

Planning Large-Scale Excavation and Construction Activities within an Aerially Constrained Site for Construction of a Repository for Low and Short-Lived Intermediate Level Radioactive Waste at the Bulgarian National Disposal Facility - 15372

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ABSTRACT

The Bulgarian State Enterprise for Radioactive Waste Management (SERAW) is planning the construction of a near-surface repository for low and short-lived intermediate level radioactive waste, the National Disposal Facility (NDF), at the Radiana Site adjacent to the Kozloduy Nuclear Power Plant (KNPP). The Site, a rectangular area approximately 1.2 km east-west by 0.4 north-south, is located on a sloping area between the second and sixth loess terraces above the River Danube with elevations ranging from approximately +40 m to elevation +95 m. Construction of the NDF will be divided into three phases separated by approximately 20 years each. The first phase will see the construction of the primary support facilities, referred to as the Auxiliary Buildings and including the Waste Reception and Buffer Storage (WRBS) Building, and the first set of 22 reinforced concrete disposal cells and supporting infrastructure, including a network of subsurface observation galleries, the Infiltration Network Control (ICN) Galleries. Each disposal cell will be 20.15 m long by 17.05 m wide by 9.45 m in height. The disposal cells will be arranged in two parallel rows. Disposal activities will be conducted using overhead cranes installed inside of track mounted mobile roofs. Each row of disposal cells will be serviced by one mobile roof. The mobile roofs will be supported by massive concrete foundations.

Construction at the site will present several logistical challenges that will need to be overcome to fully realize the NDF. First in order to begin construction of these facilities nearly 1 million m³ of soil will require excavation and handling. Consistent with requirements to minimize potential environmental impacts identified in the site Environmental Safety Assessment (EIA) excavated soil will, to the extent possible, remain onsite. Approximately three quarters of the soil can be accommodated within the site boundaries.

Another challenge results from requirements imposed by the ground conditions. The subgrade at the site, which consists primarily of loess, will require considerable improvement. To this end a 5 m thick loess-cement cushion will be constructed across much of the site. Specifically, the cushion will be required beneath the disposal cells and the WRBS Building.

Construction of the loess-cement cushion in the disposal area will require detailed planning and coordination, particularly as the cushion beneath the disposal cells also contains embedded structures, including the ICN Galleries as well as massive concrete foundation beams required for the two mobile roofs. Construction of these structures will require planned interruptions in the construction of the loess-cement

cushion. Specific cement types and strict quality requirements will be required for completion of the loess-cement cushion as well as for completion of the ICN Galleries.

The construction planning will need to account for the large volumes of soil to be excavated as well as ensuring sufficient material supplies in terms of both quality as well as quantity. Large quantities of materials including both dry cement for mixing with the loess, and wet concrete for pouring of the mobile roof foundations are accounted for by the plan. However, even after completion of these activities additional challenges are addressed by the plan related to the contemporaneous construction management of the auxiliary buildings and the disposal cells.

INTRODUCTION

The Bulgarian State Enterprise Radioactive Waste (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 Bulgarian National Disposal Facility (NDF) for low and short-lived intermediate level radioactive waste (termed Category 2a radioactive waste under Bulgarian regulations¹). 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 is to be constructed at the Radiana Site, which is owned by SERAW, who will also operate the Facility (Figure 1). The site is situated to the south of the Kozloduy Nuclear Power Plant (KNPP), 3.5 km to the south east of the town of Kozloduy, and 4.0 km to the south of the Danube River. To the north, the future repository site borders the area under control of the KNPP, and to the south Road No 11 connecting Harlets and Kozloduy. The site is situated between the second and sixth loess terraces from the River Danube, the elevation between the terraces being approximately 55 m (from elevation +40 m to elevation +95 m). The gradient at the site varies between approximately 3% and 12%. The NDF will be constructed in the sloping area largely associated with the sixth terrace (T6) along the southern half of the site. The site is accessed via the KNPP Administration Road (a Class IV road connecting the town of Kozloduy and the village of Harlets).

The NDF will be constructed in three phases each separated by approximately 20 years. However, upon the completion of the first phase the NDF will already be fully operational and capable of receiving and disposing of 6,336 preconditioned and prepackaged waste packages. Phase 2 and Phase 3 will increase the available disposal capacity of the NDF by an additional 6,336 waste packages each. After the final waste package has been emplaced and the facility decommissioned a final multi-layer engineered barrier will be constructed over the site to serve as both a protective cover and to restore the topography at the Radiana site.

