

Design and Construction of a Loess-Cement Cushion as an Integral Component of an SL-LILW Repository – 16077

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ABSTRACT

The Bulgarian State Enterprise for Radioactive Waste Management (SERAW) is planning the construction of a near-surface repository for short-lived low and intermediate level radioactive waste, the National Disposal Facility (NDF), adjacent to the Kozloduy Nuclear Power Plant (KNPP). The NDF will be constructed as a reinforced concrete vault-type repository system, where prefabricated cubic waste packages (2 m on a side) will be emplaced in large reinforced concrete disposal cells. Waste emplacement operations will be conducted in three phases over a total of 60 years of operations. After the last waste packages have been disposed, an engineered multilayer cover will be installed over the site to further isolate the waste from the accessible environment.

The Radiana Site where the NDF will be constructed is a sloping area located between the second and sixth loess terraces above the River Danube with elevations ranging from approximately +40 m to elevation +95 m. The unsaturated zone at the location selected for waste disposal ranges from 13 m to 16 m in thickness. After construction, the unsaturated zone will consist of a 5 m thick, engineered loess-cement cushion installed over naturally occurring Pliocene clays and sandy clayey sediments of the Brusarci Formation with a thickness above the top of groundwater ranging from 8 m to 11 m.

The loess-cement cushion is a key component of the "engineered fill" barrier as identified in the Intermediate Safety Assessment Report (ISAR) for the NDF [1]. This barrier consists of engineered fill both below the disposal cells, i.e., the loess-cement cushion, and above the disposal cells, i.e. the final multilayer cover to be installed at closure of the facility. The loess-cement cushion component of this barrier will act to provide a geotechnically stable foundation for the disposal system. In addition, the barrier will raise the base of the disposal cells and increases the unsaturated zone thickness above the top of the groundwater table, as well as to serve as a chemical barrier that will act to sorb radionuclides thereby retarding their migration to the underlying groundwater.

In addition to its assigned barrier functions the loess cement cushion also houses key embedded components required as part of the overall NDF safety concept, including systems necessary for operational and post-closure performance monitoring as well as the support foundation structures required for the mobile roofs, which are designed

to handle and protect the waste during emplacement operations. The post-closure monitoring period, i.e., the period of institutional control, is given by as 300 years.

While similar although less massive cushions have been previously constructed as foundations for various structures at the KNPP, the loess-cement cushion planned for construction at the NDF including the embedded structures will represent a first of its kind construction in terms of both its physical dimensioning as well as its requirements for long-term performance. This paper describes the design of the cushion, its functions and its construction as planned for the NDF as an integral component of the site safety concept.

