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ENVIRONMENTAL GEOTECHNICS IN THE SERVICE OF SUSTAINABLE DEVELOPMENT ON THE EXAMPLE OF NORTH-EAST ESTONIA – SILLAMÄE

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The aim of the current paper is to analyse the environmental problems associated with harbour construction at Sillamäe, waste depositories (WD) and recultivated areas in the mining industries, and to offer solutions that would actually promote sustainable development. The authors have chosen the Sillamäe WD as a sample area, for the complexity of problems in that area makes the case a warning example.

Introduction

Human activities have affected the environment since the dawn of mankind; with the acceleration of development, these influences and accompanying risks have only grown. With the development of application of nuclear energy, the issue of the human activities connected with radioactive waste management has become topical all over the world. Uranium mines and their inseparable satellites – radioactive waste repositories – can be found in 35 states [1]. These repositories differ from ordinary mine waste repositories by the content of hazardous substances that migrate by air, dissolve into water bodies, or filtrate into groundwater.

Disintegration of radioactive waste is a long-term process that humans cannot control. Therefore, the only way to protect human health and nature would be isolation of waste repositories from the immediate organic world. One solution is to deposit the waste underground. This is an expensive and often impossible undertaking, as the old mines are often destroyed, flooded, or amortized. Another solution would be isolation of the WD from the surrounding environment. Separating a WD from the organic world – the process of sanitation – demands the co-operation of many specialists from

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geologists to social scientists. At the same time, a waste depository is an engineering construction that has to maintain its functionality and constancy for hundreds of years irrespective of the reigning policies, legislation, or currency.

In the mining industry, the environmental effects connected with WDs and the recultivated areas often constitute the critical factor. These are technogenic constructions that are associated with risks in the environmental, medical, human resource and land use capacities. Ignoring these risks results in higher responsibilities, bigger insurance fees, and pollution taxes for the landholder

From the engineering-technological point of view, the closing down of a WD and the recultivation of mines is a complicated process that requires the consideration of a variety of important factors. A fundamental factor is the geological make-up of the region and the geotechnical conditions at play there. The environmental effects brought about by human influence on the geosphere, also the accompanying risks and the possible solutions are nowadays being studied within a new, evolving science – environmental geotechnics – that combines in itself geology, hydrogeology, engineering geology, geotechnics and other adjacent disciplines. The resulting synthesis provides us with initial input that leads on to the evaluation of the environmental condition and the planning of the sanitation process – an exploit that has been followed actively since the 1950s. In the temporal context of geological processes, this is a very short time.

The environmental impact of waste repositories and the possibilities for alleviating those issues

The world practice in waste depository sanitation proves that problems will rise in all the stages of the project – during investigation, in designing, at sanitation works and during the future exploitation of the object. Even though the aim is to isolate the depository entirely from the surrounding environment – for a long time and with no further maintenance – experience shows that the initial expectations tend to be fairly optimistic and the need for accompanying environmental measures and extra investments usually comes up much earlier than it has been foreseen [2].

On the one hand, the construction of waste repositories resembles other engineering constructions that have been built for hydrotechnical purposes. The difference appears at the assessment of the temporal factor and the risks. The main problem in waste depository sanitation tends to be the lack of experience in considering the time factor. Taking into account the lifespan of radionuclides, waste repositories are supposed to “work” for a 1000 years (in Scandinavia, 10,000 year periods are being considered).

Scientists comparing relative toxicity of highly radioactive compounds and industrial uranium waste and its changes in time have reached very interesting results. They compared radiotoxic hazard of these compounds determining the amount of water needed for diminishing the content of each radioactive element to the level that would correspond to the drinking water standards [3]. The results are presented in Fig. 1.

The research results prove that the so-called "low-enriched" uranium waste is one order of magnitude more toxic in its whole concentration range as compared to the content of highly radioactive single elements, and the impact of hazardous waste may go on for millions of years. This provokes the question: how long should the estimated time period be, and are we able to calculate such temporal distances, basing on contemporary know-how?

It is believed that depositories should function according to the set requirements for at least 200 years without any need for more serious maintenance. Considering the time factor, the resistance of the used materials must be assessed.

The predicted age of technogenic materials (e.g. concrete, geotextiles, asphalt) is up to 100 years.

If natural soils are used, their resistance to weather and time can be assessed during a longer period (e.g. investigations of the erosion crust of silt- and clay soils) and, consequently, also a prognosis made about the environmentally hazardous exploitation of waste repositories in the future.