¹ Regulation for Safe Management of Radioactive Waste, adopted by the Council of Ministers Decree No. 198 of 03.08.2004, promulgated in SG No. 72 of 17.08.2004



Figure 1: Radiana Site where the NDF will be constructed in relationship to the KNPP

The NDF is designed to receive, manage and dispose of waste packages arising from the decommissioning of KNPP Units 1 to 4 and operational waste from KNPP Units 5 and 6 consistent with KIDSF purposes. The NDF will receive preconditioned radioactive waste contained in 1.95 m on a side, cubic, reinforced concrete waste packages. The waste packages will be disposed of in the reinforced concrete disposal cells. The 22 disposal cells to be completed as part of Phase 1 will be arranged in two parallel rows of 11 disposal cells each. The external dimensions of the disposal cells are 20.15 m long \times 17.05 m wide and 9.45 high with a minimal wall thickness of 0.5 m. Each disposal cell will have three chambers for waste package emplacement. The disposal cells are designed to contain the waste for a period of at least 300 years after closure. Performance of the disposal cells waste retention capability will be confirmed throughout this period by periodic monitoring of potential infiltrating water collected in a specially designed drainage system installed in the Infiltration Control Network Galleries, which provides monitoring access beneath each line of disposal cells.

The main components of the first phase of the NDF include the 22 disposal cells located on Platform 1; the WRBS Building; Auxiliary Buildings for management and operational support; all of the associated infrastructure including fencing enclosures, drainage, fresh water supply and sewage systems; electrical, heating, ventilation, air conditioning and fire safety systems; as well as two mobile roofs and associated cranes, railways, and support systems needed for waste emplacement; roadways; lighting systems; signage; and security installations.

Considerable effort will be required to prepare the site for construction. The required land will be cleared of vegetation and tree stumps removed, the topsoil layer will be excavated and segregated for later reuse, and a large volume of native soil, including

loess with inter-bedded clays, sands, and gravels, will require excavation to achieve the construction horizon at elevation +50.00 m. To the extent possible all soil excavated in preparation for construction is to be stored onsite as prescribed by the NDF Environmental Impact Assessment.

Due to the nature of the subsurface soils at the site, improvement of the subsurface soil conditions will be required to ensure an adequate foundation for construction. In particular the foundation requirements for the waste handling, storage and disposal facilities, i.e., the Waste Reception and Buffer Storage Building and Disposal Cell Platform 1, will require significant subsurface enhancement to provide suitable foundations. The design solution selected for the subsurface improvement for these facilities is the installation of a 5 m massive loess-cement cushion up to elevation +55.00 upon which the structures can be constructed.

Construction Sequencing

For construction planning purposes the site has been divided into eleven areas and subareas based on construction timing and sequencing needs. The eleven areas are shown in Figure 2. In order to access the main site an initial construction staging area will be established adjacent to the KNPP Administrative Road near the future NDF Main Road. This staging area will remain active throughout the excavation phase of NDF construction. The initial staging area (Area 1) will support development of the stockpiles (Area 2), i.e., the temporary stockpile area (Area 2a) and the main soil stockpile (Area 2b); construction of the main road (Area 3) to a completion level adequate for moving heavy equipment; excavation and later construction of the Rainwater Collection Pond (Area 4); excavation of the Phase 1 construction staging area (Area 5) and the main NDF facilities area, i.e., the slope area (Area 6), the Auxiliary Buildings Area (7a) and the Phase 1 Disposal Cell Platform Area (Area 7b). The primary street access for excavation equipment and dump trucks will be through a newly planned road from the southwest corner of the Radiana Site.

Once the main excavation has been conducted and the final profiles of the slopes have been achieved a new staging area dedicated to Phase 1 construction (Area 5) will be completed to provide adequate support facilities for the remainder of site construction. Subsequently, the Deep Drainage and ICN Tank plateau (Area 8) will be prepared and the NDF Emergency Access Road, which shall also function as an alternate construction road, will be completed to a level adequate for moving heavy equipment.

