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To cite this article: M P Sadykov 2019 *J. Phys.: Conf. Ser.* **1399** 022001

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Substantiation of uranium mining by ISL based on a geo-technological modeling

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Abstract. This article focuses on the use of geo-technological modeling techniques for mine planning and optimizing the extraction of uranium reserves. In the course of the research, there is calculated a time to achieve 80% of the extraction of uranium from each predictive block within an ore-body. These results of uranium mining are analyzed for the entire field based on an annual uranium extraction from each settlement block, taking into account a target total production, the productivity of factory for the enrichment of productive solutions and requirements for the concentration of uranium in working solutions.

1. Introduction

Numerical geo-technological modeling is widely used during the various stages of the development of a uranium deposit by an in-situ leaching method (ISL) [1]. From the point of view of ISL projects, mining planning, the optimization of well-testing sites and uranium extraction during mining, the restoration of the original properties of aquifer and its re-cultivation after the completion of the uranium mining process have different goals and objectives [2]. The experience with uranium deposits developed by the ISL method shows that to achieve each goal, an integrated geo-technological model can be used, linking the processes of filtering solutions in groundwater with a reactive mass transfer and the use of which can significantly improve the economic performance of a mining project. When such a model is developed, starting from the early stage of the project, it can provide a full cycle of forecasting the process of ISL, including mining planning, the optimization of uranium mining and the re-cultivation of a facility after mining [3].

2. Methodology

Geo-technological aspects associated with the extraction of uranium by an ISL method are very complex [4]. However, for predictive modeling, this complexity can be reduced to a relatively small number of fundamental processes occurring at ISL. The accuracy of an assessment can be enhanced by using our knowledge of these fundamental processes, regardless of how imperfect this knowledge may turn out to be [5]. There are two reasons for using an approach based on geo-technological modeling:

- Increase of accuracy in extrapolating the extraction of uranium over the long term;
- Consideration of changes in basic parameters (power, uranium content, sulfate content, the design parameters of a well-field, etc.) when evaluating the extraction of uranium at the various points of an ore deposit.



Considering the available technical data on the ISL experience, there was used geo-technological modeling, based on the construction of current tapes using studies performed by the US Mining Bureau (Peterson, 1985; Schmidt et al., 1981) [6]. Using this approach, a two-dimensional (2D) task for the well field is reduced to a one-dimensional (1D) task. The steps used in this procedure include:

- Data evaluation, the construction and analysis of current lines;
- Analysis of the direction and speed of solutions and reactive mass transfer;
- Predictive modeling.

The ISL geo-technological model uses an analytical or numerical model for analyzing current lines and the PHREEQC model to simulate changes in the concentration of uranium in a productive solution over time. Data on the initial extraction of uranium are necessary and were used to calibrate the geo-technological model.

The purpose of constructing current ribbons is to determine and analyze the flow region in which solute transfer with chemical reactions takes place. The current tapes were constructed using a two-dimensional stationary flow filtration model caused by the injection of a leach solution and the pumping out of a productive solution. In each case, a balance was achieved between the total costs of injection and extraction. Each streamline is characterized by flow and time to reach a pumping well.

The next step is the simulation of reactive mass transfer according to a conceptual model along with current ribbons obtained during the analysis of current lines. In order to simplify data processing, there was used one “tube” of current (that is, one reaction path), which consisted of 20–100 cells to represent all current strips in this task, and all cells inside the current tape were assigned a single time step. Each individual cell selected for the calculation is an observation point, which represents the end-point of the calculated current line [7].

The results of the PHREEQC calculation are concentration values for selected cells, which change over time and that represent flow lines to pumped wells [8, 9]. These concentrations were integrated in such a way as to plot the graphs of the concentration of uranium overtime for a changing production solution extracted from one pumping well or the group of pumping wells over time. This was achieved by calculating the averaging of concentrations with weights, using the weights coefficients obtained by analyzing streamlines. Then, the concentration averaged with weights and time-varying concentration was used to calculate a uranium extraction rate and cumulative uranium extraction.

Ore bodies were divided into linear row blocks and hexagonal cells depending on their deposit configuration. Productivity values (uranium reserves per unit area) for each estimated calculation block/cell were calculated based on a 3-D geological block model for calculating reserves.

There were constructed predicted geo-technological models for the linear block of wells and for a hexagonal cell to calculate uranium production based on a filtration coefficient, productive aquifer thickness, paleo-valley width (for a linear block), the flow of a pumped well and ore deposit productivity.

3. Results and discussion

Based on the construction of current ribbons and the simulation of the reactive mass transfer of ISL processes, the extraction of uranium was calculated for predicted linear blocks and hexagonal cells, varying the values of deposit productivity. The results of these predictive calculations include:

- The concentration of uranium in a productive solution in time;
- Uranium mining (in tons) depending on time;
- Percentage of the extraction of uranium in time, calculated depending on the productivity of an ore deposit.

