UDC: 621.039.74

AN APPROACH TO MONITORING OF THE GEOSPHERE AND UNDERGROUND ENGINEER BARRIER SYSTEM OF DEEP GEOLOGICAL INJECTION FACILITIES AND SOME RESULTS OF MONITORING

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Article received on October 23, 2018

The paper focuses on the approach applied by the Federal State Unitary Enterprise «National Operator for Radioactive Waste Management» (FSUE NO RAO) at the sites of deep geological injection facilities for liquid radioactive waste to monitor the geosphere and underground engineered barrier system (geological monitoring). Monitoring activities are regulated by relevant legislative provisions of the Russian Federation and are aimed at demonstrating the safety of LRW disposal. The paper overviews the characteristics of such facilities operated by FSUE NORAO and monitoring results as for the end of 2017.

Keywords: *liquid radioactive waste, waste disposal, deep geological injection facilities, monitoring, observation well, geosphere.*

In Russian Federation, deep well injection of liquid radioactive waste (LRW) has been implemented at 3 sites — deep disposal facilities for liquid radioactive waste (DDF LRW) established in 1960's. Since 2013, LRW disposal operations are being implemented by Federal State Unitary Enterprise «National Operator for Radioactive Waste Management» (FSUE NO RAO).

According to the RW classification system established by provisions of the Resolution of the Government of the Russian Federation № 1069 "On Criteria Used to Categorize Solid, Liquid and Gaseous Waste as Radioactive Waste…" [1], LRW are considered as radioactive waste of Class 5. Intermediate- and low-level waste are subject to disposal in DDF LRW.

In keeping with relevant requirements presented in Article 30 of the Federal law of July 11, 2011 № 190-FZ "On Radioactive Waste Management…" [2] and provision of federal norms and rules in the field of atomic energy use "Radioactive Waste Acceptance Criteria for Disposal…" (NP-093-14) [3], prior to their disposal, LRW resulting from the operation of nuclear enterprises should be brought in compliance with waste acceptance criteria approved for each specific DDF LRW.

LRW disposal implemented by FSUE NO RAO suggests that the waste is emplaced into subsoils (emplacement horizon) within the boundaries of a mining allotment in keeping with effective permits, including relevant licenses on the subsoil use issued by the Federal Agency for the Subsoil Use (Rosnedra) and those of the Federal Service for Environmental, Technological and Nuclear Supervision (Rostechnadzor).

Observations (monitoring) over the disposal process and radionuclide behavior within their containment area (subsoil and underground structures' monitoring (geological monitoring)) is viewed as an important type of industrial activities implemented during DDF LRW operation to demonstrate the safety.

Monitoring activities are regulated by relevant provisions set forth in the national legal framework. Federal norms and rules in the field of atomic energy use "Radioactive Waste Disposal. Principles, Criteria and Main Safety Requirements" (NP-055-14) [4] stipulate relevant requirements to RW disposal system monitoring, including those associated with the state of natural and engineered safety barriers. As it comes to DDF LRW, natural barriers are viewed as elements of a natural geological formation (host rocks). Such elements should be characterized with low flow properties and should limit the spread of radionuclides to the over- and underlying horizons. Well structures are considered to be part of the engineered barrier system.

Subsoil monitoring and monitoring of underground structures implemented at DDF LRW is aimed at shaping the plume of the water altered due to LRW disposal in subsoil; timely identification of processes associated with waste disposal; evaluation of wells technical state; identifying the early signs of DDF abnormal operation caused by the early failure of engineered safety barriers; accumulation, documentation and storage of monitoring data and data processing results using regularly updated databases. Artificially altered is the water the contents of which differs from the natural one in terms of some chemical or radionuclide indicators due to LRW disposal.

The monitoring results indicating the state of subsoils and underground structures are used as initial data to verify the models developed and applied to demonstrated the long-term safety of DDF LRW, and if necessary, to optimized LRW disposal modes.

