Fund for financing the decommissioning of the Krško NPP
Radnička cesta 47, HR-10000 Zagreb, Croatia

ARAO- Agency for Radwaste Management, Ljubljana
Celovška cesta 182, 1000 Ljubljana

Third Revision

of the

Krško NPP

Radioactive Waste and Spent Fuel Disposal

Program

version 1.3

September 2019

ARAO- Agency for Radwaste Management, Ljubljana

Fund for financing the decommissioning of the Krško NPP, Zagreb

Document title	**Third Revision of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program**
Text version	**1.3**
ARAO Doc. No	**19-1/08-01-002**
Fund Doc. No	**3-1/19-2-4/18**
Date	**September, 2019**

	Name (Organization)	**Signature**
Prepared by		
	ARAO: Leon Kegel	Leon Kegel
	Fond NEK: Andrea Rapić	
	Fond NEK: Zdenko Vrankić	
	Fond NEK: Goran Kukmanović	
Approved by	**ARAO director: Sandi Viršek, MSc.**	
	Fund director: Hrvoje Prpić, MD MBA	

1. Executive summary

Abbreviations

ARAO	Agency for Radwaste Management, Ljubljana, Slovenia (Agencija za radioaktivne odpadke)
CLC	Compensation to Local Community
DGR	Deep Geological Repository
DS	Disused Sources
DSB	Dry Storage Building
Fund	Fund for financing the decommissioning of the Krško Nuclear Power Plant and the disposal of NEK radioactive waste and spent nuclear fuel, Zagreb, Croatia (Fond za financiranje razgradnje i zbrinjavanja radioaktivnog otpada i istrošenoga nuklearnog goriva Nuklearne elektrane Krško)
HLW	High Level Waste
IC	Intergovernmental Commission
LILW	Low and Intermediate Level Waste
N2d	Slovenian Type of LILW Container
NPP	Nuclear Power Plant
RC	Republic of Croatia
RCC	Croatian Type of LILW Container
RS	Republic of Slovenia
RW	Radioactive Waste
SF	Spent Fuel
SFDS	Spent Fuel Dry Storage
SRSF	Solid Radwaste Storage Facility
SNSA	Slovenian Nuclear Safety Administration
VAT	Value Added Tax

1.1. Introduction

1.1.1. Krško LILW NPP and Intergovermental Agreement

The Krško Nuclear Power Plant is located in Vrbina in the Municipality of Krško, in the south-eastern part of Slovenia near the border with Croatia. Krško NPP is a Westinghouse 2-loop pressurized water reactor with the original net capacity of 632 MWe which was upgraded to 727/696 MWe (gross electrical power/net electrical power) after the replacement of the steam generators in 2000 (rated thermal capacity of 1,994 MWt).

Krško NPP was constructed as a joint venture between Slovenia and Croatia during 1974 – 1981 period. The plant was connected to the power grid on October 2, 1981 and went into commercial operation on January 1, 1983.

The operating company *Nuklearna elektrarna Krško (NEK)* is co-owned (50:50) by the Slovenian state-owned company *Gen-Energija* and the Croatian state-owned company *Hrvatska elektroprivreda (HEP)*. The electricity generated by Krško NPP is equally shared between the two countries.

Agreement between the Government of the Republic of Slovenia and the Government of the Republic of Croatia on the Regulation of the Status and Other Legal Relations Regarding the Investment, Exploitation and Decommissioning of the Krško NPP (Intergovernmental Agreement) was concluded on December 19 2001, ratified by both sides in 2002 and 2003 and in force since March 11 2003 [1].

Agreement *inter alia* states that management of radioactive waste (RW) and spent fuel (SF) are joint responsibility of contracting parties which must ensure effective joint solution for the management of RW and SF from the economic and environmental protection standpoint. Management of RW and SF generated by the operation of Krško NPP as well as from the decommissioning of facility will be conducted in accordance with the *Krško NPP radioactive waste and spent fuel disposal program* that will be drafted by two expert organizations which will be named by contracting parties. Krško NPP *radioactive waste and spent fuel disposal program* among other issues should include: proposition of possible division and takeover of RW and SF with waste acceptance criteria and assessment of required financial resources and time schedule for RW and SF management operations. Program should be confirmed by Intergovernmental commission (IC) which is formed by contracting parties in order to monitor implementation of Intergovernmental Agreement and commence other businesses in accordance with Intergovernmental Agreement.

Contracting parties will regularly contribute into special national funds. Funds will finance, half each, joint activities related to decommissioning of Krško NPP and RW and SF management.

Final shutdown of the power plant had been foreseen for 2023. In 2012 lifetime extension for additional period of 20 years, till January 14, 2043, has been approved by the owners and Slovenian regulatory body Slovenian Nuclear Safety Administration (SNSA) [2], pending the successful conclusion of periodic safety reviews in 2023 and 2033. Lifetime extension was also supported by the IC decision on 10th session held on July 20, 2015. ([3], conclusions No. 1.2 and 2.1).

1.1.2. Previos revisions of Krško NPP radioactive waste and spent fuel disposal program

Immediately after Intergovernmental Agreement came into power, IC met and decided that instead of two programs required by the Intergovernmental Agreement single document encompassing both decommissioning and RW & SF management should be

prepared with the title *Program of NPP Krško Decommissioning and SF & Low and Intermediate Level Waste (LILW) Disposal* (DP Rev.1).

The main purpose of DP Rev1. was to estimate decommissioning and RW and SF disposal costs for Krško NPP, in order to establish decommissioning fund in Croatia and correct annual installments for then existing decommissioning fund in Slovenia.

DP Rev.1 was completed in the first half of 2004 and peer reviewed by *Electricite de France (EDF).* Following approval of document by IC, Slovenian government was on October 7, 2004 on the 93rd regular meeting informed about the document [4]. Croatian government had approved the document and then additionally DP Rev.1 was confirmed in Croatian parliament [5] on December 8, 2004.

Krško NPP decommissioning and RW and SF disposal discounted costs were estimated to be approximately 350 million € (in 2002 prices). The corresponding 19 equal installments deposited from 2004 through 2022 in one joint fund assumed empty at the beginning of 2004 were estimated to be 28,5 million € annually.

On the 8th IC Meeting held on August 29, 2008 ToR for the DP Rev.2 was confirmed.

Search for common solutions for RW and SF management in DP Rev.2 was governed and bounded by national RW and SF management strategies and separate LILW repository project that Slovenia started in 2004. Respecting potentially different interest of two parties to Intergovernmental Agreement, 5 different decommissioning and RW and SF disposal scenarios were considered within framework defined by the boundary conditions given in ToR.

IC on the 10th session held on July 20, 2015 accepted report on the progress of DP Rev.2 and having in mind new circumstances decided to halt all the activities on DP Rev.2. Also, IC decided that dry SF storage should be established in Krško NPP. Building and operation of dry storage should be NEK Ltd. operational cost.

IC appointed ARAO and Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Krško NPP Radioactive Waste and Spent Nuclear Fuel that was in a meantime by Croatian law [6] appointed as national operational organization for RW and SF management, to prepare ToR for Third Revision of the Krško NPP *Radioactive Waste and Spent Fuel Disposal Program and* Revision of the *Krško NPP Decommissioning Program*.

1.1.3. Third revision of the Krško NPP radioactive waste and spent fuel disposal program (DP Rev. 3)

On the 11th IC session held on November 21, 2017 ToR for the *Third Revision of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program* (DP Rev.3) was accepted and ARAO and Fund were appointed to prepare the DP Rev.3. IC also appointed Project Implementation Coordination Committee (ICC) with four members from each side to

monitor preparation of both Programs and to negotiate proposal for possible joint LILW repository solution. On the same session Croatian side informed Slovenian side that the offer to participate in establishment of Vrbina LILW repository, as presented by Slovenian side on the previous IC session based on study *Investment Programme for LILW Repository on Vrbina site, Rev C* [7], is not acceptable.

ToR for DP Rev 3. lists following general objectives of this revision:

- review of the DP Rev.1 and DP. Rev.2 in accordance with Article 10 Paragraphs 3, 6 and 7 of the Intergovernmental Agreement considering: (1) new RW and SF quantities estimated in the Third Revision of the Krško NPP Decommissioning Program; (2) new estimates of operational RW inventory; (3) new circumstances that developed since the last revision, such as: new RW and SF disposal national strategies and programs, extension of Krško NPP's lifetime, agreement between the co-owners regarding an on-site SF dry storage at Krško NPP, etc.; (4) possible division of RW in accordance with Article 10, Paragraph 3 and 7 of Intergovernmental Agreement.
- construction of possible RW and SF management/disposal scenarios based on the conducted review and within technical-technological framework of the best known practices defining: which storage and disposal facilities are needed to dispose RW and SF efficiently (facility types, capacities and locations); when they need to be put into operation and how long must they remain in operation for the management/disposal to be safe and economically efficient; and management of these facilities, including number and type of employees; etc.
- estimates of nominal costs (in euro (€) 2018 prices) for developed Krško NPP RW and SF management/disposal scenarios. Nominal costs should be also discounted separately for Croatia and Slovenia.

Common solutions for RW and SF management and disposal are limited and determined by national RW and SF management strategies in Croatia and Slovenia as well as with the national legislation that, in the case of both countries, is aligned with the relevant EU directives. Croatia's national RW and SF strategy was approved in Croatian Parliament in 2014 [8] and National program for the implementation of strategy by Croatian Government in 2018 [9]. Slovenia's *2nd National Programme for Managing Radioactive Waste and Spent Nuclear Fuel* for period 2016-2025 was after public debate process adopted by the Government in March 2016 and then approved in the Slovenian Parliament by the Resolution on April 2016 [10].

This revision due to the approved Krško NPP lifetime extension and in line with ToR and national RW and SF management strategies considers only one variant for decommissioning and RW and SF management where Krško NPP stops its operation in 2043. In this revision due to absence of current decisions, some aspects that could further optimize the RW and SF strategy and related costs estimates were not considered such as possible

life extension of the Krško NPP past 60 years or possibility of constructing second Krško NPP unit. According to IAEA and US Nuclear Regulatory Commission (NRC) [11] many plant operators in the United States are seeking licence renewals. This helps avoid electricity supply shortages and support the country in reducing carbon emissions. Extended operation will defer the production of decommissioning wastes, and will extend the period available to set aside funds to cover the cost of decommissioning. The years of additional electricity production will also reduce the costs of waste management and decommissioning per unit of electricity generated [12].

Also, development of new RW and SF management technologies and establishing shared or multinational facilities for RW and SF management could further optimize the overall costs.

According to ToR and for the purpose of costs analysis, SF and HLW generated by decommissioning is managed and disposed jointly first in dry-storage on the location of Krško NPP and disposed in joint repository. Based on existing Slovenian-Croatian Intergovernmental Agreement and conclusions from 10th Meeting of Intergovernmental Commission held in July 2015, SFDS facility can only be operated at NPP Krško site under domain of NEK until the end of NPP operation (year 2043, for the storage of Slovenian and Croatian part of SF). Further operation of SFDS at NPP Krško site is subject of additional negotiation and potential further agreement between Slovenian and Croatian government.

LILW generated by operation and decommissioning of Krško NPP is managed and disposed separately. LILW is divided and taken over by both sides and then it is managed and disposed in national repositories. Exception is radioactive waste from decommissioning of the SF dry storage that will occur after shutdown of national LILW repositories and will be disposed in the common HLW disposal facility. Division of existing operational LILW in Krško NPP storage and its takeover with removal from location of Krško NPP starts in 2023 as defined in Article 10 of Intergovernmental Agreement.

