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Development of the Vrbina LILW Repository Design

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ABSTRACT

Planning activities for a low- and intermediate-level radioactive waste (LILW) repository project began shortly after the start of regular operation of Krško Nuclear Power Plant (NEK) in 1983. Generic Preliminary Design solutions for the LILW repository were prepared in 1987 for two alternatives: shallow-ground disposal and tunnel-type disposal. Design solutions were adopted and sited at the candidate sites identified in Step 3 of the LILW repository site selection process in Slovenia which took place in the 1990–1993 period.

After the interruption of the site selection process, an analysis of all possible disposal concepts was systematically carried out. In addition, NEK underwent changes in the conditioning and packaging of waste, which significantly affected the disposal concept. Considering these facts, revised generic Preliminary Design solutions were developed for disposal into surface disposal cells and near-surface tunnel-type disposal in 1999.

The generic Preliminary Design solutions were technologically updated and expanded with the inclusion of disposal alternatives within the process of siting the LILW repository. For the design solution - disposal into below-ground silos - which was evaluated as the most suitable disposal alternative for the Vrbina site, Conceptual Design documentation and Basic Design documentation were made, followed by optimization of the Basic Design, which was completed in 2011.

Considering the optimized design solutions and thorough field research conducted at the Vrbina site, elaboration of the Design documentation for obtaining a construction permit started in 2014, focusing on the open issues of the structural stability of the disposal silo, especially from the point of view of seismicity and nuclear safety. At the same time, the process of developing, testing and certifying the disposal container was carried out. The adopted design solutions were elaborated in detail in the Detailed Design which was completed at the end of 2021.

1 INTRODUCTION

After a failed attempt at implementing an All-Yugoslav solution to the problem of LILW disposal, which ended in 1985 with the publication of the study titled "Disposal of Radioactive Waste and Irradiated Nuclear Fuel for the Program of Construction of Nuclear Power Plants in the Yugoslav Power System until 2000" [1] which also presented the preliminary design concepts of LILW disposal (shallow-ground disposal with monolith or box-type disposal cells), an assessment of the situation showed that the utilities of Slovenia and Croatia are the only relevant partners for providing LILW disposal services. Consequently, an agreement was reached on March 19, 1985 between the utilities of the two republics and NEK on the preparation of an agreement on the financing and implementation of preliminary works (incl.

design) for the LILW repository. With prior approval of the agreement in February 1987, the Self-governing Interest Community for Electricity and Coal Mining (ISEP), the holder of social interest in the field of LILW disposal, was involved. The agreement between the Utility of Slovenia (EGS), the Utility of Croatia (ZEOH) and NEK was concluded in April 1989. Upon approval of this agreement, ISEP instructed EGS to appoint an organization that will ensure early implementation of all the activities needed for the LILW repository, and thereby smooth operation of NEK. For such purposes, NEK, designated as the authorized investor, had established the Radwaste Disposal Project Office (RW Office NEK) as early as the end of 1986.

2 DEVELOPMENT OF THE VRBINA LILW REPOSITORY DESIGN

2.1 Generic Preliminary Design Solutions

The RW Office NEK was responsible for providing documentation for the implementation of the LILW disposal project. Consequently, Preliminary Design solutions for the LILW repository facility at the generic site were developed in 1987 for LILW shallow-ground disposal (tumulus-type) [2] and for tunnel-type disposal [3].

The planned capacity of repositories was 112,000 200-liter drums (with LILW from NEK and from the planned Prevlaka Nuclear Power Plant) and 3,600 m^3 of institutional waste. Waste is conditioned at the repository site with a capacity of 5,000 drums per year, using concrete disposal containers of 2.35 x 2.35 x 2.45 m, for 18 drums, weighing 30.6 t for shallow-ground disposal, and in containers of 3.14 x 1.74 x 1.27 cm, 8 drums, 16 t, for tunnel- type disposal, respectively.