Management of Excavated Materials

In preparation for the first phase of construction at the Radiana Site, the site will be cleared of existing vegetation. Roots and felled trees will be removed. In addition any existing structures not designated for preservation by SERAW will be removed from the site. For Phase 1 construction an area of approximately 343,300 m² will require clearing. Additionally, the organic rich portion of the top soil layer will be removed as needed for later reuse in revegetating the site. It will not be necessary to remove the top soil from the stockpile areas. In total an estimated 67,824 m³ of top soil will be collected and stored for later reuse. The availability of Area 2a has not yet been determined, however at most only the western portion of the area will be available for temporary use in soil management.

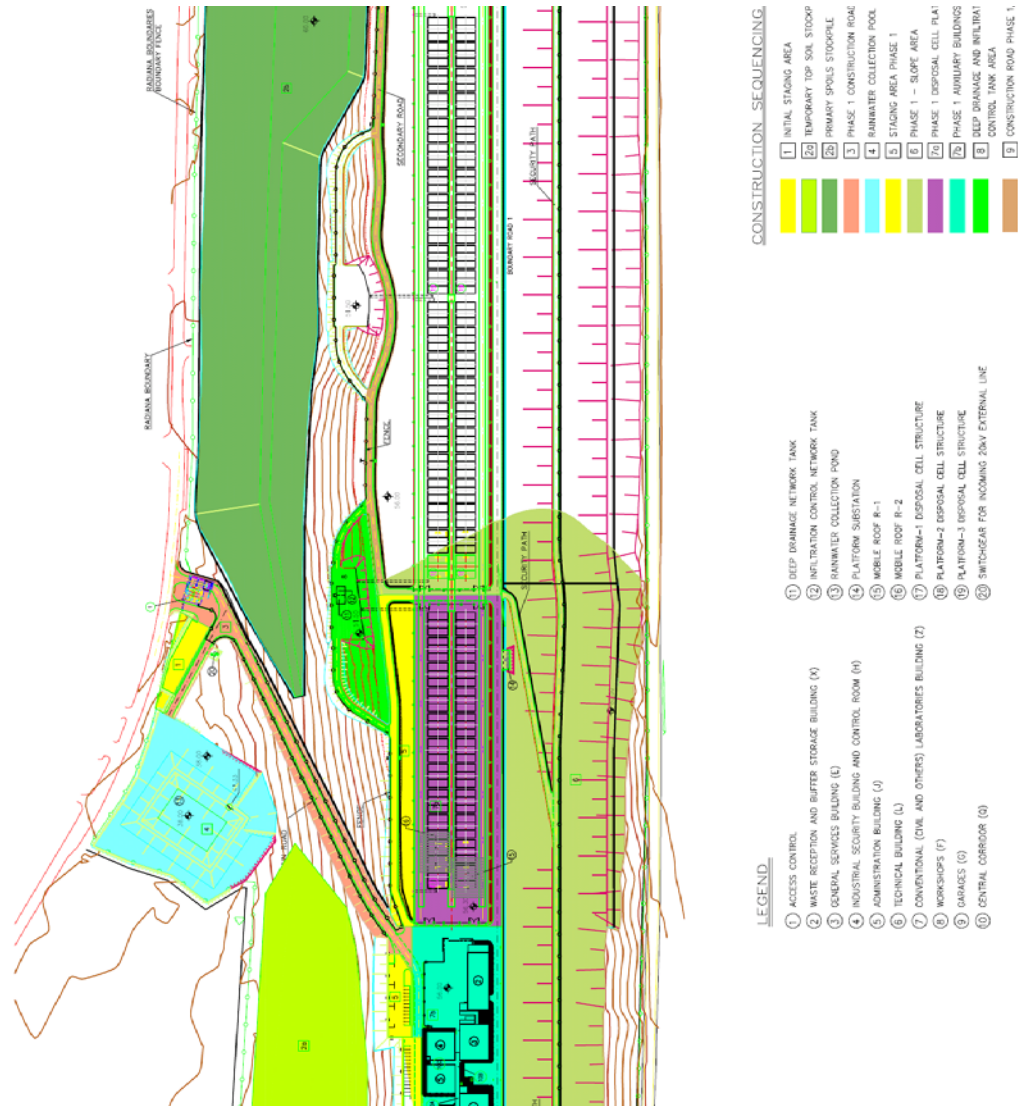


Figure 2: Construction Sequence at the NDF Site

After the site has been cleared and the top soil stored an additional estimated soil volume of 977,963 m³ will require excavation in order to establish the designed slope geometry and platform configuration for the NDF, and related infrastructures including roads, site drainage, the Rainwater Collection Pond, among others.

