Stage I of the project

- Analysis of filling technologies used in the disposal rooms of LLW and ILW, in the case of DNDR similar deposits and selecting filling technology applicable to DNDR Băița, Bihor.
- Laboratory Experiments on the behavior of filing materials in saturated medium. Proposals of alternatives for gaps filling.
- Analysis of the reaction in time of the storage system of packages with radioactive waste, in terms of changing the technology for filling gaps

In the case of works done in this stage, an assessment was carried out on the experience and the current practices of storing LLW and ILW in the European Union. Emphasis was placed on the operation and management of these deposits and on their evolution over time. In many cases, the deposits were initially established as facilities necessary for waste management at private or national research centers, from the fuel cycle related stations or electricity generation ones. Over time, many have been adopted as national deposits even though many times they were still managed by the initial organization. As national waste management organizations were created, the responsibilities related to the property, investments, financing, management and operation of these facilities have also evolved. The various deposits analyzed showed variations on the nature and scope of such development in the different countries.

The report is structured to provide:

- An overview of the main technical requirements for radioactive waste deposits;
- An overview of the various types of deposits in operation;
- Detailed description of the deposits that are similar to the deposit at Băița, Bihor;
- Detailed descriptions of deposits that represent "best practices" in the EU.

The report concludes that there is a wide range of storage concepts of LLW and ILW in the course of implementation within the European Union. The selection of these concepts is determined by:

- The types and volumes of generated waste
- National strategy for radioactive waste management
- Regulatory approach for managing waste safely

The degree of isolation of the waste repository for the environment depends on the waste-storage system performance as a whole, taking into account the waste package, engineering works in the deposit and the geology of the site. These components of the system must be selected or designed in such a way that as a global system to ensure the isolation required by the radiological safety of the population and the environment now and in the future at a predetermined level.

All these components have a specific role, depending on the method of storage and represent a unique system, able to meet the main objective of radiological safety, which is to prevent, delay and limit the release of radionuclides from the waste in the environment, at a level at which adverse effects would remain acceptable. In addition, the institutional control and passive markers must be implemented, at the system components (natural and engineering), which can facilitate, at least for a while, the protection against human intrusion.

At the same time, an important goal of the project is shaping the release of radionuclides in the disposal galleries. For a robust assessment on implementation of engineering barriers, have been studied practices used for similar deposits (in geological formations), experiments conducted for the analysis of their effectiveness, the proposed in-situ and laboratory experiments and the assessment of the reaction over time.

In this stage, were evaluated two different modeling concepts for the source term. First concept is based on computer analytical approaches developed previously by the research team. These approximations have a high conservative degree and are the upper limit for the release of the radionuclides in the disposal galleries. At the base of these approximations is the mixed cells cascade concept, based on fundamental hypotheses widely used for this case. The second concept developed by this work, for the evaluation of the source team, is represented by a complex approach of the numerical solution of radionuclide transport equation. The release from the waste form includes three mechanisms: surface rinsing, diffusion and leakage (uniform release). These release mechanisms, can be optionally represented, either analytic or numeric. Within simulations in this work, was preferred the numerical modeling of the release mechanisms. Simulations based on the transport equation solution were performed with DUST-MS software and considered a mono-dimensional simulation of the disposal gallery.

In order to improve the insulation of radiological waste and radiological safety, it is suggested to lay out the first 3 rows of packages, fill the gaps between them, and then place the next two lines, following the closure of the gallery. Metal casings, will be made in two phases, respectively, for the first three rows and then for the last two rows.

The methods of filling the gaps between the packages, the following are suggested:

OPTION I MODIFICATION OF GAPS FILLING

I.1 Filling with damp materials:

- I.1.1 Bentonite slim paste (bentonite + water + cement + sand)

- I.1.2 Bentonite concrete paste (bentonite + water + cement)

- I.1.3 Alcaline concrete paste (bentonite + water + limestone powder)

I.2 Filling with dry materials:

It is also suggested the settlement of the first 3 rows of packages, filling the gaps between them, and then placing the next two lines, and then, following the closure of the gallery.

As methods of filling with dry materials of the gaps between the packages, the following three are proposed, related to the second option:

- I.2.1 Powder bentonite;

- I.2.2 Powder bentonite + sand – in proportion of 50%, each;

- I.2.3 Powder bentonite 30% + clay 20% + sand 50%.

In all sub-options used, it is necessary to use mobile equipment, for the transfer of damp materials, respectively, a pneumatic transport system of dry material, through flexible hose/tubes.

OPTION II INCREASE OF ISOLATION DEGREE

In order to increase the degree of insulation of waste packages was determined, during the course of this phase, the need to assess the use of modern insulation materials, such as geomebranes and geocomposites. Two insulation options have been identified, namely:

II.1 The fitting of a multilayer system, on the walls and the vault of each storage gallery, to isolate the radioactive waste packages, similar to the technical solution used in The Czech Republic, at Richard Repository.

II. 2 Coating the barrel layers of each gallery, with a multilayered system, consisting of a bentonite geocomposite and a geomembrane.

The analysis of the possibility to apply these additional sub-options will be carried out later.

Bentonite geocomposites (known in the engineering practice by the English term Geosynthetic Clay Liner), are defined as manufactured products, that associate geosynthetic materials and bentonite, being used in the construction industry and geotechnics, in order to achieve a tight barrier.

These have appeared as a result of the need to achieve a tight effective barrier, using a material easy to put in the work, uniform and resistant to punching. These products combine a natural material, bentonite, which presents a very low permeability due to its swelling capacity, with geosynthetic materials, which have a protective role and possibly a sealing role.

Stage II of the project

In order to achieve the objectives of this stage, there were considered the essential principles that must underpin the DNDR Closing Strategy in compliance with the nuclear safety conditions summarized below.

A storage facility has to be closed after the operation period so as to provide those safety features which have been identified as being important in the post-closure safety scenario. Closure plans which include the transition from active to inactive management of the facility will be defined and practicable so that the closure is performed safely, as planned.

The safety of a facility depends on a number of activities and design features including the filling and sealing or blocking of the disposal facility after disposal. The disposal facility should be closed according to the closing requirements specified by a regulating entity in the facility authorization, taking into account any change that may occur during closure.

Filling gaps and placing seals or locks may be delayed for a period after the completion of waste disposal, for example to allow monitoring in order to assess safety aspects after closure or for reasons of public acceptance.

All technical and financial resources necessary for closing under nuclear safety conditions must be adequately ensured.

The main performance requirements for filling consist of the capacity to prevent preferential paths for the migration of contaminants in the vertical and horizontal directions and provide a certain support to sustain the walls of the gallery (in the vertical direction).

With DNDR, an important objective of the project is modelling the release of radionuclides from radioactive waste disposal galleries. The major objective is to evaluate the current practice for filling the access and ventilation galleries with materials which comply with the security requirements, finding effective solutions for isolation or delay of radionuclide migration by creating an additional global "confinement" of conditioned radioactive waste disposed at DNDR Baita, Bihor.

During this stage, the Consortium members developed the subsections listed below, as planned.

Evaluation of the closing technology used in other countries for similar installations. Preliminary feasible options for DNDR

In this chapter, radioactive waste streams were reviewed, estimated to be deposited DNDR, also attaining an updated inventory, presenting the physicochemical properties of the waste. To achieve consistent and robust analysis there were presented the technologies applied in the management of stored radioactive waste in order to demonstrate the fulfilment of acceptance criteria, according to the authorized limits (WAC).

The natural environment chosen as location was also rated.

The policy broadly adopted for radioactive waste disposal involves their placement in a repository designed not to lose containment functions for a wide range of events and to prevent radionuclides release in quantities which could endanger humanity and the biosphere.

Since DNDR is considered a geological repository, according to IAEA documents, the issue regarding the reversibility of decisions and recoverability of waste inherently occurs, although, so far, these possibilities have not been considered. Moreover, the deposit characteristics imposed the DNDR evaluation in terms of nuclear safety as a surface deposit.

In addition, to facilitate feasible technical decision making concerning the closing concept at DNDR – Baita, there have been conducted studies on the concepts developed or to be developed, to European facilities with similar characteristics. These studies have focussed on three components:

- Overall strategy: with or without waste retrieval;
- Approaching nuclear safety, disposal system performance;
- Foreseen closing plan.
- The report concludes that there is a wide range of storage concepts for low and intermediate level waste being implemented in the European Union. The selection of these concepts is determined by:
- The types and amount of waste generated;
- National Strategy for radioactive waste management;
- Regulations for safe waste management.

There are some analogies appropriate for DNDR-Baita Bihor in KLDRA-Himdalen-Norway and Bratsvi/Richard-Czech Republic, which were described in detail. These deposits have similarities in terms of waste inventory and origin, similar concepts on storage in mine galleries and similar concepts on closing.

Proposal for DNDR closing technology based on preliminary experimental data obtained

In this subchapter, we analyzed and evaluated filling materials and concepts used in similar facilities. The requirements of a repository sealing system protrudes that the filling has certain fundamental characteristics. These include recreating the equivalent initial groundwater flow and geochemical/transport conditions of the repository site. In order to meet these requirements, the filler must be capable of ensuring that the swelling clay, used as a buffer material, stays in the original place if it comes in contact with the corrosion-resistant packages used to dispose the radioactive waste.

In conclusion, the overall function of the filler (assumed to be clay, an aggregate or a mixture of such materials) may be achieved by maximizing the dry density of the filler and by minimizing void spaces in the sealed galleries. In order to achieve this, the focused was on the development of improved compaction and appropriate techniques for placing the filler.

In order to achieve its purpose, the filler must be chemically and mechanically stable on long term and should not have or develop properties that could degrade significantly the function of other barriers in the storage system. This has been interpreted as meaning that the filler should be sufficiently compact in order to preserve the buffer material set in the designed geometry, which has a hydraulic conductivity low enough to prevent the movement of contaminated water.

The interactions between bentonite and cement were also examined. The interaction between the bentonite buffer material and the small amount of alkaline solution in the cement based material degraded, used in the construction and operation of the deposit, is considered to be hazardous in the long term for the chemical stability of the bentonite. In this report, calculations of the transport patterns have been performed to emphasize the alteration of the bentonite due to the small amount of alkaline solution. In case of one-dimensional calculation models, most of the primary minerals in the bentonite cannot re-precipitate and form structures with other smectites.

Based on these evaluations, a preliminary solution regarding the closing concept at DNDR - Baita was determined. Closure will be performed in accordance with the approved closure plan, which will include updating safety assessments and a description of the planned checks for the post-closure phase, the monitoring and surveillance program and the record keeping system.

A preliminary analysis revealed that the material filling the access galleries is the host rock previously excavated, processed by crushing to be brought to the size of ballast used for roads.

The following galleries are to be sealed at DNDR closure:

- Access gallery, of approx. 240 m length;
- Ventilation gallery, of approx. 340 m length.

This preliminary concept proposes that the filling is performed in 50 m sections.

