ECOLOGICAL RECONSTRUCTION OF RADIOACTIVE MINING WASTE DUMPS – CASE STUDY OF NATRA WASTE DUMP

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Abstract: *Located in the south-eastern mountains of Anina the uranium mining exploitation Ciudanoviţa, opened in 1950 by Sovrom-Kvarţit mining company, represents the cause of a long term process of environmental degradation with direct and indirect influences on all components of the environment, but especially on local human population. Following mining operations, there are extensive areas of land occupied by waste dumps containing radioactive material, derived from opening, preparation and exploitation works of uranium deposits. These dumps generate significant risk of contamination by radiations, as well as a high potential for environmental pollution. The purpose of this paper is to design a series of ecological reconstruction works of the waste dumps in the area, namely Natra waste dump. In order to achieve the goal there were established several objectives, including: studies on the chemical and physical stability of the dump, redesigning measures to avoid the occurrence of landslides, the containment of radioactive material in relation to the biosphere, the level of intervention and the appropriate reuse of the land. Given the severity of the negative effects on the environment caused by radioactive emissions, even in the case of relatively low intensities, isolation and ecological reconstruction of such waste dumps is not only appropriate, but mandatory.*

Key words: *ecological reconstruction, radioactive material, stability, waste dump*

INTRODUCTION

Prospecting of uranium in the Ciudanoviţa area began in 1950, and in 1953 the SOVROM - KUARTIT Society found a significant number of anomalies using gamma surface exploring, putting into evidence the mineralization formations at Frumosu, Maidan (Brădişorul de Jos) and Ciudanoviţa. In 1956 - 1958 the Natra - Dobra, Dobra South and Dobra North deposits were discovered and operations started in 1962 at Dobra South and Natra, and in 1978 at Dobra North deposit. Known reserves were depleted at Natra perimeter and the mining activity was suspended in 1988. Activities at the Dobra North perimeter were seized in 1990 due to the economic aspect. Reunited under the Banat Branch the mining activities were permanently suspended in 2001, following the completion of mining works and stockpiling (UNC, 2006). Although waste dumps containing radioactive material presents a major risk factor, reconstruction and rehabilitation works were made only partly, leaving the radioactive material exposed to the environment.

Because radioactive elements, even in very small amounts found in the waste dumps in this area, are major environmental pollutants, with a devastating effect on any biological forms, the proper stabilization of these waste dumps is required. Natra is the last dump closed, for which there were no isolation works for raioactive material executed, which is why it was chosen as the object of this paper. In the following pages we will summarize the present situation of the Natra waste dump as well as the works needed to bring it in a state that permits reintegration in the natural environment.

MATERIAL AND METHODES

In preparing this paper, the authors turned to the technical documentation provided by the National Uranium Company - Banat Branch (NUC - BB), studied the literature on the effects of radiation on the environment and humans, conducted field visits and made the necessary studies in the ecological restoration activity of degraded lands.

The need for ecological reconstruction of radioactive waste dumps

Trough the activities of the Ciudanoviţa mining field, since 1956, a large number of pollutants were emmited in the environment in various forms, leading to a possible biological hazard for people in critical groups and natural ecosystems located close to the exploitation area (NUC, 2008).

The entire mining activity causes, due to its nature, multiple negative effects on the environment, as exemplified by (LAZĂR, 2010):

- changes in topography and landscape degradation of exploited areas;
- ocupation of large land areas for mining activities, waste dumps, storage of useful mineral substances, industrial facilities and access roads, that become unusable for long periods of time;
- land degradation by vertical and horizontal sliding of surfaces, waste dumps and tailing ponds;
- contamination of surface water and groundwater;
- hydrodynamic imbalance of groundwater;
- negative influences on the atmosphere, flora and fauna;
- soil pollution, which can affect its long-term fertile properties;
- spread of radiation into the environment, with a strong negative impact.

Pollution or contamination with radioactive material means unwanted or accidental presence of materials with radioactive contents in environmental factors or living organisms, in excess of their natural radioactive element contents (LAZĂR AND DUMITRESCU, 2006).

Waste dumps are considered open sources, susceptible for dispersion.

Human exposure to sublethal doses have the following results:

- reducing the normal physiological activity, characterized by slowing growth, mitigated resistance to toxins, decreased immune system capacity;
- reduced longevity;
- declining birth rates due to infertility;
- altering of the genome by introducing unfavorable mutations.

