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## **IMPROVEMENT OF METHODOICAL RECEPTIONS FOR LOG DATA INTERPRETATION AT EXPLORATION AND DEVELOPMENT OF INFILTRATION URANIUM MINE FIELDS**

D.A. Legavko

*Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia*

**Abstract.** The description of the software realization for automated interpretation method of primary logging complex data in open hole of technological wells, constructed during the development of infiltration uranium mine fields by in situ leaching method is presented. The description of the software module that implements the previously developed methodical approach for interpretation of resistance logging data in the sandy-clay section is provided. Short characteristics of the program for gamma-ray logging data interpretation and calculation of linear stocks of uranium with using the method of morphological join of balance ore intervals are given.

**Keywords:** gamma-ray logging, resistance logging, automated interpretation, infiltration uranium deposits, underground leaching.

### **Introduction**

In recent decades, with the discovery of infiltration uranium deposits, the rapid development of the most progressive method for the production of this valuable raw material – In-situ leaching (ISL) began. This method is widely used around the world in infiltration deposits formed in the permeable sedimentary rocks of depression zones of the earth's crust. The opening of ore bodies and extraction of uranium in such deposits is carried out through the network of technological wells with the depth from 5 to 800 m and they number into hundreds and thousands at the existing enterprises. Construction of such a number of wells is followed by large volumes of well logging (WL) at all stages of exploration and deposit operation [Yazikov, Legavko, 2012]. At the stage of exploration and operational experience, WL is carried out in conjunction with laboratory core research, cluster hydrogeological observations and a number of other hydrological and engineering-geological studies that allows to expand the statistical information base for effective application of WL methods in the future when solving geological and geotechnical problems at the production stage.

In shifting to the field development, the process of well construction and conducting geophysical studies in them takes flow line character. In this case, the WL data is practically the only reliable basis for calculating stocks of uranium and designing optimal ore body opening systems; at the same time, results of their interpretation must be obtained in a short time to make reasoned decisions on further work associated with construction and operation of production blocks and individual technological wells. Large volumes of WL, strict time limits for registration and processing of geophysical data, and high significance of results of geophysical studies require maximum formalization of methods and automatization of registration and interpretation of WL data, that is especially important at the stage of operation of fields. However, despite the widespread use of digital recording of research logging data and the rapid development of electronic technology, the majority of uranium deposits in Russia and the CIS countries still use outdated borehole and ground-based geophysical equipment and soft-

ware, which has a number of technical and methodological limitations. In addition, the basic interpretation procedures are often carried out manually.

### **Formulation of the problem**

To improve the accuracy of results and ensure their repeatability, as well as to reduce the time and production resources for WL and processing of obtained data, new advanced hardware solutions, modern methods of automated data recording and their further interpretation are required. First of all, a maximum automation of interpretation processes is needed to solve two main tasks of geophysical support of uranium mining in infiltration deposits: lithological sectional layering with determination of layer-by-layer rock filtration coefficient according to electric logging data of apparent resistance (AR) and calculation of uranium stem stocks according to gamma-ray logging (GRL).

### **Automated electric logging interpretation**

The developed method of automated lithological sectional layering with obtaining stratified filtration characteristics of rocks based on the results of electric logging AR is described in detail in [Legavko, Legavko, 2011]. To date, the author developed the software for implementation of the above method and is carried out its trial operation at one of the uranium mining enterprises of the Republic of Uzbekistan. The software is represented by the *LitInt* application, implemented in the *Delphi* programming environment and operating under the *Windows* operation system. The application is designed for simultaneous work with logging data of one well and interpretation within one continuous interval. Interpretation of several ore horizons uncovered by one well and having significant differences in the parameters of the geological section is carried out by consecutive interpretation of well log data separately on the interval of each ore horizon. Main service functions of the program and interpretation processes are almost completely automated that allows the successfully use of the *LitInt* application for continuous interpretation work.