There will be used four sections of 240 m for filling the access gallery, and 6 venting sections, of 340 m.

A. The main materials used and their justification

1. According to preliminary analysis conducted in this project, filling with natural host rock excavated, presents the best chemical compatibility with storage gallery walls. The mechanical strength of this material in the long term is superior to that of the cementitious material. Accordingly, it is proposed to fill the galleries named above with previously excavated rock, processed by crushing to be brought to the size of ballast used for roads.

2. Sealant layer of approx. 3 m, consisting of a mixture of 30% swellable bentonite, 20% non-swelling clay and 50% sand, preventing the formation of preferential channels and the migration of radionuclides, without affecting the other materials by excessive swelling.

3. Bentonite slurry filling between layer 2 and sealing membrane 4 intended to ensure the diffusion of potential radionuclides escaped through the other layers.

4. 1 m thick sealing membrane, made of bentonite concrete, intended to ensure retention of the possible radionuclides escaped by penetrating other barriers.

5. 3 m thick bentonite concrete sealing membrane, which delimits the gallery disposal area.

6. Waterproofing shotcrete, made of 10 cm Xipex concrete, applied on all surfaces of the gallery, except the floor.

7. 10 cm thick concrete bottom plate, made of porous concrete, for drainage achieved through controlled diffusion and retention of potential radionuclides.

A comprehensive experimental program was initiated and is to be conducted in the future to confirm the proposed technical solutions.

B. Sealing and anti-intrusion protection

Sealing and anti-intrusion plugs will be provided in the DNDR project feasibility phase.

There will be provided waterproof plugs, made of hydotechnical concrete, 15 m thick, at the outer ends of the access and ventilation galleries, as well as a plug of the same material, 10 m thick, at the intersection of the ventilation and access galleries.

The analysis of DNDR closure systems under limit conditions

Preliminary risk assessment scenarios

Developing a scenario aims to achieve a model for monitoring the possible and plausible evolution in time. The analysis of this model shall generate the values of certain safety indicators, representative for the scenario (e.g. substance concentration at certain points in the environment or doses received by individuals in the vicinity of the deposit) which will indicate the safety level of the system analyzed.

Based on the methodology set out in the preliminary safety analysis, we consider that the storage system developed in the former mining galleries for uranium ore at Baita Bihor is and will be affected by external, internal factors and contaminants, which can be divided into the following categories: features, events and processes (*FEPs - Features, Events, Processes*). Internal factors and contaminants are linked to the structure of the deposit itself, framed in the gallery, while external factors are related to the external environment of the deposit galleries. With this approach, features, events and processes caused by external factors are those which determine the characteristics of the baseline scenario.

In case of radioactive waste repositories, it is important to develop long-term scenarios after their final closing. Taking into account the specificity of The National Repository for Radioactive Waste Baita Bihor, which accepts low and intermediate level waste, it is considered that a period of 10,000 years after the permanent closure of the repository is of interest for the safety assessment. In the safety assessment, the long term baseline scenario considered year 1985 as the initial time of the assessment, the date of the first waste disposal at Baita Bihor. This value is maintained in the project.

The development of a proper baseline scenario for the storage system analyzed starts from a review of all possible external factors, determining which of them are specific to the respective system.

In order to develop and justify the baseline scenario associated to The National Repository for Radioactive Waste Baita Bihor, taking into account the upgrades done so far and the waste containment solutions, together with the closing solutions proposed in the current project, we used the same methodological approach from the preliminary safety assessment documentation; for a coherent analysis of the deposit situation we used the baseline elements of this documentation, updated according to the considerations of this project. The results of this methodology are presented in the paper.

This project proposes the change of the buffer material between the drums, since bentonite, in the form it is used at the moment (as bentonite powder) has a low efficiency, in terms of long term safety of the storage system.

Currently, the lost shuttering used to fix bentonite, is made of wood. Since in time they will degrade in contact with infiltration water, we propose the use of reusable shuttering, and the replacement of bentonite with bentonite concrete.

The conceptual model is based on the description of the following:

- Features, events and processes (FEPs) associated with the storage system;
- The relationship between features, events and processes, and

- The size of the model, expressed in terms of space and time.

A schematic representation was made to the conceptual model for the disposal subsystem, corresponding to storage galleries without buffer material and to storage galleries with buffer material, including the interactions between the key components of the model.

Due to the deposit location in the mountains, the water inside the storage system comes only from water infiltration and rainfall. The water content in the deposit varies widely, depending on the position of the galleries, creating well-defined "wet" and "dry" areas.

It was assumed that the concrete matrix within each drum may have cracks, most likely resulting from contractions occurred in the initial concrete casting in the barrel and cracks developed later.

After the loss of confinement, it is assumed that the release of radionuclides from different types of waste can be described by the following types conceptual models:

- The delayed release through single fracture - it is considered that radio nuclides are present in a container surrounded by an annular layer of inactive mortar.
- The heterogeneous release - it is considered that the radionuclides are present as surface contamination on solid materials (e.g.: small metal parts, plastic waste, etc.). It is considered that cracks occur along the interfaces between cement and waste components.
- The diffusion controlled release - in this case, it is considered that the radionuclides are closely mixed with mortar so that the cemented waste form provides a degree of confinement.
- The heterogeneous diffusion controlled release – it is identical to the heterogeneous release, except for the fact that some of the contamination is located within the waste components matrix. Therefore, diffusion inside the waste components will act to limit the advection release rate of the heterogeneous model.

Stage II Conclusions

The main conclusion that results from the work done so far is that there has been carried out an assessment and characterization of the following components needed to formulate a closure concept:

- Inventory of radionuclides and physicochemical characteristics;
- Geological and hydro geological environment;
- Treatment and storage technologies;
- Engineering barriers systems;
- Compliance with the acceptance criteria;
- Sealing techniques and associated issues in case of similar facilities.

Based on the characterization of these components a preliminary concept was developed, taking into account:

- Fillers and related technologies;
- The interaction between the filler and cement matrix used in radioactive waste containment;
- Starting an in-situ and laboratory experimental program for evaluating the performance of the filling and closing materials.

There was also performed an analysis of external, internal factors and contaminants, which can be divided into the following categories: features, events and processes established in the safety analysis, as well as a reassessment of the conceptual model and its constituents by introducing the performance of the proposed buffer and closure materials.

To validate the closing solution the experimental program described in this step shall be completed, allowing the selection of the final optimal alternative as well as the analysis of the evolution of engineering barriers and closure materials and technologies.

In conclusion, the objectives of the stage were fully met creating the prerequisites for further developing the next stage of the project, namely: " Finishing NRRW Băița, Bihor Closure Plan in safety conditions”

Stage III of the project

DNDR Baita Bihor closure can be considered as the last important operation step, in addition to the storage system.

This activity is defined as a systemic activity to be carried out after the termination of waste placing operations being carried out with the intention to provide the final configuration of the storage system. Closure activities must complete the storage system design because the whole system is designed to isolate the hazardous constituents (especially radionuclides), for an enough long period of time, which is acceptable considering the risks posed on humanity and ecosystems. The repository closure involves taking into consideration a combination of factors, scientific, technical, regulatory and socioeconomic, to be integrated and optimized for selecting alternatives acceptable from the points of view of all stakeholders.

The engineering barriers system is essential in the storage security scenario. Even if the host rock provides important performance potential, the correct design of the engineer barriers system that meet multiple security functions is essential.

1. Developing the conceptual technology for DNDR closure, based on all experimental data obtained

Activities related to repository closure must be developed to meet the national and international legislation.

DNDR Baita Bihor closure implies designing the closure system of the access and ventilation tunnels and the remediation system of rock layers above the storage area.

DNDR Baita Bihor closure will be based on the experience in mine closure in Romania. There are significant differences between the closure of existing mines in comparison to the radioactive waste repository, influencing the closure plan and some aspects of closure technologies, namely:

The period of institutional control. In case of ore extraction mines, the post-closure control period is generally 30 years. For radioactive waste repositories containing radionuclides of relatively short life, less than 30 years, such as DNDR Baita Bihor, it is considered that radioactive decay up to an acceptable level is achieved after 10 half-lives, which means that the institutional active control and passive control period shall be 300 years.

Waste stability. Radioactive waste is fixed in a cement matrix that transforms them into a solid form, acceptable for storage. Radioactive waste packages consisting of the metal container filled with radioactive waste immobilized by cementing, tested to withstand the conditions of handling, transport and storage.

Radioactive contamination. Unlike conventional mines, at DNDR Baita Bihor, the radiation field, especially the risk associated with the exhausted radioactive sources inventory, requiring protection and handling measures specific to these types of waste.

The main components of the closure systems at DNDR Baita Bihor are: 1. The roof consisting of rock layers partially altered by mining activities; 2. Buffer filling in the storage galleries; 3. Separation walls between the storage galleries and the access tunnel; 4. Sandwich fillings of the access and ventilation tunnels; 5. Sealing plugs of the access and ventilation tunnels; 6. drainage systems; 7. Markings indicating the presence of closed repository for future generations; 8. Waterproof layer of Xypex additive gunite on the walls of the access and ventilation tunnels; 9. Porous cement layer on the floor of the access and ventilation tunnels.

In order to close the Baita Bihor DNDR repository, to restore the natural environment in the entrance area of the access gallery 50 and to ensure the sealing of the storage system, three different constructive solutions for refurbishing the degraded area of the roof of DNDR Baita Bihor were analyzed and described in detail, as follows:

-**Alternative 1** - The execution of terrace landscaping projects and the restoration of the excavated area and the access area into gallery 50, on an estimated area of 13100 m^2; **- 2 Alternative** – The installation of a geogrid on the entire degraded surface, in order to restore the excavated area and the access area into gallery 50, on the same estimated area (13100 m^2); - **Alternative 3 –** The execution of terrace landscaping projects and the restoration of the excavated area and the access area into gallery 50, on an estimated area of 3600 m^2 and the installation of geogrids, on the remaining area of 9500 m^2.

Each of the three variants can be carried out in two sub-variants for closing the repository:

- **Subalternative A** which includes the decommissioning of the reception platform, the demolition of the administrative building and the related infrastructure and covering this surface in order to reconstruct the ambient, reforming the natural slope. - **Subalternative B** which includes setting up a public museum in the administrative building to present the evolution of DNDR Baita Bihor, with the role of popularizing the storage system performance, to increase public confidence in the security of the storage system. This entire building can be used to accommodate institutional control equipment of the repository.

As a result of the analysis performed, it is recommended to select the **Alternative 3B**, in terms of cost-benefit. Figures 4.1-1 and 4.1-2 show the design recommended.

