RESULTS OF STUDIES IN THE EXISTING WELLS OF THE YENISEYSKIY SUBSURFACE SITE INCLUDING THOSE PERFORMED TO IDENTIFY THE MAIN FRACTURE SYSTEMS AND ROCK ANISOTROPY

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Conditions in the crystalline geological massif, governing the long-term safety of radioactive waste disposal were reduced to two fundamental factors: features of the host rocks and the fracture network inherent in the studied area of the massif [3]. Refinement of the parameters identified early in the geological study of the cracks is seen as a highest priority task in the safety assessment of radioactive waste disposal. These parameters should be also taken into account in the development of requirements for the composition and structure of the engineered barrier system preventing the release of radionuclides outside the disposal system. The paper describes the work and the approaches applied in the processing of borehole survey results for the prospecting and appraisal stages of geological exploration of the Yeniseisky area performed using a purpose-developed probe with video logging equipment.

Keywords: radioactive waste, radioactive waste disposal, underground research laboratory, rock mass characterization, studies of the near-wellbore zone, video survey of wells, identification of the main fracture systems.

Geological study of the Yeniseisky site [1, 2] indicates that various types of tectonic disturbances can be found within the block proposed for URL construction. Moreover, core logging of the wells drilled in this area, as well as the data from borehole geophysical studies provide basic information about the rock mass disturbance at the target depth interval [3]. This information gives an idea of the quantitative characteristics of rock mass disturbances. However, since the exploration wells were drilled with no concern given to proper core orientation in space, actual spatial position of tectonic faults and fracture systems still remains to be investigated [4]. Another point to note is that during core drilling, technogenic chips and cracks are formed introducing additional uncertainties to the assessment of the actual rock mass state which is another factor complicating the description of core structural features. In this regard, it was decided to study the wellbores using purposely-designed downhole equipment, namely, a research probe allowing to identify fracture system orientation, fracture network parameters and to record the thickness of structural faults.

Preliminary geological materials obtained from the geological exploration performed at the prospecting (2003–2010) and appraisal (2010–2014) stages have been used as initial data to specify the survey intervals in the wells [3, 5, 6]. In the drilled wells, geological core logging, groundwater inflow
Testing, areal and borehole geophysical studies were performed, geological columns were plotted at a scale of 1:500 (Figure 1) [2]. At the time of the survey, the upper part of all wells was cased with 127 – 219 mm diameter strings.

Data from previous stages of the geological study performed for the Yeniseiskiy site were used to construct its three-dimensional geological model developed in Micromine software. Based on the available concepts regarding the geological structure of the massif, predicted were the areas corresponding to the largest faults that had to be considered as essential from the long-term safety perspective.

Field work completed at the Yeniseiskiy site in 2020

The work performed at the Yeniseiskiy site during the 2020 field season featured surveys involving a total of 7 wells (R-1, R-3, R-4, R-5, R-8, 1-E, PR-1). Figure 2 gives the idea of the surveyed wells location relative to the boundaries of the licensed area (in accordance with license No. KRR 16117 ZD).

Table 1 summarizes the surveys performed in wells R-1, R-3, R-4, R-5, R-8, 1-E, PR-1.

To develop survey plans for each well, a consolidated list of intervals was compiled involving data...
on the depths of rock interfaces, their lithological differences, zones of disjunctive disturbances, areas with increased fluid loss/hydraulic permeability and fracturing derived from previous geological studies and model predictions. In the course of the surveys performed, the planned list of intervals was also supplemented on an on-going basis given the information received from the cameras of the research probe. For example, areas with traces of rock falls, caverns, areas with healed and open cracks were of particular interest. These areas were added to the list of final well survey materials. These methods allowed to identify the position of geological boundaries, tectonic zones with an accuracy of several centimeters and to specify their location, size, orientation of cracks and voids, groundwater flows, as well as the dip angles of the cracks.

Description of the research process and equipment involved

For well survey purposes, a multifunctional downhole research probe was developed. The probe provides visual examination of wall structure within vertical or horizontal wells with a diameter of over 56 mm at a depth of up to 700 m not filled with water or filled with an optically transparent liquid. The probe is equipped with two video cameras providing visual control over the immersion process also allowing to identify the intervals of interest and to generate primary information for subsequent office data processing (Figure 3).