DDF LRW monitoring involves the acquisition of actual data on the subsoil and underground structure state based on hydrodynamic, geo-chemical and geo-physical investigations performed in observation wells. Monitoring is implemented based on regulations developed specifically for each particular DDF LRW and agreed upon with design development organization, regional department of the Federal Medical and Biological Agency (FMBA) and regional bodies of Rosnedra.

Hydro-dynamic monitoring is implemented by measuring the levels of reservoir fluid in injection and observation wells and/or head pressures to determine the impacts of LRW disposal on the groundwater flow, as well as the effects of waste disposal on the subsoil state.

Level gauges, self-powered recorders, as well as highly sensitive depth gauges are used for hydrodynamic monitoring purposes with relevant verification and calibration operations performed in keeping with relevant standards. Hydrodynamic monitoring results are commonly depicted in tables, diagrammatic maps of repression domes and isopiestic lines, as well as diagrams presenting water level changes. The results enable to demonstrate if the preferential filtration flows and the hydrodynamic ground water flow mode has been correctly identified, as well as allowing for their further tracking. The following parameters are being assessed and evaluated based on hydrodynamic monitoring results: hydrodynamic structure of the flow, repression dome dimensions, potential hydraulic connection between different horizons, technical state of the wells, engineered safety barriers, operational parameters of injection wells, conductivity of the host geological environment, etc.

Evaluation of hydrodynamic monitoring results allows, if necessary, to develop and implement appropriate managerial arrangements regarding the DDF LRW operation mode.

Geochemical monitoring is implemented by means of sampling reservoir fluids from production (disposal), buffer and overlying horizons and determining their physical and chemical properties, composition, as well as radiation-hygienic characteristics in order to assess their compliance with hygienic criteria and radiation safety standards according to GN 2.1.5.1315-03 [5], SanPiN 2.1.4.1074-01 [6], SanPiN 2.6.1.2523-09 (NRB-99/2009) [7]. It also enables to assess the technogenic impact of LRW disposal on the state of the sub-soils in keeping with SP 2.1.5.1059-01 [8]. Hydrological and chemical monitoring is performed in DDF LRW monitoring wells in accordance with annually established schedules.

Sampling of reservoir fluids and their transportation is carried out in accordance with national standards and regulatory recommendations. The parameters are measured according to approved procedures in accredited laboratories.

For hydrogeochemical monitoring, the key monitored characteristics demonstrating the state of the subsoil are as follows:

- total salt content and macro-component composition;
- nitrate ions concentration;
- turbidity and suspended matter content;
- pH;
- density;
- total specific alpha activity of groundwater;
- total specific beta activity of groundwater;
- specific activity of particular radionuclides.

Hydrogeochemical monitoring results are stored as measurement protocols and electronic databases.

Geophysical studies (GIS) are performed by measuring geophysical fields in wells with changing characteristics such as radioactive emissions, temperature, fluid electric conductivity and others associated both with LRW disposal impacts and inherent underground geosphere conditions.

GIS methods are also widely used to monitor the technical state of underground structures. Cement-bond sonic logging, electromagnetic flaw detection-thickness gauging, gauging and other methods are used to monitor the technical state of wells. Assessment of wells' technical condition also involves evaluation of their performance and the state of structural elements: casing and cement stone in the annulus space of the casing. Results of ongoing research serve a basis for the decision-making on wells further operation, maintenance or phase-out.

The distribution of the plume associated with artificially altered waters spread in the subsoil and its changes in space and time can be demonstrated by means of GIS. These studies also allow to identify potential vertical filtration inhomogeneities of the host rock mass and to determine the depths and capacities of the injection horizons and separating low-permeability strata. Another point is that they enable to identify zones with potential decompression of backfilling materials in the annular space of wells.

Rock maps and profiles indicating the plumes of artificially altered water spread, geophysical well profiles are developed based on GIS findings.

Tools used for GIS purposes have necessary certificates and other documents providing the evidence for their metrological certification.

