Detailing the tectonic structure of a nuclear industry construction site using an Earth’s natural pulsed electromagnetic field method

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Abstract. This paper presents results of an integrated geophysical research aimed at detailing the tectonic structure of a nuclear industry construction site. A synthetic review of experiments is given accompanied by a sensitivity comparison between an Earth’s natural pulsed electromagnetic field (ENPEMF) method and vertical geoelectric survey, magnetometry, and seismology methods.

1. Substantiation of the method

Technological wastes of different composition and radioactivity levels are conditioned and contained depending on those differences. Naturally, the most challenging problem is disposing of highly radioactive waste and long-lived radioactive waste requiring isolation from biosphere for hundreds of thousands of years. By the late 1970s underground storage into a geological formation was established as the basic technique for the most types of radioactive waste. The latest research demonstrated that geologic repository remains the only scientifically sound and technically feasible solution for the long-term waste isolation problem [1]. The current IAEA regulations recommend depositing liquid and immobilized liquid radioactive waste into stable crustal blocks. The integrated geophysical research was carried out to find a geological environment site consisting of stably low-permeability and low-watered rocks having high restraining attributes. The survey methods used were Earth’s natural pulsed electromagnetic field (ENPEMF), magnetometry, geoelectric survey, and seismology methods.

The authors of this paper used the ENPEMF method to substantiate a radioactive waste repository site. This method enables mapping of active fractures, tectonic faults, spots with dangerous geological processes and determining the level of danger for constructions planned or built at a respective location. Radio-wave methods applied are based on the phenomenon of electromagnetic emission: the emissive ability of dielectric materials when they are acted on. Electromagnetic emission emerges in the process of charge generation and relaxation on fracture planes during the stress state of rocks. Pulses emerge both when the dielectric uniformity changes and when electrolyte-filled capillaries rift. Observing electromagnetic emission allows monitoring of the stress-strained state of the rock formation.
2. Technique for processing of Earth’s natural pulsed electromagnetic field recorded parameters and interpretation of the research results

In the course of field work, one of the recorders was set up within the research site and was used as a variation post. Three other identical recorders were used to measure the ENPEMF intensity and amplitude parameters at the predefined survey waypoints. A layout of the survey stakes is shown in Figure 1. Each of the route recorders and a variation recorder measured the ENPEMF parameters in two channels of primary reception in North-South and West-East directions. At each survey waypoint, measurements were made for two minutes with a sampling interval of 1 second. Variation recorder performed continuous monitoring measurement with a sampling interval of 1 second. The recorders were synchronized in time once a day before the start of measurements.

The spatial distribution of the ENPEMF intensity was chosen as an informative feature for the calculation of ENPEMF anomalies. To calculate this, first we have performed a comparative analysis of the data recorded by the variation station and the route station. Then the high amplitude pulses recorded by both stations at the same time were excluded. These pulses were considered to be generated by distant sources non-relevant to the local geological structures, e.g. tropical thunderstorms. After this the average intensity of the pulse flow was calculated for each measuring waypoint, as well as for the variation station for the same time frame. Dividing the waypoint intensity by the reference station intensity we have obtained a ratio representing a spatial change in the ENPEMF for each waypoint.

The criteria for mapping the Earth’s crust active fractures to interpret ENPEMF anomalies were developed at the Institute of Monitoring of Climatic and Ecological Systems, Siberian Branch of the Russian Academy of Sciences (IMCES SB RAS) and summed up in papers [2-5]. All rock discontinuities including splits, fractures, and zones of jointing come together with increased values of the ENPEMF. Paper [2] provides examples of tracing of geological paleo splits, indicated by increased ENPEMF intensity differing from the background values by 1.5-2 times, whereas modern active splits provide anomalies with a 10-1000 times increase compared to the background values. Negative anomalies in the ENPEMF structure are usually associated with zones of compression or tectonic dislocation centerlines, since they are filled with low-radiating gouge. Thus, major active geological
splits are distinguished in the ENPEMF as a bay anomaly with a positive excess in the ENPEMF intensity of 10 or more times on the fault side and decrease in the intensity compared to the background values over the centerline. Plots with a complicated stress-strained state of the rocks are usually indicated by a positive anomaly in one of the ENPEMF reception directions and a negative anomaly in the other direction channel. Such plots are prone to possible landslides, cavings, and other local geodynamic processes.