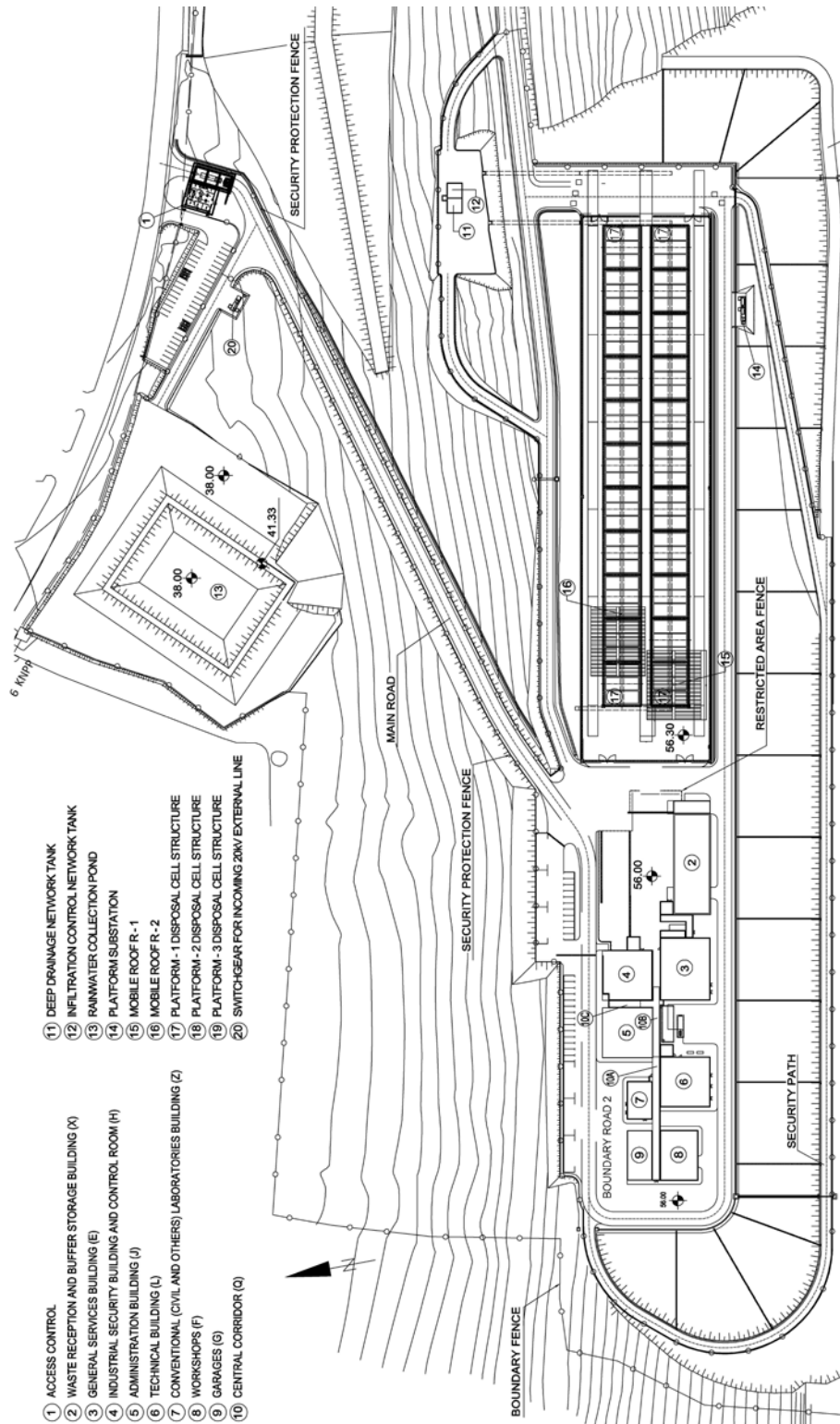
INTRODUCTION

Consistent with negotiated agreements reached with the European Commission as part of Bulgaria's accession to the European Union, Bulgaria shut down four older VVER-440 reactors (Units 1 to 4) located at Kozloduy Nuclear Power Plant (KNPP). Two VVER-1000 reactors (Units 5 and 6) remain in service. The State Enterprise "Radioactive Waste" (SERAW) of Bulgaria will decommission the KNPP's Units 1 to 4 and dispose of the resulting radioactive waste. Short-lived low and intermediate level waste (SL-LILW) from decommissioning activities will be disposed of at the National Disposal Facility (NDF) planned for construction at the Radiana Site. The NDF is located south of the KNPP and will be constructed and operated by SERAW following license approval by the Bulgarian Nuclear Regulatory Agency (BNRA).

SERAW with grant funding from the Kozloduy International Decommissioning Support Fund (KIDSF), administered by the European Bank for Reconstruction and Development (EBRD), is responsible for the development of the NDF. The Technical Design, including the construction organization and execution plan for the NDF was developed by the Consortium of Westinghouse Electric Spain S.A.U, DBE Technology GmbH of Germany and Empresa Nacional de Residuos Radiactivos, S.A. (ENRESA). Technical expertise in design development is provided by the Consortium's local subcontractor EQE Bulgaria AD.

The NDF will be constructed as multi-barrier system designed to contain radionuclides and to prevent their propagation to the accessible environment. The NDF disposal concept follows a vault like emplacement strategy where waste contained in 2 m on a side cubic reinforced concrete waste packages will be emplaced inside reinforced concrete disposal cells with a capacity of 288 waste packages each. Each disposal cell will be constructed with three chambers holding each with a capacity of 96 waste packages. In total, 66 disposal cells will be constructed on three separate approximately equal platforms of 22 disposal cells each.

To ensure adequate structural support each platform will be constructed on an improved foundation constructed as a 5 m thick cushion of compacted loess-cement. The loess-cement cushion will also include embedded structures integral to the safety design of the NDF. The thickness of the loess-cement cushion both ensures adequate space for these features as well as providing a geotechnically stable foundation for the disposal cells. Loess-cement cushions with a thickness of 2 m have been previously used as improved foundations at the KNPP.



- 11 DEEP DRAINAGE NETWORK TANK
- 12 INFILTRATION CONTROL NETWORK TANK
- 13 RAINWATER COLLECTION POND
- 14 PLATFORM SUBSTATION
- 15 MOBILE ROOF R - 1
- 16 MOBILE ROOF R - 2
- 17 PLATFORM - 1 DISPOSAL CELL STRUCTURE
- 18 PLATFORM - 2 DISPOSAL CELL STRUCTURE
- 19 PLATFORM - 3 DISPOSAL CELL STRUCTURE
- 20 SWITCHGEAR FOR INCOMING 20kV/EXTERNAL LINE

- 1 ACCESS CONTROL
- 2 WASTE RECEPTION AND BUFFER STORAGE BUILDING (X)
- 3 GENERAL SERVICES BUILDING (E)
- 4 INDUSTRIAL SECURITY BUILDING AND CONTROL ROOM (H)
- 5 ADMINISTRATION BUILDING (J)
- 6 TECHNICAL BUILDING (L)
- 7 CONVENTIONAL (CIVIL AND OTHERS) LABORATORIES BUILDING (Z)
- 8 WORKSHOPS (F)
- 9 GARAGES (G)
- 10 CENTRAL CORRIDOR (C)

Note: Structures 18 and 19, associated with future construction phases, are not shown on the drawing

Figure 1: Phase 1 General Layout of the NDF The first phase of construction as shown in Figure 1 will include all support buildings and infrastructure required for full operation of the facility as well as the first set of 22 disposal cells. Subsequent construction phases, to be constructed at 20 year intervals (Phase 2 and Phase 3), will expand the storage capacity by an additional 22 disposal cells each. The NDF will be divided into two separate zones: the Disposal Zone and the Buildings Zone.

After the first phase of construction the facility will have full operational functionality and will be capable of handling the receipt, inspection, management and disposal of 6,336 waste packages of conditioned radioactive waste contained in reinforced concrete waste packages. The Buildings Zone will be constructed in its entirety during Phase 1 NDF construction. The Buildings Zone will consist of the auxiliary buildings housing the entire management and support infrastructure needed for the conduct of safe and efficient interim storage and disposal operations at the NDF. All disposal operations will be conducted in the Disposal Zone, which consists of Platforms 1, 2 and 3.

Once operational the NDF will be accessible from two separate roads: the Main Site Access Road and an emergency evacuation road located off the KNPP Administrative road to the north of the site. A third road for construction support will provide access to the site from Road II-11 connecting Hurlitz and Kozloduy at km 91+860.

Phase 1 of the NDF is depicted in Figure 1. Phases 2 and 3 will expand the storage capacity by the addition of Platforms 2 and 3 respectively to the east of the Phase 1 disposal platform.