1.2. Krško NPP spent fuel and high level waste management

At the end of 2017 there were 1,210 spent fuel assemblies stored in the pool for spent nuclear fuel at the Krško NPP site, taking into account two containers of fuel rods from the fuel reconstitution [10]. Final shut down of Krško NPP reactor is foreseen in 2043. Conservative estimates for end of operation in 2043 are < 2,500 spent fuel assemblies. During Krško NPP decommissioning also 82.1 t of high level waste (HLW) will be generated [13]. This HLW is represented by the activated material which mainly comes from In-Core Instrumentation System, Nuclear Instrumentation System and Rod Control and Position System. Presently spent fuel assemblies are stored in Spent Fuel Pool (SFP).

1.2.1. Krško NPP SF&HLW pre-disposal management and storage

The IC decided on its 10th session in July 2015 that the construction of a spent fuel dry storage facility (SFDS) at the Krško NPP site to be used until the cessation of the NPP's operation is part of a joint solution for spent fuel disposal and in accordance with Article 10 of the Intergovernmental Agreement. SFDS is part of Krško NPP Safety Upgrade Program and it would consequently improve nuclear safety due to its passive nature and by reducing the number of fuel assemblies in the SFP.

Costs for SFDS project that includes investment for construction, operation, spent fuel relocation from wet storage pools to Dry Storage Building (DSB) and costs for SF storage canisters until the cessation of the NPP operation should be covered and be part of the Krško NPP operational costs (Figure 1-1). The construction of dry storage on Krško NPP site is scheduled for 2020. The first relocation campaign from the SFP to the DSF within the Krško NPP is anticipated for 2021. The Third Revision of the NPP Krško Decommissioning Program strategy assumes that SFDS may be in operation for at least 60 years after the end of NPP Krško operation.

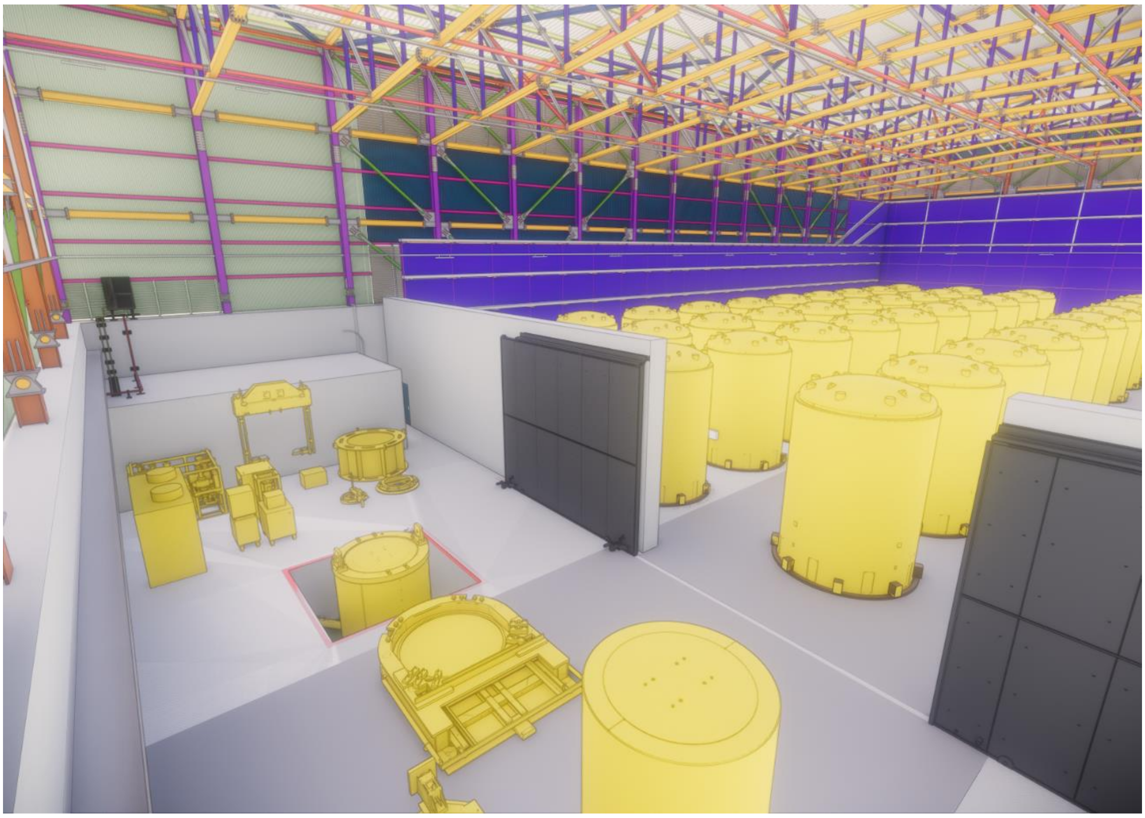


Figure 1-1 DSB Cross section

The SFDS will be based on Holtec lnternational's HI-STORM FW Dry Storage System (HI-STORM). HI-STORM FW is designed to provide physical protection of the spent fuel, radiation shielding, and passive heat removal with enabling efficient cooling through natural convection during interim storage. In this system spent fuel is stored in a Multi-

Purpose Container (MPC) and placed within Hl-STORM over pack. At Krško NPP site concrete pad for storing HI-STORM over packs is located inside DSB. The concrete pad in DSB is an approximately 47 by 69 meter slab of reinforced concrete with a thickness of roughly 1.75 meter. The main function of the concrete pad in DSB is to store the HI-STORM over packs in a seismically stable and isolated area that can withstand all of the applicable structural and seismic loads associated with long term storage operations. The concrete pad can store up to 70 HI-STORM over packs, each of which can hold up to 37 fuel assemblies, with a maximum capacity of 2,590 fuel assemblies.

1.2.2. Krško NPP SF&HLW disposal

SFDS at Krško NPP will be used for storing of all SF and HLW generated at NPP until deep geological repository (DGR) will be developed. The duration of the storage period is determined by considering cooling of SF and optimal loading of disposal canisters in two variants or scenarios: a storage period of 60 years after Krško NPP shut down until 2103 (an optimal solution) and a storage period of 32 years after Krško NPP shut down until 2075 (an alternative solution). Transport of the spent nuclear fuel from SFDS to the repository is planned by road.

Start of operation of DGR is set based on the chosen dry storage period. Two basic scenarios foresee Krško NPP operation until 2043 and differ in the start of DGR operation. In the first scenario the disposal of SF starts after 50-year period of storage in 2093 and in the second scenario, after shorter storage period in 2065. In both cases all activities necessary for DGR would be the same, operation would last for 10 years only.

The disposal concept for both scenarios follows the SKB KBS-3V model of disposal and includes at the repository site all structures, systems and components needed for the repository to operate as an independent nuclear facility [14]. Because of operating requirements and of necessary physical protection measures, the entire repository area will be divided into four areas: unfenced area with support buildings and systems, industrial area with fences due to industrial security (including offices, production buildings and workshops), technological above ground area with fences due to radiological and nuclear safety (with encapsulation plant, service buildings and auxiliary systems) and underground facilities (access ramp and tunnels, service area and disposal tunnels with disposal boreholes)

The encapsulation plant is part of the disposal concept in both basic scenarios. Encapsulation plant (EP) is located at the repository site. The plant will contain units for acceptance of transport containers with SF, for encapsulation of SF in copper canisters including handling area, for dispatching and transportation of canisters to underground disposal facilities, unit for treatment and packaging of LILW, office building, store and auxiliary facilities and systems.

In the proposed concept the encapsulation plant has an annual production capacity to encapsulate 60 copper canisters per year which allows sufficient capacities for all SF in operational period. After the encapsulation is completed, the plant shall be decommissioned, and radioactive decommissioning waste shall be transported to the repository. The operation period for encapsulation plant is 10 years in both basic scenarios after 1 year of trial operation. Its operation ceases simultaneously with the repository operation.

Spent fuel will be encapsulated according to the Swedish concept. Fuel assemblies will be inserted and sealed into massive copper canisters. Their main function is to isolate spent fuel assemblies from their environment. Canister is approximately a 1 m-diameter and 4.7 m-high cylinder with 5 cm-thick anticorrosion overpack of copper. From the inside it is reinforced by cast iron insert which can accept four PWR fuel assemblies. The insert also serves as a pressure-bearing component. After inserting the spent fuel assemblies into the canister, the lid of the canister is sealed by an electron beam welding machine. The weight of canister filled with SF is about 25 t.

The underground part of the repository is situated at a depth of 500 m below the ground surface. Alternatively, the depth of 800 m is also considered. It consists of two areas: central service area and disposal area. The underground level can be reached in several ways: for personnel through service shaft, for waste and other cargo through spiral ramp (with at least 15 m curve radius to enable access by long vehicles and 10% slope) or alternatively through access vertical shaft with 8.0 m clear diameter. The ramp is 5 km (alternatively 8 km) long, 7m wide and 7m high. Service shaft has 5m of clear diameter. It contains two elevators (cages). The main cage shall be used for transportation of personnel and light equipment. The small cage shall be used in case of emergency for personnel rescue. Both cages may be used for shaft inspection. Service shaft is also used as part of ventilation system (air intake). The repository is supplied with a 3 m wide ventilation shaft which can serve as an emergency exit as well.

Out of the 571 disposal boreholes required to accommodate all the fuel canisters, only a few tens are required to start the operation. The rest will be drilled as required for waste emplacement activities.

Long lived institutional LILW, decommissioning HLW and long lived LILW from Krško NPP, HLW and other RW from SFDS decommissioning, long lived LILW and eventually HLW from operation and decommissioning of geological disposal facility and encapsulation plant will be disposed of in one of the abandoned vaults of the service area. Alternatively, a special repository room will be excavated approximately 70 m above transverse drift.

Closure of the geological repository starts with backfilling of the underground tunnels and disposal areas. The disposal tunnels will be sealed with a concrete plug of 6 m

thickness. It is assumed that the decommissioning stage will last for 5 years and the closure stage will last for 2 years.

Construction of the geological repository will start 6 years prior to the start of regular operation. It will begin with construction of auxiliary aboveground structures. Then, construction of the encapsulation plant and of the underground structures will begin. Construction of these structures will last for 5 years.

As basic scenario costs of establishing DGR in Croatia or in Slovenia were estimated. VAT (value added tax) is used in accordance with the Slovenian and Croatian tax regulations [15,16] in force in 2018. Compensations to local communities were determined using proposal for novelation of Slovenian Decree [17,18].

In addition, options and alternative solutions were analyzed, e.g. post-closure monitoring for 50 years, encapsulation in regional encapsulation plant and disposal in multinational repository as well as several alternatives to the basic design

1.3. Krško NPP LILW management

1.3.1. LILW inventory

Based on the inventory of Krško NPP storage and assessments of future generation of LILW through operation of Krško NPP and decommissioning of facility, overall quantities of LILW to be divided by Croatian and Slovenian side are presented in the Table 1-1. RW generated by decommissioning of SFDS facility will be disposed in joint Deep Geological repository (DGR) since both national LILW repositories will be already closed at the time of decommissioning.