An estimated volume of 622,839 m³ can be stored onsite in Area 2b. A further estimated soil volume of 89,739 m³ will be excavated in the development of the loess-cement cushion. The total onsite storage capacity is therefore estimated as 712,578 m³. The remaining soil volume, estimated at 265,385 m³, will require offsite transport and disposal.

Special consideration must be given to storage of the loess designated for reuse in construction of the loess-cement cushion. Specifically, only collapsible loess, present on site from approximately 1 m to 10 m below ground surface, is suitable for construction of the cushion. Loess-designated for reuse in the loess-cement cushion may not be compacted and a suitable temporary storage area will be required, possibly the western portion of Area 2a. In general soil in Stockpile 2b will be stored using a layer-wise emplacement of lifts. Each lift will be placed with a thickness of approximately 25 cm and subsequently compacted to an average density of at least

that of the naturally occurring predominantly loess soils. The stockpile therefore will have a shear-strength consistent with that of the natural soils thereby allowing a slope height to width configuration of 3 to 8. The maximum allowable height of the stockpile was determined as 60 m above mean sea level.

Water Management

After completion of the NDF Main Road allowing access to the primary excavation areas (Areas 6, 7a and 7b) work will begin on establishing the Rainwater Collection Pond (Area 4). Provision of adequate temporary drainage is a necessary component for water management during both excavation and subsequent site construction. Therefore the Rainwater Collection Pond will be completed to its final configuration early in the construction sequence in order to manage runoff from the excavation exposed areas of the site. Note that allowance must be made for water drainage and utilities that cross the road prior to its completion, i.e. installation of concrete culverts, drains and utility conduits.

The Rainwater collection pond will service the facility throughout the excavation and construction phase and will continue servicing the facility over its operational life. During excavation a network of temporary berms and ditches will be used to manage excess water. Excess water will be directed either to the pond or to the public stormwater system adjacent to the KNPP Administrative Road. The excavated slopes will be protected from runoff and adverse weather conditions until such time as a final vegetative cover has been installed to protect the slopes from erosion.

General Excavation

Once the Main Road has been established, the general site excavation will begin. The general site excavation for the platform areas and slopes will require removal and handling of an estimated 847,911 m³ of soil in order to establish the designed slope configuration and platform areas for the NDF facilities. To ensure continued slope stability the excavation will be conducted by progressively removing layers of soil starting from the top of the slope and moving across the slope in a step-wise fashion as shown in Figure 3 until the designed geometry has been achieved. This approach ensures that the maximum slope angle will never exceed that of the final design throughout the excavation process. Temporary construction roads for trucks and equipment can be cut into the slope using bulldozers and temporary berms and drainage ditches can be installed as needed.

The excavation will continue to the level of the planned final NDF facilities surface at approximately 56 m above mean sea level. At the NDF surface elevation approximately 2 to 3 m thick layer of alluvial clay is expected to be encountered. This layer separates the excavated surface from the underlying naturally occurring alluvial gravel layer (Layer 3b) at the site. Pending additional excavation, required for installation of the loess-cement cushions, the alluvial clay will function to protect the alluvial gravels from disturbance by heavy equipment travel. As needed, temporary concrete panels can be installed to provide an adequate base for moving equipment as needed.

In order to achieve the desired slope configuration up to nine excavators can be operated onsite. In this case at least 18 large dump trucks with an individual capacity of 20 m³ should provide sufficient capacity to continuously move the excavated

material to either the onsite stockpile or a nearby offsite location. For this purpose it is assumed that approximately every other truck load will travel to a nearby (i.e., within 10 km of the site) offsite location for soil disposal. Assuming a continuous excavation rate of 60 m³ per hour per excavator and two work shifts per day approximately 140 days will be required to complete the earthwork activities, including excavation of site roads, the Rain Water Collection Pond, and as needed for the Phase 1 Control Tank Plateau. Other potential equipment selections and excavation strategies may result in moderately different duration estimates, however as can be seen the excavation works will require a considerable timeframe when planning the effort.