THE MULTI BARRIER SYSTEM

The NDF is designed with a multi-barrier system of passive elements that do not require monitoring or maintenance after closure. The multi-barrier system is intended to guarantee the safe isolation of radioactive waste from the environment for as long as the radionuclides in the waste remains a hazard. These barriers act in series, so that the failure of one or more barriers or their degradation in time is compensated by the containment capability of the other barriers.

The Bulgarian Regulation for Safe Management of Radioactive Waste, Supplementary Provisions, adopted by the Council of Ministers Decree No. 185 of 23 August 2013, promulgated in SG No. 76 of 30 August 2013 [2], defines a barrier as:

""Barrier" is any physical (engineered or natural) barrier, which prevents propagation of radioactive substances and also of ionizing radiation and protects the radioactive waste from unfavorable internal and external impacts"

Therefore a barrier is defined as any material, structure or feature that for a defined period of time, prevents or substantially reduces the propagation of radioactive substances i.e., the rate of movement of radionuclides from the waste to the environment, or prevents the release of radioactive substances from the waste.

There are three engineered barriers considered as important for safe confinement of radionuclides inside the repository:

- Reinforced concrete waste package
- Reinforced concrete disposal cells containing the waste packages
- Engineered fill above and below the disposal cells, i.e., the multilayer cover and the loess-cement cushion respectively

In addition to the three main barriers, additional sub-barriers are demonstrated as important to safety in the ISAR conducted to support licensing of the NDF [1].

The multi-barrier system as identified in the ISAR [1] is depicted in Figure 2.

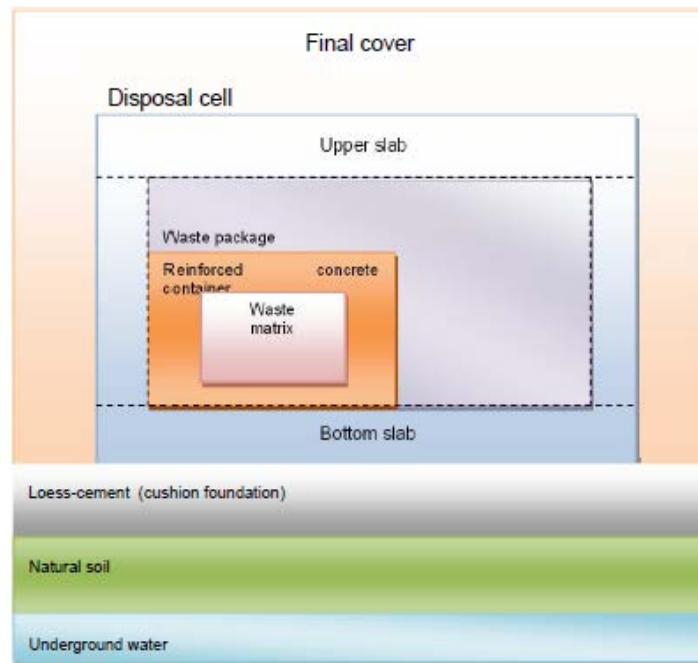


Figure 2: Outline of Engineered and Natural Multi-Barriers System

The loess-cement cushion component of the engineered fill barrier will serve to ensure a geotechnically stable foundation and will raise the thickness of the unsaturated zone beneath the disposal cells above the excavated basement. The cushion will be composed of selected site soils (i.e., collapsible loess found within the upper 10 m of the site) mixed with 5% cement. Together these components will act as a chemical barrier to retard the migration of any radionuclides dissolved in water leaking through the bottom of the disposal cells in accordance with the sorption capacity of its component materials. The cushion as planned for construction in the Disposal Zone is shown in cross-section in Figure 3.

A separate loess-cement cushion will be installed beneath the Waste Reception and Buffer Storage (WRBS) Building in the Buildings Zone. This cushion will be constructed as a homogeneous 5 m thick improved foundation without embedded components to ensure the geotechnical stability of the building during the operational

period. The cushion beneath the WRBS Building does not serve a long-term safety function.

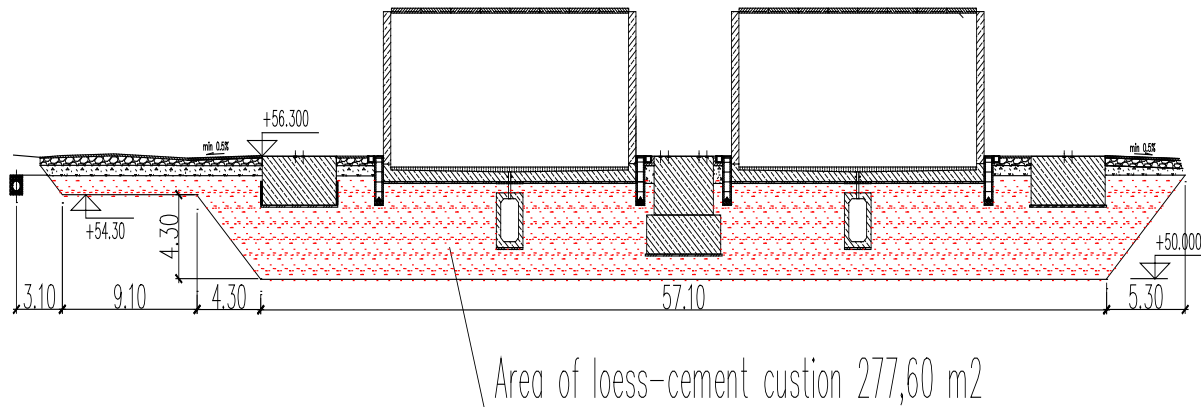


Figure 3: Typical Cross Section of the Loess-Cement Cushion supporting the Disposal Cells, including Embedded Structures

FUNCTIONS OF THE LOESS-CEMENT CUSHION

The as-found ground conditions at the site do not provide adequate structural stability for construction of the disposal system. Various ground improvement strategies were evaluated in combination with alternate locations within the site prior to the selection of the loess-cement cushion. Without consideration of the cushion additional excavation would have been required to reach a suitable base for construction. The loess-cement cushion in effect allows the disposal cells to be installed at a higher level and thereby increases the thickness of the unsaturated zone above the local water table.