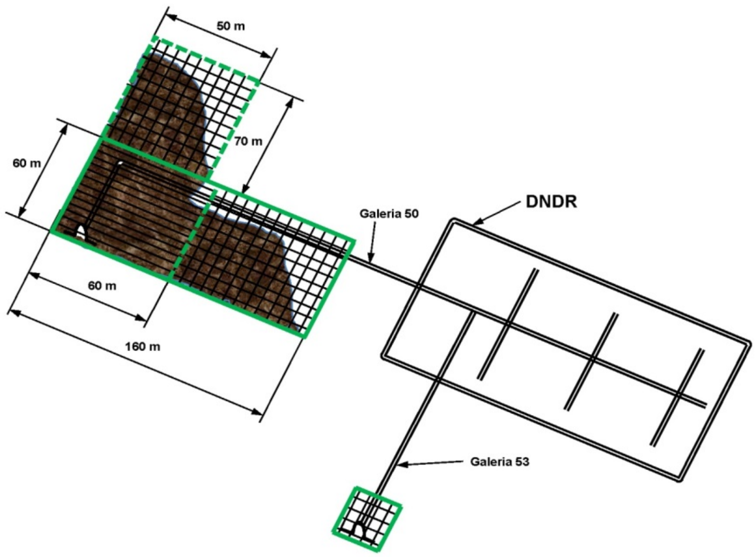


Figure 4.1-1 Siting and arranged areas at DNDR, Băița, Bihor.

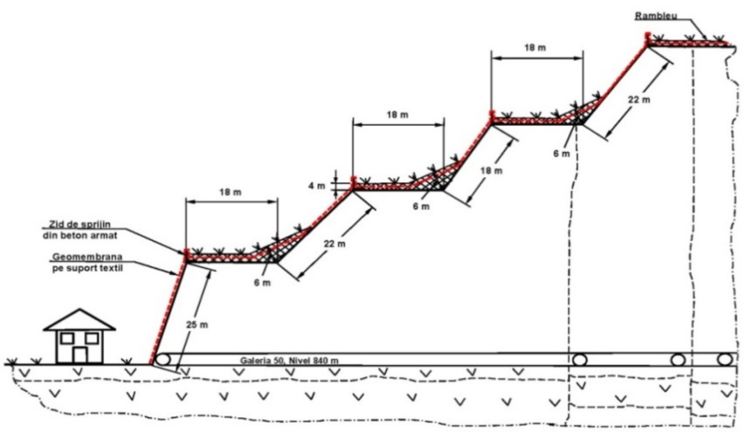


Figure 4.1-2

Structural section through the roof of DNDR, Băița, Bihor

Access and ventilation tunnels are in an area where meteoric water infiltration is important due to the reduction of the rock layer above. In order to separate areas with different infiltration rates, it was chosen to fill these tunnels with a sandwich filling. This filler has the role of stabilizing the storage area by avoiding the formation of subductions and layers of stagnant water in the storage area. This technical solution was shown in stage II. Furthermore there were provided two sections in which the crushed rock filling was mixed with 30% bentonite and 20% non-expandable clay, for the additional retention of radionuclides escaped from the storage galleries. These sections will be located adjacent to storage galleries and they represent an improvement of the shutdown system.

In order to determine the DNDR Baita Bihor closure solution, there was performed a characterization of the physical parameters of bentonite used as buffer material in waste storage, through experimental measurements conducted by partner P1, IFIN HH. In order to analyze the time evolution of the concentrations of radionuclides from the repository, there were made several runs of the AMBER 5.7.1 code on the mathematical model established in the Preliminary Safety Report. The parameter values, characteristic to bentonite and which were determined experimentally, have been modified. The runnings indicated four cases of evaluation in which radioactive isotopes Co-60, Cs-137 and I-241 were followed, as they represent about 90% of the inventory.

The concentrations of above mentioned isotopes were analyzed, as they are relevant to repository development itself ("*near field*") being in direct contact with the waste and buffer material (bentonite). The results' analysis showed that it manifests an improvement in radionuclides retention.

The overall conclusion of the calculations is that bentonite characterized in experimental measurements has a positive role in the overall behavior of the deposit, in post-closure period, exposure doses calculated for individuals of critical groups being well below the permissible limit.

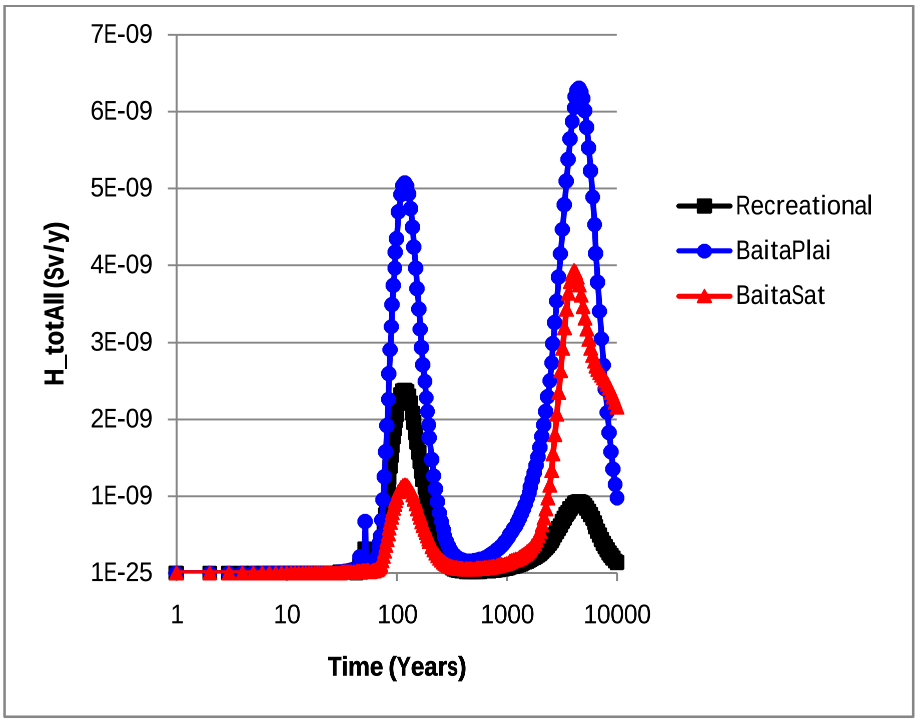


Figura 4.1-4

Annual individual effective doses for the three critical groups considered, added up after all exposure routes and all radionuclides

2. Elaborating the final version of the conceptual technology for DNDR closure. Setting up the parameters necessary for post-closure monitoring.

Given the fact that within this project, the institutions involved have actively cooperated in establishing the main elements and largely the details of the Closure Plan, based on the experimental results, at this stage there was developed the content of the "Closure Plan for the National Repository for Low and Intermediate Radioactive Waste, Baita, Bihor County(DNDR)" and its submission to CNCAN for approval.

For possible evolution modes of the post-closure stage, the repository must be designed for the effective dose limit for members of the population of 1 mSv/year, with an effective dose constraint of 0.3 mSv/year, taking into account all possible ways of exposure to radiation. The safety evaluation studies should take into account exposures resulting from the occurrence of events with extremely low probability of occurrence.

- Effective dose limit used for comparison with safety criteria during post-closure phase shall be assessed by reference to the critical group. - Long-term security of repositories shall be achieved through a favorable combination of the site characteristics, engineering characteristics of the deposit concept, form and content of waste, operating procedures and institutional controls. – A repository siting shall be monitored during the post-closure period as long as monitorization is a safety indicator, as shown in the safety analysis. - Effective and safe isolation of waste depends on the performances of the entire storage system. The contributions of different components of the system to the repository safety are variable and depend on the storage concept, site characteristics and closure period. - Waste acceptance requirements and engineering barriers model shall be determined for each site and storage concept and shall be set based on site-specific safety assessment.

In accordance with the field practice, the stages associated to the life cycle of a deposit are the following:

- Pre-operational phase, which includes the following activities: site studying, design, siting and repository construction; - Operation phase, which includes the following activities: operation and closure of the repository; - Post-closure phase, which includes the following activities: active institutional control and passive control of the repository.

Regarding the confirmation of the waste immobilization matrix, *compression tests* were carried out for the following systems: cement – volcanic tuff – water (1: 0.1: 0.5); -ciment - bentonite - water (1: 0.1: 0.5); cement paste (as reference system).

Samples were kept in laboratory conditions, as well as in real storage conditions, in the most unfavorable areas in terms of moisture, yielding relevant results. In order to implement a system with enhanced stability and efficiency, a number of fillers were considered to prove/disprove the opportunity to use them as buffer filler: alkaline concrete (BA) with 30% cement, 15% lime, 25% clay, 30% water; bentonite concrete (BB) with 30% cement, 10% bentonite, 30% clay, 30% water; bentonite mud (NB) with 8.25% cement, 8.25% bentonite, 16.5% clay, 66% water, 1% calcined soda; sand + bentonite (nb) in equal proportions; sand + bentonite + clay (nba): 50% sand, 30% bentonite, 20% clay;

For STDR, BA and BB samples, compression tests were carried out, for STDR, BA, BB and NB permeability tests were carried out, while BA, BB and NB samples were tested for leaching. It was found that BA and BB samples show increased resistance to compression in simulated conditions, which can be explained by the fact that the clay, in the presence of moisture, acts to the saturation of the matrix and water absorption through the free pores, leading to a stable matrix in short time. This, of course, contributes to increasing resistance for a longer period and reducing cracks. At the same time, the STDR sample demonstrated reliability in real storage conditions. All values obtained are within the limits provided for storage without deterioration, considering that resistance to compression for conditioning materials to achieve engineering barriers have to be greater than 5 MPa.

Corrosion buffer simulated environments packages

In order to study the corrosion in the time of waste packages in contact with buffer materials, tests were performed using miniature metal drums (dimensions: 72 mm diameter x 110 mm height), similar to the waste package; They are filled with waste conditioning material used in the present (fig. 4.2-1). The test drums were embedded up to 3/4 of the height of the drum in buffer filling materials mentioned above (STDR, BA, BB and NB). Samples were placed in the experimental gallery at DNDR, and are to be further reviewed every 6 months. After the first 6 months, samples consisting of test metal barrels, embedded in NB, were completely destroyed. Bentonite mud crashed and detached from the metal drum. The barrel was etched all over the surface which was in contact with bentonite mud. The other samples did not change visibly (fig. 4.2-2 ÷ 4.2.4).

Figure4.2-1

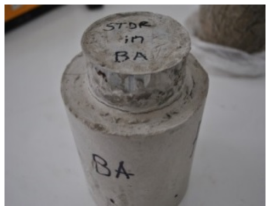


Figure 4.2-2

Figure 4.2-3

Figure 4.2-4

Permeability tests on filling material

For determining the water permeability under pressure through concrete samples, one sample was molded in the form of a cube with sides of 100 mm in the STDR recipe, BA (alkaline concrete) and BB (concrete bentonite).