Table 1-1 Overall quantities[(1)] of LILW to be divided by Croatian and Slovenian side

Period of LILW generation	Type of LILW	Source of data	Mass (t)	Volume (m^3)	Activity[(2)] (Bq)	Management after division and takeover.
1983–2018	Operational	Inventory	4,877.4	2,294.9	5.98×10^{13}	No WMF on site. Croatian half: Transport and treatment with conditioning in RCC in the third country. Slovenian half: Transport and treatment with conditioning in N2d containers in Slovenia.
2018–2023		Assessment	264.0	163.4	1.44×10^{13}	

Period of LILW generation	Type of LILW	Source of data	Mass (t)	Volume (m^3)	Activity(2) (Bq)	Management after division and takeover.
2024–2043			883.7	546.6	4.33×10^{13}	No WMF on site[1]. [19] Croatian half: Transport and treatment with conditioning in RCC in the third country. Slovenian half: Transport and treatment with conditioning in N2d containers in Slovenia.
2043–2058	Decommissioning		2,860.0	2,842.0	4.93×10^{12}	WMF on site (3). Treatment and conditioning in N2d containers and RCC as planned in the Third revision of the Krško NPP Decommissioning program. Transport in corresponding LILW repositories in Croatia and Slovenia after 2050.
2103–2106			392.0	407.4	6.7×10^{11}	WMF on site (3). Treatment and conditioning on Krško NPP site. This LILW will be disposed in HLW repository.
Total			**9,277.1**	**6,254.3**	**$1{,}23\times10^{14}$**	

(1) Presented here are quantities in the Krško NPP storages or projections of quantities to be generated by operation after 2023 and by decommissioning of Krško NPP. Quantities to be disposed will be adopted from this quantities and adjusted for each side depending on the disposal containers types.
(2) Activity presented here is nominal activity. This is activity of the LILW in the time of placing LILW in the vessels for storage or for further treatment and conditioning. Since most of the radionuclides in LILW are shortlived (half-life under 30 years) activity will be quite different in the time of their disposal in the repository.
(3) This is suggested and assumed by PDP Rev.6 and Third revision of the Krško NPP Decommissioning Program.

[1] Currently there is no on-site capacity for treatment and conditioning of operational LILW in Krško NPP. Such a facility was planned and construction permit was obtained (construction permit nr. 35105-25/2014/5-01031383 TŠ, GB; 16. 6. 2014) but investment into such facility was not yet approved by the supervisory board of the Krško NPP.

1.3.2. Division and takeover

In this document first analysis of division and takeover was provided. Analysis confirms that takeover and division is technically feasible and economically not excessively demanding but that present circumstances in SRFS as well as present level of knowledge of waste packages should improve.

The storage capacity at Krško NPP necessitates as early as possible start of emptying, on the other hand, it may hamper an optimum emptying strategy. Due this fact to couple the emptying strategy with any planned division and takeover may be quite difficult, if no manipulation and buffer storage is planned and build for all needed operations.

The proposal for the division of LILW is equitable and reasonable, but from long-term safety and environmental burden points of view, the most important aspect is the content of long-lived radionuclides in waste. Therefore, basing the division on total activity without full knowledge of long-lived radionuclides and with present knowledge of waste is in itself not the best approach. Renewed waste characterization, including improved determination of the difficult-to-measure nuclides (DMN) will determine the accordance of the inventory and the division with WACs for long term storage and disposal, since takeover of waste packages from Krško NPP in conformance to specifications with national (storage and/or disposal) WACs is expected.

Takeover of the decommissioning LILW will take part from year 2050 up to year 2058. Until this time there might be radical changes in strategies (recycle, reuse, free release, etc.). Instead of setting numbers of containers to be shared, in next iteration of this document it is better to agree on the principles and the regular revision of those developments which might influence the division.

Each side will manage its own half of LILW in accordance with national RW management strategies and programmes.

1.3.3. Management of Krško NPP LILW in Slovenia

Slovenian national strategy included in ReNPRRO16-25 [10] defines construction of the LILW repository for Krško NPP LILW and the disposal of LILW inventory in the repository as soon as possible. The strategy envisages two scenarios: the baseline scenario allowing for disposal of only half of the waste generated in Krško NPP and the entire Slovenian LILW not originating from the Krško NPP, and the extended scenario in which an agreement is reached between Slovenia and Croatia on joint LILW disposal in accordance with Intergovernmental Agreement on the Krško NPP. The extended scenario provides for the disposal of all LILW waste from the Krško NPP and the entire Slovenian LILW not originating from the Krško NPP.

Under the baseline scenario disposal is foreseen in 2 phases: in the first phase from 2020 to 2025 presently stored operational LILW will be disposed with other sources and in

the second phase from 2050 and 2061 the rest of operational LILW together with decommissioning LILW will be disposed with final closure of the repository. LILW from other source is LILW that meets the waste acceptance criteria for disposal but originates from the Central Storage Facility for Radioactive Waste (CSF) in Brinje and its decommissioning and from TRIGA Research Reactor decommissioning. From 2025 till 2050 the repository will be in temporary standby mode. The repository is to be constructed in 3 years following maximum 2 years of trial operation. Repository will be closed down in 2062, and long-term monitoring and maintenance will begin.

In December 2009, Decree on the National Spatial Plan for a LILW Repository in Vrbina, in the Municipality of Krško [10] was adopted by the Government of Republic of Slovenia. With adoption of the Decree disposal concept with disposal in silos has been determined. Silos is built from the surface, but placed in low permeability silt layers in a saturated zone under groundwater. The concept combines the properties of surface type repositories (disposal from the surface) and properties of underground repositories (the placement of disposal units in low permeable saturated geological formations. The location and design of the repository enable enlargement of repository volume with additional silos. Disposal capacity of 9.400 m^3 of radioactive waste generated in RS is planned. The LILW repository includes all structures, systems and components required for its operation as an independent nuclear facility [21].
The silo is designed as reinforced concrete cylindrical construction with internal diameter of 27.3 m. The composition of the silo wall comprises a primary lining of 1.2 m and a secondary lining; their total thickness is 2.2 m. In the silo, the disposal of the first level of containers is arranged at the depth of 49.2 m. Inside the silo there is a vertical communication tract in the form of a shaft. The central part of the communication tract consists of stairs and elevator, and the side parts are intended for the installation lines. The communication tract ends as an entry facility within the hall above the silo Figure 1-2.

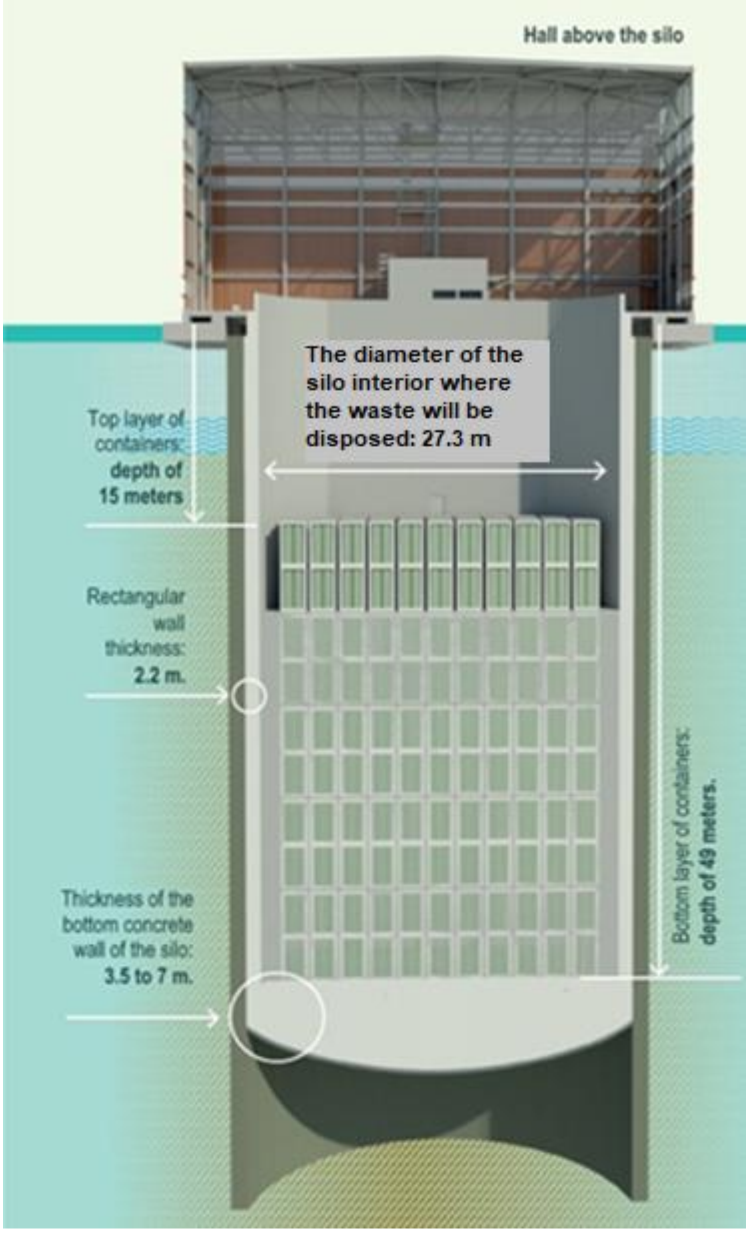


Figure 1-2 Presentation of the concept of the silo design [17].

The net floor area of the silo allows the arrangement of 99 containers at each level. The height and location of the facility is adapted so that 10 levels of containers and the planned sealing layer, i.e. a reinforced concrete slab and a part of the clay layer, are situated below the level of the existing aquifer, and the entire clay layer extends nearly to the surface. For the vertical communication tract, temporary exits to the interior of the silo are planned along its height, which will facilitate access to working levels during the exploitation of the repository. As the filling of the silo will progress, these exits will gradually be put out of use/filled with concrete.

Waste will be disposed of in metal drums which will be inserted into concrete containers and be top-filled with mortar [10].

The N2d container which is reinforced concrete container designed for waste disposal in LILW repository will be used as overpack for LILW to be placed in the silo (Table 1-2). This is the only container to be used for disposal packages. N2d has obtained in RS STS (Slovenian Technical Consent). In its final position in the silo, N2d container provides 300-year protection of the environment against the hazards posed by LILW.

Table 1-2 N2d properties

Dimensions (mm)	
Outside: Width x length x height Inside: bottom/top height before/after lid placement	 1950 x 1950 x 3300 1490/1490 x 1550/1550 3070/2870
Bottom slab thickness	230
Wall thickness (bottom/top)	230/220
Thickness of lid	200
Volume of the container	
Gross volume – outer dimensions	12.28 m^3
Net volume – after lid placement	6.31 m^3
Weight	
Empty container with lid	14.92 t
Lid	1.36 t
Maximum allowable weight of container	40 t

Waste will be prepared for disposal at the Krško NPP, where it will be packed in the so-called final package units (containers). Currently there is no on-site capacity for treatment and conditioning of operational LILW in Krško NPP. Such a capacity was planned but not yet approved by the supervisory board of the Krško NPP [10].

Entry and waste reception procedure will be performed at the repository site entry control point, where formal compliance of the disposal package with WAC for disposal will be checked, including visual control, measurement of surface radiation, and checking of supporting documentation and labeling. If all requirements are fulfilled, transport will continue to the hall above the silo where each individual container is disposed with a portal crane to a predetermined position in the disposal silo [22] [10].

Transportation of containers to the LILW repository will be provided by the Krško NPP [7]. The transportation will be carried out on the local road or on the section of the future regional road from Krško to Brežice and local road and access road to the LILW repository. The entire trip is approximately 1,200 m long.

Project and other documentation are being prepared since the adoption of the Decree on the NSP. Project solutions and its development are inputs for preparation of documentation needed for procedures related to environmental impact assessment and obtaining a building permit.

Field research confirmed the preliminary results and provided the necessary input data for repository design and safety analysis. Most of the main field research was carried out on the micro location of the first disposal silo. Safety analyses were harmonized with the development of project solutions. Conceptual design documentation [20] was prepared in 2016 based on the design documentation prepared for obtaining a building permit and with optimization of the project solutions (introduction of the standby phase, disposal technology optimization, treatment and conditioning optimization) and is an integral part of application for obtaining an environmental approval. Basic design project documentation, which is in the final phase of revision, is also being prepared.

The Project bases for the repository in the environmental impact assessment phase have been developed. The reference documentation for the draft Safety Report has been finalized in accordance with the guidance from the SNSA Practical Guidelines [21]. In April 2019 preliminary approval for the radiation and nuclear safety of nuclear facility was issued by the SNSA in the procedure of issuing environmental protection approval [22]. In order to obtain a building permit for the construction of the LILW repository, the design project documentation will be completed and finalized on the basis of the external expert review required by the ZVISJV-1 [23] while the process of cross-border environmental impact assessment and process of environmental approval should be completed.