The loess-cement cushion also provides a stable base of support for the filled disposal cells. This conclusion is supported by finite element analyses that were performed to demonstrate the geotechnical stability of the cushion over long periods of time. The analysis considered construction of the loess cement cushion over the Pliocene sandy clays as well as the geometry of the excavation and the weight of the filled disposal cells and estimated settlements in the cushion resulting from the weight of the disposal cells. The resulting settlement was found to range from 9 cm to 12 cm [1]. Figure 4 presents the profile used in the analysis. These values are similar to those that have been observed at the KNPP and are within the structural tolerance of the disposal cells, even under seismic loads. The disposal cells are designed to contain radionuclides over the length of the operational period, which including emplacement of the final engineered cover is set as 75 years, as well as the subsequent 300 year period of institutional control.

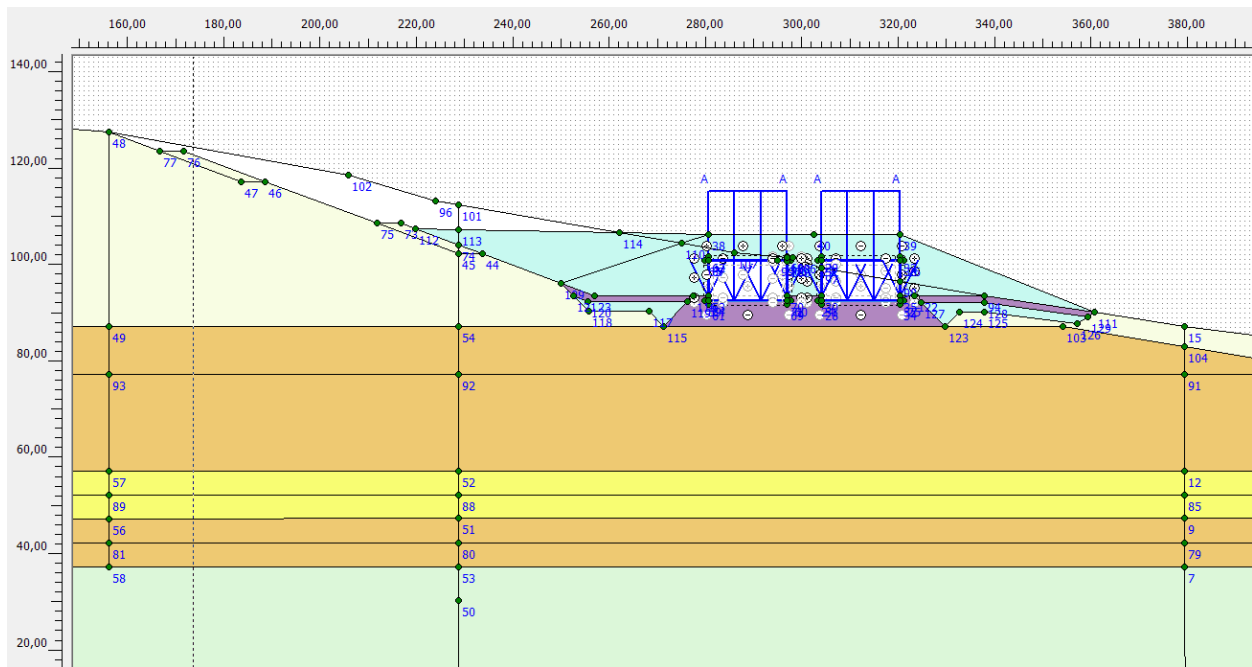


Figure 4: Profile used in Support of Structural Calculations

With respect to long-term safety, the loess-cement cushion delays the release of radionuclides to the accessible environment. By increasing the distance above the water table, the loess-cement cushion in consideration of sorption capabilities of the material, increases the travel time for potential releases from the disposal cells, when compared to the alternative solution with a lower placement of the disposal cells. The cushion provides a thick additional layer of material with homogenous properties that is accounted for in release simulations. This layer therefore significantly enhances the performance of the unsaturated zone. Consequently, the release of radionuclides into the biosphere, as simulated in the long-term safety calculations for the NDF, is significantly retarded and as a factor of radioactive decay reduced as compared to a model without consideration of the cushion. The degree of radionuclides retardation after release attributed to the loess-cement cushion is dependent on the individual radionuclides of concern. Figure 5 illustrates the retardation affect using C-14, which was found to be the main contributor to post closure dose at the NDF [1], where the red curve is the cumulative flux of C-14 released from the vaults into the Loess Cement Cushion while the blue curve shows the release from the cushion into the underlying sand layers. Because the sorption capacity for the loess-cement material is rather high for C-14, a significant retardation for the main mass available for transport can be observed in the order of hundreds or even thousands of years. It is noted that for this particular radionuclide a slightly smaller total mass (i.e., approximately 80 %) is released into the underlying layers as a consequence of decay.