After excavation the slope shall be compacted by 4 to 6 passes using appropriate equipment to ensure a smooth surface; the final slope must be relatively flat to avoid rill and gully erosion. A geotextile membranes or similar shall be provided to ensure protection of the excavated slope from erosion until such time as the final surface is completed.



Figure 3: Representative Cross Section Showing Phase 1 Sequence of Excavation

Loess-Cement Cushions

Once the NDF surface level has been achieved the future disposal cell platform area will be excavated in preparation for installation of the loess-cement cushion. The excavation will be conducted in using the same approach as used in the general excavation. Clay and gravel from the excavation will be transported offsite for disposal.

A staging area for developing the loess-cement mixture will be established in the future Auxiliary Buildings Area (Area 7b). A large capacity portable soil-cement batching plant will be used for mixing. The loess-cement will be made by mixing the excavated native loess with Portland Cement Class 40. Uncompacted, collapsible loess to be used in the mixture will be retrieved from its temporary storage area and staged in Area 7b for batching along with an adequate supply of cement. The adequacy of the native loess will be confirmed by laboratory analysis before use as well the composition of the mixture before emplacement. Additional loess will be obtained from the temporary storage area as needed.

The design width of the loess-cement cushion for Platform 1 is 57.10 m. This width is adequate to accommodate the requirements for the outermost reinforced concrete

foundations for the mobile roofs and to ensure an adequate margin based on a transverse stress distribution angle of 40° beneath the disposal cells.

The loess-cement mixture will be made from sulphate resistant Cement Type 1, Class 42.5N and the naturally occurring collapsible loess that was collected and segregated for later reuse during excavation. The cement content in the loess-cement mixture will be constant from bottom to top at approximately 5 %. The exact cement content is currently being confirmed by laboratory testing. During construction of the loess-cement cushion the minimum general deformation modules (E_0) for the emplaced lifts will be ensured by proctor testing, where $E_0=140$ MPa. The compaction process should be completed within four hours as a maximum, but within a preferred timeframe of two hours after the loess-cement mixture has been prepared. The loess-cement should only be mixed and placed when the ambient air temperature is at least 5 degrees C and rising. Hot weather conditions will require introduction of additional moisture to the materials, faster placement and compaction operations, and additional curing considerations. Therefore seasonal considerations must be taken into account when scheduling these activities.

Assuming a total volume for the Platform 1 cushion of approximately 105,085 m³, average loess to cement mixture of 5%, and 60 work days for emplacement of the loess-cement lifts, a daily cement requirement of about 87.5 m³ or approximately 131 tonnes will be needed.

The design calls for three interruptions in the emplacement of the loess-cement cushion during construction of Platform 1 to allow construction of the main components of the mobile roof foundations and the ICN system as described in the following section.

The cushion beneath the WRBS Building although significantly smaller in area will be constructed in a similar fashion as the Platform 1 cushion. Emplacement of this smaller cushion will be continuous without interruption.

Construction of Platform 1

Construction of the reinforced-concrete mobile roof foundations and the Infiltration Control Network (ICN) Gallery will be closely integrated and coordinated with construction of the loess-cement-cushion.

The loess-cement cushion will be emplaced in a four step process in order to accommodate the installation of subsurface components of the ICN Gallery and the mobile roof foundations. During breaks in emplacement of the loess-cement temporary concrete road panels shall be used to provide a foundation for moving the required equipment (e.g., cranes, concrete mixer trucks, concrete pumps, etc.) and to protect the loess-cement cushion.

The first step in constructing the loess-cement cushion consists of installing lifts of approximately 0.25 m thickness from elevation +50.00 m to elevation +51.50 m. At this elevation construction of the ICN Gallery as well as the lower block of the central reinforced concrete foundation beam shared by both mobile roofs will be carried out.