2.2 Design Solutions for Candidate Sites Identified in the Site Selection Process in the 1990–1993 Period

The first siting process for the LILW repository as an important step in developing a waste disposal system (i.e. waste, facility design, the site) was started in 1990. The siting process was carried out in accordance with the Guidelines for the LILW Repository Site Selection issued in 1990 by the Republic Administration for Nuclear Safety (and revised in 1991) [4]. The Guidelines were used as the rules according to which, under given natural, spatial and social conditions, the most suitable sites for disposal of LILW in Slovenia would be selected. Potential Preliminary Design solutions for shallow-ground disposal and tunnel-type disposal (elaborated in 1987, see Item 2.1) were also defined in the Guidelines. The siting process which was predominantly technically oriented was divided into four steps. In Step 1, the unsuitable areas were excluded by taking into consideration the rough exclusion criteria. In Step 2, the remaining suitable areas were screened to identify the potential sites with respect to the preference criteria. In Step 3, the candidate sites were assessed and selected from among the potential sites. In Step 4, the final step, a detailed site investigation and confirmation of one or two most suitable sites should follow. The siting process, taken over from the RW Office NEK by the Ministry of Energy (ME) in 1991, was interrupted (and later finished) at the end of Step 3 in 1993 due to public opposition.

Step 2 resulted in the selection of 36 potential sites (in the 10 acceptable areas from Step 1) having a total area of about 9 km^2. All the potential sites were qualitatively assessed from the point of view of suitability for the siting of a tunnel-type disposal or shallow-ground disposal facility, or both. Acceptability of the potential site for repository facility siting was discussed in detail in Step 3 of the siting process, considering the natural features, technical

requirements and economic feasibility. The decision-making process was supported by the Preliminary Design solutions for shallow-ground disposal and tunnel-type disposal (see Item 2.1), adopted and placed to the candidate sites [5]. One candidate site for shallow-ground disposal, two sites for tunnel-type disposal, and two sites for both disposal options were identified in Step 3 of the siting process.

2.3 Analysis of Disposal Possibilities and Introduction of New Technologies at NEK

In order to avoid the challenges encountered in the spacing of the project solutions at certain potential sites, and in order to expand the process of developing disposal design solutions, a study under the title "Preparation of Bases for the Realization of the LILW Repository" [6] was prepared in 1995. The study provided an overview of LILW disposal methods from across the world, presented a matrix of possible disposal methods and types of disposal facilities, and included an assessment of disposal solutions considering exclusion and comparison criteria in the field of technical feasibility, economy and safety. The results of the assessment were subject to expert judgment, which led to the decision that the most suitable disposal types were shallow-ground (tumulus-type) disposal, tunnel-type disposal and underground silo disposal. The study was directed by the Agency for Radwaste Management (ARAO) which took over from the ME all the obligations regarding the LILW repository on October 20, 1992 and became fully operational in 1993.

Due to optimization of the storage capacities, NEK performed in the 1994-1995 period a supercompaction campaign of 200-liter drums filled with LILW, and insertion of supercompacted drums (packs) into tube-type containers - TTC (T1, welded lid). In 1998, NEK started operation of an in-drum drying system (IDDS) for drying radioactive liquids and sludges, and a system for drying spent resins, and introduced TTC with a flanged lid (T2). Introduction of TTC as a unique waste package with an internal diameter of 640 mm, and 2,700 mm high, had an important influence on later design solutions.

2.4 Revision of Generic Preliminary Design

Based on the new findings and circumstances, a revision of the Preliminary Design of the near-surface repository was made in 1999 [7]. As an integral part of the project documentation, Design Bases were initially created. Revised Preliminary Design was prepared for the repository at the generic site under saturated geological conditions, which was then assessed as the most probable geological environment for the repository in Slovenia. According to the Preliminary Design, all the packages filled with LILW are delivered to the conditioning plant at the repository site, and placed into concrete disposal containers with dimensions of 2.45 x 2.45 x 3.2 m (adjusted to the TTC height). Containers are disposed of in disposal units (box-type vaults), with a capacity of 192 containers each. When a disposal unit is fully loaded, the gaps between the blocks are backfilled with the mixture of native soil and bentonite clay, and the unit is covered with a reinforced concrete plate. The disposal units have internal dimensions of 20 x 20 x 10 m, a bottom plate 0.6 m thick, and walls 0.4 m thick. The units are half-buried. After closure, the disposal units are topped with a multilayer low-permeability cap which protects the structures from water, and ensures durability of the disposal system. The disposal capacity of 10 disposal units is 13,200 m^3 (all waste from NEK, and Slovenia's institutional waste).