The effects of radiation pollution are felt, in all cases, in the atmosphere, water and soil, influencing living organisms, sometimes up the food chain due to bioaccumulation. The effects of this pollution include (MIHAI, 2010; BRAGEA et al., 2008):

- direct (due to interaction of radiation with biological medium, changing the composition and structure of matter, sometimes with genetic mutations);
- indirect (when the biological structure is not affected, but the environment in which it is placed is).

In general, the adverse effect of radiation depends on the type of radiation, the energy of the radiation and irradiation time, resulting in (BRAGEA ET AL., 2008):

- short term effects after strong irradiation (specific diseases, death);
- long term effects, due to the accumulation of weak radiation (increases risk of cancer);
- genetic effects, manifested in offspring of the irradiated parents.

The danger of radioactive pollution is given by uranium and plutonium present in the environment as well as the presence of radon gas in both mouths of galleries and at the surface of low grade ore stockpiles or contaminated land.

Taking into account the depletion of industrial reserves and economic criteria of profitability, NUC - BB owned mines were closed completely, leaving behind the mine openings and waste dumps as sources of pollution.

Establishing the leven of intervention

Recovery and rehabilitation of degraded lands consist of establishing and implementing all of the interventions and measures necessary to prepare the area for environmentally compatible reuse.

Dump reclamation is based on a complex interdisciplinary analysis on components of the affected territory. The results of the analysis determine the best solution for rehabilitation, to restore a compatible ecosystem.

Major issues to be considered long-term for the rehabilitation of waste deposits include physical stability, chemical and biological stability. After closing, the waste dumps must be physically stable under the conditions of extreme events such as floods, seismic shocks and disturbing forces standing, including wind erosion and rain, so they do not pose a threat to public health and safety and the environment. Regarding chemical stability, leaching of contaminants contained in the waste material into the environment and their migration should not endanger public health and safety, so the quality standards downstream of watercourses can not be exceeded (LAZĂR, 2010).

Ecological reconstruction of terrains involves revegetation of large areas of land, whose quality does not ensure proper development for plants. It is important that the methods of improvement and cultivation of these lands and the choice of species to ensure sustainable development of vegetation, which aims not only at the successful installation of plants in the first stage, but also at reaching the capacity of self-support of plant communities.

Given the dump site and the types of reconstruction possibilities for such an objective, for the Natra dump the naturalistic reconstruction was chosen, which involves minimal intervention and low costs (LAZĂR, 2010).

RESULTS AND DISCUTIONS

Following the activities of over 40 years of prospection and exploitation, numerous waste and low grade ore dumps have resulted. After transport of ore to the processing plant, heavily contaminated soil surfaces remained behind, as well as waste dumps and low grade ore dumps below 0.025%, resulted from radiometric sorting (NUC, 2008).

Most dumps are located on the sides of streams (Natra, Lişava, Dobrei) sometimes blocking their course. With no special measures established, the dumps have undergone alteration processes, followed by leaching and migration of certain "hazard" elements to the environment.

Description and localization of site area

Topography - the dump is located in a hilly area surrounded by hills Prisaca, Golgota to the west and Janos to the south. Their placement was intended to damage areas as small as possible, situated in rough terrain, with the little economic importance.

The elevation of the terrain, along the valleys where the primary waste dump was formed and expanded is between 360 and 420 m. The slopes are between 5° and 40°. Because of the steep angles and due to the presence of water runoff during periods of heavy rainfall, there are erosion and some minor slip phenomena present (NUC, 2010).

Climate - specific temperate continental climate with light Mediterranean influences and vertical differentiation due to the elevation. The area has a semialpin microclimate with a predominantly wet and cold character, with semnificant amounts of precipitation as rain and snow. Thus the annual average rainfall in the Ciudanoviţa area is 806 mm annually. The average temperature in winter is between -2° and -3°C, and in summer between 25° and 22°C. Wind regime in the area is generally dominated by West and Northwest circulation. The Banat mountainous topography causes significant changes in air movement, creating local peculiarities such as the formation of "cascade" winds called Coşava.

Vegetation - typical to central Europe, featured biomass is dominated by mesophilic forests (*Fagus sylvatica*, *Quercus petraea*, *Carpinus betulus*, *Acer pseudoplatanus*). Circumpolar species are found in beech forests and grasslands resulting from cleared forests (*Dryapteris Filis mas*, *D. Dilatatat*, *D. Cristata*, *Polipodium vulgare*, *Vaccinium mirtillius*). Among the submediterranean species we have: *Carpinus aventalis*, *Cornus mos*, *Fraxinus arnus*, *Calomita officinale*. Among the Balkan species that grow in the xerofile meadows we can mention: *Montana pulsatile*, *Camponula glomerata*, *Linum austriacum*.