Assuming a goal - 80% uranium extraction and using the obtained graphs, the dependence of 80% uranium extraction time on productivity as a polynomial function was calculated based on a regression analysis using the formula:

$$T_{80\%} = a + bxP + cxP^2 \quad (1)$$

where:

$T_{80\%}$ – 80% uranium recovery time (year);

P – Ore deposit productivity, (kg / m²).

Based on the $T_{80\%} = f(P)$ dependence, shown above in the equation (1) and in Figure 1, there was calculated a time taken to achieve 80% of the extraction of uranium from each prediction block within an ore body.

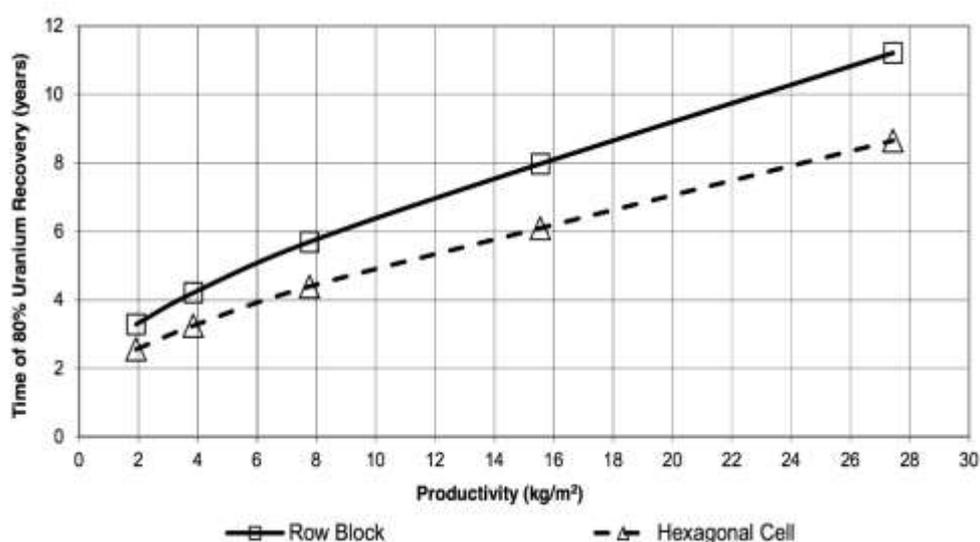


Figure 1. Relationship between the time of 80% extraction of uranium, depending on the productivity of an ore deposit.

The annual production of uranium from each settlement block was calculated by the formula:

$$U_{year} = (P \times A \times 0.8) / T_{80\%} \quad (2)$$

where:

$T_{80\%}$ – 80% uranium recovery time (year);

P – Ore deposit productivity, (kg / m²);

A – Block area (m²).

The average concentration of uranium in leach solutions within each calculation block was calculated by the formula:

$$C_{average} = (U_{year} \times 1000) / (Q \times 24 \times 365) \quad (3)$$

where:

$C_{average}$ – average concentration of uranium over time 80% of the extraction of uranium (mg / l);

U_{year} – annual production of uranium from each calculated (kg / year);

Q – total flow of pumped wells in a calculation block (m³ / hour).

The uranium production schedule was developed for the entire field based on an annual uranium extraction from each settlement block, taking into account: a) target total production, b) factory enrichment of productive solutions and c) requirements for the concentration of uranium in these solutions. A similar approach using geo-technological modeling can be used to optimize the field of wells and determine the distance between extraction and injection wells.

The proposed model approach can be used to justify the development of the field at the initial stage, design a system of pumping and injection wells, predict the operational parameters of the ISL system, predict the time of uranium extraction from the individual blocks or parts of the field, justify the production schedule and optimize well landfills to improve the economic performance of field development. In addition, such a model approach can predict and help optimize an aquifer re-cultivation process after the completion of uranium mining based on the analysis of the reactions occurring in the process of restoring the original properties of a horizon. Such processes include the circulation of special solutions, the purification of groundwater using reverse osmosis, as well as the introduction of alkaline or other solutions into a productive horizon. If the geotechnical model is developed at the initial stage of field development, its predictive ability will increase in time, creating a dynamic tool for the effective continuation of the operation of the ISL facility.

4. Conclusion

Concluding it can be said that this model approach can be used to justify the development of a field at the initial stage, to forecast the time of uranium extraction from the individual blocks or parts of a field and to improve the economic indicators of field development. Assuming a target of 80% uranium extraction was calculated based on regression analysis from each forecast block within an ore body. Furthermore, this model approach can predict and help optimize the aquifer re-cultivation process after the completion of uranium mining based on the analysis of the reactions occurring in the process of restoring the original properties of a horizon.

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