The *LitInt* application has a graphical interface built on the basis of standard visual components of *Windows*. The main part of the main program window is occupied by a tablet, designed to display the processed logs, supporting data and interpretation results (Fig. 1). To the left of the tablet is a panel with a list of graphic information at the upper part displayed by the program on the tablet. The multifunctional text editor is in the bottom part of the panel designed to display the log data and interpretation results in text form.

At the top of the window there is a main menu and a toolbar with the buttons to control the main functions. A program tablet is an area for constructing graphic information. Horizontal axis is the axis of depths, vertical axis is the axis of values. Axis of depths is the same for all diagrams displayed on the tablet. The units of measurements and scale of the axis of values correspond to the graphical information of the diagram marked in the list.

The tablet has horizontal and vertical scroll bars, which allows you to scroll the displayed information in the corresponding directions. The application includes functions of vertical and horizontal scaling. There are several ways to control the properties of the displayed diagrams - changing the color, the original scale of the values; enabling / disabling data visualization and their removal is carried out using a list of graphical information. To use these functions, you need to “right-click” on the selected item in the list of graphic information and use the menu that appears.

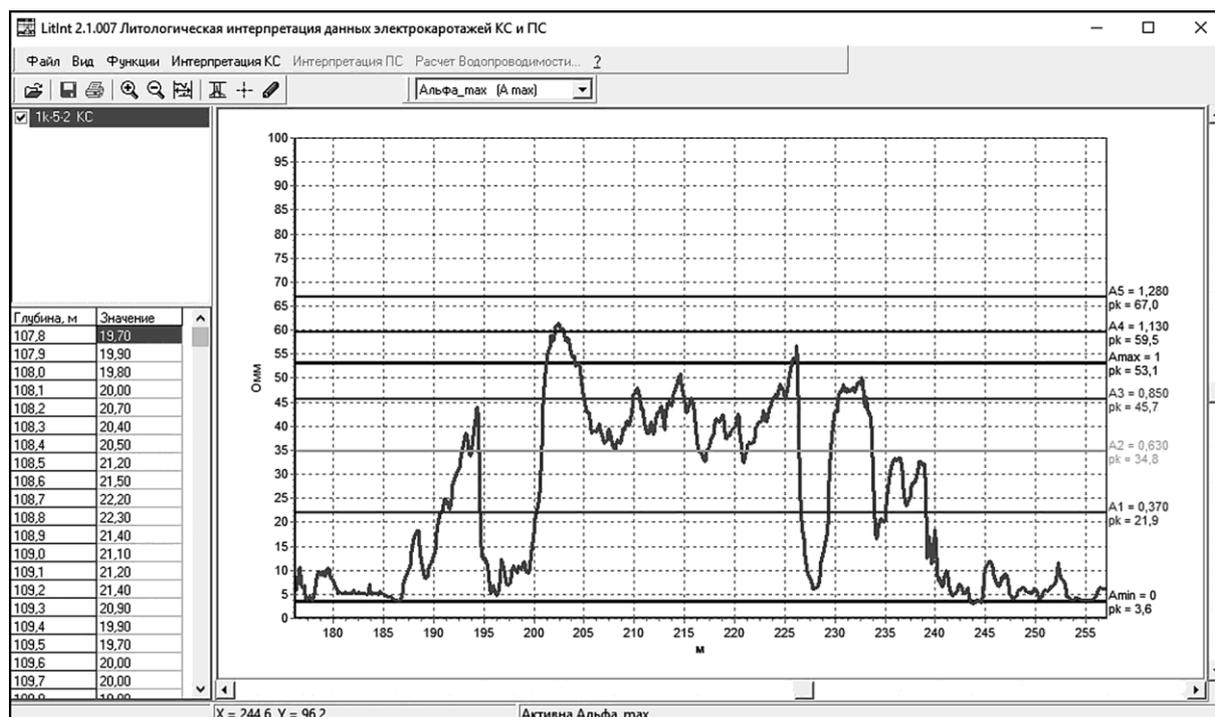


Fig. 1. Main window of the LitInt application used for the electric log data interpretation