Decisions regarding the monitoring of subsoil and underground structures, its frequency, methods and tools applied are made depending on the depth of the investigated horizon and its purpose, the location of the observation well, data on the presence of LRW components according to previous studies, the spread of artificially altered waters plume inside the investigated horizon.

Each year, findings of subsoil and underground structures' monitoring are passed to regional bodied responsible for the subsoil uses.

Presented below are the brief characteristics of the LRW DDFs operated by FSUE "NO RAO" and monitoring results for 2017.

Seversk LRW DDF

Seversk LRW DDF is located in Seversk, the Tomsk Region at SCC site within the Tom-Ob basin, on the right bank of the River Tom.

LRW is injected into sedimentary rock mass composed of interbedded terrigenous sandy-argillaceous rocks belonging to the Cretaceous age (Figure 1) at a depth of 260—430 m (with two production levels), overlapped by a thick (over 50 m thick) layer of low-permeable Late Cretaceous clays. From the bottom the rock mass is confined by low-permeable Lower Cretaceous clays. Thus, the unique structure and properties of the rock mass ensure reliable isolation of LRW from the human environment and human impacts.

Currently, at the LRW DDF site operated are 15 injection and 212 observation wells located both in the operational and buffer/overlying horizons and covering an area of over 10,000 hectares.

Figure 2 presents the hydrogeochemical monitoring results for 2017 demonstrating that the plume of artificially altered water is confined not only to the boundaries of the mining allotment, but also stays within the site boundaries.