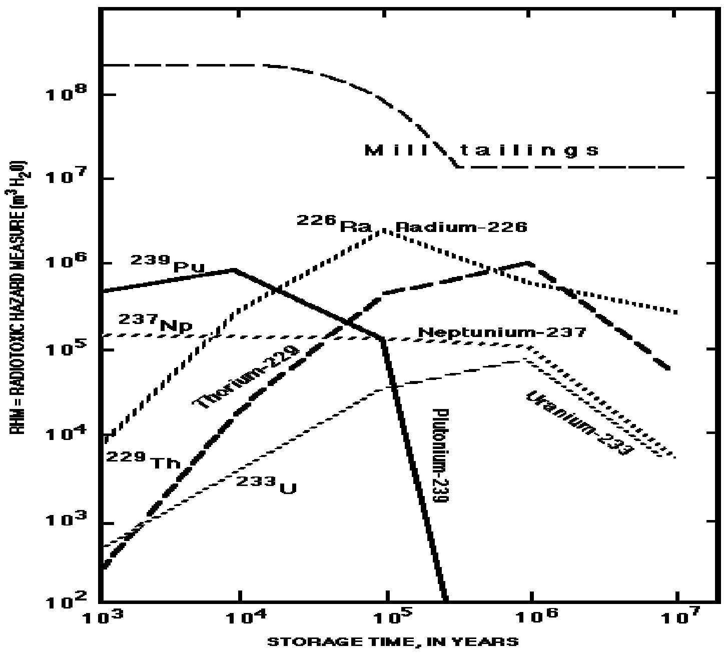

Fig. 1. Comparison of toxicity of low-enriched uranium mill tailings with radioactive elements from high-enriched uranium

For this, all the factors influencing the functionality and perseverance of WDs should be studied very carefully. The main environmental changes brought about with the exploitation of WDs are the following:

1. Radiation and release of radon;
2. Hazardous dust and its migration;
3. Filtration of precipitation into the natural environment under the waste depository;
4. Migration of technogenic waters into groundwater or open-water bodies;
5. Environmental changes connected with removal and cleaning of WD waste water;
6. Permanence of the waste depositories, including surrounding dams;
7. Changes occurring in engineering- and hydrogeological conditions because of the closing down of depositories;
8. Environmental impacts related to the cleaning of polluted ground- and surface-waters;
9. Future use of the WD grounds;
10. WD-conditioned restrictions in the future land use (e.g. planning) in the surrounding area.

World practice of environmental impact and investigations of WDs show that while the above-mentioned environmental impacts are characteristic of all repositories, the proportion of particular impacts varies and depends on natural and technogenic conditions. In solving WD problems, the environmental impacts to be considered should be approached as a whole.

The risks and risk management of the geotechnical hazards to the environment

Investigations and measurements have proved that the stability of the dam of Sillamäe WD has not been reinforced with a sufficient reserve. This has been induced by the deficient shear strength of the Cambrian clay layer lying under the dam. As for soil properties, the questions concerning the strength of blue clay and the impact of the dilutions filtrating from the dam on the geotechnical properties have remained unclear. The change of clay properties in time has an unfavourable effect on the tenacity of the dam.

The analysis of geodynamic processes shows that the perseverance of the waste depository will in the future be depending mainly on three main factors:

1. The erosion brought about by coastal processes and the consequent decrease in counterbalance, which alters the balance in soil.
2. Changes in the deposition conditions and physical-mechanical properties of soils that have been induced by geodynamic processes. The decrease in the strength of the Cambrian clay that is located under the dam facilitates the development of creep processes, and the water infiltrating from the depository will penetrate the micro-fissured clay massif.

3. Hydrodynamic regimes that can, when changed, increase or decrease the hydrodynamic strength affecting the overall strain. Due to the hydrogeological make-up, groundwater moves through the pebble layer resting under the WD towards the sea from its hinterland side.

At the same time, one should not underestimate the storm-induced changes that can raise the water level over 150 cm above the usual average (increases coastal erosion) with the westward winds in the Gulf of Narva or decrease the water level by the eastward winds down to 110 cm below the Kroonlinn zero (the counterbalance mass of the WD slope is decreasing and thus also the safety factor of the slope).

Taking into account the above-mentioned processes, the aim of the counter-measures and the WD sanitation plan has been to increase the counter-balance of the WD dam, to ensure a set hydrodynamic regime and to slow down coastal erosion.

After sanitation, the depository will look like a hill covered by vegetation, and the surface will no longer be releasing radioactive dust. Water will run down the sides of the slope without filtration into the soil; the surface water coming from the mainland will be directed elsewhere by a trench and a diaphragm wall.

The waste will keep on emitting radon, but this will disintegrate through the depository cover, i.e. before reaching the ground (the half-life period of radon lasts ca 3.5 days).

A belt of concrete piles that will be erected on the coast will secure the stability of the dam; also a coastal reinforcement will be built to safeguard against the erosive activity of waves.