Location and Description of Natra waste dump

Natra waste dump was formed by the union of two dumps originating from the gallery Shaft 1 and 50 by filling the valley, downstream from the shaft elevation (+349 m), over a length of approximately 340 m, leaning on the right bank of the stream, with extension in the water thalweg (Figure 1).

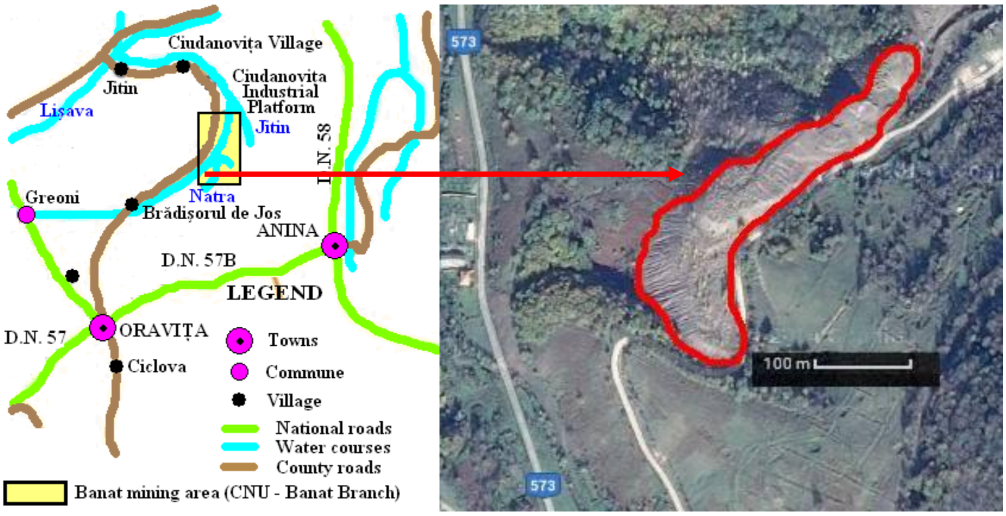

Fig. 1. Location of Natra waste dump

Shaft 1 Natra stockpile was formed over 30 years, by tailings spilled from Natra mine, with 0.6 m^3dumpers along the creek. Similarly the galery 50 stockpile was formed and currently together with the Shaft 1 stockpile forms a single waste dump called Natra waste dump (NUC, 2006).

The material from the dump is represented by sandstones and redish-purple or gray microconglomerates. It consists of waste rock from the opening and preparation works of the Natra deposit.

Geometry of Natra waste dump:

- surface area approximately: 14,377 m^2 ;
- variable hight (in one level): 0 – 20 m;
- variable slope angle: 20 – 34^o;
- base terrain slope angle: 5 – 23^o;
- volume of waste material deposited approximately: 90,000 m^3;

Physical and geomechanical characteristics:

- volumetric weight: γ_v = 18.4 - 21.2 (kN/m^3);
- specific weight: γ_s = 26.5 - 27.8 (kN/m^3);
- compressibility module: M_{2-3} = 125 – 200 (daN/m^2);
- internal friction angle: φ = 15 - 45º;
- cohesion: c = 3 - 19 (kPa);
- natural humidity: w = 6 - 17 (%);
- granulometry between: 10 – 250 mm.

Following field visits, observations were made about the technical condition of the dump (slope and upper platform). We distinguish some erosion phenomena (gullies and trenches), especially on the western and north western slopes (Figure 2a). The upper platform is affected by uneven settling of the material due to how the material was stored, without compacting and leveling at the end of the storage process (Figure 2b). From the observations made there have been no areas found to be affected by active landslide, but considering the intensity of erosion and rainfall (dripping water on the surface of approx. 2,000 m^3/year and ha) and the absence of vegetation on more than 80% of the dump area (whose reinforcement effect on slope stability is well known), such events can occur at any moment.

a b

Fig. 2. Slope erosion and uneven settlement of upper platform

To characterize the dump and bordering area from a radiologicall point of view, there were sample materials taken from the composition of the Natra dump and the following content in radioactive elements and heavy metals were identified: the levels of uranium in rocks from the dump are between 10-25 ppm, and the gamma dose rate varies between 0.25 – 0.70 Sv/h, and the content of Radon is 50 Bq/m^3.