After completion of these system components, emplacement of the loess-cement will resume and continue until the second hold point at elevation +53.70 m is reached. The second hold point will allow construction of the formworks for the exterior mobile roof foundation beams and completion of the central beam. Crushed stone shall be used to temporarily fill the void space in the exterior beam formwork so that construction of the loess-cement cushion can be resumed with minimal delay. Concreting of these two foundation beams shall occur during a subsequent construction phase. After completion of the concrete construction works emplacement of the loess-cement cushion shall again resume and the loess-cement cushion shall be raised to +54.90 m, at which point construction of the disposal cells shall commence. Once all of the work on the disposal cells and mobile roof foundations has been completed the loess-cement cushion can be raised to its final design elevation of +55.30 m and work related to supporting infrastructure, including the construction of the mobile roofs with installed overhead cranes can be completed.

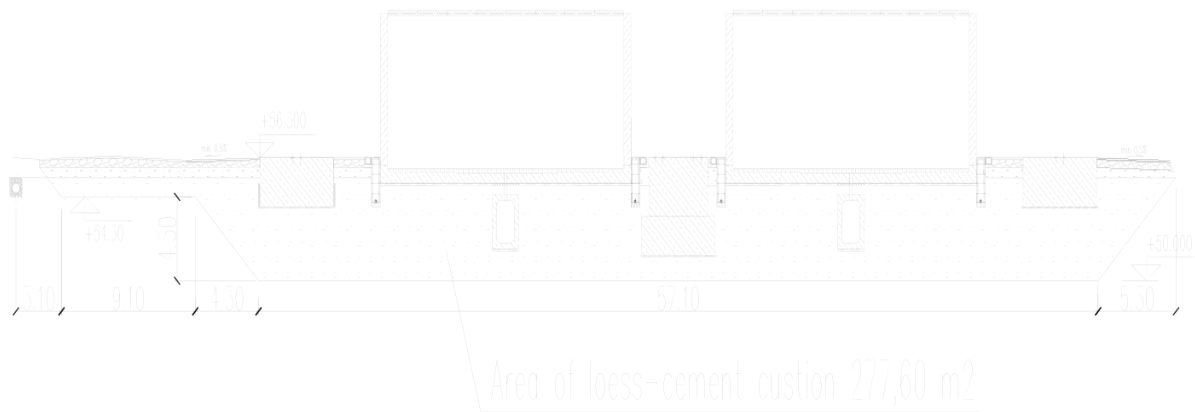


Figure 4: Cross Section showing the Loess-Cement Cushion - Phase 1 Disposal Cell Platform

Peak Concrete Requirement

Concrete mixing facilities located nearby at the KNPP are planned for use in providing the required volumes for the NDF. The largest single-pour concrete structures at the site are the mobile roof foundations. The peak concrete amount is foreseen for the foundation along the central foundation beam shared by both mobile roofs with a cross section of about 5.0 m × 5.0 m and length of 235 m. The total amount of concrete required to complete the entire foundation is 5,875 m³.

A single strip with a width of 5.0 m, height of 2.0 m, and length of 53 m (i.e., the length of one segment between expansion joints) shall be completed as a single-pour. Thus a single-pour amounts to 5 m × 2 m × 53 m = 530 m³. Assuming a volume for a standard mixer truck to be used in pouring the concrete to be 8 m³ then a single-pour of 530 m³ concrete will require 66 truckloads. A feasible strategy for achieving the pour assumes three concrete pumps evenly spaced along the foundation length with two dedicated concrete mixer trucks per pump, however alternative strategies may also be developed.

In addition to the actual pouring another critical point for construction organization shall be in ensuring the uninterrupted production and provision of the required 530 m³ of concrete of adequate quality. Because it shall be necessary to work continuously

over several days to complete a single pour, human resource will require adequate consideration and careful planning. Quality monitoring and sample collection requirements must also be taken into consideration.

The required concrete for the beams as well as the ICN Galleries and the disposal cells is concrete class is C35/45. However, due to the large volume needed for the foundations, the contractor will need to take measures to ensure an adequate supply. Additionally, the contractor will have to take special measure to address exothermic reactions as a result of curing from the large volumes involved.

The unit weight of the concrete used in the disposal cells shall be 25 kN/m³ which will require aggregates with higher density; normally from igneous rocks such as granite, granodiorite, basalt, gabbro, or similar.

Finally it is noted that concrete cannot be mixed and poured when temperatures are below 5°C. Concreting exposed to temperatures lower than 5°C faces serious risks from freezing that can result in damage and failure of the structure and a decrease in the bearing capacity of the concrete. Therefore special consideration must be given to concreting in the autumn and winter months.