The construction and operation of the repository will be financed from the Slovenian Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Radioactive Waste from the Krško NPP (Sklad NEK) and proportionally from the state budget for radioactive waste not originating from Krško NPP.

Based on the presented technological concept and scenario defined by national strategy costs for LILW management including investment costs for establishment of all needed facilities were estimated. Appropriate contingencies were added. VAT was estimated according to national regulations.

In June 2019 Government of Republic of Slovenia in its 36th session confirmed report of the interministerial working group that has examined the system of compensation payments for restricted land use of space for LILW repository. In line with government material, Ministry of the Environment and Spatial Planning should prepare novelation of the Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas [17] and submit it for confirmation to the Government of Republic of Slovenia. The cost of compensation in this revision are based on the draft Decree proposal and included upon decision of the ICC from its 19th meeting. All novelated cost of compensation are prepared in this document according to presentation from this meeting.

1.3.4. Management of Krško NPP LILW in Croatia

Strategy for the Management of Radioactive waste, Disused Sources and Spent Nuclear Fuel (the Strategy) was adopted by Croatian Parliament on October 17, 2014. The Strategy defines basic objectives and guidelines for the management of institutional radioactive waste (IRW) produced in RC, disused sources (DS), LILW and SF from Krško NPP as well as for the remediation of locations with naturally occurring radioactive material (NORM).

The objectives set out in the Strategy include establishment of a long term storage and then repository for IRW, DS and LILW from Krško NPP. In order to fulfil those objectives, the Strategy sets up general guidelines regarding the legislative framework, responsibilities, funding, human resources and public participation. Also, regarding RW management the Strategy offers official interpretation of the key LILW and SF Disposal Articles in Intergovernmental Agreement (Articles 10 and 11).

After the adoption of the Strategy on November 18, 2018 Croatian Government adopted the *National Programme for the Implementation of the Strategy (Programme for the period up to 2025 with a view to 2060)*. The National Programme sets out dates for two objectives stated in the Strategy for the period up to year 2025: establishment of the Central National Storage Facility (CNSF) for IRW and DS and construction with commissioning of long term storage facility for LILW from Krško NPP. Planned duration of long term storage for LILW from Krško NPP is 40 years. Since a long term storage facility for LILW is foreseen to be established in 2023, the establishment of repository for LILW is not required before 2051. Therefore, activities regarding the site selection, site characterization and confirmation for repository are not planned to start in the next 10 years, within the span of this National Programme.

The Strategy anticipates establishment of special Radioactive Waste Management Centre (RWM Centre). The preferred location for the RWM Centre is Čerkezovac, the location of the military logistic complex without perspective for future use by army. Čerkezovac is located in Dvor Municipality on the southern slopes of the Trgovska gora massif.

Table 1-3: Basic technical data and properties of RCC

Parameter	Value / Characteristics
Shape and outer dimensions	Cube, 1.7 x 1.7 x 1.7 m
Internal dimensions	1.43 x 1.45 x 1.45 m
Mass of LLW that could be placed in container	~ 5000 kg
Mass of concrete container	Up to 7,500 kg
The maximum mass of IRCCs loaded with waste	15,000 kg
Useful volume	2.85 m^3
Durability	300 years
Reinforcement	Steel armor
Stackability	3 layers

Parameter	Value / Characteristics
Transportation	Suitable for transport

Based on the Strategy and National Programme scenario for Krško NPP LILW management was developed and financially optimized having in mind Croatian regulation, best safety practices and international recommendations. After being taken over from storage in Krško NPP, LILW will be treated and conditioned into a form suitable for subsequent operations. Treatment and conditioning procedures will be carried out in a dedicated waste management facility. Croatian half of LILW will be conditioned by packaging into concrete containers. Containers will be stored in long term storage (operational in 2023) and later disposed in the appropriate LILW repository to be established in Croatia (operational in 2051).

Since there will be no waste management facility on site in Krško NPP, possibly not earlier then beginning of Krško NPP decommissioning, scenario assumes that Croatian part of operational LILW will be treated and conditioned in appropriate facility in the third country and subsequently transported to Croatia. However, since *3rd Revision of the NPP Krško Decommissioning Program* assumes treatment and conditioning facility will be operating during Krško NPP decommissioning process, LILW management scenario assumes that Croatian part of decommissioning LILW will be treated and conditioned on site and then transported to Croatia.

For transport, storage and for disposal of Croatian half of Krško NPP LILW Iron Reinforced Concrete Containers (RCC) will be used (Table 1-3).

In order to fulfill obligations defined by International Agreement, RC will take over Croatian half of operational LILW after division, in a packages LILW is currently placed in SRSF. Operational LILW will be then transported to third country where it would be treated and conditioned in RCCs. The required treatment and conditioning of LILW is described in detail in a supporting study [23]. Operational LILW will be divided in two consignments: LILW generated up to 2023 will be transported after 2023 to third country where it will be treated and conditioned in RCCs; LILW generated from 2024 to 2043 will be transported after 2050 to third country also, where it will be treated and conditioned in RCCs. However, first batch of RCC with LILW will be transported to long term storage facility in RWM Centre in Croatia, waiting opening of LILW repository, while second batch of RCC with LILW will be transported directly to LILW repository in Croatia that will be operational from 2051.

Floor space of storage facility will be 1,643 m^2 measuring 62.7 x 26.2 m, with 12 m height inside the hall. It will be possible to store 230 RCCs in single layer with a spacing of 0.3 m between containers, or overall 690 containers in 3 layers. 373 m^2 of storage space will be reserved for container inspections and for fire access. The storage also has 396 m^2 space for manipulation with RCCs. This space will be used for placing the controls for the

bridge crane, air-dehumidifying equipment and fire-fighting equipment. Part of the space will be reserved for RCC acceptance inspection or as a spare storage space. The storage facility will be designed in accordance with requirements for Čerkezovac earthquake zone. The basic construction is made of reinforced concrete elements.

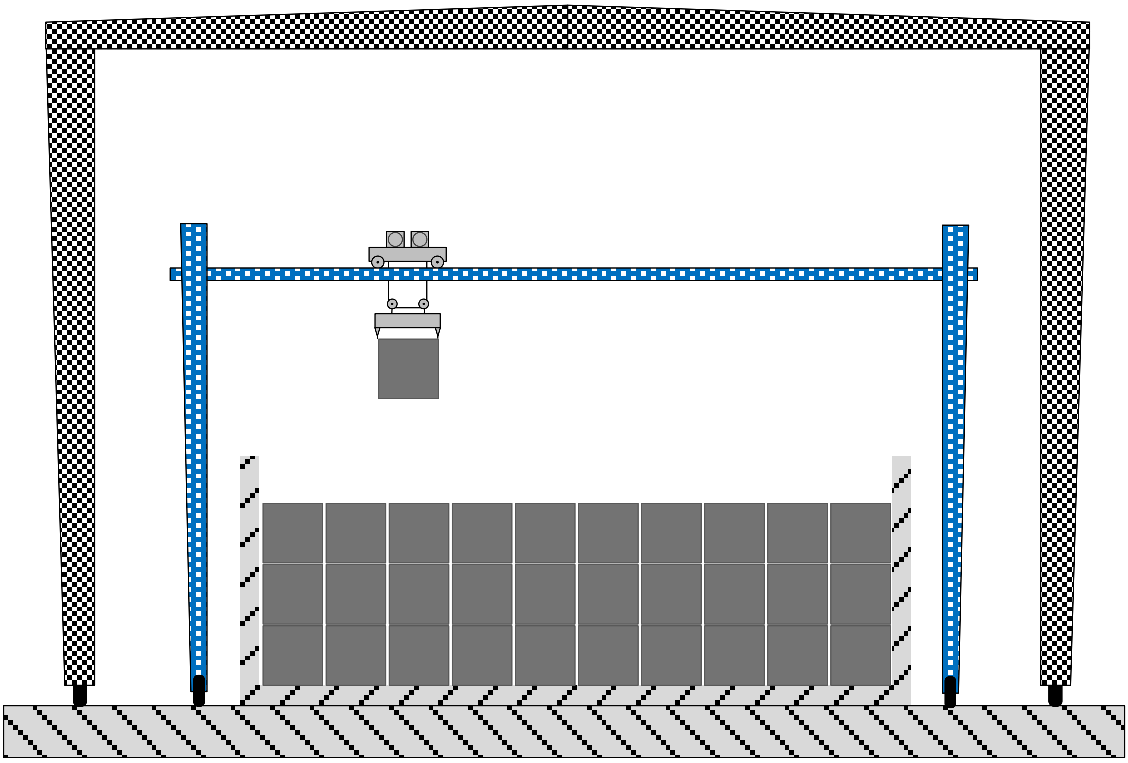


Figure 1-3 Disposal technology in single unit of LILW repository -- side view

Establishing the LILW repository for Croatian half of Krško NPP will start in 2038 with site investigation and launch of the different processes to obtain necessary permits in accordance with regulations, starting with the location permit. The location permit would be issued by 2044 and by the end of 2046 a building permit would be issued. LILW repository will be of near surface type utilizing reinforced concrete cassettes for the placement of RCC with LILW. For the purpose of this analysis original design by ELETROPROJEKT from Zagreb in the form of conceptual design [24] was adapted to the dimensions of the RCC (Figure 1-3).

Single concrete cassette or cell or unit with dimensions 19 x 24 x 7 m (w x d x h) could accommodate 390 RCC concrete containers placed within cell in the 10 x 13 x 3 structure. 4 repository cells are needed for placement of Croatian half of Krško NPP LILW, IRW and DS. Most of the RCC will be with Krško NPP LILW but place for additional 98 containers with IRW and RW as well for RW generated by decommissioning of long term storage is reserved. 4 cassettes with RCC will occupy an area approximately 50 x 70 m. Cassettes or units in repository will be constructed using reinforced concrete.

Based on the presented technological concept and scenario defined by national strategy costs for LILW management including investment costs for establishment of all needed facilities were estimated. Appropriate contingencies were added. VAT was estimated according to national regulations.

1.4. Overview of the costs

Overview of costs is done through five costs categories: (1) Investment costs, (2) Operational costs, (3) Contingency, (4) VAT and (5) Compensation to local community (CLC).

Regarding SF dry storage, construction costs are part of Krško NPP operating costs e.g. costs of Krško NPP operator. The same is true for SF storage operational costs during the Krško NPP lifetime. SF and HLW dry storage operational costs after 2043 and decommissioning costs are included in the Third revision of the NPP Krško Decommissioning Program. Only the costs foreseen for compensation for restricted land use (compensation to local community) are considered here.

Investment costs for SF Disposal management presented here unite Investment and construction costs for disposal unit and encapsulation plant, decommissioning and closure costs in addition to siting, project administration, R&D and site purchase costs in single item to be compared with operation costs which envelop operation and maintenance costs for disposal facility as well as for above ground facilities. There is difference in total costs for baseline scenario as result of VAT difference between RS and RC (Slovenian VAT for disposal unit in Slovenia is 22% as compared to Croatian VAT of 25% for disposal unit in Croatia).

Included in overview of the costs here are optimized costs for division and takeover e.g. costs with the assumption that ARAO and Fund staff will actively participate in the takeover and division.

Different presentation of the LILW management costs for RS and RC (in the chapters 5 and 6) was unified by regrouping the costs into 5 similar categories. For RS it was done using only cost financed by Sklad NEK and for RC it was done assuming that treatment, conditioning and transport costs are part of investment costs.