Influences induced by regional development in the waste depository area

The industrial zone in the town of Sillamäe lies on the western side of the town, in the area between the Gulf of Finland and the Tallinn–Narva–St.Peterburg road. The central object in this area is the *Silmet* factory. On the factory area there stand the power station of the town, the former auxiliary buildings of the plant, storehouses and the servicing infrastructure. The free economic zone developed by the *Silmet Group*, the old uranium mines, and the waste depository are in the immediate vicinity. A port is being built at the eastern side of the WD, into the Gulf of Sillamäe. A few kilometers away from the plant area, there lie empty and half-constructed industrial buildings dating back to the end of the Soviet era. An outline of the described area is presented in Fig. 2.

Due to the favourable location and geographical conditions of the old harbour site from the beginning of the previous century, the new port was built on the same site. The old harbour had been used up till the 1940s. In order to protect the safety of the secret uranium plant, the harbour was

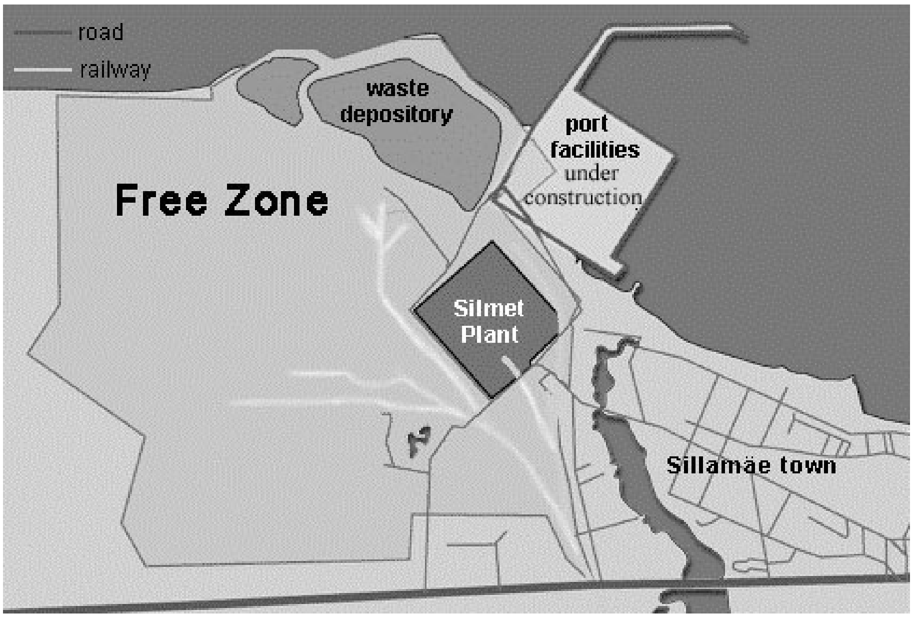

Fig. 2. The development plan of Sillamäe harbour and the free economic zone [4]

closed down and demolished. Now a modern, multifunctional commercial port is planned to be erected here as a part of the Sillamäe free economic zone. In the 1990s, preparations were made for constructing an oil port west of the WD, but these plans remained unfulfilled mainly due to heightened environmental requirements and the lack of sufficient resources for meeting these demands.

The pulp and waste water accompanying the production of rare earth metals, tantallium, and niobium is being channelled to the WD from the *Silmet* factory. Contemporary waste contains a lot of nitric compounds and other matter hazardous to the Baltic Sea.

Even though the amount of waste water is much smaller than a few years ago, this kind of waste management does not meet the EU standards, and the enterprise requires environmental reorganisation.

The shutting down of industrial production at Sillamäe resulted in complicated social issues that are hard to solve. The hydrometallurgical works along with the power station gives jobs to the majority of the Sillamäe inhabitants, making it the main employer in the town. The social and environmental issues of Sillamäe should therefore be viewed in the context of the whole industrial region of Northwest Estonia.

In the future perspective – at a novel technological level – also reproduction of metals from waste and the underground deposition of hazardous waste could be considered. Preliminary research has proved that lantanium (La), scandium (Sc), niobium (Nb) and strontium (Sr) could all be produced from the material deposited at the Sillamäe WD [5]. Currently, the production of these metals would not be economically effective.

Joining the EU and the accompanying investments into infrastructure and the development of small enterprising, the founding of the port and the continuance of the plant create favourable preconditions for the development and intensive use of the area in the future. As this is a territory that has been in use for some time already, dangers and influences related to the former exploitation of the area should be taken into account in the planning of new enterprises and constructions. The main conditions determining the future use of the territory will be economic, social, legislative and environmental-geotechnical.

The investigations and prognoses that have been launched there point out that the environmental-geotechnical conditions in the described territory are very complicated. Many questions still remain unsolved. The main hindrance to solving those problems is not even the lack of funding, but the lack of a general conception and model. As investigations have proved [2], such a conception appears to be missing in most of the recultivation projects in the world.