Based on the same starting points for waste and for the site, a new revision of the Preliminary Design for the tunnel-type repository was also prepared in 1999.

2.5 Complementary Preliminary Design of Disposal Part of the Repository

Based on the new findings and the experience gained in the area of LILW repositories and the related issues, and, in particular, with the purpose of providing suitable design solutions under the circumstances of repository site selection, complementary Preliminary Designs of the disposal part of the near-surface and underground repository were elaborated in 2005.

The existing solutions for a surface repository were supplemented and optimized in view of developing a preliminary design on an alluvial plane, using data of the site on the left bank of the Sava River in the immediate vicinity of NEK. The Preliminary Design was developed in two basic alternatives: the first one deals with a disposal structure erected on an elevated rockfilled plateau, and the second one deals with an entrenched repository. The key basic design elements are the following: the disposal cells (vaults) are sufficiently distant from the underground water table oscillation (above or below water table). The waste disposal containers (of 2.45 x 2.45 x 3.2 m) are inserted into disposal cells which have a reinforced concrete structure, a box-type form (vaults), and the inner dimensions of 20 x 20 x 10 m. The cells are built in series of five. The walls of the trench where the disposal cells are entrenched are executed with a slurry wall. During the filling process, the cell series are covered with a temporary roof. The disposal containers are put into disposal cells from above by means of a gantry crane. Each disposal cell is provided with a draining system which enables separate draining of contaminated and non-contaminated drainage as well as defining of a seepage water accurate location. The cover of the repository constructed on the plateau is designed as a multi-layer barrier of materials of different permeabilities which provides suitable impermeability for precipitation water, or as a barrier of high hydro-insulating materials – for the entrenched alternative. [8]

The Preliminary Design of an underground repository for the generic site was developed in several options wherein different combinations of the following items were considered: geological environment - soft rock, hard rock; disposal cell form - disposal tunnels, disposal silos; disposal container size - 3.2 x 1.85 x 1.85 m for disposal into tunnels, 2.45 x 2.45 x 3.2 and 1.85 x 1.85 x 3.2 m for disposal into silos; disposal cell variants - cells with primary lining, cells with primary and secondary lining; and access - access by a horizontal gallery and access by an inclined tunnel. [9]

2.6 Design Solutions within the Scope of the Process of LILW Repository Siting

Considering the requirements of the Ionising Radiation Protection and Nuclear Safety Act (issued on September 21, 2004, Official Gazette of the RS, No. 102/04), i.e. that the LILW repository shall be operable in 2013, and upon the initiative of the Minister of Environment with the purpose of designing, engineering and siting the repository in accordance with this anticipated time schedule on November 30, 2004, the LILW Repository State Location Plan Development Program (Official Gazette of the RS, No. 128/04) was adopted. Following the Program, all the municipalities of Slovenia were invited on December 1, 2004, to participate in the process of the repository site selection. By the application submission deadline, May 4, 2005, eight municipalities had decided to take part. After preliminary verification of suitability, and after coordination with municipalities, twelve proposed locations in five municipalities were assessed from a safety, functional-technical, economic, environmental and social perspective in the Pre-comparative Study prepared by ARAO between May and October 2005. A feasible repository design alternative was identified for each location (considering the Preliminary Design solutions, see Items 2.4 and 2.5). For the potential location of Vrbina in the