Summarizing the above, during the above-described field work the following criteria were selected as an indicator of danger of geodynamic structures of different kinematics at a radioactive waste deposit site:

- 10 or more times excess of the ENPEMF compared to the background values: extremely active;
- 1.3 - 10 times: low active or associated with the zone of jointing;
- Differing from the background values by 30% or less: non-active structures.

Background values: values equal to 1.

3. Mapping of geophysical anomalies at a probable nuclear industry construction site

Measurements of the ENPEMF parameters were carried out on the site allocated for the engineering survey based on the predefined 417 waypoints over 18 tracks. The measuring pitch for the tracks was set at 50 m. The distance between the tracks was 50-100 m. On top of that, an additional measurement was carried out at test point 91 to confirm reproducibility of the results. The total number of the recording points of electromagnetic fields was 508.

A generalized layout of the ENPEMF anomaly is presented in Figure 2a. Red areas indicate increased ENPEMF intensity compared to background values, and blue areas show decreased intensities. For comparison, Figure 2b shows a magnetic field anomaly layout based on magnetometry results. Among the methods used in the research, magnetometry is closest to the ENPEMF method in terms of the data processing approach. Both methods compare data of separate waypoints to data of the variation station. Conclusions about the Earth’s crust anomaly are made based on the differences between the waypoint and variation measurements. However, the difference between the methods is crucial and that is the fact that the ENPEMF records lithosphere emitted pulsed magnetic fields, while magnetometry is based on recording a semipermanent Earth’s magnetic field. Figure 2b demonstrates two distinguishing positive magnetic field anomalies. Considering that pyroliths possess enhanced magnetic properties, anomalies of such kind are traditionally associated with volcanicity. Interpreting the result above, magnetometry work performers identified magnetic field anomalies as concealed tectonic zones currently not manifesting themselves.
The same waypoints indicated ENPEMF anomalies, notably, the southern one was a positive anomaly, which we interpreted as a zone of jointing, and the northern one was negative, interpreted as a zone of increased loose deposits. The conclusion about residual deposits at the negative anomaly location are confirmed by vertical geoelectric survey data, specifically low resistance values at waypoints 11-13 in Figure 3. The zone of crush or the existence of jointing at the positive anomaly location is confirmed by the disturbance in the reflection pattern of the seismology survey at times up to 50 ms in proximity to the 50th waypoint at a refraction time section (Figure 4). The zone of jointing at the same location was also revealed by the only exploration hole of 120 m at the survey site, the cobble residual soil by porphyrite was traced to the bottom hole.

Aside from the two above-listed anomaly spots, the ENPEMF method mapped a zone of jointing in the north-western part of the survey site. The work plan did not involve study of this location using geoelectric survey or seismology methods, since they need much effort and time costs. Magnetometry did not confirm this anomaly, but its existence can be assumed because of the intersection of four different types of tectonic faults at that location, discovered using aerospace remote sensing data by Kochkin and Tarasov in 2007 (Figure 1). Despite the fact that none of the methods used in the course of the geophysical survey revealed extensive lineaments and no tectonic fractures were discovered on the site, the location interpreted by the two authors as an intersection of tectonic faults is a tectonic zone.

![Figure 3. Sections of apparent resistivity reconstructed based on the result of qualitative interpretation of the geoelectric survey.](image1)

![Figure 4. Time section of CMP by compressional waves using refraction data + CMP. Waypoint numbers are listed horizontally.](image2)

4. Conclusions
The above-described integrated geophysical research using the ENPEMF, vertical geoelectric survey, magnetometry and seismology methods has not revealed any active geodynamic structures causing potential threat to engineering construction operations at the research site. The mapped tectonic fractures copied from the geological maps have not been confirmed by any of the methods used. A few crushing zones and higher rock-weathering zones have been discovered in the surveys. The ENPEMF method proved to be most informative and time and cost saving among the methods used in the integrated research.

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