For lithological separation of rocks and determination of the filtration coefficient  $K_{\phi}$  of the allocated layers, a correlation dependence between the rock resistance and their filtration coefficient is used. In this case, the rock resistance is mediated by the normalized geophysical parameter  $\alpha_p$ , obtained by normalizing the AR log data using the double difference parameter, and the correlation dependence is set in the form of a table of the relationship between the boundary values of  $\alpha_p$  and  $K_{\phi}$  for lithological types of rocks composing the studied ore horizon. The window "Lithology table" is used to set the correlation between  $\alpha_p$  and  $K_{\phi}$  (Fig. 2).

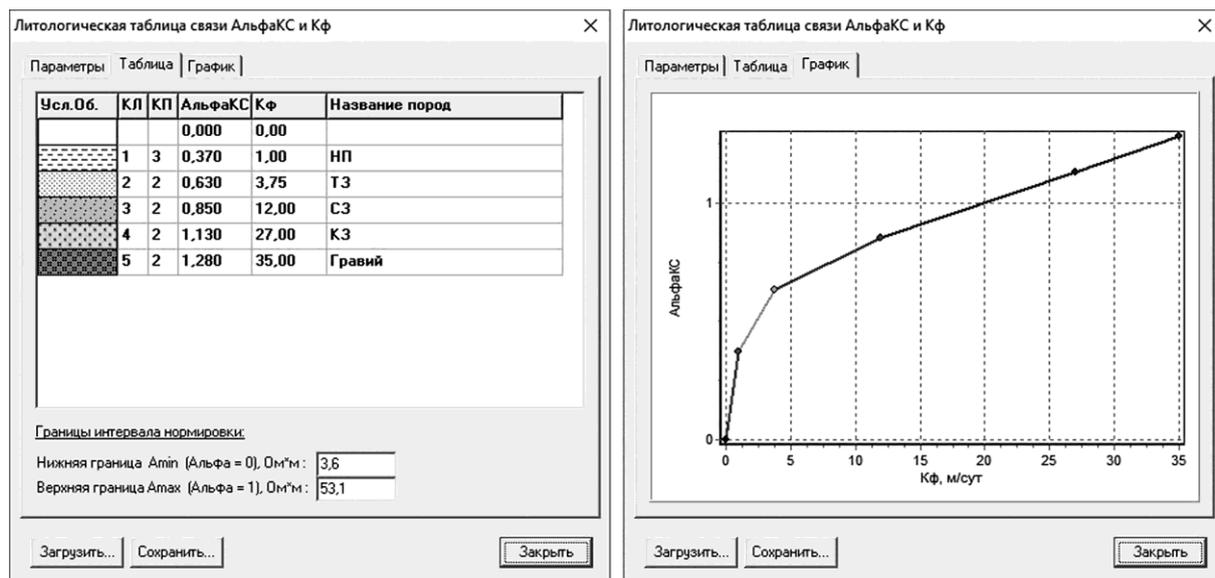


Fig. 2. "Lithology table" window. Displaying of the relation between the boundary values  $\alpha_p$  and  $K_{\phi}$  in a tabular (left) and graphic (right) view

In the table, the user can describe any number of lithological rock types into which it is necessary to divide the section of the studied horizon, indicating for them the corresponding digital code, legend, description, as well as the boundary values of the filtration coefficients  $K_\phi$  and the corresponding  $\alpha_\rho$  values.