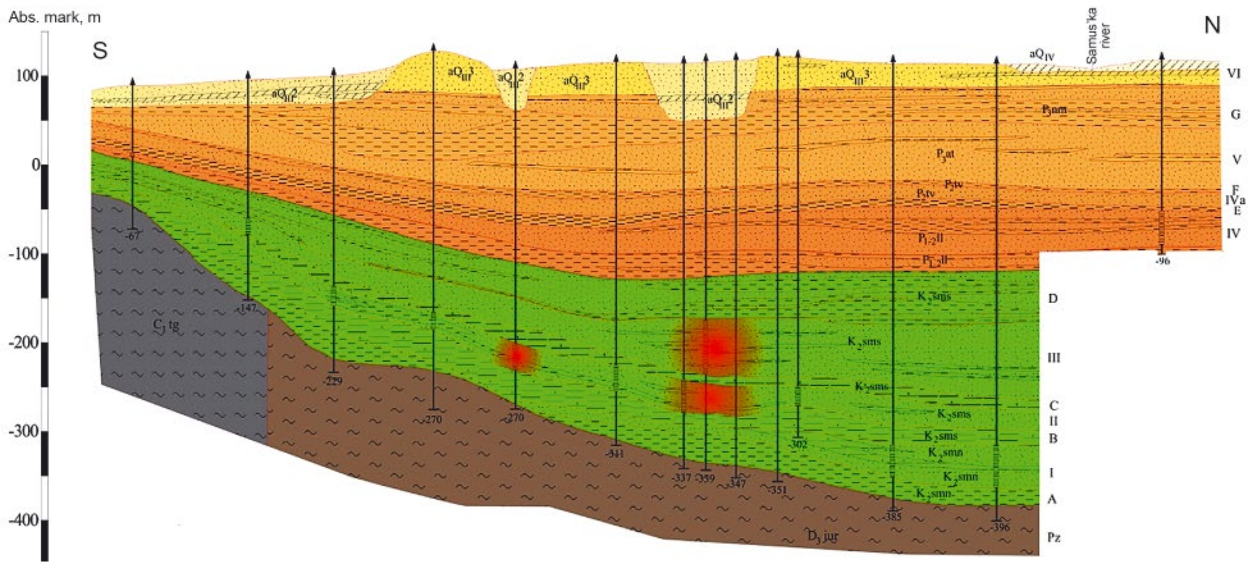

Figure 1. Cross-section of a sedimentary mantle in Seversk LRW DDF region

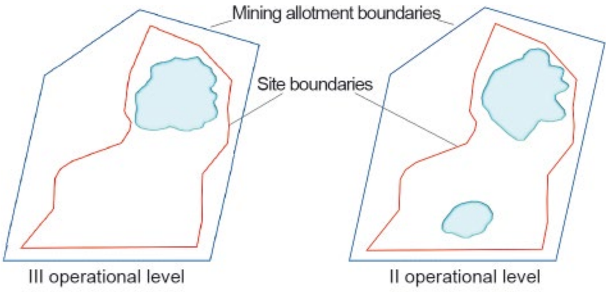

Figure 2. Monitoring results for Seversk LRW DDF in 2017 (plume of artificially altered water shown in blue)

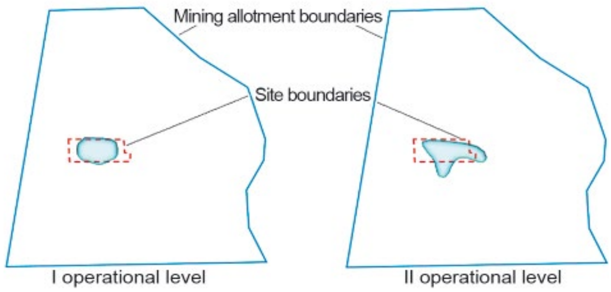

Figure 4. Monitoring results for Zheleznogorsk LRW DDF in 2017 (plume of artificially altered water shown in blue)

Monitoring investigations in 2017 have shown that no water level fluctuations occurred in the monitored horizons evidencing the minimal impact of LRW DDF operation on the subsoils.

Based on geophysical studies of wells performed in 2017, the size of the surface area covered by artificially altered water plume spreading within the mining allotment was confirmed. The state of wells' engineered structures was identified allowing to evaluate whether their further routine operation is possible.

Zheleznogorsk LRW DDF

Zheleznogorsk LRW DDF is located in Zheleznogorsk, 60 km northward from Krasnoyarsk at the MCC site, on the right bank of the Yenisey River.

Sedimentary Jurassic formations involving sand and clay rocks (Figure 3) are used for LRW disposal purposes.

Disposal depth accounts for 180—150 m. In terms of its structure, LRW DDF is located in mild humus area bounded by crystalline basement rock outcropping beyond the site boundaries. From the west, LRW DDF site is separated from the Yenisey River by low-permeable inactive right-bank tectonic disruption.

The sedimentary Jurassic stratum is separated from over and underlying rocks by regional low-permeable clay rock masses with a thickness of over 40 and 45 m, respectively.

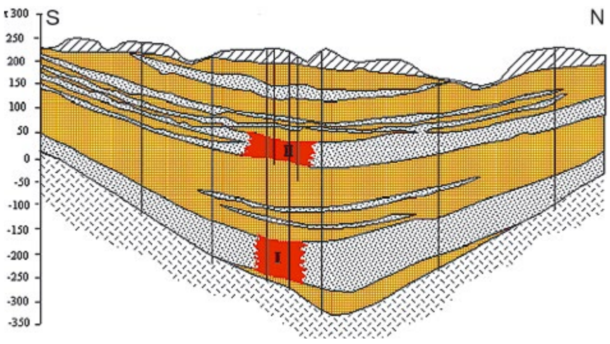

Figure 3. Cross-section of Zheleznogorsk LRW DDF site

Thus, structure and characteristics of the disposal horizons and the separating rock masses ensure the required level of safety both during LRW DDF operation and in the long-term considering relevant geological timeframes.

Today 13 injection and 74 observation wells are operated at LRW DDF disposal, buffer and ground levels covering a total area of over 4,000 ha. Hydrogeochemical monitoring performed in 2017 (Figure 4) demonstrated that the area of artificially altered water expands slightly beyond the boundaries of LRW DDF industrial site, although, lying within the boundaries of the mining allotment.