municipality of Krško, an alternative of disposal into below-ground box-type disposal cells was defined in the agreement between ARAO and the Municipality of Krško. The best assessed locations were confirmed by the decision adopted by the Government of the Republic of Slovenia on November 17, 2005. Besides the locations of Globoko in the Municipality of Brežice, and Čagoš in the Municipality of Sevnica, a potential location of Vrbina in the Municipality of Krško was selected as well. In January 2006, the Spatial Planning Directorate asked all three municipalities and other spatial planning authorities to provide guidelines for the preparation of a national spatial plan. The call was accompanied by the material for obtaining the guidelines in which indicative possible design solutions for the repository facility at individual sites were indicated. During this period, a field research program was also prepared for all three potential sites. In response to the call for guidelines, the Municipality of Sevnica informed ARAO that it was withdrawing from the procedure in accordance with the decision of the Municipal Council and from any activities related to the selection of a repository site in the municipality. Activities related to the repository design started to flourish intensely in May 2006 with the elaboration of Design Bases as one of the fundamental design engineering starting points. During the preparation of Design Bases, the Municipality of Brežice decided to withdraw the Globoko site from the process and to try to identify an alternative site for participation in the procedure. (Vrbina-Brežice, the alternative site in the municipality of Brežice, was later withdrawn from the process as well.) Consequently, the preparation of Design Bases continued only for the Vrbina site in the municipality of Krško. In addition, the preparation of Expert Bases for the Comparative Study of Alternatives started in July 2006 for the Vrbina site (Krško) only. As part of the preparation of Expert Bases, technical suitability of the possible design solutions for disposal facilities at the Vrbina site was verified. The original disposal design solution from the Pre-comparative Study, i.e. disposal into below-ground box-type disposal vaults - cells (Alternative A) was expanded with the inclusion of Alternative B – disposal into below-ground silos (proposed by ARAO, from a technical and safety perspective - especially in terms of intrusion), as a more appropriate alternative than Alternative A; Alternative C – disposal into underground silos; Alternative D – disposal into tunnels; and Alternative E – disposal into surface disposal cells. A detailed analysis of the existing geological data, results of preliminary geological research, and other factors of the alternatives' feasibility showed that only Alternatives B, C and E were suitable as regards technical adequacy. For the selected alternative solutions, technical documents needed for the Comparative Study of Alternatives were elaborated. In the Comparative Study of Alternatives, a multilateral assessment of acceptability of the environment affecting activities was made in 2006 by comparison of the alternatives from five points of view: functional, safety, environmental, spatial and economic, and from the point of view of acceptability in the local area. The overall assessment result showed that the highest degree of acceptability at the Vrbina site was attained with the design solution of below-ground silos construction (Alternative B).

In 2007, the design documentation relating to all three suitable disposal alternatives (B, C, and E) was dealt with in detail within the Conceptual Design (IBE). The solutions of below-ground silos construction (Alternative B) were developed in detail in the Basic Design documentation of 2009 [10]. The site and the concept of the disposal solution were formally approved within the scope of the Decree on National Spatial Plan (Official Gazette of the RS, No. 114/09, December 31, 2009). Key design data: The repository was designed for the disposal of half of the short-lived LILW from NEK and of all the remaining short-lived LILW of Slovenia (9,400 m^3) with a possibility of further extension of the disposal capacities to include the entire LILW quantity from NEK (18,200 m^3). The repository consists of a disposal part composed of a set of modular disposal units (silos), and other structures required for the

acceptance, conditioning and storage of radioactive waste. Besides technological facilities, an information centre, an administrative building and a service building are anticipated on the site as well. All buildings and disposal structures of the repository are constructed on a plateau which will protect them against floods. Prior to disposal, the total LILW quantity is inserted into concrete disposal containers (N3a type) with external dimensions of 2.55 x 2.55 x 3.25 m. The containers are disposed into a disposal silo with an inner diameter of 27.3 m and a useful (net) height of 33 m. The water which will eventually seep through the silo wall is collected in the pool at the bottom of the silo and drained via an inspection gallery to the access shaft where sampling will be performed prior to pumping to the surface.