BA and STDR samples were tested for permeability after 36 days from the molding, during which they were stored in a thermostatic bath, in water at 200^0 C. Testing was carried out at a pressure of 30 bar for 545 hours. The passage of water through the sample stopped completely after approx. 300 hours. Only a few drops of water passsed through the STDR sample and therefore it was not possible to calculate the permeability coefficient. Through the BA sample passed 20 mL of water, the permeability coefficient being 3.4 x 10-11 cm / s. The BB sample was tested to determine the permeability after 112 days after pouring, all the while being kept in the thermostatic bath, in water at 200^{0}C. Permeation test was carried out with water pressure of 30 bar for 1152 hours. After this time 51 mL of water were harvested. Darcy permeability coefficient of the sample is 2.6 x 10^{-11} cm / s.

Considering the results obtained, it can be concluded that the three mixtures of materials studied, have properties to slow down the possible migration of stored radionuclides, if damage is done to the conditioning matrix.

Leaching Tests on the filling buffer material

For preliminary leaching tests, the samples for analysis were prepared as follows: in metal test barrels was introduced a colored marker. After 28 days since the preparation, the samples were placed in the mixtures set out above: BA, BB and NB (to simulate actual storage conditions). After 7 more days, the samples were totally immersed in water (with the same pH as that of the water collected by the drainage system of the repository). One set of samples was placed in-situ and another set in the laboratory. It was found that the values of pH and conductivity are higher for BA samples due to the presence of quicklime. So far (tests will be continued in the coming months) after aprox.12 months, the tracer migration has not been highlighted, nor in the laboratory samples.

This leads to the conclusion that under saturated conditions, the studied conditioning matrix and filling materials exhibit good retention properties. Increased pH and conductivity are more pronounced in the BA sample due to the presence of lime.

Another aspect addressed in this stage refers to chemical and radiological monitoring of the site, including monitoring of radon emissions in order to evaluate the impact on environment. There

are presented the main elements of the monitoring program; if they are confirmed as complete as it will be considered that it can be applied in the closure, post-closure and active institutional control phase (except repository area measurements).
Given the above mentioned and the fact that the repository is located in an abandoned uranium mine, the Radon measurement in the DNDR repository galleries is important for the protection of the occupationally exposed personnel. In order to protect the staff, the repository was designed and executed with a ventilation system, which aims to keep the concentration of Radon, during the execution of radioactive waste packages repository operations under the limitations imposed by the existing rules (CNCAN Radiological Safety Norm) on the operational radiation protection in mining and preparation of NMR 01 uranium and thorium ore.
The theoretical basis was also established for the evaluation methodology of radionuclides retention in conditioning and repository systems: retention capacity of absorbent material for a particular radionuclide is usually characterized by constant K_d distribution.
The distribution constant is the ratio of the number of ions retained per absorbent material unit and the number of ions remaining in the volume unit if equilibrium is established between the two phases: $Kd = \frac{V}{m} \cdot \frac{C_2}{C_1}$ where: (1)
C1 = ion concentration in solution remaining after the equilibrium/balance; $C_2 = C_0 - C_1$ the concentration absorbed on the solid material; C_0 = ion concentration in the initial solution.
Equation (1) is valid under conditions of fully reversible variations. In reality, it is found that the reversible desorption process is not complete and is very slow. The degree of retention of a radionuclide by an ion exchange material depending on many factors, including: the chemical form of the radionuclide; Mineralogical composition; The physico-chemical properties of the absorbing material; The physico-chemical properties of the carrier solution.
As a result of the processes of sorption and desorption, the radionuclide migration speed is much lower than that of the carrier water. The efficiency of the repository system barriers which includes also the locking system shall be checked through the monitoring system described in Phase II which includes 20 points of sampling from the DNDR supervised area. It is proposed that in the post-closure period of active institutional control to be in operation only 7 key control points of established characterization parameters.

3. The analysis of the evolution of DNDR fastenings in limit conditions. Final scenarios for risk assessment.

The measures outlined in the closure strategy are in accordance with the provisions from the mining field, the only major risk is represented by the migration of radionuclides deposited before the time set for 300 years for the institutional control and unauthorized human intrusion in the repository by damaging the fastenings. The risk analysis and the assessment of the evolution of fastenings was done from two perspectives:
1. A HAZOP study (Hazard and Operatibiliy Study) was performed to close the repository to address all risks and hazards in a systematic manner.
2. Environmental risks associated with repository closure.
1. HAZOP study. The closure operation presents, in the life period of a repository, the most important risk because it is estimated the need for movement of large volumes of soil and stone. These risks can be mitigated by improving the condition of the access road and the development of safe and effective operating procedures for closure.

There have been a number of cases selected to investigate the uncertainty in the parameterization and concept of the performance assessment model, for the analysis of the sensitivity model (used to help assess post-closure safety functions of the various barriers), and to examine additional safety and performance indicators.

The results of these studies have shown that:

- the bentonite filling acts as a physical and chemical barrier on a long-term for the migration of contaminants. - concrete walls and floor drainage system actively provides a limited benefit (less than a factor of two) on long-term safety. Assuming that the concrete remains functional in the active sewage during active institutional control, it has no significant effect on the dose compared to when it is degraded over time. – the geosphere has long-term safety function to mitigate the release of radionuclides in the biosphere. - the effect of leakage rates from upper galleries on dose level was also estimated.

Increasing the drain storage facilities leads to preferential migration of radionuclides down through the unsaturated zone. This increases the travel time of radionuclides, causing decay of radionuclides with relatively short life period as Cs-137.

The consideration of complementary safety and performance indicators, such as intake on flora and fauna, and environmental concentrations show that the calculated impact associated with post-closure scenario of reference is acceptable and usually doses are at least two orders of magnitude below the relevant "comparison" level.

2. Environmental risks

Regarding environmental factors, the pollution and sometimes the irreversible degradation of these as a result of mining activities are strong arguments for the application of standards and correct policies for ecological restoration. Consistently, due to the present impact of uranium mining, is summed a potential impact of radioactive waste disposal. Consequently, within the risk assessment were considered both activities and their cumulative impacts.

The objectives proposed in this phase were:

- conducting an analysis of the evolution in time of environmental quality, that determines the level of degradation or improvement of its quality; - evaluating the environmental impact due to activities carried out during the operation period, to establish a knowledge base necessary to further address the issues of closure; - Identify and classify impacts associated with mine closure of the repository; - Establishing priorities for closure by identifying, analyzing and assessing risks in the studied area - addressing risks from the studied area in terms of natural or human hazards and of a more complex nature, of interaction between them - NATECH (hazards and technological risks caused by natural disasters), - development of a conceptual model of closure, based on previously identified risks and impacts.

An effective strategy to address environmental quality factors and identify local, regional and national priorities is represented by the impact and risk assessment. An integrated method was used for qualitative assessment of environmental impact and risk, which is the new trend of combining both risk assessment procedures - environmental impact. It takes account of environmental issues (impact and risk), of cause - effect relationship and sources generating environmental impacts and their consequences, especially if they are characterized by a high probability event. The impact induced on each valued environmental component is given by the ratio between the units of importance derived of each environmental component and the quality of the environmental component. Each environmental impact calculated according to a particular quality indicator corresponds to an environmental risk, which can be calculated for each environmental impact induced and subsequently as an average of the values obtained either directly, considering the average value of the induced impact on the respective environmental component.

A preliminary analysis based on field data, on natural risk refers to landslides. During mining works the landscape has undergone many transformations that have led to its fragility and to the possibility of geomorphological processes such as: landslides, mudslides, ravination. We used the methodology for assessing the risk of landslides. In assessing the potential for landslides, following the work of covering the area above the access gallery and the mine dump (present both at the edge of the above ground platform and at the edge of the ventilation manifold/gallery 53), were taken into consideration several criteria; criteria were established on the basis of factors which by acting alone or interconnected, can decisively influence the stability of slopes.

In the reference area for the sealing system, located above the entrance portion in the access gallery, can be considered as the probability of landsliding (P) and the corresponding risk coefficient (K) is reduced, the remaining repository adjacent areas being included in the probability of low sliding. The peculiarities of mountain relief and vulnerability given by the mining activities have caused soil erosion on significant surfaces. Directly influenced by the action of water and wind, soil erosion is a form of degradation. Analyzing the soil erosion susceptibility map of the study area was found that the highest amounts of eroded soil are in the mining area and on the sides with steep slopes.

In terms of risk management, the closure should be treated with the same rigor as all other stages of the repository life cycle. In all these stages, the major risks need to be addressed so as to minimize or even eliminate threats to activity as usual for each stage.

It is well known that there is no risk 0, that is why we must pursue a smaller value that is acceptable to the environment and to the population.

The first step in estimating the risk factor of closure consists in major risk classification of the closing and breaking it into smaller subcategories, which allow a detailed picture of the risks of mine closing. It starts from the concept of risk, namely from identifying the typology associated to the closing, in order to reach a decision on the optimal closing model.

The risk factor for the environmental component, calculated preliminary for the fastenings at DNDR Baita Bihor emerged as being located around 600, being framed conservatively in the moderate risk class. Depending on the established technical details of closing it may suffer positive changes. The values obtained show that aspects of repository closing are relatively low, but must be addressed in a responsible manner.

The risks on health and safety of the local population and surrounding areas, requires special attention during closing. The financial risk is relatively low because there are prerequisites for ensuring the necessary funds given the importance of the objective. The risks concerning the final mode of land use are the lowest, reflecting the value of the land and its practically zero use in production, post-closure.

The results obtained in this stage reflect the environmental and radiological safety features specific to the studied perimeter and specific aspects of closing which were taken into account in the elaboration of the DNDR Baita Bihor Closing Plan. The closing is an inevitable stage in the life cycle of a radiological plant and early planning of this stage contributes to its ultimate success. Given that DNDR Baita Bihor is located in an area contaminated with natural radionuclides, such closing is similar to mine closing of this type. Additionally, due to the

presence of artificial radionuclides, coming from institutional radioactive waste with greater mobility, increased insulation measures are required for these radionuclides through the design of appropriate engineering barriers.
This project deals with the possible impact of repository activities on the environment, focusing on mine closing, as part of the life cycle of mining, with the final destination as radioactive waste repository, containing radionuclides of relatively short low and intermediate life waste.
Nuclear safety issues are dealt with in terms of a repository located in a geological cavity, applying DNDR-05. Essential aspects of the proposed process of closing are approached and are described the activities necessary to bring the system to a steady state.
The main conclusion of this stage is that the experimental program confirmed the technical solutions for filling voids between waste packages. By identifying all components of the locking system and highlighting critical components was created the basis for the preparation of DNDR Baita Bihor Closure Plan, using the data obtained in the experimental program according to the plan of this project.
By developing this stage, was set the stage for the next step "Proposing a locking system for DNDR Baita Bihor" in which are to be included the confirmed performances of the other identified components of the locking system, including any CNCAN observations on the content of the closure project.
The innovative results of activities carried out under this phase of the project were disseminated through submission within prestigious international conferences, being published in Proceedings edited in 2014. The paper "The present status of the closure plan of DNDR Baita Bihor" presented in the session 106, no. 14023 at the Waste Management conference 2014 in Phoenix, Arizona, USA, showed the characterization of closure components of the DNDR closure plan.
The paper "Research on the development of DNDR closure plan Baita Bihor, on corrosion monitoring", presented at the European Federation of Corrosion Conference 2014, Pisa, Italy, has highlighted aspects of the corrosion on components of the repository closure system. Also the results of activities developed in this phase were used to compile the first 5 chapters of "The Final Radiological Safety Report for the National Radioactive Waste Repository for Low and Medium Activity, DNDR Baita Bihor", submitted presently to CNCAN for evaluation.