Hydrodynamic monitoring observations show no significant fluctuations in the water levels of the monitored horizons. Geophysical well studies have demonstrated that the plume of technologically altered water is confined to the boundaries of the mining allotment. No faults associated with wells' engineered structures impeding their operation or potentially affecting LRW DDF safety have been identified.

Dimitrovgrad LRW DDF

Dimitrovgrad LRW DDF is located 6 km away south westwards from the city of Dimitrovgrad (Ulyanovsk region) at RIAR site.

LRW is disposed of into terrigenous-carbonate rocks of the Carboniferous age at a depth of 1,114—1,514 m (Figure 5). Stagnant mode is considered typical for the disposal horizons. They are overlaid by a thick (over 40 m thick) stratum of low-permeable clay rocks providing the isolation of the disposed LRW from the overlying horizons. Considerable disposal depth, disposal horizons' structure, rock conductivity and capacity along with the engineering solutions implemented ensure the safety of LRW DDF both at operational and at the post-operational stages.

A total of 4 injection wells are available at the site. 28 observation wells are in place to monitor the state of the subsoil and underground structures covering an area of over 15,000 ha.

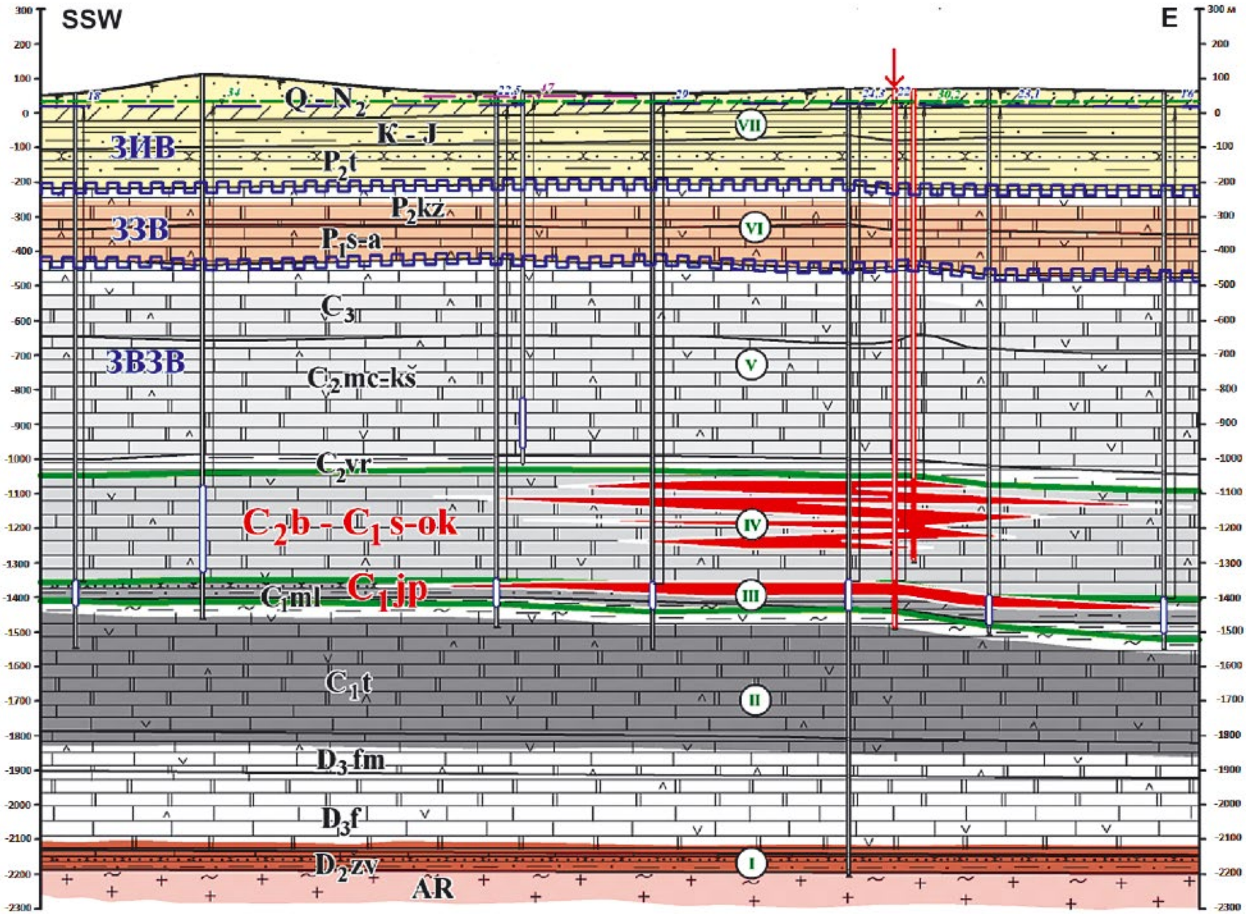

Figure 5. Geological cross-section of Dimitrovgrad LRW DDF

Hydrogeochemical monitoring results for 2017 presented in Figure 6 show that the plume of technologically altered waters is confined within the mining allotment boundaries.

Highly sensitive depth gauges are used to perform hydrodynamic observations in wells at depths of about 1.5 km. These observations have demonstrated that the disposal and overlying horizons are not interconnected. No hydrodynamic response associated with LRW disposal has been identified in the overlying formations.