To grasp the impact of waste dumps and mine water on the contamination process of sediments, soil and vegetation with radioelements and heavy metals, the collected results were interpreted trough discriminant analysis determining both the base background values and the contamination proocesses:

- the sediments in the Natra creek between galery 50 and the confluence with Lişava have uranium contents between 10 - 70 ppm , and the radon varies between 0.3 – 1 Bq/g, which means a concentration of radon due to the clay minerals present in the sediments, acting as a concentrator for radon;
- the soils samples collected from the mining area, to the confluence of Natra and Dorea creeks with Lişava have an average Ra concentration of 0.15 Ra Bq/g and 10 ppm U, and 100 meters downstream from the mining area they have background content values;
- vegetation - a concentration process, especially of radon, is being observed in the collected plants from the base of the waste dump as well as the ones collected as far as 100 m away from the dump.

In the vegetation that grows spontaneously on the horizontal surface of the waste dump a high process of concentration for some of the elements has been observed, compared to the contents of the dump material, caused by the bioaccumulation effect.

Table 1.

Content of heavy metals and radioelements in the biotope and biocenosis elements (in ppm)

Biotope/biocenosis elements	U	As	B	Pb	Mo	V	Cu	Zn	Ni	Co
Sediments/rocks	90	70	60	40	1	100	40	120	20	10
Soil	100	170	50	40	1	60	40	170	30	8
Grass	108	250	400	50	10	15	260	400	45	15
Wild rose	20	-	400	60	3	10	80	150	20	8
Coltsfoot	150	-	1000	150	5	-	200	600	30	10

Note that each species has different capacities for assimilation and concentration, which is between 0.2 and 16.

The grass focuses particularly arsenic, molybdenum and copper. Uranium, boron and zinc accumulate in wild rose and coltsfoot. For all studied plants, vanadium has no semnificative assimilation phenomena linked to plants and cobalt and nickel are present in similar concentrations for both elements of the biotope and biocenosis.

Stability analysis of the waste dump for the initial geometry

A first step in designing the earthworks is the stability analyzes on the initial geometry of the deposit. This stability analysis was performed with the Bishop and Janbu methods, using the specialized software, "Slide".

These analyzes were conducted on the longitudinal section of the waste dump and the parameter values and results factored in the analisis are presented in Table 2.

Table2.

Stability analysis of the waste dump for the initial geometry

Material	Characteristics			Stability analysis	
	Volumetric weight γ_v (kN/m^3)	Angle of internal friction φ (°)	Cohesion c (kN/m^2)	Janbu	Bishop
Waste material	21.40	19.00	30.00	1.039	1.141
Base terrain material	18.70	22.00	16.00		

Following these analyzes, we can notice that coefficient values established by the two methods are very close to the limit of balance, imposing carrying out reconstruction works to lead to an increase of the stability reserve pool and ensure conditions necessary for the type of proposed redevelopment(Lazăr et al., 2012; Lazăr et al., 2015; Rotunjanu, 2005). These works are described in the following paragraphs of the paper.

Design of reconstruction works

For reversing the effects of erosion on the slopes and in order to increase stability, the elements of the waste dump will be remodeled by excavating material to obtain a slope with an angle of 25°, material resulting from these works being deposited at the top of the heap and then leveled. In this way we also eliminate the microdepression resulted by the uneven settlement of the material.

Leveling Natra dump will be executed from the creek bed with the same name to the eastern slope of the river. The total calculated excavation volume is 37,416 m^3, and the total embankment volume is 31,942 m^3. The excess material is transferred into the contaminated material waste dump and will be excavated in the southern part of the dump, an area showing sharp degradation and heavy contamination according to the material investigation.

The dump is being perimetrally protected against slope water infiltration using trapezoidal apron guard ditches with reinforced concrete base and rectangular stepped guard ditches for areas with steep slopes. These channels will empty into the Natra creek. Channel length is 270 m to 145 m for the trapezoidal profiles and the rectangular profiles are made in 44 steps (NUC, 2010).

After geometrization of the deposit, in order to isolate it from the environment, it is necessary to adopt a technical solution viable in economic terms. In literature there are several types of insulation for radioactive waste deposits, most assuming the use of geomembranes with different construction types and with different degrees of radiation protection, which involve high costs, but also much cheaper options, involving the creation of multilayer barriers using natural materials.

