. There is no time variable in the formula which means that the volume is stable over time. These features of the testing scheme allow reliable estimation of uranium reserves within the sampling volume, and uranium recovery in field tests as well. Maintaining a stable sampling volume of the geological medium is the main advantage of the two-spot testing scheme.

Pregnant solutions which are moving towards the recovery well are diluted by fresh groundwater when they are pumped off. The degree of dilution of pregnant solutions is controlled by the flowrate ratio of the recovery and the injection wells. The pregnant solutions from the recovery well are sampled and then pumped into a discharge well. There is no processing of the pregnant solutions. The discharge well is usually located far enough from the test site so as to avoid influencing the discharge on the test. The main objective of the ISL test is a determination of ISL parameters as follows: uranium recovery, average uranium content in pregnant solutions, specific consumption of lixiviant and the liquid:solid ratio. Taken together, these parameters are usually used for evaluation of amenability of deposits or orebodies to ISL mining in terms of geology and hydrogeology.

Two-spot tests were widely implemented on the deposits of the former USSR and Mongolia and they are currently applied in the Russian Federation and China [3]. The duration of ISL tests vary from 2 to 6 months, with an average of 3 months. Thus, two-spot testing is a comparatively cheap and quick exploration method which allows evaluation of the suitability of deposits for ISL mining.

Site selection for the ISL field test was based on the results of exploration drilling. Eventually it was decided to conduct the test in the southern part of the deposit, where uranium mineralization occurs below the groundwater table. There are two orebodies detected within the selected test site. The upper orebody is at a depth of 25–35 m, the lower one is at a depth of 43–50 m. The orebodies are divided by a layer, 8–10 m thick, in which the uranium grade is significantly below 0.01% U. The upper orebody is more regular in thickness within the test site and has a higher grade than the lower orebody. For these reasons it was decided to conduct the ISL test only on the upper orebody.

The test site has the following geological and hydrogeological characteristics (for the upper orebody): 9.6 m average thickness of the orebody; 0.078% average uranium grade; 13.2 kg/m² average productivity; the aquifer is unconfined; groundwater depth is 18 m; the upper boundary of the orebody lies at a depth of 27 m; discharge flowrates of the injection and the recovery wells are about 2 m³/h; the orebody has neither overlying nor underlying aquitards which is typical of the entire deposit.

The following parameters were set out for the test: the distance between the injection and the recovery wells was 6 m, screening interval was 25–35 m for the whole thickness of the orebody, the recovery and the injection flowrates ratio was 5. Concentration of sulphuric acid was initially planned to be 15 g/L, but almost at the beginning of the test it was increased to 30 g/L and maintained at this level throughout the test. The test duration was 10 months.

During the test, groundwater level monitoring was conducted in 5 monitoring wells and in 2 operating wells, the injection and discharge flowrates were monitored, leaching and pregnant solutions were sampled. In leaching solutions, sulphuric acid concentration and pH were analysed, in pregnant solutions uranium content, sulphuric acid concentration and pH were analysed.
3. RESULTS AND DISCUSSION

On test completion, the actual flowrate ratio of the recovery and the injection wells was 5.1, which is very close to the design value.

The uranium content in pregnant solutions throughout the test was typical for leaching with rapid increase in values at the beginning, rising to maximum of 170 mg/L and followed by slowly decreasing values. By test completion, the uranium content in pregnant solutions was 125 mg/L.

The average uranium content in pregnant solutions was increasing throughout the test. By the test completion it was 109 mg/L.

Sulphuric acid specific consumption always decreased during the test, as normally happens. By test completion, the specific consumption was 70 kg/kgU.

The liquid:solid ratio varied linearly during the test and was equal to 2.2 when the test was stopped.

According to the requirements of the actual guidance documents, ISL two-spot testing should be conducted until the leaching process is complete. ISL process completion is considered to occur when the uranium content in pregnant solutions decreases to minimum industrial values (10–15 mg/L). Only completed ISL tests give reliable uranium recovery and other process parameters which can be used for further feasibility analysis. Taking into account that the uranium content at the end of the test was still 125 mg/L, the test should be regarded as not completed to the normal end. Its results cannot, therefore, be used directly for any estimations, as they are not supposed to characterize the ISL process in full. In this case, ISL parameters can be estimated by their extrapolation beyond the test time frame. Extrapolation is available if the ISL parameters’ trends clearly appeared during the test. The results available show that these trends appeared, so they were used for extrapolation of the relevant parameters.

A liquid:solid ratio value typical for ISL mining or which is often used in ISL development plans is 4. Therefore, the other test parameters were extrapolated to this liquid:solid ratio. According to uranium leaching dynamics, a liquid:solid ratio of 4 could have been achieved by the 458th day of the test. By that time, uranium recovery could be about 85%. By the end of the test, actual sulphuric acid specific consumption achieved the level values which were not expected to change significantly even if the test had been completed. Therefore, the final sulphuric acid specific consumption is on the same level as it was at the end of the test, i.e. 70 kg/kgU. The average uranium content of the pregnant solutions will be definitely higher than minimum industrial level of 10–15 mg/L and it is expected to be about 60–90 mg/L.

ISL tests results are usually assessed by comparison with their criterion quantities. The results are considered positive if all the parameter values meet their criterion quantities, which are as follows: uranium recovery >50%, average uranium content ≥20 mg/L, sulphuric acid specific consumption <150–200 kg/kgU and a liquid:solid ratio <10. The extrapolated results tally with their criterion quantities. Consequently, the studies conducted by Uranium One Group confirmed the distinct possibility of applying ISL mining to the Nyota deposit.

The described ISL test at the Nyota deposit is the first one ever carried out in Africa and it yielded encouraging results. On this basis, it can be concluded that ISL mining is definitely possible, thereby making the mining business more economically efficient and environmentally friendly.

REFERENCES