Overview of the costs is presented in Table 1-4. Costs are in rounded in mil. € 2018. TOTAL DGR in SLO and TOTAL DGR in CRO represent overall costs assuming DGR is in RS or RC, respectively.

Table 1-4 Overall Krško NPP SF and LILW management costs

	Investment costs	Operation costs	Contingency	VAT	CLC	Total
	in mil. € 2018					
SF dry storage	-	-	-	-	37,12	37,12

SF disposal	**SLO**	405,07	240,47	193,67	171,53	126,12	1.136,86
	CRO	405,07	240,47	193,67	194,92	126,12	1.160,25
Division and takeover		-	0,24	-	-	-	0,24
LILW management SLO		84,89	58,00	5,56	27,38	164,47	340,30
LILW management CRO		93,59	31,07	13,47	24,31	44,00	206,44
						TOTAL DGR in SLO	1.720,96
						TOTAL DGR in CRO	1.744,35

1.5. Conclusions

1.5.1. Conclusions

SF&HLW predisposal management and storage

a) In line with recent national policies in RS and RC, construction of dry storage facility for spent fuel (SFDS) at Krško NPP site for a minimal operational life of 60 years with the possibility of extending its operation is approved. SFDS capacity is sufficient to allow storage of all planned SF and HLW inventory from its start of operation in 2021 until final unloading of the core in 2043. Additionally, SFDS project will provide safe and cost-effective storage solution for RW generated from Krško NPP decommissioning including highly activated metal components. SFDS storage can also be used to store solid and conditioned ILW and HLW coming from potential reprocessing of SF. Baseline and sensitivity scenario are considered regarding the operation period and decommissioning of SFDS.

SF management and disposal

a) The reference scenario for repository in suitable hard rock has been prepared. Baseline and sensitivity scenario are considered regarding the start of SF/HLW repository operation and decommissioning. Options of SF disposal in a regional repository and/or use of regional encapsulation plant were considered. SF repository will accommodate also HLW originating from Krško NPP decommissioning and long-lived LILW from operation and decommissioning of nuclear facilities and other nuclear applications.
b) Location of repository is still generic assuming it is somewhere on the territories of RS and RC.
c) Transport of the spent nuclear fuel to the repository is planned by road.

Predisposal RW management

a) The issue of takeover and division as required by Intergovernmental Agreement and by ToR for Third revision of the Krško NPP Disposal Program is in this revision addressed explicitly, based on the supporting study.
b) The storage capacity at SRSF in Krško NPP is full. On one hand, it necessitates as early as possible start of emptying, on the other hand, it may hamper an optimum emptying strategy. Due this fact to couple the emptying strategy with any planned division and takeover may be quite difficult, if no manipulation and buffer storage is planned and build for all needed operations in the future.
c) Present proposal for the division of LILW is equitable and reasonable, but from long-term safety and environmental burden points of view, the most important aspect is the content of long-lived radionuclides in waste. Therefore, better characterization of stored waste aiming at full knowledge of long-lived radionuclides, particularly at difficult to measure radionuclides (DMR), is needed prior to division and takeover.
d) According to supporting study there are at least three waste streams needing additional treatment. These waste streams (highly corrosive waste because of content of the boric acid, hygroscopic waste with unwanted property of swelling and not grouted waste with unsatisfactory void fractions) are not presently stabilized in the manner to fully satisfy disposal requirements. Therefore additional treatment is necessary.
e) Two sides are intending LILW conditioning in different containers (overpacks): RS in N2d containers and RC in RCCs.
f) Additional characterization of presently stored LILW prior to division and takeover as well as treatment and conditioning for operational LILW is needed to prepare waste to fit in containers and match requirements set in WACs for long term storage or disposal. Conditioning of Croatian half of operational LILW due to the inability of RCC to accommodate TTCs (prevailing quantities of LILW are presently in TTCs) requires repacking (if not treatment) of almost all the waste in the Croatian half.
g) Treatment and conditioning facility is not foreseen neither in Vrbina repository nor in the RWM Centre plans. For now, there is no agreement of the Krško NPP owners on the investment establishing needed treatment and conditioning capacities within Krško NPP prior to the end of Krško NPP operation (2043).
h) *Third revision of Krško NPP decommissioning programme* assumes that conditioning (but not treatment) capacity for decommissioning waste on the Krško NPP site will be available after 2043.
i) For now, RC believes that the only possibility for treatment and conditioning of the operational LILW foreseen to be taken over in 2023 as stipulated in Intergovernmental Agreement is in an appropriate facility in the third country. RS is planning the conditioning before disposal on NPP Krško site.

<u>RW management and disposal</u>

a) RS and RC are having different RW management schedules as well as storage and disposal technologies. Due to differences in locations for repositories and chosen disposal technologies there are differences between Croatian preliminary WACs for disposal and Slovenian WACs for disposal.
b) There is dramatic reduction in the estimates of operational and decommissioning LILW volume to be disposed in this revision (volume of 6,254.3 m^3 was estimated in the *Third revision of Krško NPP Decommissioning Program*) as compared to the first revision (17,599 m^3, estimated in *NPP Krško Decommissioning Plan* in 1996 and *Proposed Strategy of LILW Management,* ARAO 2000).
c) Croatia has preferential site for RWM Center and has started with preliminary works.
d) Main site investigations for Slovenian Vrbina repository were concluded in 2015, design project documentation and safety case has been prepared and in April 2019 preliminary approval for the radiation and nuclear safety of nuclear facility was issued by the Slovenian Nuclear Safety Administration in the procedure of issuing an environmental protection consent.
e) Dates set in Intergovernmental agreement for the start of two national Krško NPP management programmes with takeover of stored operational LILW from Krško NPP SRSF in the period 2023 – 2025, considering the current status of storage and disposal facility development in both countries, are challenging and will be very difficult to reach.

1.6. References

[1] Agreement between the governments of Slovenia and Croatia on the status and other legal issues related to investment, exploitation, and decommissioning of the Nuclear power plant Krško (Official Gazette RC, International Agreements 9/2002; Official Gazette RS 23/2003)

[2] 3570-6/2009/32, SNSA License amendment dated 20. 06. 2012

[3] IC Minutes of 10th Meeting, dated 20. 07. 2010.

[4] Zapisnik Vlade RS s 93. redne seje, 7. 10. 2004

[5] As required by Croatian law on the ratification of Agreement (the Decision on obtaining prior consent for the confirmation of the Program of decommissioning Krško NPP and disposal of LILW and SF of December 8, 2004; Official Gazette RC 175/04).

[6] Zakon o radiološkoj i nuklearnoj sigurnosti (NN 141/13, 39/15, 130/17 i 118/18)

[7] Odlagališče NSRAO Vrbina, Krško, Investicijski program, Rev. C,. IBE, d.d., 2013

[8] Strategija zbrinjavanja radioaktivnog otpada, iskorištenih izvora i istrošenog nuklearnog goriva (NN br. 125/14)

[9] Nacionalni program provedbe Strategije zbrinjavanja radioaktivnog otpada, iskorištenih izvora i istrošenog nuklearnog goriva (Program za razdoblje do 2025. godine s pogledom do 2060. godine) (NN br. 100/18)

[10] Resolucija o nacionalnem programu ravnanja z radioaktivnimi odpadki in izrabljenim gorivom za obdobje 2016–2025 (ReNPRRO16-25, Ur. L. RS št. 31/16)

[11] https://www.iaea.org/newscenter/news/going-long-term-us-nuclear-power-plants-could-extend-operating-life-to-80-years (IAEA, 2018)

https://www.nrc.gov/reactors/operating/licensing/renewal/slr/guidance.html (USNRC

[12] Nuclear Power Plant Life Management and Longer-term Operation, OECD/NEA, 2006, NEA No. 6105

[13] 6th Revision of the Preliminary Decommissioning Plan NPP Krsko, Document No.: 4520/CA/F010420 7/02, NIS Ingenieurgesellschaft mbH, June 2019

[14] Reference Scenario For Geological Disposal Facility In Hard Rock With Cost Estimation For Its Implementation, ARAO- NRVR---0X/02B, IBE, Ljubljana, February 2019

[15] Value Added Tax Act, Off. Gaz. RS 13/11, 18/11, 78/11, 38/12, 83/12, 86/14, 90/15

[16] Value Added Tax Act, Off. Gaz. RC 73/13, 99/13, 148/13, 153/13, 143/14, 115/16

[17] [UV8] "Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas", Off. Gaz. RS 92/14, 46/15 and 76/17 – ZVISJV-1

[18] [UV3] "Decree amending the Decree on areas of restricted use due to nuclear facilities and on the conditions for construction in these areas (UV3)"; Official

Gazete of the RS, nr. 36/04, 103/06, 92/14, and 76/17-ZVISJV-1

[19] Opredelitev NEK do možnosti priprave NSRAO na odlaganje v NEK, dopis št. ING.DOV-319.18/6243, september 2018.

[20] Odlagališče NSRAO Vrbina, Krško, Idejna zasnova Rev.C. 2016.

[21] Praktične smernice - Vsebina varnostnega poročila za odlagališče nizko in srednje radioaktivnih odpadkov. 2012.

[22] Safety Analysis and Waste Acceptance Criteria Preparation for Low and Intermediate Level Waste Repository in Slovenia - General overview of Safety Assessmnet Report. Konzorcij EISFI (ENCO, INTERA, STUDSVIK, FACILIA, IRGO), 2012.

[23] Javys: Treatment and Conditioning of Radioactive Waste from Krsko NPP at The Javys Treatment Facilities. Feasibility Study, 2016

[24] Elektroprojekt. Odlagalište nisko i srednje radioaktinog otpada - površinski tip. Idejno rješenje, Zagreb, studeni 1994

2. Introduction

Abbreviations

AB	Advisory board
ARAO	Agency for Radwaste Management, Ljubljana, Slovenia (Agencija za radioaktivne odpadke)
DP Rev. 1	Program of NPP Krško Decommissioning and SF & Low and Intermediate Level Waste (LILW) Disposal, Revision 1
DP Rev. 2	Program of NPP Krško Decommissioning and SF & Low and Intermediate Level Waste (LILW) Disposal, Revision 2
DP Rev. 3	Third Revision of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program
EDF	Electricité de France
EU	European Union
Fund	Fund for financing the decommissioning of the Krško Nuclear Power Plant and the disposal of NEK radioactive waste and spent nuclear fuel, Zagreb, Croatia (Fond za financiranje razgradnje i zbrinjavanja radioaktivnog otpada i istrošenoga nuklearnog goriva Nuklearne elektrane Krško)
HLW	High Level Waste
IAEA	International Atomic Energy Agency
IC	Intergovermental Commision
ICC	Implementation Coordination Committee
LILW	Low and Intermidiate Level Waste
NIS	Ingenieurgesellschaft mbH
NPP	Nuclear Power Plant
PT	Project Team
RC	Republic of Croatia
RS	Republic of Slovenia
RW	Radioactive Waste
SF	Spent Fuel
SFDS	Spent Fuel Dry Storage
SID	Strategy Immidiate Dismantling
SNSA	Slovenian Nuclear Safety Administration
TC	Technical Co-operation
ToR	Terms of Reference

2.1. Krško NPP

The Krško Nuclear Power Plant (Slovene: *Jedrska elektrarna Krško, JEK* or *Nuklearna elektrarna Krško, NEK*; Croatian: *Nuklearna elektrana Krško*, *NEK*) is located in Vrbina in the Municipality of Krško, in the south-eastern part of Slovenia near the border with Croatia. NPP Krško is a Westinghouse 2-loop pressurized water reactor with the original net capacity of 632 MWe which was upgraded to 727/696 MWe (gross electrical power/net electrical power) after the replacement of the steam generators in 2000 (rated thermal capacity of 1,994 MWt).