For this reason, for Natra dump, we suggest the building of radioprotection barriers that consists of 3 successive layers of material (Figure 3), which shall be deposited all over the dump, about 1.4 ha.

Fig. 3. Multilayer barrier

The first layer, in direct contact with the radioactive material deposited, will have a thickness of 1 m and will be made of compacted sodium bentonite. This is the most important layer because it provides both waterproofing for the deposit (thus preventing water infiltration inside the dump and the transport of heavy metals and radioactive material) and the conditions needed to retain radiation and radioactive gas deposits inside the dump's body.

The next layer consists of a drainage material (gravel limestone) with a thickness of 50 cm, which is intended to take over and redirect excess water from rainfall to guard channels.

The last of the layers will consist of topsoil, thickness of 1 m, necessary to ensure the conditions for revegetation of the dump, the total volume of soil being about 15,000 m^3.

Given that this multilayer barrier will fully cover the deposit it will act as a uniformly distributed overload (overload negatively acting on the stability of the deposit).

The overload presented by the multilayer barrier gives us reason to design the construction of a system of counterbenches (grey andesites caught in an array of metallic mesh) at the base of the dump, in contact with the surrounding land. On the eastern side it has a dual role, to increase stability reserve and protect the river bed of Natra creek. All these modifications to the initial geometry, isolation with the multilayer barrier and construction of the counterbenches lead to a change in the tensions of the landfill, and is therefore required that a new stability analysis must be performed (which takes into account the presented situation) to verify the compliance with the long-term stability of the Natra waste dump.

Stability analysis of the reconstructed waste sdump

A final analysis was performed on the end result configuration of waste dump, considering overloads caused by the multilayer barrier and the positive effect of the counterbenches. The same methods were used for the stability analysis as with the initial version, geotechnical parameters considered and results for this analysis being presented in Table 3 and Figure 4.

Table3.

Stability analysis of the reconstructed waste dump

Material	Characteristics			Stability analysis	
	Volumetric weight γ_v (kN/m^3)	Angle of internal friction φ (°)	Cohesion c (kN/m^2)	Janbu	Bishop
Waste material	21.40	19.00	30.00	1.398	1.535
Base terrain material	18.70	22.00	16.00		
Bantonite layer	24.00	30.00	16.00		
Drainage layer	26.40	60.00	33.00		
Topsoil layer	18.70	22.00	16.00		

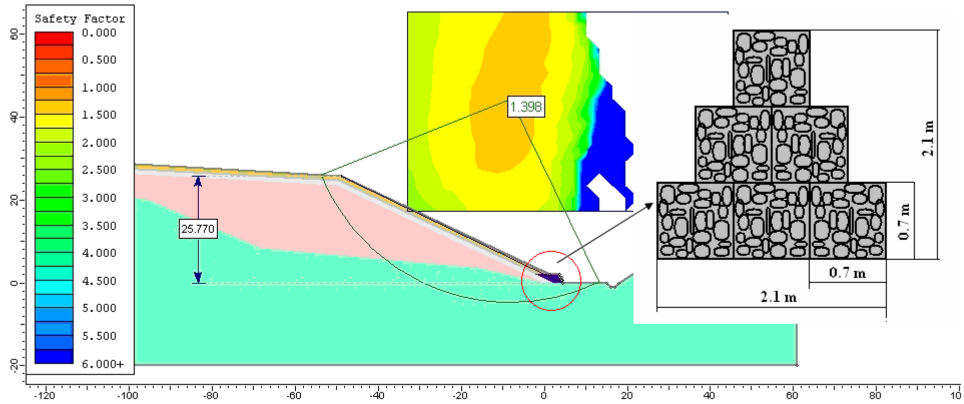

Fig. 4. Stability analysis of the reconstructed waste dump (Janbu)

After performing the stability analysis, considering the end design parameters, it can be seen that the stability coefficient by the application of both methods is over 1.3 (a stability reserve greater than 30%) which is consistent with technical construction and mining waste dumps conservation (long term stability) (Lazăr et al., 2012; Lazăr et al.; 2015, Rotunjanu, 2005).

Revegetation of Natra waste dump

Ecosystem recovery success is conditioned by restoring of the internal processes and ecosystem components, such as rare species and the habitats' important characteristics (Lazăr, 2010).