Balance of the Facility

The balance of facilities, i.e., the remaining NDF facilities, is comprised of the WRBS Building, the Auxiliary Buildings and the security installations, including the Access Control Building and Vehicle Gate located at the main site entrance. The Auxiliary Buildings, including the WRBS Building are intentionally separated from the Disposal Zone in order to reduce the potential occupational dose rate. NDF operations are technically and administratively controlled and directed from the Auxiliary Buildings.

The Auxiliary Buildings include general support services for radiological monitoring, industrial security capabilities, operational control facilities, administrative offices, as well as both radiological and conventional laboratories, workshops, garages and heating, ventilation and air conditioning requirements.

The primary construction challenges at the site from a logistical stand point will have already been completed with the completion of the Phase 1 Disposal Cell Platform. Therefore construction of these facilities and the remaining infrastructure support features can be integrated into the schedule to take advantage of work crew and equipment availability. Ideally, work will begin at an as-early-as-possible stage to maximize advantages presented by work force availability and minimize the need for separate remobilization of work crews and equipment. However, because the balance of facilities does not present any significant construction challenges by comparison, the work can be organized in a more flexible manner. In order to minimize schedule risk within this area multiple construction sites should be considered. At a minimum, separate efforts should be considered related to construction of the WRBS Building and the remaining buildings.

The WRBS Building is intended to temporarily store up to a maximum of 120 waste packages and therefore shall also be constructed as previously indicated on a loess-cement cushion to ensure its structural integrity. Due to the presence and waste package handling operation to be conducted in the building the building must meet radiological safety requirements over the entire period of its operational life.

Therefore the exterior walls as well as the interior shield walls provided for the building shall be constructed in a fashion similar to the disposal cells. Walls with radiological safety functions shall be constructed as 0.50 m thick reinforced concrete structures to provide radiation protection to the operational workers, the public and the environment. The building will be equipped similarly as the mobile roofs with an overhead crane to move waste packages within the building.



Figure 5: Cross Section Showing the Loess-Cement Cushion - WRBS Building

The remainder of the auxiliary buildings are intended to provide all support functions needed for the NDF to function as an independent facility. These building will generally be completed applying conventional construction techniques.

SUMMARY AND CONCLUSION

Construction of the NDF at the Radiana Site located on the southern side of the Kozloduy Administrative Road south of the Kozloduy NPP will present significant logistical challenges in preparing the site for construction and in ensuring adequate material supplies. Because of the nature of the site location on a slope rain water management will be a crucial element in construction and subsequent operation of the site. As a preparatory step to construction the Rain Water Collection Pond should be completed at an early stage to serve in the construction stormwater management system.

After completion of the pond the first major challenge will be to conduct the required earthwork activities, which will entail excavation of nearly one million cubic meters of soil and formation of the onsite stockpile, intended to contain approximately two-thirds of the material. The remainder of the soil will either be reused onsite or transported to a nearby offsite location for storage. To complete the excavation, assuming nine excavators and at least 18 dump trucks working in two shifts, approximately 140 days of continuous work will be required. The actual number of days may vary depending upon the equipment and strategy chosen by the contractor. However, it is evident that in planning the site works the excavation duration should not be underestimated.

Another critical schedule element will be in the construction of the loess cement cushion and in ensuring an adequate supply of dry cement for the mixture. Additionally considerable, not to be underestimated, effort will be required in

coordinating the construction activities particularly in the disposal area where the ICN Galleries and mobile roof foundation beams will be constructed as embedded structures within the cushion. The schedule will also have to take into account curing requirements for the large volumes of concrete involved as well as the installation of the reinforcement steel needed to ensure meet longevity requirements for the ICN Galleries and the disposal cells. Finally, seasonal restriction on mixing and emplacing the loess-cement as well as pouring and curing of the large concrete volumes for the key structures will need to be considered when planning these activities.

The balance of facilities, that is the WRBS Building, Auxiliary Buildings, security installations and infrastructure systems, should be integrated into the schedule to take advantage of work crew and equipment availability. The key facility to consider in the schedule should be the WRBS Building, which due to radiation protection requirements will be constructed in a manner similar to the disposal cells. The remainder of the facilities, which will generally be constructed using conventional construction methods, should then be scheduled to accommodate an as early as possible time table in support of a license to operate.