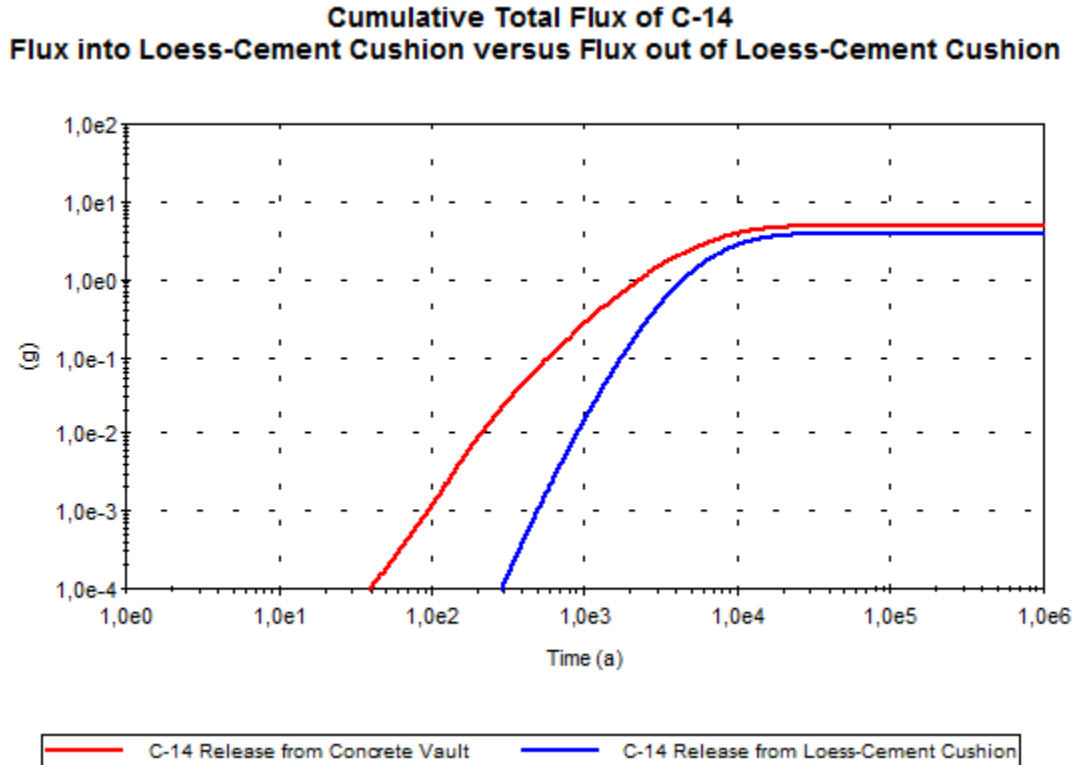


Figure 5: Retardation of C-14 in the Loess-Cement Cushion

THE DISPOSAL ZONE

Each platform in the Disposal Zone is intended to house up to 6,336 reinforced concrete waste packages to be emplaced in two parallel rows of 11 reinforced concrete disposal cells. After filling of each disposal cell, removable reinforced concrete roof panels will be installed over the openings, followed by emplacement of a reinforced concrete closure slab that will seal each disposal cell.

The disposal cells will be constructed on an improved foundation built up from a mixture of compacted loess-cement to form a 5 m thick cushion below the disposal cells, i.e., the loess-cement cushion. A system of monitoring galleries, the Infiltration Control Network (ICN) galleries, will be installed beneath each row of 11 disposal cells as embedded structures inside the loess-cement cushion. Drains in the floor of each disposal cell chamber will be connected to surveillance pots located in the ICN galleries, which will function to monitor for the presence of radionuclides in any water that may infiltrate into the disposal cells as part of the monitoring system. The galleries themselves will be constructed in place from reinforced concrete.

During filling operations, each disposal cell will be protected from the elements by a mobile roof equipped with a 40 metric ton rated bridge crane for emplacing the waste packages. In total two mobile roofs will be installed to support waste emplacement operations in the Disposal Zone. The foundations for the mobile roofs will be made

from reinforced concrete and will also be embedded in the loess-cement cushion forming the improved foundation for each disposal platform, Platforms 1, 2, and 3.

After all disposal cells have been filled and sealed, approximately 60 years after initiation of operations, the NDF will undergo decommissioning and a final engineered multi-layer cover will be emplaced over the Disposal Zone and the site will be closed. After closure, approximately 75 years after initiation of operations at the NDF, a 300-year period of monitoring will commence. Monitoring will consist of periodic entry into the ICN galleries to check for potential radionuclides in infiltration water if observed in the surveillance pots. Should radionuclides be detected an assessment of potential remedial actions will be conducted, including potential waste retrieval operations.

REQUIREMENTS FOR DEVELOPMENT OF THE LOESS-CEMENT CUSHIONS

Loess-cement cushions shall be installed as an improved foundation supporting the disposal cells housed in the three foreseen disposal platforms (Platforms 1, 2, and 3). As stated previously a separate cushion will also be installed beneath the WRBS Building. Although the loess-cement cushion beneath the WRBS Building does not serve a post-closure safety function, similar requirements will be placed on its construction as for those located in the Disposal Zone. Therefore, the cushion beneath the WRBS Building is not considered further as a separate structure in this paper.

General Requirements

The loess-cement cushion will be prepared by mixing previously excavated native loess from the site with sulphate resistant Type 1, Class 42.5N cement. Only the collapsible loess found onsite from approximately 2 m below ground surface (bgs) to approximately 10 m bgs is considered suitable for use in preparing the mixture. The loess should be protected from over-moistening prior to use.

The cement content in the loess-cement cushion will be uniform over the entire thickness. A cement content of 5% by the dry weight of the loess has been determined as suitable. The cushion will be constructed in accordance with the specific Bulgarian requirements described in "Guidance for Foundation of Buildings and Structures in Collapsible (Loess) Soils by Means of Loess-Cement Cushion" [3].

The cushion will be 5.00 m thick by 57.10 m wide by 258.45 m in length. The design width is intended to provide adequate space for the two parallel rows of disposal cells and the mobile roof foundations. The thickness provides adequate space for construction of the ICN galleries as well as accounting for settlement.