Krško NPP was constructed as a joint venture between Slovenia and Croatia during 1974 – 1981 period. The plant was connected to the power grid on October 2, 1981 and went into commercial operation on January 1, 1983. In 2004, the Krško NPP started operating with eighteen-month fuel cycles.

Final shutdown of the power plant had been foreseen for 2023. In 2012 lifetime extension for additional period of 20 years, till January 14, 2043, has been approved by the owners and Slovenian regulatory body Slovenian Nuclear Safety Administration (SNSA) (Slovenian: *Uprava Republike Slovenije za jadrsko varnost, URSJV*) [1], pending the successful conclusion of periodic safety reviews in 2023 and 2033. Lifetime extension was also supported with the IC decision in its 10th session held on July 20 2015. ([2], conclusions No. 1.2 and 2.1).

The operating company *Nuklearna elektrarna Krško (NEK)* is co-owned (50:50) by the Slovenian state-owned company *Gen-Energija* and the Croatian state-owned company *Hrvatska elektroprivreda (HEP)*. The electricity generated by Krško NPP is equally shared between the two countries.

2.2. Intergovernmental Agreement on Krško NPP

Agreement between the Government of the Republic of Slovenia and the Government of the Republic of Croatia on the Regulation of the Status and Other Legal Relations Regarding the Investment, Exploitation and Decommissioning of the Krško NPP (onward: Intergovernmental Agreement) (Slovenian: *Pogodba med Vlado Republike Slovenije in Vlado Republike Hrvaške o ureditvi statusnih in drugih pravnih razmerij, povezanih z vlaganjem v Nuklearno elektrarno Krško, njenim izkoriščanjem in razgradnjo;* Croatian: *Ugovor između Vlade Republike Hrvatske i Vlade Republike Slovenije o uređenju statusnih i drugih pravnih odnosa vezanih uz ulaganje, iskorištavanje i razgradnju Nuklearne elektrane Krško*) was concluded on December 19 2001, ratified by both sides in 2002 and 2003 and in force since March 11 2003 [3].

Agreement *inter alia* states that management of radioactive waste (RW) and spent fuel (SF) are joint responsibility of contracting parties which must ensure effective joint solution for the management of RW and SF from the economic and environmental

protection standpoint. Management of RW and SF generated by the operation of Krško NPP as well as from the decommissioning of facility will be conducted in accordance with the *Krško NPP radioactive waste and spent fuel disposal program* that will be drafted by two expert organizations which will be named by contracting parties. Krško NPP *radioactive waste and spent fuel disposal program* among other issues should include: proposition of possible division and takeover of RW and SF with waste acceptance criteria and assessment of required financial resources and time schedule for RW and SF management operations.

Program should be confirmed by Intergovernmental commission (IC) which is formed by contracting parties in order to monitor implementation of Intergovernmental Agreement and commence other businesses in accordance with Intergovernmental Agreement. Equal number of IC members are named by both sides.

Intergovernmental Agreement requires also that Krško NPP decommissioning will be done in accordance with the *Krško NPP decommissioning program* which includes management of all the radioactive and other waste generated during decommissioning up to its transport from the location of Krško NPP, assessment of required financial resources as well as target dates for *Decommissioning program* implementation. *Decommissioning program* is confirmed by IC and as well approved by Slovenian regulatory body responsible for nuclear safety.

Radioactive waste and spent fuel disposal program and *Decommissioning program* are key enforcement mechanisms of Agreement regarding decommissioning as well as RW and SF management. Periodical revisions of both programs should be made at least every five years in order to develop technical projects of increasing accuracy before actual implementation of decommissioning and waste management activities.

Intergovernmental Agreement states that location of Krško NPP could be used as temporary storage for RW and SF during its lifetime which was until 2023 in the time of drafting the document.

If the parties do not reach an agreement on a joint solution of RW and SF disposal until the end of the regular lifetime, the parties agree that they shall, no later than two years after this deadline, finish takeover and transfer of RW and SF from the site, half each.

Parties to the Intergovernmental Agreement approve funding in equal parts for drafting and implementation of *Radioactive waste and spent fuel disposal program* and *Decommissioning program.*

If contracting parties arrange joint RW and SF management expenses will be financed in equal parts. If such an agreement is not realized contracting parties will individually bear costs of all national RW and SF management activities.

Contracting parties will regularly contribute into special national funds in the amount estimated by both of the programs. Each of the funds will finance half of all the joint activities related to decommissioning of Krško NPP and RW and SF management.

With Slovenia's and Croatia's accession to the EU the Intergovernmental Agreement became a part of the EU *acquis*. Directive 2011/70/Euratom [4] acknowledges the specific case of joint Slovenian-Croatian responsibility for radioactive waste from Krško NPP and explicitly supports the application of the Intergovernmental Agreement.

2.1. First revision of the Program of Krško NPP Decommissioning and SF & LILW Disposal (DP Rev.1)

Prior to Intergovernmental Agreement in 1995-1996 *Ingenieurgesellschaft mbH* (NIS) prepared Krško NPP decommissioning plan and cost estimate (NIS study) [5].

Immediately after Intergovernmental Agreement came into power, IC met and decided that instead of two programs required by the Intergovernmental Agreement) single document encompassing both decommissioning and RW & SF management should be prepared with the title *Program of NPP Krško Decommissioning and SF & Low and Intermediate Level Waste (LILW) Disposal* (DP Rev.1).

The main purpose of the joint DP Rev1. was to estimate overall costs of decommissioning and RW and SF disposal for Krško NPP in order to establish decommissioning fund in Croatia and correct annual installments for existing decommissioning fund in Slovenia. On the 2nd IC meeting Terms of Reference (ToR) was confirmed with the idea that DP Rev 1. should be an extensive revision of the NIS study.

Drafting of DP was entrusted to expert organizations APO Ltd. and ARAO appointed by the governments of Croatia and Slovenia which formed a joint Project team (PT) as the operative body. Also, IC nominated an Advisory board (AB), which was supervising the activities and resolving the issues that had been raised by the PT. Krško NPP was supplying the data needed. Consulting firms from Croatia and Slovenia were involved in the project development, and the IAEA experts gave critical contribution to specific issues through Technical Cooperation (TC) projects and workshops in Croatia and Slovenia.

DP Rev.1 was completed in the first half of 2004 and peer reviewed by *Electricite de France (EDF).* Following approval of document by IC, Slovenian government was on October 7, 2004 on the 93rd regular meeting informed about the document [6]. Croatian government had approved the document and then additionally DP Rev.1 was confirmed by voting in Croatian parliament [7] on December 8, 2004.

Slovenian Nuclear Safety Administration (SNSA) adopted DP Rev.1 in the letter to the responsible Ministry of environment, space and energy number 3927-2/2004/4/24,

dated July 15, 2004 [8] stating: *"…SNSA is endorsing DP, Rev.1 under the condition that comments given should be used for supplementing the text and that text should be revised with appropriate frequency. Related to that, SNSA is proposing that the team that prepared the document and NPP Krško immediately starts the work on the next revision*."

After consideration DP Rev.1 recommended decommissioning and RW & SF management scenarios named SID-45 (two versions: disposal and export of SF) which were the basis for costs estimates using combined strategy of immediate dismantling (SID) with 45 years of dry storage for SF before its disposal or export. Both of those scenarios foresee that decommissioning activities will begin immediately after the Krško NPP shut down in 2023 and would be completed by 2036. Both of SID-45 scenarios were based on the assumption that the LILW repository is built at the latest by 2018, and in operation until 2037 with closure in 2042. Another assumption is that just after the end of NPP's lifetime in 2023, dry storage of SF starts operation. The decision on the export or on disposal of SF has to be taken at the latest by 2030 what opens sufficient time to develop SF repository before 2065 if that scenario is chosen. Both scenarios are structurally similar, with almost identical discounted expenses, what allows simple switching from one scenario to the other for several decades from 2004 onward if needed. Furthermore, building of dry storage on NPP location allows simple adjustments on time scale (e.g. opening of SF repository several years later than planned, or changes in schedule of SF export) without significant adjustments in the financial planning.

Based on both SID-45 scenarios Krško NPP decommissioning and RW and SF disposal discounted costs were estimated to be approximately 350 million € (in 2002 prices). The corresponding 19 equal installments deposited from 2004 through 2022 in one joint fund assumed empty at the beginning of 2004 were estimated to be 28,5 million € annually.

2.2. Second revision of the Program of NPP Krško Decommissioning and SF & LILW Disposal (DP Rev.2)

On 8th IC Meeting held on August 29 2008 ToR for the DP Rev.2 was confirmed. Work was as in the previous revision assigned to the PT jointly formed by expert organizations APO Ltd. from Croatia and ARAO from Slovenia. PT was made responsible for planning and management of all activities and for preparation of the integrated document of DP Rev.2. IC named AB with experts from both countries to supervise PT work and for resolving issues raised by the PT.

It was decided that work on one of supporting studies related to dismantling and decommissioning of Krško NPP needed for DP Rev.2 should be entrusted to Krško NPP Ltd. Technical specification for *NPP Krško Preliminary Decommissioning Plan with Plant*

Specific Inventory Database Development was drafted and reviewed by PT. Krško NPP was responsible for funding and management of the work that was entrusted to the *Siempelkamp NIS Ingeniurgesellschaft mbH* [9].

In order to engage stakeholders as early as possible into the discussion on various issues and in particular to issues rising the LILW management, PT decided at the beginning of the project to prepare the document *Preliminary Analysis of Early Available Inputs for the Second Revision of NPP Krško Decommissioning Program*. The aim of PT was to gain attention of different involved parties to the fact that inflation, new compensations to local communities and new cost estimates for various technological solutions will significantly raise annuity to decommissioning funds. This awareness document was presented to wide audience from both of the countries during Workshop in Ljubljana (January 2009) where it was extensively discussed.

Search for common solutions for RW and SF management in DP Rev.2 was governed and bounded by national RW and SF management strategies and separate LILW repository project that Slovenia started in 2004.

Respecting potentially different interest of two parties, 5 different decommissioning and RW and SF disposal scenarios were considered within framework defined by the boundary conditions given in ToR. Scenarios described all necessary activities needed to ensure safe NPP decommissioning and RW and SF management, including establishment of facilities (number, capacity, time of operation) in technically correct sequence with precise time schedule. However, formulation of scenarios for the reasons of plausibility required set of preconditions not covered with ToR or boundary conditions.

4 scenarios were developed assuming Krško NPP end of operation in 2023 and 2043 (20 years of lifetime extension) with joint and separate national LILW management on own territory. Fifth scenario was added by PT as an alternative adaptation of the former SID-45 scenario (DP. Rev. 1) with lifetime extension, which translates all activities for 20 years into the future, including joint LILW disposal that starts in 2038 with somewhat lower compensation to local community up to the time of repository opening. All other elements were the same as in scenario describing lifetime extension and joint LILW management but where LILW disposal starts at 2018 as required by the Slovene strategy at the time.

Expenses for all 5 scenarios were evaluated in the €2009 prices (as nominal costs), and distributed in time according to the planned sequence of activities. Reasonable long-term rates were adopted for discounting calculations, in order to obtain the annuities to be deposited by the NPP owners into the national decommissioning funds.

It was assumed that each national fund will receive 13 annuities in case of 2023 Krško NPP shutdown, or 33 annuities in case of 2043 Krško NPP shutdown. Annuities are conservatively assumed to be paid at the end of the year (the first one at the end of

2010, the last one at the end of 2022 or 2042, respectively). The annuity for each fund is calculated taking into account amounts accumulated in the funds at the end of 2009. For discounting calculations in DP Rev.2 the following values were chosen: inflation 1,38%; interest 4,48%; discount 3,06%. However, for compensations to local communities, the average past revalorization of the basis was used as the inflation rate.