The boundaries of the normalization interval and the table of connection of the boundary values are displayed on the graphic tablet of the interpretation program in the form of lines parallel to the depth axis drawn over the AR logging curve (see Fig. 1). The lines of the connection table have the meaning of boundary filtering coefficients. By moving them along the axis of resistances, the interpreter can change the boundary values of the parameter  $\alpha_\rho$ , thus changing the original table of connection  $\alpha_\rho$  and  $K_\phi$ . In this case, the relationship between the apparent resistance curve and the table of the connection of the boundary values of  $\alpha_\rho$  and  $K_\phi$  is clearly visualized, according to which the section is lithologically divided.

At the beginning of the interpretation, the straight lines corresponding to the boundaries of the normalization interval are set to the level of the minimum and maximum values of the apparent resistance of the log curve, and the lines of the boundary values of the filtration coefficient to the level corresponding to the value of  $\alpha_\rho$  in the resulting boundaries of the normalization interval according to the initial connection table. The interpreter is given the opportunity to consecutively adjust the position of the normalization interval boundaries by moving them along the resistance axis with the help of a “mouse” or arrows on the keyboard. In this case, the lines of the connection table are automatically moved to a new level of the value  $\alpha_\rho$  corresponding to them in the new boundaries of the normalization interval. After setting the boundaries of the normalization interval, the interpreter can, if necessary, consecutively change the position of the lines of the connection table, thereby changing the original table itself. In this case, on the tablet to the right of the line, the value of the parameter  $\alpha_\rho$ , corresponding to the position of the moved line is displayed.

Visualization of the boundary value connection table by applying its nodal points to the interpreted diagram and the ability to control the table by moving these lines along the resistance axis allows not only to visually connect the log curve with the correlation dependence  $\alpha_\rho$  and  $K_\phi$ , but also to get a convenient interpretation tool, a kind of palette. Such a palette allows you to divide the section into a given number of rock types according to the boundary values of the desired parameter. And in cases where for some reason it is not possible to adjust the connection table on the reference well, but it is known what lithotypes the section should be divided into and what are the boundary values of the filtration coefficient for each lithotype, the program running in the “manual” mode (mode of manual managing of the connection table) is an indispensable tool in the hands of an experienced interpreter.

After setting the normalization interval and adjusting the lines of the boundary value table, the automatic interpretation process starts - the program processes the algorithm described in the article [Legavko, Legavko, 2011] and draws the obtained lithological section in the upper part of the tablet. Boundaries, thickness, lithotype code, and filtration coefficient are determined for each selected layer in the section (Fig. 3). The user has the opportunity to view and edit the obtained lithological section through a text editor in the main window of the program or by moving the cursor along the section, adding or removing the boundaries of the layers and, if necessary, changing the lithotypes of the rocks of individual layers and their filtering coefficients.