The minimum deformation modulus for the emplaced lifts will be $E_0 = 110$ MPa and confirmed. The deformation modulus will be determined for the respective pressure range by plate loading testing (E_{OPLT}) in accordance with Bulgarian requirements in BDS EN 1997-2 [4]. It is noted that based on the actual relationship to the disposal cell and mobile roof foundations the requirements may vary.

Prior to construction, an onsite in-situ test will be conducted to demonstrate the adequacy of the selected construction methods. In addition the onsite test will ensure

that the final parameters for the mixture and its emplacement are appropriately tailored to the selected construction method, i.e., optimal water content (i.e., density-moisture relationship), emplacement strategy and equipment, compaction requirements (i.e., type of roller and number of passes needed to achieve desired compaction), and verification of stress/strain values.

The mixture of soil, cement, and water will require a high degree of homogeneity that should result in a mixture of uniform color with the required moisture and cement content throughout. To minimize risks in preparation of the mixture an appropriately scaled soil-cement mixing plant will be necessary that is equipped with adequate measuring capabilities to proportion the mix in accordance with the final parameter specifications. The actual quantities used in the mixture shall not vary by more than 0.5 percent from the approved quantities.

The mixture should follow the recommendations given in "Laboratory Analyses and Field Monitoring Experiment for Justification of the Design Parameters of the NDF Loess-Cement Cushion" and confirmed by the in-situ field test [5].

Emplacement Requirements for the Loess-Cement Cushion

The loess-cement cushions in the disposal zone will consist of four distinct stages of construction, which will raise the cushion to predefined elevation horizons in order to allow for construction of the ICN gallery system and the mobile roof foundations. The general sequence of events is shown in Figure 6 with the final configuration shown in Figure 7. The loess-cement cushion beneath the WRBS Building will be completed in a single stage without interruption.

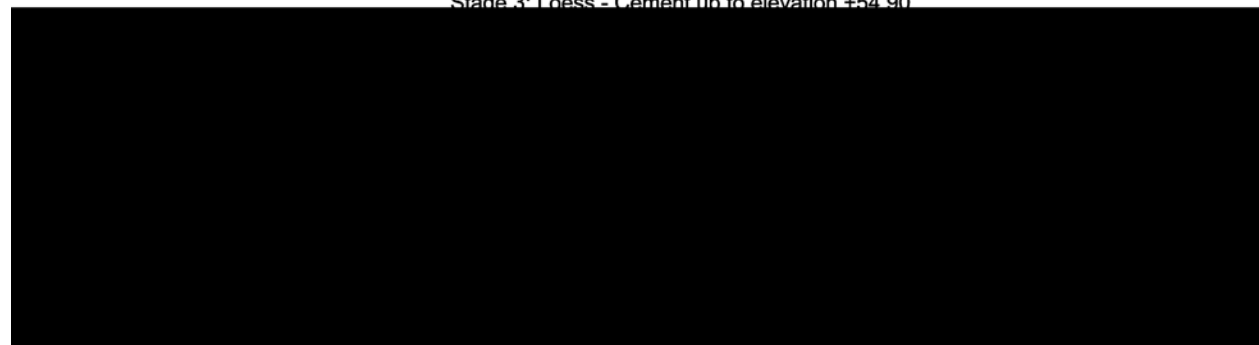
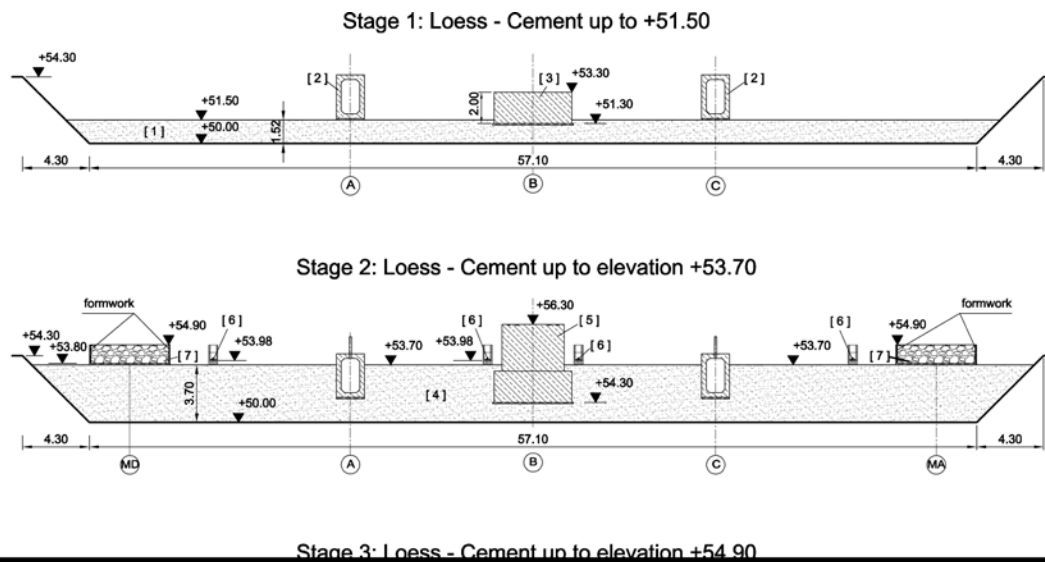
The first stage of loess-cement emplacement in the disposal zone will raise the cushion from its base elevation of +50.00 m to elevation +51.50 m after a thickness of 1.50 m of cushion has been emplaced. The second stage of loess-cement emplacement will raise the cushion to elevation +53.70 m after an additional thickness of 2.20 m is emplaced. The third stage of loess-cement emplacement will raise the cushion to elevation +54.90 m, i.e., to the disposal cell base level, after an additional thickness of 1.20 m of Loess-cement is emplaced. The final layer will be 0.40 m thick and will be emplaced to elevation +55.30 m. The final configuration of the loess-cement cushion is shown separately in Figure 7.