As was stated earlier in the paper, we envisage restoring the natural cadence of the landscape by naturalistic recovery of Natra waste dump, and for the choice of species there have been taken into account the region's natural features (climate, soil and plant life). This was considered getting a herbaceous vegetation coverage of 100% and planting hazelnut saplings (*Corylus Avellana*).

These works will take place in two stages.

The first stage consists of grassing the entire surface of the dump area, these works being done in the spring, mechanized for the upper platform and manually on the slopes.

The second stage, that of planting saplings, will be held in the autumn (dormant stage), hazel saplings planted at a distance of 4 meters between them (in other words each hazelnut sapling has a land area of 4 m^2). Planting is done in pits at a depth of 30-40 cm. For planting seedlings the following scheme was chosen (Figure 5).

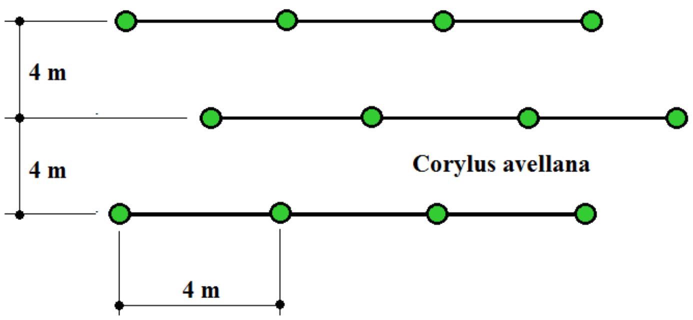

Fig. 5. Hazelnut sapling planting scheme

The plantation of hazel seedlings will be carried out under the supervision of specialized personnel of the Forestry Authority and a representative of the company that supplies the seedlings. For planting, in the first phase the terrain will be, after that, the contracted personnel will dig planting holes and plant the seedlings. After plantation works are finished the perimeter will be surrounded by a protective fence so that animals do not destroy the seedlings. The number of seedlings needed is of aprox. 2,500.

We mention that hazelnut saplings will be planted only on the upper platform of the Natra dump, and the reason we chose a species of shrub trees to the detriment of tall trees is the necesity to maintain the integrity of the multilayer system (bentonite). Thus a species with traceable roots was chosen to avoid the danger of perforating (damaging of any kind) of the bentonite layer.

The monitoring of the hazelnut culture will be conducted by specialists (agronomists, researchers from land reclamation institutes etc.) and they will observe the growth rate of plants, the number of mature plants, the coverage of the recovered surface by mature plants etc.

The monitoring process will be seasonal - runs every year from September 1 to October 31. There will be used control surfaces placed after planting and will be carried out under the technical guidance for annual inspection of regeneration. Percentage of completions can reach up to 10 % in the second year after planting, and 5% in the third year after planting (Vasti-Vinter and Zaharia, 2013).

CONCLUSIONS

The exploitation of uranium ores in the Liaşva-Ciudanoviţa-Natra zone have resulted in numerous waste dumps containing radioactive material, dumps which represent an ecological hazard and require imediate ecological reconstruction (to ensure isolation of radiation to the environment and reintegration in their natural environment).

In this paper was presented a case study, Natra waste dump, which covered both the analysis of the initial situation on the ground (physical stability and aspects of environmental contamination) followed by the design of restoration works and solutions to ensure radiological protection of the area .

Thus, given that the initial geometry of the heap provides a stability coefficient on the edge of balance and the fact that radioactivity in the area exceeds the admissible limits, geometrization works were presented to ensure a superior stability coefficient and allow the construction of a protective barrier against radiation.

After modeling the waste dump in the final configuration, with 25º slopes and multilayer barrier coating, arose the need for the contruction of counterbenches to act as support for the stored material. Analyzing the new stability coeficient of the objective in these conditions we obtained values for the stability coefficient above 1.3, which means that the conditions required by the legislation are met.

In the last part are presented a few aspects of the revegetation process (aimed at reintegration into the surrounding landscape), without going into details. So for this step was proposed a total surface grassing, and the upper portion of the deposit has been proposed to be planted with hazel trees (primarily aiming at integrity of the radiation protection barrier to not be affected). The solution identified for the Natra waste dump, using a multilayer barrier can be applied successfully to other dumps containing radioactive material from both the perimeter Banat and the other perimeters of the country where there are such deposits (Băiţa-Bihor, Crucea-Suceava, etc.).

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