The front camera is designed to obtain primary information about the location of the research probe in relation to the elements of the geological structure and to identify specific features of rock mass sections. Its side camera was used to study the features of the geological section in a greater detail: the side camera was mounted on a rotating axis providing an image along the entire circumference of the borehole surface. The research probe was equipped with “coordinate” and “orientation” units used to identify the position of disturbance zones within the rock mass. To obtain high-quality image, all cameras were equipped with low-power

Table 1. Results of the near-wellbore zone surveys

<table>
<thead>
<tr>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total survey area (including casing)</td>
<td>3,265.70 lin. m</td>
</tr>
<tr>
<td>Total footage of the surveyed open hole areas</td>
<td>1,719.40 lin. m</td>
</tr>
<tr>
<td>Allocated intervals for priority detailed study</td>
<td>275 pcs.</td>
</tr>
<tr>
<td>Total number of intervals allocated for the study</td>
<td>1,309 pcs.</td>
</tr>
<tr>
<td>Total number of wells surveyed</td>
<td>7 pcs.</td>
</tr>
</tbody>
</table>

Figure 2. Location of the surveyed wells relative to the boundaries of the licensed Yeniseisky subsoil area and the URL construction site [10, 7]

Figure 3. Surveys of near-wellbore zones at the Yeniseisky site
diode lamps with a light spectrum close to the daylight. The video signal and data on the position of the probe relative to the cardinal points, the depth of probe immersion, the ambient temperature (°C) were displayed on the computer screen and recorded in the primary survey files: the azimuth value coincided with the image axis of the side camera (Figure 4). Primary files were generated automatically.

Surveys involved visual examination of the records with primary description of the revealed structural disturbances, i.e., cracks, caverns, etc. The identified faults were linked to the data of the geological columns and a three-dimensional geological model and their initial description was entered into the database for each depth interval selected at the preliminary stage. Factors being able to reduce the visibility in the aquatic environment (the wellbores were filled with water), such as suspensions present in the wellbore, had a significant impact on the generated primary video survey data. Of a particular concern for the video survey were the areas with an increased fracturing coefficient prone to collapse, as well as areas with rough wellbore walls (Figure 5). The field survey data were submitted for detailed study with appropriate descriptions developed based on field data analysis.

During the field data analysis of primary documentation, linear structures (fractures) were identified based on the digital images obtained during the near-wellbore zone survey. The spatial characteristics of the largest systems and single cracks were also specified, namely, such characteristics as angle of incidence, strike angle, thickness. The methods and approaches used in the processing of primary data were based on international scientific experience in the field of lineament analysis. During the processing, of major relevance were the panoramic images (360°) of boreholes at different depth intervals (Figure 6).

In general, surveys carried out at the target depth intervals (400—500 m) i.e., at the URL construction site have demonstrated that the massif can be basically considered as monolithic (Figure 7).

In some areas, some discontinuities were found to be present within in the geological medium.

Figure 4. Readings of the side camera during the survey (an example of measured values displayed and the correspondence of the electronic compass readings to the cardinal points)

Figure 5. Areas of wellbores passing through rocks prone to collapse and increased rock mass fracturing zones

Figure 6. Panoramic shot of a wellbore at a depth of 113.1 m with a regular grid applied.
Research activities at RW disposal sites

Basically, these are systems of fractures, including single fracture manifestations, namely, the mineralized and the open ones (Figure 8).

Research result processing method

The survey has generated a total of over 1,000 panoramic images and 10 GB of video files. Rapid processing of large data sets has required the use of automated methods. Therefore, primary field data involving panoramic images of wellbore sections with identified structural defects were evaluated using automatic digital lineament study method. Its algorithm is shown in Figure 9.

Image snapping in a local rectangular coordinate system was performed using geographic information system (GIS) QGIS [8]. In order to set a rectangular projection for the image, it was saved from the GIS with the indication of the required projection (Google Maps Global Mercator projection with EPSG-90091 was used). Directional image filtering method was applied to improve the characteristics of images with certain directional gradients. Directional image filtering is commonly implemented in three main directions: N-S to 0°, NE-SW to 45°, E-W to 90° to emphasize all possible directions of image structures [9]. The size of convolution kernel (13 × 13) pixels was identified empirically since the processed images displayed some noise and in case of a smaller filter core, image distortion not related to the structural features of the borehole walls could manifest itself. The original image featured three spectral channels: R, G, B. In this case, the R channel was applied to the filter input, since the data obtained in the red and infrared spectral ranges appear to be more sensitive to geological and structural features.

![Figure 7. Monolithic section of the massif. Well R-1, depth 436.00 m](image)

![Figure 8. Open and mineralized cracks at a depth of 226.60 m (well R-3)](image)

Figure 7. Monolithic section of the massif. Well R-1, depth 436.00 m

Figure 8. Open and mineralized cracks at a depth of 226.60 m (well R-3)

Figure 9. Flowchart showing the steps of panoramic well image processing
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Figure 10 shows the original well P-3 panorama image at a depth of 117.35 meters (Figure 10a), as well as an RGB composite image plotted based on the directional filtering performed in the main directions: NS to 0°, NE-SW to 45°, EW to 90°, the red channel was filtered in the EW direction, the green one — in the NE-SW direction and the blue one — in the NW-SE direction (Figure 10b).