Prior to emplacing lifts the floor and sloped sides of the loess-cement cushion excavation will be at a minimum be properly compacted and formed to an elevation of +50.00 m. Adequate compaction shall be confirmed by Proctor compaction testing consistent with Bulgarian requirements in BDS 8004-84 [6] and BDS 15130 [7]. However, based on results in the recent geological report "Lithostratigraphic Boreholes along the Longitudinal Axis of the NDF Disposal Modules at the Radiana Site for Justification of the Pliocene Sediments Upper Surface Elevation" collapsible loess is possible at the planned excavation base elevation in the northwest corner of Platform 1. If encountered alternative stabilizations measures may be required to ensure adequate ground stability for emplacement of the loess-cement lifts. After compaction and prior to emplacement of the first lifts, the base of the excavation will

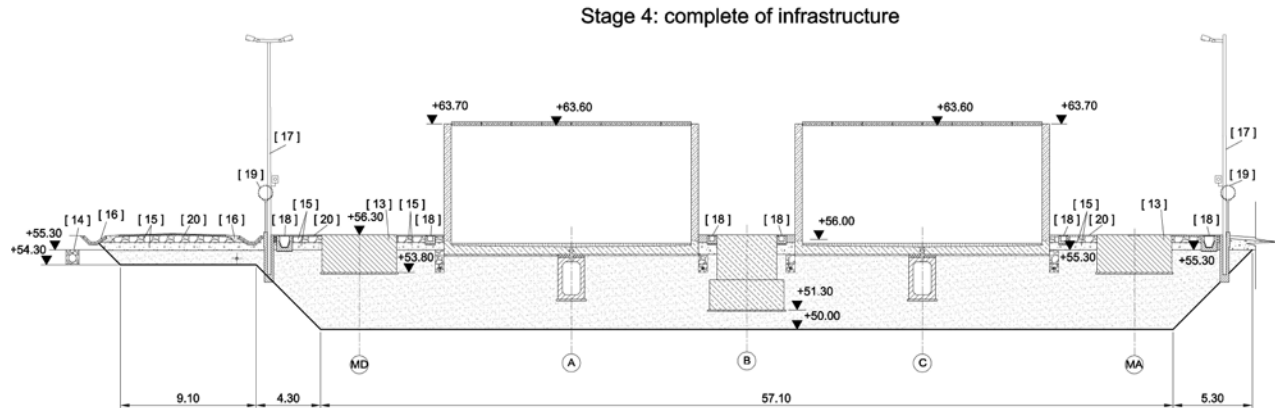
be wetted to approximately the same degree of moisture as determined appropriate for the mixture to ensure proper bonding.

The mixture will be emplaced in lifts of approximately 25 cm thickness and subsequently compacted to approximately 20 cm. The final thickness may vary based on actual field-testing results to be verified by the field test prior to construction. The emplacement and subsequent compaction of each lift must be completed within 4 hours as a maximum, but within a preferred timeframe of 2 hours after preparation of the loess-cement mixture. It will not be possible to place an entire layer in a single pass as a result the lifts will be placed in sections so that the sections are properly overlapped to preclude the formation of preferential vertical pathways or through-going joints.

The loess-cement will only be mixed and emplaced when the minimum air temperature is at least 5 degrees C and rising. During hot weather conditions, additional moisture and/or faster emplacement may be necessary. Prevailing weather conditions will therefore likely constrain loess-cement emplacement operations to the April through October/November timeframe.



Notes: Legend is provided with Figure 7; for orientation, left is south and right is north
 Figure 6: Development Sequence for Construction of the Loess-Cement Cushion



Legend:

- | | |
|--|--|
| [1] Loess-cement cushion up to +51.50 m | [11] Pre-cast roof panels |
| [2] ICN galleries | [12] Removal of crushed stone and stabilization of formworks |
| [3] Mobile roofs center foundation (Axis B) 1 st step to +53.30 m | [13] Complete mobile roof foundations along Axis MD and MA |
| [4] Loess-cement cushion up to +53.70 m | [14] Installation of drainage system |
| [5] Mobile roofs center foundation (Axis B) 2 nd step to +56.30 m | [15] Excavation of road bed |
| [6] Deep drainage system | [16] Installation of concrete drainage interceptor ditch |
| [7] Formwork for exterior mobile roof foundations (Axis MD and MA) to +54.90 m with temporary crushed stone backfill | [17] Installation of site lighting |
| [8] Loess-cement cushion up to +54.90 m | [18] Installation of stormwater channels |
| [9] Disposal cell floor slab | [19] Installation of restricted area fence |
| [10] Disposal cell side walls | [20] Laying of asphalt pavement |

Figure 7: Final Configuration of the Loess-Cement Cushion

Protective Measures for Construction of the Loess-Cement Cushion

Throughout construction of the loess-cement cushion, protective measures will be required to ensure the adequacy of the cushion for its designed purpose is maintained. To this end, limits will be required for areas upon which equipment may operate. The loess-cement surface will need to be protected during the scheduled interruptions. Appropriate methods of protection include placement of polyethylene sheeting covered by a 10 cm thick layer of clean sand over the sheeting as a protection against improper drying of the loess-cement before completion of cement hydration. Reinforced concrete road panels may be temporarily installed in areas defined for the movement of personnel and equipment.