In 2017, geophysical studies performed in wells were carried out in keeping with the established schedules. Their results enabled to get a more precise picture demonstrating the spread of artificially altered waters. Moreover, according to the geophysical studies performed, no faults associated with wells' engineered structures impeding their operation or potentially affecting LRW DDF safety have been identified.

Thus, an integrated approach served a basis for the development and operation of FSUE NO RAO system enabling to monitor the subsoil and underground structures' state. Such approach suggests that results of hydrodynamic, hydrogeochemical and geophysical studies in observational wells are obtained, accumulated and processed. Activities associated with subsoil and underground structures monitoring are performed using FSUE NO RAO resources with the engagement of specialized organizations, which, in particular, ensures the independence of the monitoring results.

The approach based on integrated interpretation and comparison of data from various studies, as well as verification of reports by the subsoil manager, allows to state with high degree of confidence that the results of such monitoring are reliable and the monitoring system is effective in general.

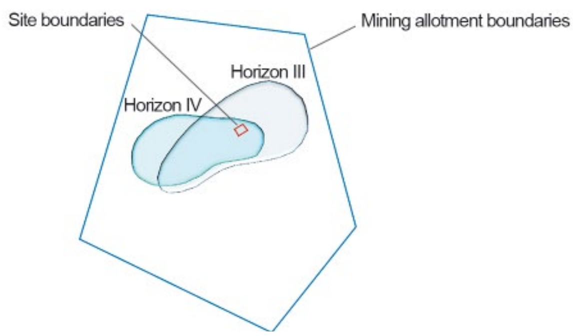

Figure 6. Subsoil monitoring results (covering the area of artificially altered water plume) at the Dimitrovgrad LRW DDF site in 2017

Evaluation of FSUE NO RAO activities (covering the time period till the end of 2017) associated with LRW DDFs operation based on the results of subsoil and underground structures monitoring suggesting the use of an integrated approach and their comparison with the data of forecast long-term safety calculations demonstrates that the safety of LRW disposal is ensured both at present time and in the long-term perspective.

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Bibliographic description

Pron I.A., Tkachenko A.V., Martyanov V.V., Trofimova I.V., Yakovleva I.V. An Approach to Monitoring of the Geosphere and Underground Engineer Barrier System of Deep Geological Injection Facilities and Some Results of Monitoring. *Radioactive Waste,* 2018, no. 4 (5), pp. 42—48. (In Russian).