2.7 Design Optimization Process

Immediately after the Basic Design was completed, further design solutions' development and optimization activities took place. The development as well as the optimization were mainly focused on verifying the solutions adequacy in relation to the actual requirements, and on increasing technical feasibility, robustness and safety. In the optimization process, remarks from domestic and foreign Basic Design reviewers as well as the findings resulting from the safety and functional analysis of the repository were considered. Moreover, opinions of expert missions of the International Atomic Energy Agency (IAEA) on NEK decommissioning issues and the related LILW disposal were considered in the optimization process as well. The optimization process was influenced also by the guidelines provided by a special IAEA expert mission for disposal facilities. In 2010, a study under the title "Development of the Disposal Technology Solutions" [11] was prepared in the form of a detailed technical analysis made in particular from the aspect of optimization of non-disposal structures and the repository operation. The most important optimized solution was that the conditioning of LILW generated by NEK is fully performed at NEK. NEK will also take over the conditioning of LILW from other producers. Disposal containers suitable for immediate disposal are transported to the repository from NEK. The optimization study titled "Revision and Optimization of Design Solutions – Disposal Silo" [12] prepared in 2011 was dedicated exclusively to the disposal silo, and was mainly focused on the robustness of the silo and on providing maximum tightness of the silo, and control over groundwater seepage. To enhance water control performances and to improve construction feasibility, the common self-dependent access shaft and inspection galleries were abandoned. The access path to the lower part of the silo and the groundwater pumping system were relocated into the shaft constructed in the silo wall. Waste conditioning at NEK, and LILW package insertion into disposal containers were analysed in the study called "Revision and Optimization of Design Solutions – Disposal Technology" [13] carried out in 2011. As to disposal containers, a comparative analysis proposed that the most suitable alternative is the one where LILW is conditioned at NEK (without additional processing) and placed in (smaller) N2a disposal containers type (1.95 x 1.95 x 3.25 m). These enable better technical feasibility and constitute the only real alternative to the container of N3a type.

2.8 Design for Obtaining a Construction Permit

The bases for the preparation of the Design for Obtaining a Construction Permit (PGD) for the LILW Repository Vrbina, Krško, which began in 2014, were optimized solutions of the Basic Design and Design Bases, which determine, among other things, the facility states and the list of safety-relevant structures, systems and components, and were prepared by ARAO. In addition, the following were taken into account in the preparation of the PGD: geo- and

hydrosphere research, hydrological and hydraulic properties of the site, seismicity analysis of the site, the basis for earthquake design, and the guidelines from the special Architectural Commission. The PGD, covering all the repository and related facilities, was divided into three separate projects: Repository Facilities, Preparatory Work, and Infrastructure Facilities [14]. In 2017, preparatory work, i.e. construction of an anti-flood plateau, was already completed. The repository is designed for the disposal of half of the LILW from NEK, considering the extension of the operational period until 2043, and for the disposal of the total volume of Slovenia's institutional waste. The disposal containers which will be filled with LILW out of the disposal site will be inserted (up to 200 containers per year) into the disposal silo with a diameter of 27.3 m, lining thickness of 1 m, and a capacity of 990 disposal containers (99 containers each, arranged in 10 layers) using a single failure proof gantry crane and a special gripper. Due to new findings regarding the near-field geology (limited ability of self-sealing), and with the aim of achieving a more robust, safer and technically feasible construction, the subconstruction solution from the optimized Basic Design (reinforced and anchored shotcrete primary lining) was changed into a 1.5 m thick slurry wall. All the PGD project documents were reviewed in detail by independent experts, and verified by DRI Investment Management, a certified verifier. In addition, key design guidelines were given, and a positive opinion on the solutions was obtained for the project documentation dealing with underground disposal structures (silo) by the Faculty for Civil and Geodetic Engineering, University of Ljubljana, an authorized expert on radiation and nuclear safety. The final edition of the PGD was produced in 2020.

Simultaneously with the elaboration of the PGD, a prototype of the disposal container was developed, tested and certified (type N2d, 1.95 x 1.95 x 3.3 m). The Slovenian Technical Approval - STS-17/0019, Code S-01576/17, ZAG, was issued on April 24, 2018 for the prototype of the disposal container type N2d.

Consent for construction as well as a decision on the status of the repository as a nuclear facility and on the facility of national importance were issued in January 2022 by the Slovenian Nuclear Safety Administration. Construction permit (No. 35105-95/2021-255/37) was issued on July 27, 2022 by Ministry of the Environment and Spatial Planning.

2.9 Detailed Design

Based on the PGD in the 2020–2021 period, a Detailed Design of all the structures, system and components, i.e. design documentation for implementation of construction (PZI), including some detailed structural stability analyses, was prepared for the LILW Repository Vrbina, Krško, project. [15]

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mechanical part), ANDRA (2015-2017, disposal container development program), and Pomgrad (2015-2017, disposal container prototype manufacturing and certification).

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