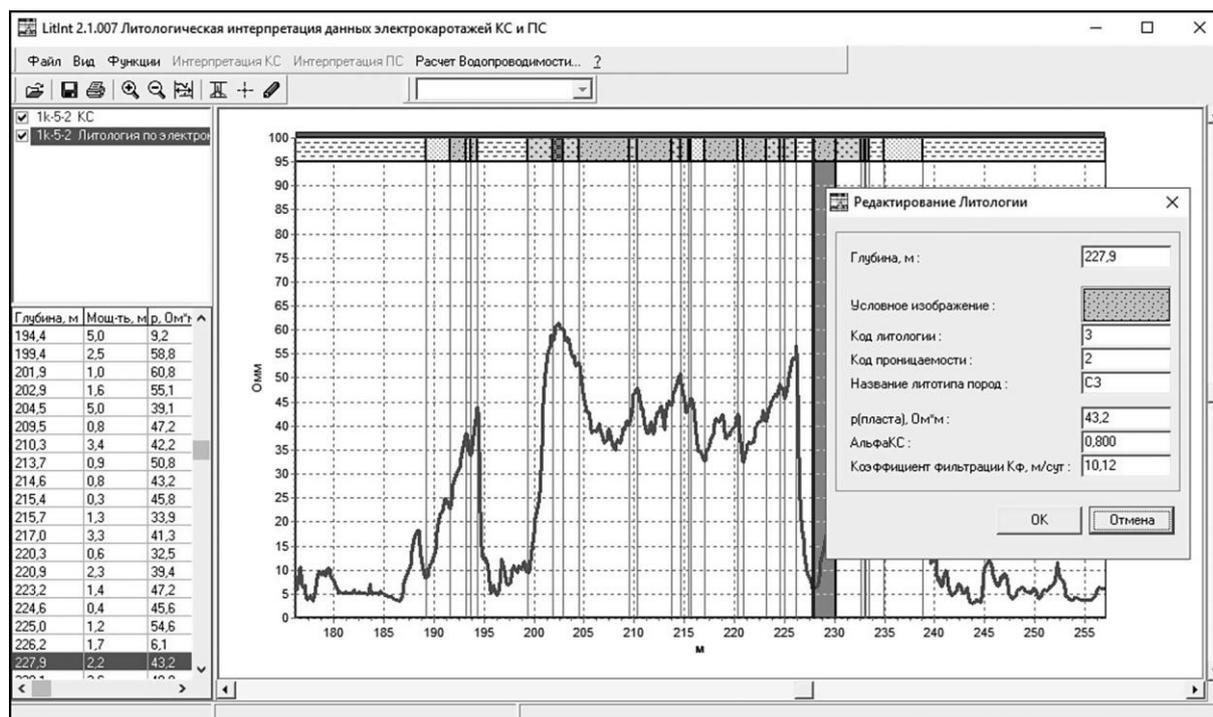


Fig. 3. Example of lithologic sectional layering

To set up a connection table of the boundary values of  $\alpha_p$  and  $K_\phi$  on the data of the reference hydro-geological well, the application includes a calculation procedure based on the interpretation of the coefficient of permeability of rocks in any given interval of depths of the ore horizon. The coefficient of permeability for the interval specified by the interpreter is defined as the sum of coefficients of permeability of the layers included in this interval, the latter being defined as the product of the filtration coefficient by the thickness of a layer.

If the interpretation process is successfully completed, the functions for saving and printing of the interpretation results become available. The program saves the results in a text file format as the boundaries of the selected lithological intervals and their calculated parameters. This file is used for the automated interpretation of gamma-ray logging to separate the section into permeable and impermeable rocks.

Besides, the application creates and prints a text report on the performed interpretation and a graphical representation of the processed diagrams and interpretation results. The text report contains "Interpretation Parameters" - a list of parameter values used in the interpretation, and "Interpretation Result" - a lithological table containing data on boundary depths, thicknesses of lithological intervals allocated in the section of the well and their filtration coefficients.