Financial analysis of scenario expenses revealed that two of the scenarios without the lifetime extension with 13 annuities only would hardly be sustainable for Krško NPP. Scenarios with lifetime extension were significantly more favorable, generally requiring smaller annuity increase. Fifth scenario with extended opening of LILW repository was the most favorable option for the joint program.

Aware of preconditions and assumptions made in scenario construction and financial evaluation of scenarios PT decided not to single out preferable scenario but made 15 recommendations instead, suggesting that DP Rev.1 annuities should be immediately replaced (already for the year 2010) with new annuities (based on lifetime extension and joint LILW management scenario) in order to ensure proper funds collection until adequate political decisions and agreements between two sides are made. PT recommended annuities for DP Rev.2 (based on the sums collected in funds at the time): 20,29 million € annually for Croatia and 16,32 million € annually for Slovenia.

2.3. Third revision of Krško NPP Decommissioning Program and Third Revision of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program (DP Rev. 3)

Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Krško NPP Radioactive Waste and Spent Nuclear Fuel (Croatian: *Fond za financiranje razgradnje i zbrinjavanja radioaktivnog otpada i istrošenoga nuklearnog goriva Nuklearne elektrane Krško*) was founded in 2008 (onward: Fund). Fund activities apart from financial related to the acquisition, maintenance and increase of value of assets for financing the preparation, review and implementation of the Krško Nuclear Power Plant Decommissioning and Radioactive Waste and Spent Nuclear Waste Disposal Program include also RW and SF operational role defined by Croatian law [10]. Fund, as Croatian expert organization is responsible for establishing a radioactive waste management facilities in Croatia, i.e. the RW Management Center.

The 9th IC session was held on May 19 2010. Subsequent 10th session was held on July 20 2015. On that session IC accepted report on the progress of DP Rev.2 and having in mind new circumstances decided to halt all the activities on DP Rev.2. Also, IC decided that dry SF storage should be established in Krško NPP. Building and operation of dry storage is NEK Ltd. running cost. IC appointed ARAO and Fund to prepare ToR for

Revision of the Krško NPP *Radioactive Waste and Spent Fuel Disposal Program and* Revision of the *Krško NPP Disposal Program*. Until approval of both programs payments to the funds remain the same.

On the 11th IC session held on November 21 2017 ToR for the *Third Revision of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program* (DP Rev.3) was accepted and ARAO and Fund were appointed to prepare the DP Rev.3. In this session the *Third Revision of the Krško NPP Decommissioning Program* preparation was entrusted to Krško NPP Ltd. IC also appointed Project Implementation Coordination Committee (ICC) with four members from each side with objective to monitor preparation of both Programs and to negotiate proposal for possible joint LILW repository solution. On the same session Croatian side informed Slovenian side that the offer to participate in establishment of Vrbina LILW repository as presented by Slovenian side on the previous IC session based on study Investment Programme for LILW Repository on Vrbina site, Rev C [11]) is not acceptable.

2.4. ToR for DP Rev.3

Full text of the ToR is in the Attachments of this document.

1.4.1. General objectives

ToR for DP Rev 3. lists following general objectives of this revision:

a) review of the DP Rev.1 and DP. Rev.2 in accordance with Article 10 Paragraphs 3, 6 and 7 of the Intergovernmental Agreement considering: (1) new RW and SF quantities estimated in the Third Revision of the Krško NPP Decommissioning Program; (2) new estimates of operational RW inventory; (3) new circumstances that developed since the last revision, such as: new RW and SF disposal national strategies and programs, extension of Krško NPP's lifetime, agreement between the co-owners regarding an on-site SF dry storage at Krško NPP, etc.; (4) possible division of RW in accordance with Article 10, Paragraph 3 and 7 of Intergovernmental Agreement.

b) construction of possible RW and SF management/disposal scenarios based on the conducted review and within technical-technological framework of the best known practices defining: which storage and disposal facilities are needed to dispose RW and SF efficiently (facility types, capacities and locations); when they need to be put into operation and how long must they remain in operation for the management/disposal to be safe and economically efficient; and management of these facilities, including number and type of employees; etc.

c) estimates of nominal costs (in euro (€) 2018 prices) for developed Krško NPP RW and SF management/disposal scenarios. Nominal costs should be also discounted separately for Croatia and Slovenia.

1.4.2. Boundary Conditions

A. General boundary conditions

1. NPP Krško will be in operation until 2043 after successful completion of the periodic safety review in 2023 and 2033.
2. If the contracting parties are unable to reach agreement on joint solution for radioactive waste disposal, they will take over their share of waste in period 2023 – 2025 as stated in the agreement.
3. It is assumed that during the remaining service life of NPP Krško there will be no major incidents or accidents. The possibility of incidents and accidents or early termination of the service will be recorded in the risk register.
4. Implementation of Spent Fuel Dry Storage Project for Phase 1 (first 592 FA), Phase 2 (additional 592 FA) will be covered by the NPP Krško directly from the price of kWh. Other phases will be covered by both Funds (as part of the waste disposal costs).

B. Financial boundary conditions

5. All the nominal costs are expressed in € 2018.
6. All the costs are calculated with and without VAT.
7. Nominal costs include the costs of compensations/incentives to local communities according to local regulations which must be clearly separated from other costs.
8. Costs of institutional control of locations after decommissioning and closure of the disposal facilities will be assessed according to international experience and recommendations.
9. NPP Krško RW and SF Disposal Program states specific nominal costs and total nominal cost of disposal and predisposal management for each side separately (in accordance with management scenario). Discounted specific costs and total discounted cost of disposal of RW shall be specified separately. All management or disposal scenario costs are presented as base case scenario costs.

C. Boundary conditions for Krško NPP RW disposal/management

10. Each side will on the basis of the National program for LILW management consider one of Krško NPP LILW management scenario: disposal of half of the LILW from Krško NPP operation and decommissioning on its territory.
11. Possible division of LILW and its possible take over from the Krško NPP location in accordance with paragraph 3 and 7 of Article 10 of the BA will be organized according to agreement of the two sides.

D. Boundary conditions for HLW and SF management

12. Division of HLW and SF will not be addressed in this revision of the Krško NPP RW and SF disposal Program.
13. Dry storage for SF will be established on the location of Krško NPP where it will be in use for at least 60 years. Phase 1 and 2 of Dry storage project will be implemented on NPP Krško site before 2043. After the end of Krško NPP's lifetime, all the costs of dry storage (as well as its decommissioning) will be paid out of the national funds for decommissioning and RW and SF disposal.
14. A single SF&HLW repository on the territory of the RC or the RS is assumed to host disposal for HLW and SF generated by Krško NPP.
15. Export of HLW and SF to a repository in a third country (regional/international) will be addressed.

1.4.3. Deliverables

Expert organizations in cooperation with Krško NPP will submit the document entitled *Third Revision of the Krško NPP RW and SF Disposal Program* to the IC. The document will be prepared in English (original) and then translated at the end of the project into Croatian and Slovenian.

1.4.4. Project Organization

Cooperation between the two expert organizations to achieve the objectives of this project will take place at joint meetings. The Minutes of each meeting will be kept and signed by all parties. The Minutes will reflect clear conclusions with activities that each party must finish by the specified deadline.

For the tasks that are subcontracted to outside expert organizations (organizations other than ARAO and Fund) specification(s) will be prepared and approved by ARAO and the Fund.

Technical document that will be produced during the preparation of the final document of this project by two expert organizations will be reviewed and co-signed by other organization. This is not valid for the documents that are produced by third party organizations which will be engaged for support. All the versions of the document *Third revision of Krško NPP RW and SF Disposal Program* will be co-signed by the directors of the two expert organizations.

Project Implementation Coordination Committee (ICC) will be nominated by the IC. The ICC supports the activities for new revision of Disposal Program based on this ToR. ICC shall meet every 4 – 6 months or more frequently if needed. Expert organizations report in regular ICC-meetings on project progress and critical issues if existing. ICC regularly reports IC on project progress.

After the preliminary estimates of the total cost and the total discounted cost for SF disposal and RW management/disposal are made (after completion of the revision of technical studies), the expert organizations will prepare a presentation of the work on the project and preliminary results for the ICC.

The document Third Revision of the Krško NPP RW and SF Disposal Program will be prepared only after the ICC issues its approval in the form of conclusion in the Minutes of the meeting.

2.5. National programs for RW and SF management in RC and RS

Common solutions for RW and SF management and disposal are limited and determined by national RW and SF management strategies in Croatia and Slovenia as well as with the national legislation that, in the case of both countries, is aligned with the relevant EU directives. Croatia's national RW and SF strategy was approved in RC Parliament in 2014 [12] and National program for the implementation of strategy by RC Government in 2018 [13]. Slovenia's *2nd National Programme for Managing Radioactive Waste and Spent Nuclear Fuel* for period 2016-2025 was after public debate process adopted by the Government in March 2016 and then approved in the RS Parliament by the Resolution on April 2016 [14].

2.6. RW and SF management scenarios used in the third revision

In the previous not confirmed revision, 5 different scenarios were considered covering the work of Krško NPP until 2023 and possible lifetime extension up to 2043 as well as two possibilities of joint and separate Croatian and Slovenian management of Krško NPP LILW. One scenario was added to consider late start of LILW repository in joint LILW management scenario if lifetime extension had been approved.

DP rev.1. and DP rev.2. were analyzing open issues of joint or separate disposal of LILW and SF, especially in light of the possible lifetime extension of Krško NPP, evaluating several possible joint variants of disposal naming them scenarios: e.g. one scenario was joint LILW repository and joint SF repository assuming originally planned lifetime until 2023 or another joint scenario was separate LILW disposal in national repositories and joint SF repository assuming extended lifetime of Krško NPP.

This revision due to the approved Krško NPP lifetime extension and in line with ToR and national RW and SF management strategies considers only one variant for decommissioning and RW and SF management. Krško NPP stops its operation in 2043. According to ToR and for the purpose of costs analysis, SF and HLW generated by decommissioning is managed and disposed jointly first in dry-storage on the location of Krško NPP and

disposed in joint repository. Since IC on its 10th session approved SFDS operation at NPP Krško site only until 2043, SFDS operation beyond 2043 is subject of additional negotiation and potential further agreement between Slovenian and Croatian government.

LILW generated by operation and decommissioning of Krško NPP is managed and disposed separately. LILW is divided and taken over by both sides and then it is managed and disposed in national repositories. Exception is radioactive waste from decommissioning of the SF dry storage that will occur after shutdown of national LILW repositories and will be disposed in the common HLW disposal facility. Division of existing operational LILW in Krško NPP storage and its takeover with removal from location of Krško NPP starts in 2023 as defined in Article 10 of Intergovernmental Agreement.

Presently, there are still issues regarding management of LILW after takeover that could be optimized (e.g. treatment and conditioning, transport, compensations etc.) so for both sides there are still possibilities for adjustments of national scenarios and improvements in the overall costs. In Republic of Slovenia proposed novelation of the Decree on restricted land use [15] could significantly influence compensation rates to local communities with substantial waste management costs reduction.

The Third revision of Krško NPP Decommissioning Program was developed by the Krško NPP in line with ToR [16] and Technical specification for NPP Krško Decommissioning Plan revision 3 Development, SP-ES 1317, Revision 01, April 2018 [17]. In this document decommissioning of Krško NPP is planned in two phases, as a consequence of SF dry storage (SFDS) operation on site of the Krško NPP. First phase is "brown field" status -- decontamination and dismantling of all buildings, structures and systems, except the ones needed for SFDS operation. Second phase is after SFDS shutdown up to the "green field" status. Two options for SFDS operation dynamics were considered: until 2103 (i.e. 60 years after the Krško NPP shutdown) or until 2075 (i.e. 32 years after the Krško NPP shutdown). Based on this, 2 decommissioning scenarios were introduced:

a) Base case decommissioning scenario: "brown field" status applies for the period until the end of SFDS operation in 2103. SFDS and the rest of the buildings and systems are decommissioned after SFDS shutdown up to the "green field" status.

b) Sensitivity case decommissioning scenario: "brown field" status for the period until the end of SFDS operation in 2075 and "green field" status with complete removal of whole site together with SFDS shall be done after 2075.