Stage IV of the project

The disposal facility must be closed so as to ensure security functions that were established in the security scenario for post-closure period. The closure plan, including the transition to the operational phase of closing should be well defined and practicable, so that the closure can be done safely in the projected period.

For DNDR Baita, Bihor, were addressed both performance and regulatory criteria, thereby achieving a credible assessment of the disposal system.

The design criteria and evaluation of engineering barriers are the main performance analysis models components and relate to design details for:

- The rate of water infiltration in the storage;
- The degree of compaction of layers of containers with radioactive waste;
- The degree of compaction of buffer materials.

In the Preliminary Safety Report (PSR) 2006 the storage performance was confirmed while presenting a series of recommendations to increase storage system performance which were considered in this stage.

Locking System Components

The closing system components are:

1. The roof made of the upper layers of rock partially degraded by mining activities;
2. Sandwich fillings of the access tunnels and ventilation;
3. Plugs for closing access and ventilation tunnels;
4. Markings to indicate the presence of the repository closed for future generations.

The closing system components, classified into primary and secondary components are used to minimize the potential migration pathways of radionuclides.

The primary components are designed to minimize migration paths, respectively the in and out of water from the galleries. In this category are assigned the following components: waste conditioning matrix, bentonite powder as buffer between the packages with radioactive waste and the storage gallery walls. The sandwich fillings of the access tunnels and ventilation are also considered to be primary components. Secondary components are designed to protect primary components against degradation and damaging. To this category belong the enclosure walls of the storage galleries as well as the rehabilitated roof. The filler is permeable for the water seepage, which will prevent the formation of stagnant water layers. Each of the fill sections will be about 50m and will be provided at the end from the gateway, with a layer of impermeable mix of 3 m, consisting of 50% crushed rock, 30% bentonite and 20% non-swelling clay.

At this stage it is proposed to increase the resistance of the bentonite concrete membrane by reinforcement and incresing the waterproofing by guniting the outer surface of the membrane with Xypex cement additives. The space between the membrane and the sealing layer will be filled with bentonite sludge (sludge) to seal and stabilize the packing of the tronson (see Fig. 1).

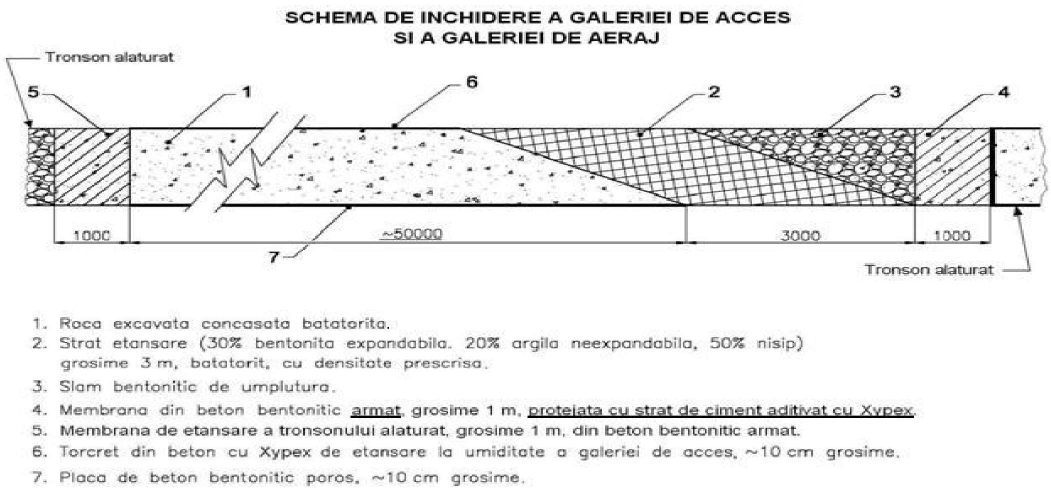


Fig 1. Section type 1 for closing the access tunnels and ventilation

Additionally, the two sections will provide similar type 2 sections of about 50 m, in which will be mixed 50% crushed rock with 50% non-swelling clay. These additional sections will be adjacent to the storage area on the two tunnels, namely, access and ventilation. **Improvements to sections of type 1 shall also apply to type 2 sections.**

Proposing the closing system of the National Radioactive Waste Repository Baita, Bihor

After the pre-closing period of 10 years, is provided the final closure of the DNDR Baita, Bihor, by performing the following activities:

1 - Closing gallery 50, on the stretch of 240 m not used for storage, by settling the filler materials in sections of 50 m, separated by impermeable layers supported by membranes of reinforced bentonite concrete provided with a waterproofing layer of cement with Xypex additives applied by guniting with supportive and sealing role.

2 - Simultaneously, can start the closing of the gallery 53, ventilation, according to the same methodology. Before the start of the closing of this gallery will be build a concrete plug of 10 m at the intersection with gallery 50;

3 - Construction of the plugs with length of 15 m, for sealing the storage and preventing intrusions at the galleries 50 and 53 entry, after completion of the filling of the galleries actitivity;

4 - Fitting the damaged area of the roof of DNDR Baita, Bihor by fitting in terraces and restoring the excavated areas and the access area in gallery 50, on a surface of 3600 m^2 and installing geogrids in the remaining area of 9500 m^2.

After completing the closure of galleries, will be performed the following tasks:

1 - Fitting a Museum in the administrative building, displaying the evolution of the Baita, Bihor DNDR, aiming to popularize the storage system performance in order to increase public confidence in the safety of the storage area;

2 - Continuing the environmental supervision, according to the plan approved by CNCAN, for a period of 100 years, respectively, ensuring active institutional control over this period;

3 - Passive institutional control, for a period of 200 years by maintaining the warning system for the perimeter of institutional control.

4 - Rendering in the economic cycle of unrestricted land use, after the period of total institutional control of 300 years.

To analyze the efficiency of the natural and engineered barriers of the National Repository of Radioactive Waste Baita, Bihor were considered a series of experiments in order to obtain information on their evolution in time, determination / evaluation of migration times of radionuclides stored by the three environments that constitute the engineered barriers (Figure 2): conditioning matrix, filler materials (formes the object of the present stage) and the geological environment as well as the sorption / retention factors thereof on the same barriers. Through this analysis can be assessed the impact over time of the storage system on the environment and can intervene in the sense of optimization of technologies, methods or materials used currently, if the situation requires.

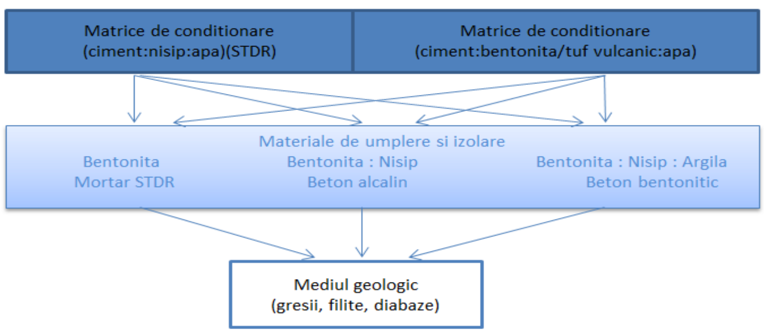


Fig 2. System of engineered barriers

We have analyzed the current storage materials and technologies and their alternatives for the two components on which we could act to improve performance: the confinement matrix and the filler materials (buffer) of the gaps between packages.

Studies were made on:

a) 3 dry filler materials / mixture (bentonite (A1), bentonite mixed with sand (A2) and bentonite mixed with sand and clay (A3));

b) three solid filler materials / mixtures (mortar matrix currently used, an alkaline concrete formula and a formula of bentonite concrete);

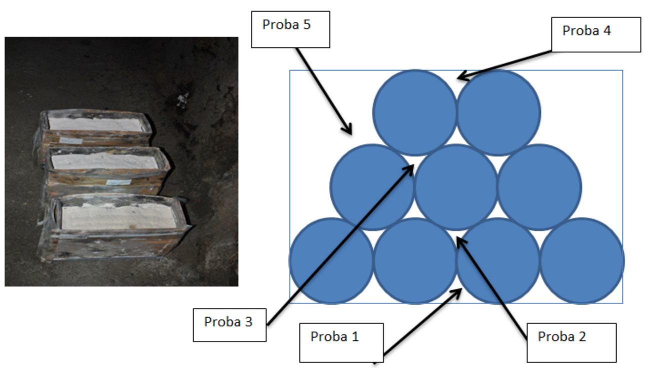
For moisture determination were performed three experimental setups that were kept in-situ in the storage, in real conditions of humidity and temperature.

The experimental assemblies were carried out so as to simulate the storage mode, in the sense that samples have been molded in the plate drums (H = 112 mm and diameter = 75 mm) using the recipe used for embedding radioactive waste (cement mortar). These have been stacked on generators in three assemblies, the gaps being filled with the three above mentioned mixtures: A1, A2 and A3.

Determination of bentonite moisture used at DNDR Baita, Bihor, under actual conditions of use

Four samples of bentonite were taken from DNDR, Baita - Bihor, from the galleries 50, 27/1, 27/2 and out of the storage place in sacks of bentonite.

An amount of 100 g of bentonite of each sample was dried in an oven at 100 ° C, up to constant mass and was determined the moisture content of each sample obtaining the following results: gallery 50 - 21%, 27/1 - 16.4 %, 27/2 - 16.4% and the bentonite in the storage - 11.9% moisture.



Cod proba	M_{proba} initiala [g]	M_{proba} uscata [g]	Umiditate [%]
A1.1	39.81	32.84	16.18
A1.2	23.13	19.08	17.51
A1.3	28.57	23.66	17.19
A1.4	29.87	24.73	17.21
A1.5	48.08	39.66	17.51
A2.1	33.69	28.98	13.98
A2.2	35.83	31.21	12.89
A2.3	42.04	37.95	9.73
A2.4	72.43	62.82	13.27
A2.5	88.65	77.34	12.76
A3.1	48.31	44.12	8.67
A3.2	54.67	49.55	9.37
A3.3	71.85	65.31	9.10
A3.4	65.45	59.43	9.20
A3.5	85.14	76.11	10.6

Fig 3. Experimental slides in order to determine the moisture content in real conditions and results obtained

The slides were stored for 12 months in the experimental gallery DNDR Baita, Bihor. The highest moisture was recorded in the experimental slide A1, in which the filler is bentonite and the lowest in the experimental slide A3 in which the filling material is bentonite + sand + clay.