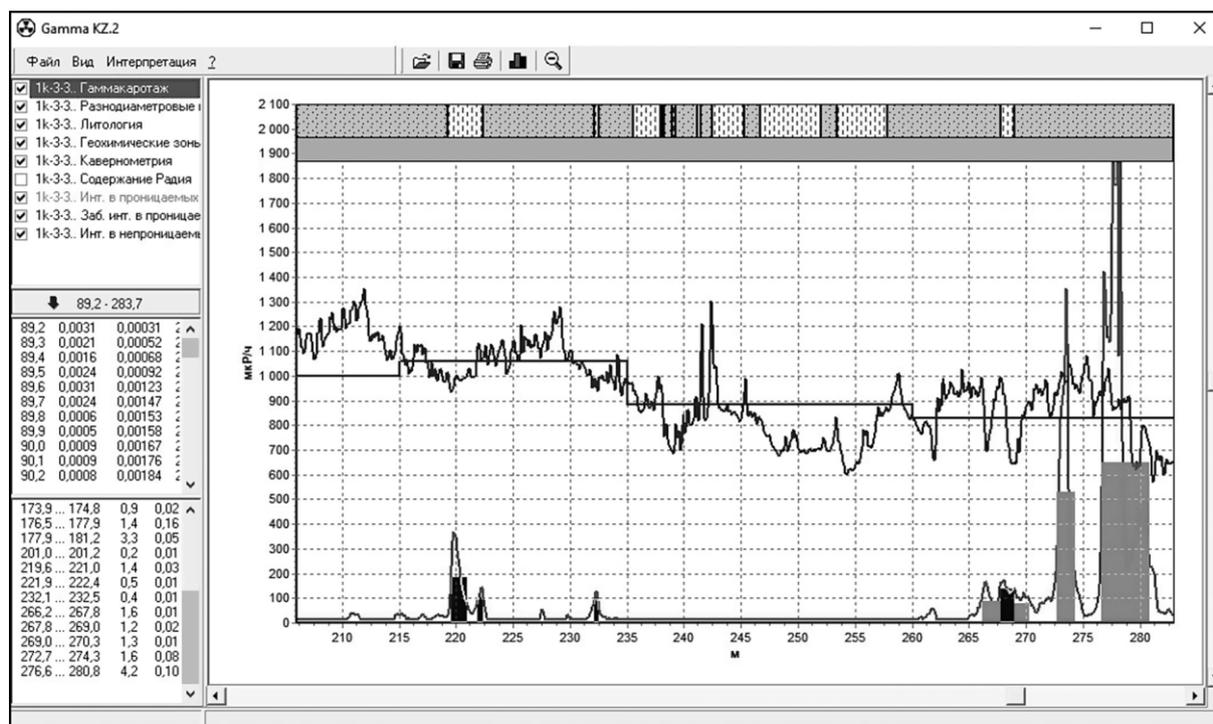
### Automated interpretation of the gamma-ray logging

The instructive methodology of the automated interpretation of gamma-ray logging data, which was modified in terms of the morphological association of elementary ore intervals, is described in detail in the article [Legavko, Legavko, 2017]. Currently, the author developed a software for implementing the above methodology and its trial operation at uranium mining enterprises in Russia and the Republic of Uzbekistan is conducted. The software is represented by the "Gamma" application, implemented in the Delphi programming environment and operating under the Windows operating system. The application has a graphical interface built on the basis of standard visual components of Windows, similar to the application interface

for interpreting AR logging data. The main part of the main program window is occupied by the tablet, designed to display the processed logs, supporting data and interpretation results (Fig. 4).

When you open gamma-ray logging data, the program automatically searches in the same directory of files with caliper measurement data and the results of lithological interpretation of electric-logging data. If the application manages to find and read such files and the information on the well with the number corresponding to the number of the gamma-ray logs is found in them, then the caliper measurement and lithological column data are automatically opened, and a single zone of equal diameter is created on the entire cavern recording interval, the value of which obtained by averaging caliper measurement data.

If it is not possible to find or open the required files, as well as if they do not contain information on the well with the current number, then a zone of equal diameter is created throughout the gamma-ray recording interval, the value of which corresponds to the nominal drilling diameter read from the gamma-ray file, and lithological interval represented by permeable rocks. The user can add, delete and edit zones of equal diameter and lithological intervals.