The principles of the conception of environmental-geotechnical model

It is especially important to develop an environmental-geotechnical model at Sillamäe, because one of the most hazardous sources of pollution in the Baltic Sea is situated there and dynamic human activity is foreseen in the area in the future. All this calls for a finer definition of the goal, the starting point and the criteria.

If the main aim is the closing down of the WD and its isolation from the surrounding environment and further maintenance, then the starting point should be the environmental-geotechnical conditions, their change in time and the accompanying risks. The criteria should be made up of measurable and assessable quantities, including the legislatively validated limits of hazardous substances, the quantities of the slope processes/positions and other quantities that depend on monitoring results.

If the aim is the founding and exploitation of the port, the starting point should be the engineering-geotechnical conditions on which the tenacity of engineering-technical buildings, the risks and environmental impact all depend on. The criteria would again be comprised of the technical parameters that can be measured at monitoring.

If the aim is the environmentally sustainable development of the whole developed region, the starting point should be the environmental-geotechnical conditions of the whole surveyed territory and the affecting factors as a whole. It is important to explicate the change of these conditioned by time, also the tenacity of constructions and their mutual impact, the human impact and the accompanying risks. Processes, phenomena and influences should be prioritised. The criteria should be determined on the basis of risk analyses of the above-mentioned processes and impacts; by managing the risks, they can be reduced to an acceptable level for both man and nature. It is also important to acknowledge who will be responsible for managing the risks and to estimate the required resources. If resources are deficient, the risks cannot be managed.

The aims and principles of future environmental-geotechnical investigations

The aims and content of the planned investigations will be determined in accordance with the developments in the future use of the area, the monitoring of the engineering-geological processes of the area and the results of risk analyses. The main principle of the research methodology is the conceptualisation of the area as one geomorphologic whole.

It must be taken into account that both geodynamic processes and geotechnical conditions are influenced not only by a variety of technogenic processes, but also by hydrometeorological conditions (changes in the water level of the Gulf of Narva); it should also be assumed that traditional theories may not necessarily apply for explaining and assessing the phenomena.

Up till now, undeservedly little attention has been paid to assessing the impact of the technogenic factors [6, 7]. Even though the future possibilities of utilising the old mines have to some extent been researched, these investigations have neglected to take a comprehensive view of all the environmental-geotechnical aspects. For example, the impact of the operating mines on the hydrogeological conditions in the area still remains unclear; also the possible impact of the hydrotechnical constructions of the future port on the coastal processes and thus also on the slope reinforcements of the WD have not been considered to the full. A northward-directed 510 m long mole and the adjacent 730 m long quay cut across the leeward, east-bound current in the lower part of the Sillamäe aquatory; they probably also influence the compensating upwind current moving westward in the deeper part of the aquatory.

Conclusions

The impact waste depositories will have on the surrounding environment in the future intensive exploitation of the areas is an issue that has remained unsolved all over the world. An important step in solving this problem is the environmental-geotechnical model that is based on risk analysis and the assessment and prognoses of reciprocated influences. In making the analyses and giving evaluations, an important role is played by the information that is acquired via monitoring. The longer and more detailed the sequence of monitoring results is, the more information we have for assessing future risks and hedging them. Following the described conception will create the prerequisites for developing an environmental-geotechnical model at Sillamäe and for using an analogous methodology for other areas that need recultivation.

The impact of WDs on the surrounding environment and the impact of the environment on the repositories is reciprocal. If we are able to predict and manage the processes, the environmental impact will remain within the limits of the norm-validated criteria and be acceptable for both human health and the natural surroundings.

The authors of the article have come to the conclusion that for reaching a better result, an active strategy should be used. Taking into account the reciprocal impact of long-term natural processes and recultivated waste repositories, actual natural energy should be implemented for reaching the goal rather than creating a barrier working against the forces of nature.

An important part in solving the problem of recultivated areas is the environmental-geotechnical model that is based on risk analyses and the assessment of the reciprocal impact of the processes. Information plays an important role in ensuring the quality of the analyses, prognoses and assessments; this information can be gained with long-term monitoring and also the integrated analyses that is enabled by the use of environmental geotechnics.

The monitoring must deliver an adequate view of the completion of natural processes, the reciprocal impacts of natural and technogenic environments and enable the long-term isolation of WDs from the surrounding environment and determine the effectiveness of the planned defence measures in the longer perspective. As the WDs must last for generations, the monitoring must be prolonged, thus enabling the assessment of the adequacy of current predictions in the future and direct the processes towards risk management.

One must not underestimate the importance of communication in the recultivation process of WDs. This is a complicated topic that requires mutual understanding by all the sides – the legislative powers, the local municipalities, the general public and various specialists. With growing effect, the development of environmental legislation keeps converting the responsibility for activities dangerous for the environment and human health into economic responsibilities. Therefore curbing the impact of similar activities simultaneously supports the compliance with the principles of sustainable development in the society.

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