Adsorption tests for the three types of tested materials A1, A2 and A3 in order to establish the degree of retention for the two radionuclides relevant in terms of radioactive inventory in the storage - Cs-137 and Co-60.

As a conclusion, the conducted research program yielded the following results:

The methodology was applied to determine the ability of sorption (R_s) and desorption (R_d) of the indigenous natural ion exchangers (bentonite and bentonite-based mixtures considered in this project). For the same working conditions the time to balance the radionuclides studied ranged from 48-72 hours. In table 1 were presented the values of distribution constants K_d obtained for the three mixtures/blends A1, A2 and A3.

Table 1. Values of distribution constants K_d obtained for A1, A2 and A3.

Additives / exchangers	**Granule sizes (mm)**	**K_d (ml/g)**	
		^{137}Cs	**^{60}Co**
Bentonite (***A1***)	0,2	1362,2	272,80
Bentonite: sand–1:1 (***A2***)	0,2 - 3	913,22	201,11
Bentonite: sand : clay–3:5:2 (***A3***)	0,2 - 3	1105,2	233,70

An important finding of this research was to highlight the very slow speeds of desorption processes, which means that the sorption processes on the materials studied, having the behavior of natural ion exchangers, are almost irreversible.

From experimental data is observed a very good behavior of the three types of materials analyzed in the sense that the retention is substantially complete after 40 days. Based on the conducted experiments, for the analysis of the evolution in time of concentrations in these compartments, computations with AMBER code have been made on the mathematical model established in RPS 2006 in which were modified the values of the parameters of A1, A2 and A3 proposed fillers. Following the runs were obtained four cases to assess the behavior of radioactive isotopes Co-60, Cs-137, in terms of migration in the storage system.

We analyzed the concentrations of the isotopes mentioned above in the storage system compartments, as they are relevant in the context of this study for the evolution of the deposit itself, being in direct contact with the waste and buffer materials (bentonite powder, bentonite powder : sand, bentonite powder : sand : clay).

The obtained cases were: **Reference case**, in which we kept the input values from the model achieved in the preliminary safety assessment, except for the operational period extended to 2040; **Case A1**, where, in the AMBER file, we replaced the values of the characteristic parameters of the filling material "bentonite powder"; **Case A2**, where, in the AMBER file, we replaced the values of the characteristic parameters of the filling material "bentonite powder:sand"; **Case A3**, where, in the AMBER file, we replaced the values of the characteristic parameters of the filling material "bentonite powder:sand:clay". There were obtained the results shown graphically in Figure 4.

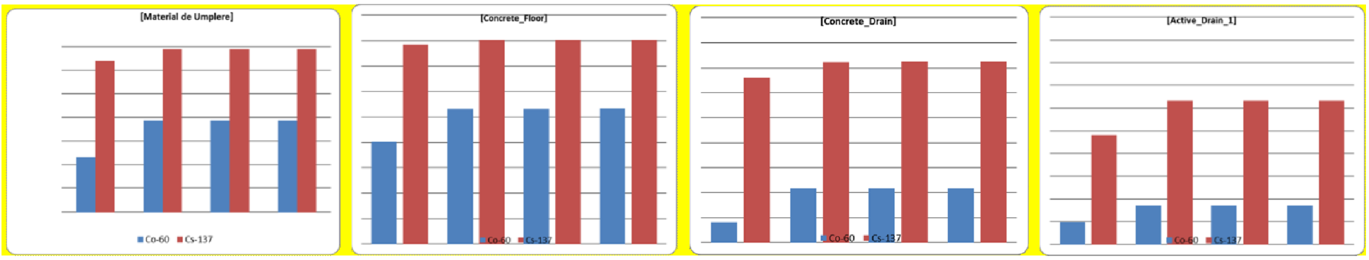


Figure 4. Maximum concentration [Bq/m^3] in the compartment [Bentonite], in the compartment [Concrete_Floor], in the compartment [Concrete_Drain] and in the compartment [Active_Drain_1]

The analysis of the results showed that the fillers proposed have similar behavior in terms of radionuclides retention in the compartments analyzed, leading to their detention in the near field and delaying their migration to the external environment.

There can be observed an increase in the concentration of isotopes monitored in the analyzed compartments compared to the reference case, which proves the retention capacity of the fillers. The explanation is that the values of the distribution coefficients, K_d, for the elements Co-60 and Cs-137 are much higher than those used for the reference case.

The final impact of the contribution of filling materials was observed in the safety indicator represented by the annual total individual effective dose summed up after all exposure routes and all radionuclides, for the three critical groups defined in the vicinity of the DNDR Baita, Bihor repository (Figure 5).

Critical groups are selected based on the assessment of the most likely habits and occupations of the population groups that may be exposed to incorporation of contaminants through the biosphere. Critical groups considered are:

- *Recreational*, which may be exposed to: external radiation from contaminated regolith and streams of water, inhalation of contaminated dust and accidental ingestion of contaminated soil;
- *Baita Plai*, which may be exposed to: external radiation from contaminated soil and water, inhalation of contaminated dust and accidental ingestion of contaminated soil;
- *Baita Village*, which is similar in activities and habits to the group "Plai Baita", except that the group is located farther from the deposit, in Băița Village.

Figure 5 shows the evolution of these annual total effective individual doses summed up after all routes of exposure and all radionuclides for the three cases analyzed A1, A2 and A3.

It can be seen that there are two periods in the post-closure evolution of the deposit, where the effective dose received by a member of the critical groups reaches peak values:

- More than 100 years, and 4582 years respectively, after the time considered zero (1985) for critical groups "Recreational" and "Plai Baita"
- More than 100 years, and 4076 years respectively, at the time considered zero (1985) for critical group "Baita Village".

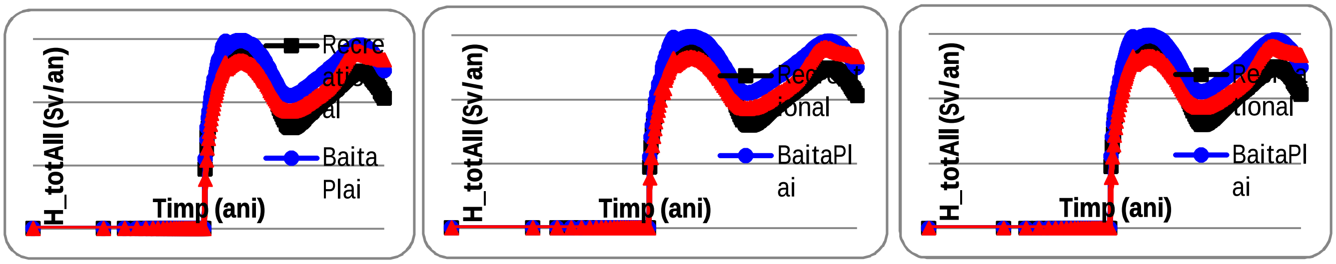


Figure 5. Annual individual effective doses for the three critical groups considered, summed up after all routes of exposure and all radionuclides for Cases A1, A2 and A3

From the study of dose values presented in this paper, it was found a decrease compared to the reference case, in which the filler modelled was hypothetical, its characteristics being parameterized using data from the published literature.

The experimental data obtained during the project yielded some of the values necessary for qualitative analysis of the behavior of engineered barriers.

Thus, there were determined by calculation the years necessary for the radioactive front to reach distances of 10, 100, 500 and 1000 m away from the repository in two versions: at speeds of groundwater flow of 10^{-3} m/day and at speeds of 1 m/day. Table 2 and Figure 6 presents the time required for the radioactive front to reach certain distances from the deposit in the worst case scenario (water front speed is 1 m/day),.

Table 2. The calculation of the time required (years) for the radioactive front to reach certain distances from the deposit, considering the speed of 1 m/day for A1, A2 and A3

Radionuclid	**Viteza de curgere a apei subterane *(u)- 1m/zi***			
	10 m	**100 m**	**500 m**	**1000 m**
Co-60 Matrice conditionare	$7,9.10^{4}$	$7,9.10^{5}$	$3,95.10^{6}$	$7,9.10^{6}$
Co-60 (A1)	$7,5.10^{3}$	$7,5.10^{4}$	$3,75.10^{5}$	$7,5.10^{5}$
Co-60 (A2)	$8,2.10^{3}$	$8,2.10^{4}$	$4,1.10^{5}$	$8,2.10^{5}$
Co-60 (A3)	$3,6.10^{4}$	$3,6.10^{5}$	$1,8.10^{6}$	$3,6.10^{6}$
Co-60 – Roca gazda	$3,4.10^{5}$	$3,4.10^{6}$	$1,7.10^{7}$	$3,4.10^{7}$
Total A1	$\mathbf{4,2.10^{5}}$	$\mathbf{4,2.10^{6}}$	$\mathbf{2,1.10^{7}}$	$\mathbf{4,2.10^{7}}$
Total A2	$\mathbf{4,3.10^{5}}$	$\mathbf{4,3.10^{6}}$	$\mathbf{2,1.10^{7}}$	$\mathbf{4,3.10^{7}}$
Total A3	$\mathbf{4,5.10^{5}}$	$\mathbf{4,5.10^{6}}$	$\mathbf{2,2.10^{7}}$	$\mathbf{4,5.10^{7}}$
Cs-137 Matrice conditionare	2.10^{4}	2.10^{5}	1.10^{6}	2.10^{6}
Cs-137 (A1)	$1,8.10^{5}$	$1,8.10^{6}$	$0,9.10^{7}$	$1,8.10^{7}$
Cs-137 (A2)	$1,7.10^{5}$	$1,7.10^{6}$	$0,85.10^{7}$	$1,7.10^{7}$
Cs-137 (A3)	$1,7.10^{5}$	$1,7.10^{6}$	$0,85.10^{7}$	$1,7.10^{7}$
Cs-137 – Roca gazda	$5,4.10^{5}$	$5,4.10^{6}$	$2,7.10^{7}$	$5,4.10^{7}$
Total A1	$\mathbf{7,4.10^{5}}$	$\mathbf{7,4.10^{6}}$	$\mathbf{3,7.10^{7}}$	$\mathbf{7,4.10^{7}}$
Total A2	$\mathbf{7,3.10^{5}}$	$\mathbf{7,3.10^{6}}$	$\mathbf{3,6.10^{7}}$	$\mathbf{7,3.10^{7}}$
Total A3	$\mathbf{7,3.10^{5}}$	$\mathbf{7,3.10^{6}}$	$\mathbf{3,6.10^{7}}$	$\mathbf{7,3.10^{7}}$

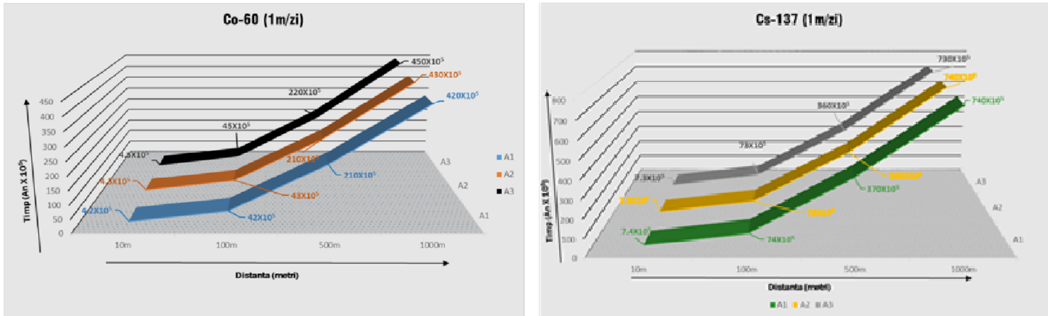


Figure 6 . The necessary time (years) for the radioactive front to reach certain distances from the deposit, considering the speed of 1 m/day for Co-60 and Cs-137

Therefore it can be concluded that the use of bentonite and mixtures based on bentonite and clay and sand as filling material for the gaps between packages is a viable alternative given the results in terms of capacity of absorption and retention, as well as the degree of moisture in the actual storage conditions and under laboratory conditions; It also can be put into practice in relatively simple technical conditions suitable for DNDR Baita, Bihor.