**Fig. 4.** Main window of the "Gamma" gamma ray logging data interpretation program

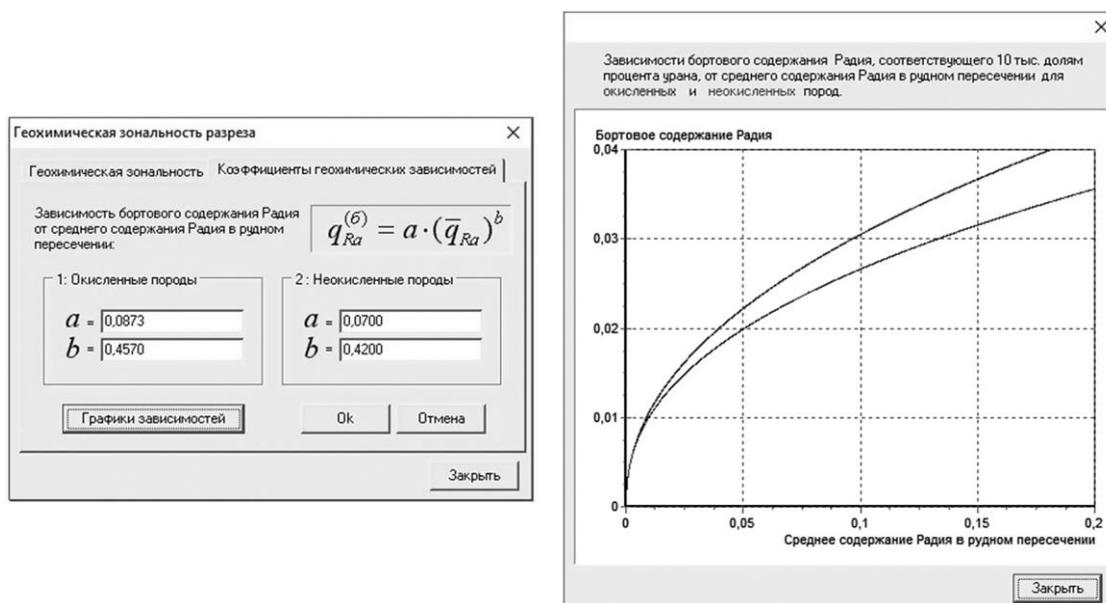
Caliper measurement data and zones of equal diameter are used to input corrections for the absorption of gamma radiation by the drilling fluid and to select the coefficients of the digital filter  $B_k$ . Corrections for the absorption of gamma radiation with caliper measurement data are calculated at each depth point depending on the diameter of the well to improve the accuracy of the calculations. The selection of the coefficients  $B_k$  is carried out for the average values of zones of equal diameter, since a change in the digital filter coefficients in a jump leads to a change in the area under the gamma-ray curve at the points of intersection of the filters with different coefficients. Therefore, the boundaries of the change of zones of equal diameter should be set by the operator carefully and reasonably. The less there are the boundaries of the change of zones of equal diameter, the smaller the calculation errors caused by the

change in the values of the coefficients of the digital filter. If possible, it is necessary to refrain from setting the boundaries of equal diameter zones in the intervals of intense mineralization.

The lithological column obtained as a result of interpretation electric logging data or input manually by the user is used in a simplified form, which involves splitting of the section into permeable and impermeable rocks. Permeability separation is used to solve two problems. The first one is the dividing of ore intervals into balance (located in permeable rocks and suitable for extraction by underground leaching) and technologically off-balance (located in impermeable rocks, the extraction of which by underground leaching is technologically impossible); the second is the correct input of correction coefficients (moisture and rock density, correction for “squeezing” radon), often significantly different for permeable and impermeable rocks.

In addition to the boundaries of zones of equal diameter and a lithological column, the user has the ability to specify the boundaries of the geochemical zones of the well section. By default, it is believed that the entire section of the well is represented by reconstructed rocks, which corresponds to the “bag” zone of the ore deposit. The user can add intervals of oxidized rocks based on the shape of gamma-anomalies, lithological section of the well and additional geological information.

The geochemical zoning of the section is used for interpretation in two directions - firstly, to select the dependence of the cut-off radium content on the average radium content in the ore interval. Dependences of cut-off on average content (Fig. 5) are built separately for reconstructed and oxidized rocks; at the same time, for each of the boundaries of the ore interval, its own dependence is selected corresponding to the geochemical zone where falls the boundary of the interval. Secondly, according to the location of the boundaries of the ore intervals in geochemical zones, their belonging to the morphological elements of the ore deposit is determined. The intervals belong to the “baggy” part of the deposit when their roof and the base fall into the zone of reconstructed rocks. Intervals with the roof in the zone of reconstructed rocks, and the base in the zone of oxidized rocks, refer to the upper wing. The lower wing includes intervals with the roof in the zone of oxidized rocks, and the base in the zone of reconstructed rocks.