Sample Measurements and Control Parameters

The material requirements and construction technology for the loess-cement cushion and quality testing must follow the appropriate Bulgarian regulations, including:

- Instructions for Making and Control of the Road Bases of Loess Soil Stabilized with Cement [8]
- Guidance for Foundation of Buildings and Structures in Collapsible (Loess) Soils by Means of Loess-Cement Cushion [3]

The following control parameters require monitoring and confirmation, where the exact values will be determined by on site testing conducted prior to construction of the loess-cement cushion:

- Dry density (ρ_d) of the compacted loess-cement mix
- Particle size distribution of the stockpiled loess soil which will be used for construction of the loess-cement
- Homogeneity of the mixture
- Loess-cement cushion design parameters for each layer
- Percentage of cement
- Standard (maximum) dry density (ρ_{ds})
- Optimum water content (W_{opt})
- Unconfined compressive strength
- Deformation modulus E_0 (or E_{OPLT} in accordance with BDS EN 1997-2) [4]

CONSTRUCTION SEQUENCE - LOESS-CEMENT CUSHION AND SUBSURFACE INSTALLATIONS

As previously stated, the first stage of loess-cement emplacement for the platforms will raise the cushion to elevation +51.50 m at which point the construction of the loess-cement cushion will be suspended to allow for the construction of the ICN galleries along the A and C axes as shown in Figure 6. Temporary concrete road panels and protective measures will be implemented to provide a foundation for moving the required equipment (e.g., cranes, concrete mixer trucks, concrete pumps, trucks, etc.) and to protect the loess-cement cushion.

The ICN galleries used to monitor for potential water infiltration beneath the disposal cells are designed with a longitudinal slope of 2 ‰. Two cross-galleries are provided at either end of the monitoring galleries for access. The western cross-gallery is not sloped, while the eastern cross-gallery, which provides drainage for the ICN system, will be sloped at 5 ‰. The design slopes of the galleries will be achieved by careful excavation and/or filling with loess cement to form the base upon which the galleries shall be constructed.

During the first suspension of loess-cement emplacement, the lower section of the central reinforced concrete foundation shared by the two Mobile Roofs will also be constructed to an intermediate elevation of +53.30 m along Axis B in Figure 6.

After these construction steps are complete, the concrete road panels and protective measures will be removed, and the second stage of construction of the loess-cement cushion can be conducted raising the elevation of the cushion from +51.50 m to +53.70 m at which point construction of the loess-cement cushion will again be suspended. Temporary concrete road panels and protective measures will again be implemented as needed. At elevation +53.70 m the second step in constructing the reinforced concrete foundation for the mobile roofs along Axis B will be completed to the final elevation for the foundation block of +56.30 m.

Also at elevation +53.70 m the formwork for the reinforced concrete foundations for Mobile Roofs 1 and 2, along Axes MA and MD, respectively, will be erected. In order to resume construction of the loess-cement cushion with minimal delay the void space inside the formwork will be temporarily filled with crushed stone. Concreting of the two foundations can occur during subsequent construction phases. The temporary concrete road panels and protective measures will be removed and construction of the loess-cement cushion will resume.

The third stage in constructing the loess-cement cushion for will raise the elevation of the cushion from +53.70 to +54.90, at which elevation construction of the Disposal Cells will commence. Once more temporary concrete panels and protective measures will be implemented.

After construction of the disposal cells, construction of the two outer foundation blocks for the two mobile roofs along Axis MA and Axis MD will be resumed. The crushed stone, which was used as a temporary, fill for the foundation void spaces will be removed, steel reinforcement installed, and the concrete poured.

Once all of the work on the Phase 1 Disposal Cells and Mobile Roof foundations has been completed, the temporary concrete road panels and protective measures will be removed and construction work on the loess-cement cushion will resume. The fourth stage in constructing the loess-cement cushion will raise the elevation of the cushion from +54.90 to +55.30, at which point the remaining platform infrastructure items will be installed. (Note that a 1 m thick extension of the loess-cement cushion shall be installed beneath the future southern platform road shown in Figures 6 and 7 on the left side of the drawing.)

SUMMARY AND CONCLUSIONS

The loess-cement cushion to be installed in the Disposal Zone is identified in the ISAR [1] as a component of the engineered fill barrier. This barrier consists of both the loess-cement cushion below the disposal cells and multilayer cover to be installed above the disposal cells at the time of facility closure. The loess-cement cushion below the disposal cells will ensure a controlled thickness of the unsaturated zone below the disposal cells and will serve as a chemical barrier to potential radionuclide transport.

The loess-cement cushion as designed for construction in the Disposal Zone of the NDF will be a first of its kind construction in Bulgaria. Although similar cushions have been used to provide stable foundations for facilities located at the KNPP these have not exceeded 2 m in depth and do not have long-term safety implications. The loess-cement cushion planned for construction at the Radiana Site will have a thickness below the disposal cells of up to 5 m. The extended thickness of the cushions as designed for the NDF will provide for geotechnical stability as well as enhance the long-term safety performance of the repository. Furthermore, the extended thickness of the cushion provides adequate space for construction of the embedded structures important to the overall safety of the facility. These embedded structures include the ICN gallery system, which is designed to provide monitoring access below each disposal cell, and the foundation beams for the mobile roofs, used to protect operational disposal cells from adverse weather conditions and facilitate waste emplacement in the disposal cells and their subsequent closure.

Because of the cushions safety function with respect to geotechnical stability as well as its barrier function, strict requirements will be applied to the construction of the loess-cement cushion, including the identification of several control parameters that will require monitoring throughout construction. The loess-cement mixture will be composited from naturally occurring collapsible loess occurring within the upper 1 m to 10 m bgs of soil onsite, sulphate resistant Type 1, Class 42.5N cement, and water to achieve the optimal water content of the mixture. Prior to begin of construction of the cushion an in-situ field test of the selected technology for mixing, emplacing, and compacting the loess-cement material will be conducted. The goal of the field test is to both demonstrate and confirm the contractor's construction approaches and methods as well as to confirm key parameters determined from laboratory and field experiments for application at the site scale.

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