Lineaments were automatically extracted in two stages: the first step provided for a boundary detection procedure to obtain the information about the areas with sharp changes in neighboring pixels with the second step involving a curve detection procedure [8]. These steps were followed using the LINE module of the PCI Geomatica software being considered as a most widely used module for automatic lineament extraction [11] (Figure 11). At the second stage, the curves were extracted and transformed into a vector form by linking the line segments. After that, polylines were plotted and drawn together into a lineament [11]. QGIS geographic information system was used to calculate dip and strike azimuths and to plot rose diagrams. Based on the built-in functionality and plug-ins, a semi-automatic algorithm was developed to calculate lineament dip and strike azimuths, as well as their lengths. The rose diagrams were plotted using QGIS Line Direction Histogram plugin. This module automatically calculates the lineament azimuths and builds diagrams. Also, the module has the ability to specify the angle step in degrees. For the current task, the angle step was set to 18 degrees.

Analysis of image processing results

Diagrams compiled for certain intervals and generalized for each of the surveyed wells were analyzed allowing to conclude that most of the fractures in all of the surveyed wells have a gentle dip. Along the strike, no prevailing fracture systems have been identified in wells R-1, R-3, R-4, R-5. No pronounced submeridional systems were identified in wells R-1, R-4, R-5 and 1-E. In well R-1, most significant disturbances were found at the interval of 122—130 m, which corresponded to the rock interfaces in this rock mass zone. Another relatively intensely disturbed interval is located within a depth range of 223—229 m, which corresponds to the matadolerite dike and its interface with the stratum of interbedded biotite and cordierite-biotite gneisses. Single open fractures with large opening aperture were also found in this well, in particular, at a depth of 248.7; 248.85; 283.15 m. No long intervals with highly disturbed rocks were found in R-3 well. In R-3 well, major discontinuities were recorded at the interval of 117.35 m (which corresponded to the interface between orthoamphibolites and biotite plagiogneisses); at the depth of 163.15 m, a large open crack was identified corresponding to the interface zone of biotite plagiogneisses and a thin metadolerite dike; some open cracks were observed in the intervals of 189.45-189.5; 219.75; 226.65 m. Exploration of wells R-4 and R-5 revealed no significant disturbances: most of the cracks either had a small opening or were completely mineralized.
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Generalized rose-diagrams for well R-8 are given as an example (Figure 12): these allowed to state that most of the cracks in the excavated section have a gentle dip with NNW and NNE systems being distinguished along the strike. When the probe reached a depth of 179 m, a blockage was found in the wellbore R-8 that could not be passed through. Thus, only a small interval of the well was studied in detail; significant discontinuities were found at an elevation of 131.65 m. In the survey intervals of well 1-E, the rocks were found to be severely disturbed: cracks with an opening aperture exceeding 1 cm were discovered. The increased disturbance of the rock mass is confined to areas of rock interfaces with different physical and mechanical properties. However, such a regularity cannot be stated in case

Figure 12. Generalized rose-diagrams compiled based on wellbore surveys: a) by dip azimuths; b) by strike azimuths. N – number of objects
of well 1-E, since interface of two media with different properties is clearly observed only at the very top of the studied interval with biotite plagiogneiss strata found below its top. It was concluded that most of the fractures within the PR-1 well have a sub-horizontal dip. Nevertheless, a sub-meridian system could be distinguished in it. The systems manifest themselves along the NW strike. Due to deep well casing, the study interval turned out to be very small with the study itself greatly complicated by the high turbidity of the water flow found in the wellbore.

Conclusion

The study allowed to describe the geological structure at the URL construction site according to the wellbore studies of existing wells. The results were refined using video logging data from 7 deep wells drilled at the Yeniseiskiy site. To interpret the video survey data, automated processing method with some software adapted for a specific task was applied. A semi-automatic algorithm was also developed to calculate dip and strike azimuths and lineament lengths based on the QGIS geographic information system. This allowed to get an insight into the spatial distribution of most extensive fracture systems and to specify most disturbed sections of the wellbore walls.

Considering the results of the 2020 field season, the study of near-wellbore zones is planned to be continued in 2021 after the well cleaning to the design depth is completed. Primary data derived from the research performed is planned to be used in DFN-modeling as well [12]. Identified areas with well-developed systems of fractures, which should be further investigated to clarify the hydrogeological parameters, are considered of greatest interest for the follow up study, in particular: interval injections using packer systems, as well as additional probe modules allowing to identify the flow direction in the wellbore within the area of structural rock mass disturbances are planned to be performed. Data on the identified fractures will be supplemented and the hydraulic permeability of the massif, including its anisotropy, will be calculated.

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**Bibliographic description**