**Fig. 5.** Window of dependences of radium cutoff content on its average content in the ore intersection in analytical (*left*) and graphical (*right*) representation

The intervals with both boundaries in the zone of oxidized rocks, belong to the outlier part of the deposit. For intervals with different morphological property, during the interpretation, different values of the radioactive equilibrium coefficient are automatically selected.

The coefficients of radioactive equilibrium, other correction coefficients and parameters, along with the settings of the interpretation algorithm, are available in the window of interpretation parameters (Fig. 6). Some of the fields in this window are automatically filled when reading a file with gamma-ray data. The remaining fields are filled in by the operator when setting up the application to work in a specific deposit of a particular mine field.

After opening gamma-ray data and automatically or manually filling of the lithological column, setting the boundaries of zones of equal diameter and geochemical boundaries of the well section, the operator starts the interpretation process, during which calculations are performed fully automatically according to the algorithm described in [Legavko, Legavko, 2017].

Figure 6 shows two screenshots of the 'Parameters of Interpretation' window. The left screenshot displays the 'Parameters of Interpretation' tab, which includes fields for 'Interval of Interpretation' (Roof: 89.2, Bottom: 283.7), 'Options' (checked: Transformation of gamma-ray values, Interpolation of Bk coefficients by density and diameter, Merging elementary ore intersections), 'Parameters of Merging' (Max power of the layer: 1, Max coefficient of dilution: 0.75, Max power of non-permeable layers: 0.3), and 'Borehole Parameters' (Coefficient: 115, Diameter: 60, Nominal diameter: 151, Density: 1.14, Thickness: 0). The right screenshot displays the 'Parameters of Ore' tab, which includes a table for 'Disturbance of Radioactive Equilibrium' (Permeable/Impermeable), 'Moisture and Ore Density', and 'Ore Conditions' (Uranium content, Minimum linear stock).

Fig. 6. Window of interpretation parameters

That is: the radium content along the borehole is calculated, the boundaries of elementary ore intersections are determined using geochemical zoning and dependencies of the cut-off radium on the average, the morphological combination of elementary ore intersections, the ore intervals are sorted into balance and technologically unbalanced ones according to the lithological column of the well, the average uranium contents in the selected intervals and calculation of the total linear stock of uranium along the wellbore.

The ore intervals obtained as a result of interpretation, in the form of rectangles with the width corresponding to the thickness of the ore intervals, and the height corresponding to the average content of uranium in them, are displayed on the tablet of the main program window and are printed. The application is capable of large-scale graphic printing of input logs, supporting information and interpretation results.

The content of the graphic document and the scales of the axes with the values of the information presented in it are controlled by the list of graphic information of the main program window. The graphic elements displayed on the tablet of the main window are printed, with a scale along the axis of values corresponding to the scale on the tablet. Comparison of the results of the interpretation of gamma-ray logging data of typical wells at different uranium infiltration deposits obtained using the morphological association described in the article [Leg-

avko, Legavko, 2017], and the results obtained using the standard instructive method [Haikovich et al., 1987], showed the effectiveness of the proposed algorithm.

### Conclusions

The results of the trial operation of the software presented in this article showed that its implementation provides an acceptable level of automation of the interpretation processes of the primary logging complex of the open hole of technological wells constructed during the mining of uranium infiltration deposits by underground leaching.

Using the methodology of morphological association of ore intervals, implemented in the gamma-ray log interpretation program (with the correct determination of morphological and geotechnological parameters of the association), provides an increase in the accuracy of determining recoverable stem resources of uranium in the interval of the ore horizon.

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