Stage V of the project

The technical solutions applied for the present at DNDR Baita-Bihor within this stage, of project finalization, were confirmed and further operational improvements recommended within the other stages of this project, are to be carried out. The IAEA recommendations were taken into account in this stage, representing the base items of the project.

Closing the National Radioactive Waste Repository (DNDR) Baita-Bihor can be considered the last important operating stage in completion of the repository system.

The reference safety levels apply to a large number of radioactive waste repository facilities, so they must be applied adequately, taking into account the extent of the potential risk to the wastes disposal. A gradual approach specific to a certain facility should be applied, so that the previsions made and the implementation means should be adequate for the risks identified in the licensing documentation.

These recommendations represented the main objectives of this project, all the activities being subordinated to these major objectives.

The safety scenario for a repository facility on its geological placement presents specific features compared to the safety scenarios for other types of nuclear facilities concerning:

- post closure safety from the point of view of operational safety;
- the period of time for developing the repository concept, for building and operation of the facility
- solving the long term uncertainties which do not occur in other nuclear facilities, often related to a specific stage in developing the facility.

Safety scenario may also develop, based on the experience gained both during construction activities and operation of the facility and optimization process implementation. This is the case of the present project of engineering barriers optimization within the project of DNDR Baita-Bihor closure. The safety scenario should identify the key uncertainties which could influence safety and the necessary management activities, especially during the research-development programs.

Post closer calculation showed that long term safety functions of the repository and geosphere against environment and against radionuclides release attenuation in the environment, in particular short life radionuclides (e.g. Co-60) and those highly absorbed (e.g. Am-241), are maintained during the whole institutional control period of 300 years. The calculations show that some of the repository components (in particular the waste matrix) can reduce the dose with 1 to 2 orders of magnitude and the geosphere also reduces dose with maximum 2 to 3 orders of magnitude for the reference post closer scenario.

Bentonite barrier used after 1996 reduces the doses with one order of magnitude during the institutional control period.

Engineering barrier system within the repository is structured in: radioactive waste confinement matrix, the materials (with bentonite) and the technology for backfilling the gaps between the packages containing the waste matrix and the host rock, which is the most important natural barrier for DNDR Baita-Bihor. Consequently, the long term behavior of these barriers were assessed in this project, taking into account both the experiments of IFIN-HH partner and international experience in radioactive waste disposal.

Experimental Program developed within this project is part of the coordinated research programs performed within IAEA projects and demonstrated the efficiency of both waste matrix, as primary barrier and host rock, as natural barrier, based on distribution and leaching coefficients. The results showed that radioactive waste confinement matrices used at DNDR Baita-Bihor provide radionuclides isolation by decreasing the dose by approximately 2 orders of magnitude, and of host rock, by decreasing dose with 3 orders of magnitude, in accordance with Reference Post Closer Scenario and confirming the calculation performed previously.

A durability analysis was performed for the closing system components which completes the long term isolation system of the radionuclides at DNDR Baita-Bihor.

The results acquired /preliminary evaluation emphasize that matrices have parameters similar to grout in the technological flow of conditioning radioactive waste, in the accepted limits for the radioactive waste conditioning matrix. For this reason it can be concluded that long term behaviour will be similar, not influencing the analized repository system. Actually, materials, both those used at present for conditioning radioactive waste and those which are to be used, are types of cement concrete because the binder used in all cases is cement. Cement represents the active part of the system and sand represents the inactive part.

High values resulted from mechanical caracterization of the matrices analised show that:

- Even if an important increase of cement concrete strength takes place în the first 28 days of lifetime, a further increase continues to take place, but its values are significantly lower.

- Water – cement ratio used is optimal; for values of this ratio of 0,38 to 0,4 the decrease is linear, so the decrease is proportional with this ratio increase.

- Analised matrices do not contain or have a reduced contain of rough pores due to the optimum water-cement ratio. This is demonstrated due to the build up of cement solution in water which takes place in the space between the agregate grains.

- Concrete strength is proportional with compression strength of cement, that's why cement dose is of major importance. Strength increase takes place due to cement dose increase.

- Micro fracture phenomenon is very reduced due to high ratio of water-cement. For these values there is a small fracture because the quantity of water lost is small so the contraction phenomenon is reduced (when hardened cement paste shows contractions which generate stress).

- The repository system humidity has a positive contribution to the cement concrete strength by reducing micro fractures

Evaluating the results from the laboratory and from samples disposed in-situ for the backfilling materials the following conclusions are envisaged:

- dry materials humidity is very low, so they are considered optimal to be used as backfilling materials;

- using bentonite and dry mixtures of bentonite, sand and clay as backfilling material for the gaps between packages is a good alternative taking into account the results of sorption and relevant radionuclides retention capacity.

Evolution of DNDR Baita-Bihor

During post-closure period of time these components will undergo inevitable processes of degradation due to local conditions at DNDR Baita-Bihor. Presence of water infiltration and of constant temperature of approximately 13°C make possible microorganism growth which can influence repository system components performances.

The general arrangement of DNDR Baita-Bihor concerning the actual filling degree of the repository tunnels showed that, for the present, in the repository are disposed 8944 drums of waste, placed in 8 of 11 tunnels for disposal. Drums fabricated of carbon steel for waste disposal are of 400 L or of 200 L. Of all disposal tunnels, 5 are already closed, 2 tunnels are in use at present for disposal and 3 tunnels are not yet in use. The repository is to be closed in 2040 by closing all disposal galleries including a part of access gallery transformed in a disposal gallery. Drain system remains functional until the final stage of closure and will be closed together with access tunnel closing plug installation, of 15m. Closure is necessary to prevent evacuation of contaminated water from the disposal galleries to the collecting reservoir and afterwards to the environment. Monitoring of environment radioactivity will continue for a period of approximately 100 years after repository closure.

The evolution described hereinafter is estimated in the basic scenario about post-closure safety evaluation of DNDR Baita-Bihor. Soon after placing the drums into the galleries, drum steel begins to corrode, so, in a few years, drums loose their sealing capacity and water can contact the waste. Cement is fragile so that water flow would initiate micro fissures in time, the fissures will increase and cement degrades chemically as result of cement and meteoric water reaction which is not in chemical balance with it.

In case of galleries filled with backfilling bentonite, radionuclides migrate (by advection, dispersion and diffusion) through bentonite buffer with a specific migration rate of radionuclides sorbed in bentonite. Anyway, various processes will come into to raise the migration rate due to compaction and washing with seepage meteoric water and by building up organic complexing agents due to wood encasement degradation. Seepage meteoric water drives bentonite either to drain system of the repository, or to geosphere. Common draining with galleries without bentonite is assumed to degrade faster, probably due to bentonite plugging.

Post closer radiological calculation showed that long term safety functions of repository and geosphere such as waste isolation against accessible environment and attenuation of radionuclides releasing in environment, especially for short life radionuclides (e.g. C0-60) and those strongly absorbed (Am-241) are maintained all over the institutional control period of time, of 300 years.

<u>Assessment the durability of access and venting tunnels closing system</u>

At DNDR Baita-Bihor arranged in abandoned mine galleries, primary barrier (radioactive waste matrix) represents the main engineering barrier against radionuclides migration. Host rock (crystalline formation, rough and impervious) is a natural, very important barrier for radioactive waste isolation. Access and venting tunnels stand in an area where meteoric water infiltration is important due to disturbances induced by mining activities.

Technical solution selected to ensure separation of areas with different rates of water infiltration consist in sandwich type backfilling. The role of this type of backfilling is to stabilize the disposal area by preventing and delaying water infiltration into the disposal galleries and avoiding stagnant water build up in the repository area.

Tunnels will be closed by backfilling sections consisting mostly of local tapped crushed rock (which will behave identically with host rock). Sorption capacities of the backfilling material experimentally determined, have similar values with those determined in similar cases in other countries.

Separation role of the zones with different humidity will be maintained at least during the institutional control period, of 300 years, taking into account isolation features of waterproof bed being composed of clay and bentonite. Instead, the role of preventing radionuclide migration is insignificant, taking into account preferential gravitational direction, both for disposal galleries and for access and venting tunnels.

<u>Closing and sealing plugs durability assessment</u>

Concrete plugs will be installed at the entrance zones of every access and venting tunnel to discourage intrusions. The life time of these components integrity should remain in the limits of the other concrete components operation life time for DNDR Baita-Bihor. In contrast with concrete matrices of waste packages contact surface water/concrete will be smaller. As a result, these plugs will keep on maintaining the blocking function of radionuclides migration on horizontal direction a longer time after the degradation of concrete matrices of radioactive waste packages. At the same time, the massively of alkaline environment induced by the concrete plug prevents migration of most of radionuclides released from the disposal galleries and which could be driven out of the repository. The main orientation of the radionuclides migration which left the degraded matrix would be vertical. Migration on horizontal orientation can take place through the drain system of the disposal galleries. The drainage blocking will be performed depending of radionuclides migration after repository closure.

Conclusively, the main role of the concrete plugs is stopping the intrusions, the roles of stabilization and preventing radionuclides migration being less important, during the post closure institutional control period of 300 years.

Cover endurance assessment

The hard rock beds over the disposal galleries of DNDR Baita-Bihor represent the repository cover. In order to maintain the integrity of surface area of the disposal zone, a technical solution was selected for terrace arrangement and reconstruction of the excavated zone of the access tunnel on an area of 3600 m^2 and installation of a geogrid on an area of 9500 m^2. By reconstructing this zone, the natural gradient of 20% is provided with vegetative soil in order to reduce the seepage rate by evapotranspiration and gravitationally drain along the gradient. Waterproof is provided by disposing a geogrid on a textile support. This geomembrane will be disposed on a compacted gravel bed of 0,5m thickness as coating support. The terraces will be filled by disposing a crushed rock filling for gradient build-up. The filling will be protected against sliding by a support wall installed at the edge of each terrace.

The main materials used for zone reconstruction are natural, such as crushed rock, gravel, sand, clay, known for endurance features. The geomembrane fabricated of polyethylene of high density represents the synthetic material with very high endurance, of the order of hundreds of years towards a thousand years. Also, the geogrids fabricated of synthetic plastic material with high endurance (polyester fibers), ensure soil stabilization, including vegetation development which provides removal of an important amount of water from the surface by absorption. Taking into account the requirement for natural gradients, during the reconstruction of the affected zone out of mining activities, it is considered that the roof endurance would raise significantly, which results in preserving the zone seepage limitation function towards the galleries of DNDR from Baita-Bihor all over the institutional control period. As a matter of fact, the ability of control and retrieval would remain at least 100 years after repository closer, during the active institutional control, in case of any unpredictable failure of the roof.

Assessment of warning markers in the repository area

Markers are passive systems that have the role to warn about the presence of o human construction, dangerous for public and to provide protection of the future generations against the risk of inadvertent intrusion into the repository. For selecting the arrangement alternative of a dedicated museum in the actual administrative building, occurred the opportunity of permanent control of the disposal area at least 30 years after DNDR closure. Further, a periodic control will be appointed through which the warning systems integrity will be controlled to provide their maintenance. This 70-100 years period will finalize the active institutional control period.

The next period is the passive control period during which the permanently marking systems durability becomes essential. The registration and information maintenance system will have an important role in providing warning systems integrity for the waste disposal at DNDR Baita,Bihor. At the same time, it is possible that more performant warning systems to be developed in the future in accordance with the evolution of technological and information systems.

Conclusively, long term warning and surveillance set of actions provided for DNDR Baita-Bihor are expected to result in maintaining the integrity of the disposal system all over the institutional control period, of 300 years, till the radioactive dose will decrease under acceptable limits.

Conditioning matrices

In previous stages, demonstrative experiments were performed and the performances assessment for engineered barriers currently implemented at DNDR Baita-Bihor was analyzed (Fig. 2-1). Based on a literature study were identified and evaluated optimized matrices for radwaste conditioning, as well as different backfilling materials, in order to achieve a real evaluation on the possibilities of improving their characteristics from the major objective point of view which is to assure the long term radiological safety functions of the disposal facility.

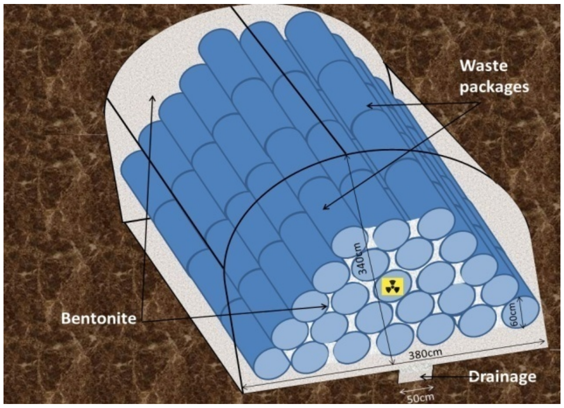


Figure 2-1: Elements of the engineering barriers system during the operational phase

Were taken into consideration new types of conditioning matrices, already analyzed or foreseen to be analysed in the near future:

(a) for immobilization of radioactive concentrates resulted from aqueous radioactive waste treatment by filtration, ultrafiltration and reverse osmosis combined methods;

(b) for conditioning of aluminum radioactive waste (reactive wastes) originated from the decommissioning of VVR-S research reactor from IFIN-HH;

(c) for conditioning of radioactive graphite (i-graphite) from thermal column of VVR-S research reactor.

Nowadays, conditioning of institutional radioactive waste disposed at DNDR Baita-Bihor is performed by cementation being used for more than 30 y a cement mortar matrix validated through different studies and technologies - for 220 L and 420 L licensed waste packages (fig. 2-2). Conditioning is achieved by incorporating radioactive waste in a monolith of a cementitious matrix within 100 L drum which is overpacked in a 220 L drum with cementitious material filling the gap between the inner and outer drums (the process is similar for the 220 L drum that is overpacked in a drum of 420 L).

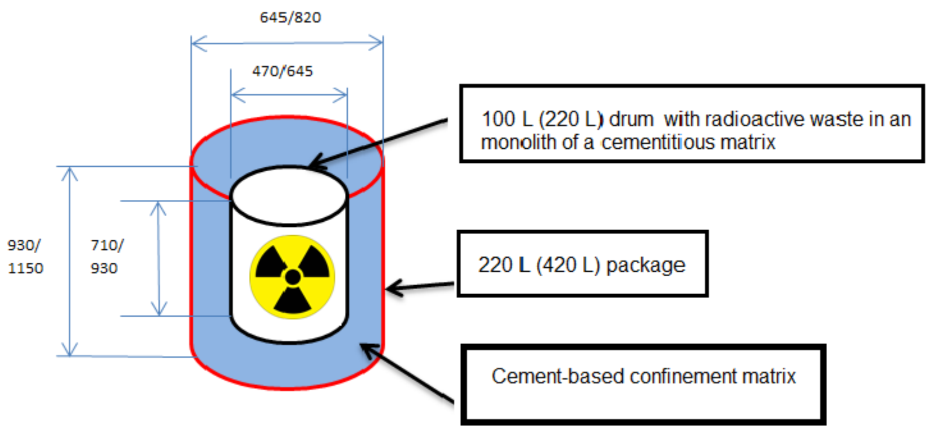


Figure 2-2: Disposal package components

<u>Assessments of radioactive concentrate conditioning matrix</u>

Liquid radioactive waste could be characterized by a complex chemical composition: salts, complexing agents, radioactive waste generated in the production of radiopharmaceuticals, decommissioning of VVR-S research reactor etc. These waste are treated by combined methods, resulting a radioactive concentrate with a complex chemical composition. This concentrate must be embedded in a matrix based on Portland cement, physically, chemically and mechanically stable, that meets the waste acceptance criteria (WAC) established and approved for the National Radioactive Waste Repository Baita-Bihor and also the radiological safety requirements under interim storage and disposal.

Liquid radioactive waste stored at STDR is considered as aqueous solutions as the water constitute more than 99%. Radionuclides and non-radioactive impurities are in most various forms in aqueous solutions, and so the following main forms of impurities in aqueous solutions should be mentioned:

- suspended particles or emulsified oil products (particle sizes from 10^{-7} m up to several millimeters),
- colloidal particles or micelles (particle sizes from 10^{-8} m up to 10^{-7} m),
- dissolved organic substances and/or surfactants (particle sizes from 10^{-9} m up to 10^{-8} m),
- ions (particle sizes from 10^{-10} m up to 10^{-9} m).

The goal of the treatment process is the minimization of the volume of liquid radioactive waste and the engendering of a secondary waste product (concentrate) which can be immobilized, obtaining packages suitable for disposal. The studied matrices were based on cement mortars as reference samples and cement matrices with simulated radioactive concentrate containing stable isotopes. The adequacy for the preparation of packages disposed at DNDR Baita-Bihor has been demonstrated, being in accordance with the requirements established for the conditioning matrices (strengthening, setting time, leachability).

Factor that could affect the closure system stability

Closure system consist of two major components:

- Improvement / coverage works of zones located above the access gallery;
- Plugs and chambers closure systems (sections) inside the repository.

The considered factors are: accidental or deliberate human intrusion, freeze-thaw phenomenon and seismicity.

Anti-intrusion analysis of proposed closure system was based on the following scenarios:

- Execution of a drilling or a exploration gallery in the repository area;
- Accidental or deliberate intrusion of an individual or group of individuals.

Both scenarios are considered to occur strictly after operational and institutional control periods.

Deep under the repository exist molybdenum deposits, but due their position, it is unlikely that any gallery and / or boreholes used for access to molybdenum deposits to pass through the repository. However, it is possible to intercept the contaminants front released from the repository. The effective individual dose rates for operational and institutional control phases were calculated in the Preliminary Safety Analysis of DNDR being demonstrated the efficiency of disposal system.

According to territorial seismic zoning of Romania, Baita-Bihor perimeter is classified as Grade VI of seismic activity. The site seismicity is weakly influenced by Vrancea seismic zone and, also, by a weak local seismic activity.

The maximum *frost depth* is evaluated to be 1.00 m. The repository is placed about 160-180 m below the surface, therefore the occurrence of freeze-thaw phenomena is not likely to occur.

3. Conclusions

Since 1985, when the repository was put into operation, until 1996, the waste drums were simply stacked in the galleries, no backfilling material was used to fill up the empty spaces between the packages.

Basically, the only barriers were considered conditioning matrix and host rock. With the development of national and international regulations, long-term safety analysis have been initiated. These analysis highlighted the requirement to implement additional engineering measures applicable to all disposal systems, as follows:

- more robust packages with additional shielding, thicker or obtained from more resistant materials, were developed;

- recipe cement matrix (for embedding radioactive waste) was optimized; research studies to identify stable matrices to condition "exotic" radioactive waste as activated metallic aluminum and i-graphite were started;

- modernization works to up-grade the entire disposal system were carried-out: replacement of the existing electric, ventilation and drainage systems, waterproofing of the transport gallery by reinforcement and guniting are only some of them.

- a preliminary safety analysis of the repository, after 20 years from the commissioning, was carried out. This analysis proved the disposal system viability and provided a series of recommendations to improve the safety and security. Among these recommendations was the analysis of the backfilling material (operational and post-closure issue), the enclosure of galleries with plugs (closure issue), etc.

During the project stages, studies and experimental work were conducted to optimize the conditioning matrices and, also, to assess various types of fillers. At the same time, the assessment of the barriers system performance in terms of structural stability and security/ safety functions as retention and delay of disposed radionuclides migration for a stated period, beyond which radioactive effects are insignificant.

Based on the obtained results, the following conclusions can be highlighted:

- Engineering barriers systems, developed and implemented in the operational phase, are suited to the purpose, the containment and isolation of radioactive waste;

- Host environment is suitable, the fracturing degree induced by mine exploitation is relatively low, as the very low volume of infiltrating water demonstrated;

- Backfilling materials evaluated can be successfully used in disposal system;

- The closure system and plugs proposed for closure of the repository drive to the conclusion that they assure the long-term security of the whole disposal system.

In conclusion, the objectives of the final stage and, consequently of the project were fully meet, being created the prerequisites for the development of closure strategy and Conceptual Closure Plan for National Repository for Low and Intermediate Radioactive Waste, Baita-Bihor.

The results obtained in the frame of this project were the basis of the Final Safety Report of DNDR Baita-Bihor, submitted to National Commission for Nuclear Activities Control, and, also, will be used in the development of Conceptual Closure Plan that should comply with the national legislation requirements and international recommendations.