On the basis of above-mentioned decommissioning scenarios and SFDS operation dynamics 2 adjusted scenarios for HLW and SF disposal were implemented:

- Base case scenario (Scenario No. 1) – start of regular operation of the SF repository in 2093; 10 years of operation; dry storage facility needed until 2103;

- Sensitivity case scenario (Scenario No. 2) – start of regular operation of the SF repository in 2065; 10 years of operation; dry storage facility needed until 2075.

All changes of boundary conditions and scenarios different than defined in ToR are explained in more detail in individual chapters of the Third revision.

2.7. Quality Assurance and Quality Control

Both of the expert organizations drafting this document (ARAO and Fund) have implemented own quality control systems. According to agreement between expert organizations supporting studies prepared for this document were mutually reviewed. Additionally, external experts review was done for supporting studies. Furthermore, Krško NPP reviewed those supporting studies that were related to division and takeover of LILW as well as storage and disposal of SF. All drafts of this document, including supporting studies on RW division and takeover and HLW and SF disposal, were reviewed by ICC also.

2.8. Peer review

In April 2019 expert organizations in cooperation with Krško NPP had prepared a joint, confirmed draft version of the document *Third revision of the Krško NPP RW and SF Disposal Program* that has been submitted to IAEA expert review with the ICC consent. 3 days long joint Slovenian-Croatian IAEA expert review mission was organized at the end of May 2019. It was successfully concluded with the expert mission's final report that is included as attachment to this document. Based on comments and recommendations in IAEA expert missions final report [18], April draft of this document was adopted and upgraded to current version, in which some changes based on ICC decisions were included also.

2.9. References

[1] 3570-6/2009/32, SNSA License amendment dated 20. 06. 2012

[2] IC Minutes of 10th Meeting, dated 20. 07. 2010.

[3] Agreement between the governments of Slovenia and Croatia on the status and other legal issues related to investment, exploitation, and decommissioning of the Nuclear power plant Krško (Official Gazette RC, International Agreements 9/2002; Official Gazette RS 23/2003)

[4] COUNCIL DIRECTIVE 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste

[5] NIS Ingenieurgesellschaft mbH, „Development of the site specific decommissioning plan for Krško NPP“, 1996.

[6] Zapisnik Vlade RS z 93. redne seje, 7.10.2004

[7] As required by Croatian law on the ratification of Agreement (the Decision on obtaining prior consent for the confirmation of the Program of decommissioning Krško NPP and disposal of LILW and SF of December 8, 2004; Official Gazette RC 175/04).

[8] Odobritev Programa razgradnje NEK in odlaganja NSRAO in IJG, MOPE, Uprava RS za jedrsko varnost, št. 3927-2/2004/4/24, 15.7.2004

[9] Preliminary Decommissioning Plan for the NPP KRSKO (PDP), Revision 5, Siempelkamp NIS GmbH, April 2010, Rev. 5, Doc.-No. 8215 / CA / F 008375 9 / 05

[10] Zakon o radiološkoj i nuklearnoj sigurnosti (NN 141/13, 39/15, 130/17 i 118/18)

[11] Odlagališče NSRAO Vrbina, Krško, Investicijski program, Rev. C,. IBE, d.d., 2013

[12] Strategija zbrinjavanja radioaktivnog otpada, iskorištenih izvora i istrošenog nuklearnog goriva (NN br. 125/14)

[13] Nacionalni program provedbe Strategije zbrinjavanja radioaktivnog otpada, iskorištenih izvora i istrošenog nuklearnog goriva (Program za razdoblje do 2025. godine s pogledom do 2060. godine) (NN br. 100/18)

[14] Resolucija o nacionalnem programu ravnanja z radioaktivnimi odpadki in izrabljenim gorivom za obdobje 2016–2025 (ReNPRRO16-25, Ur. L. RS št. 31/16)

[15] Decree amending the Decree on areas of restricted use due to nuclear facili-ties and on the conditions for construction in these areas (UV3); Official Gazete of the RS, nr. 36/04, 103/06, 92/14, and 76/17-ZVISJV-1

[16] ToR the Third revision of Krško NPP Decommissioning Program, October 2017

[17] Technical specification for NPP Krško Decommissioning Plan revision 3 Development, SP-ES 1317, Revision 01, April 2018; attachment to the NEK letter: Izpolnitev točke 2 b) Zapisnika 4. zasedanja koordinacijskega odbora, NEK ING.DOV -139.18/3091, 11.4.2018

[18] End od Mission Report on Expert Mission to provide comments and discuss the Third revision of the Krsko NPP RE and SF Disposal Program, IAEA, 2019-07-05

3. Krško NPP SF&HLW management

Abbrevations

ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
AR	At-Reactor; SF Storage area at the site of reactor
ARAO	Agency for Radwaste Management from Slovenia
BRHNEK	Bilateral Agreement Between RC and RS on NEK
BSS	Basic Safety Standards
Campaign	A set of SF transfer from spent fuel pit to the DSB and corresponding activities.
CLA	Cask Loading Area; area in FHB near the spent fuel pool, where loading of MPC in HI-TRAC takes place
CTF	Cask Transfer Facility within Dry Storage Building
DGR	Deep Geological Repository. DGR is recognized worldwide as the reference solution for the disposal of spent nuclear fuel, and high-level radioactive waste.
DSB	Dry Storage Building
DSRS	Disused Sealed Radioactive Sources
FA	Fuel Assemblies
FHB	Fuel Handling Building
Fund (Fond NEK)	Fund for financing the decommissioning of the Krško Nuclear Power Plant and the disposal of NEK radioactive waste and spent nuclear fuel, Zagreb, Croatia (Fond za financiranje razgradnje i zbrinjavanja radioaktivnog otpada i istrošenoga nuklearnog goriva Nuklearne elektrane Krško)
HI-STORM	Storage overpack that receives and contains the sealed MPC; provides gamma and neutron shielding, ventilation passages, missile protection, and protection against natural phenomena and accidents for the loaded MPC
HI-TRACK	Transfer overpack used to house the MPC during fuel loading, drying, sealing and transfer from FHB to the DSB
HLW	High-Level Waste
IAEA	International Atomic Energy Agency
ICC	Project Implementation Coordination Committee
KBS-3V	The Swedish disposal concept
LILW	Low and Intermedia Level Waste
LL-HLW	Long-Lived High Level Waste
LL-LILW	Long-Lived Low and Intermediate Level Waste
MNR	Multinational Repository
MPC	Multi-Purpose Canister; sealed canister consisting of a fuel basket for spent nuclear fuel storage, containing in a cylindrical canister shell; confinement boundary for storage conditions
MPC FB	MPC Fuel Basket; honeycombed neutron absorbing welded structure with square openings (in MPC) which can accept a fuel assembly
NEK	Krško NPP
NPP	Nuclear Power Plant

PA/SA	Performance Assessment / Safety Assessment
PDP	Preliminary Decommissioning Plan
PWR	Pressurised Water Reactor
R&D	Research and Development
ReNPRRO16-25	Resolution on the National Programme for Managing Radioactive Waste and Spent Nuclear Fuel 2016-2025, Off. Gaz. of the RS, Nr. 31/16
RRS 2009	Revised Reference Scenario 2009
RS 2004	Reference Scenario 2004
RS 2018	Reference Scenario 2018
RW	Radioactive Waste
SF	Spent Fuel
SFDS	Spent Fuel Dry Storage in Krško NPP
SFP	Spent Fuel Pool
SKB	Swedish Nuclear Fuel and Waste Management Co
Sklad NEK	Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Radioactive Waste from the Krško NPP, Krško, Slovenia
URSJV	Slovenian Nuclear Safety Administration (SNSA)
USAR	Updated Safety Analysis Report
UTF	An Underground Testing Facility
VAT	Value Added Tax
ZVISJV-1	Ionizing Radiation Protection and Nuclear Safety Act, Off. Gaz. of the RS, Nr. 76/17

3.1. Krško NPP SF&HLW pre-disposal management and storage

3.1.1. Introduction

In order to achieve the specific objective of SF management, safe handling, keeping and storage of SF are to be provided at all stages of its existence which should be followed by appropriate permanent disposal solutions in appropriate repository as internationally recognized safe end-point for SF or high-level waste (HLW) originating from reprocessed SF.

It is internationally recognized that regardless of chosen SF management option, storage of spent fuel is required for some periods of time. The storage times can vary from a few months to several decades or longer. Storage options include wet storage in storage pools or dry storage in storage casks or vaults. Almost all nuclear power reactors have spent fuel storage pools. They were included as a necessary component in the original design of the reactors. Additional storage capacity, wet or dry, are constructed for operation and safety reasons. Additional storage can be built to extend the capacity of nuclear power reactor spent fuel storage and to increase safety of stored SF.

Around 40 years of favorable experience exists with the dry storage of spent power reactor fuel and about 50 years with the dry storage of research reactor fuel. Dry storage experience exists with fuel from a variety of reactor types (CANDU, HWR, PWR, BWR, WWER, MAGNOX and HTGR). Since its conception, dry storage of spent fuel has evolved into a wide variety of systems. Examples of these are concrete canisters (Argentina, Republic of Korea, USA, England), metallic dual-purpose casks (Germany, Japan, Spain, Switzerland, USA), steel lined concrete containers or casks and/or casks made of ductile cast iron (Germany, Japan, Spain, USA), and concrete vault like structures (France, Hungary, UK, USA). Based on the operating experience to date, the spent fuel examinations carried out so far, and the results of supporting research these indicate that fuel can be stored safely for many decades.

Figure 3.1-1 Concrete casks storing spent fuel at the Connecticut Yankee nuclear power plant site (source: NAC International)

Dry storage techniques of different types have been developed (see an example at Figure 3.1-1) and are now worldwide widely adopted. Dry storage facilities are also internationally used for storage of HLW canisters from SF reprocessing or for storage of HLW generated during decommissioning. HLW from SF reprocessing are stored in air cooled casks similar to those used for spent fuel storage in Germany and Switzerland.

Spent fuel storage is also an interim step in the back end of the nuclear fuel cycle which facilitates spent fuel reprocessing and recycling of products or direct disposal. To date the direct disposal of fuel has not been exercised, but there are a few projects which are in an advanced stage of meeting this goal. In other, mainly small nuclear programmes, the plan, has been to extend storage times and durations in excess of 100 years are now being envisaged.

For many national programs for countries with small nuclear power programs the option for direct disposal is limited with several factors, such as appropriate geological and societal requirements for repository siting may be difficult to identify, the human resources required for the development, construction, and operation of a disposal facility are daunting and the financial requirements may be prohibitive. For these reasons many countries with small nuclear power programs opt for extended storage of the SF and HLW.

At-Reactor dry Storage is relevant also for NEK and it is also in line with approved National program on RW and SF management in Republic of Slovenia [1] and with approved National program on the implementation of Strategy for RW, DSRS and SF management in Republic of Croatia [1].

3.1.1.1. Responsibility of facility operator

The nuclear facility operator is competent and responsible for managing spent nuclear fuel at the site of the facility in operation. NEK is responsible for the storage of spent nuclear fuel from the NPP operation At-Reactor site.

The facility operator NEK is also a licence holder for all SF on the site. The holder of the spent fuel is in line with ReNPRRO16-25 to examine the possibility of spent fuel reprocessing until 2025.

National waste management organizations (ARAO for Slovenia and Fund for Croatia) will assume responsibility for managing spent fuel and HLW from decommissioning from operator after the cessation of operation of NEK.

The construction of a dry storage facility for spent fuel was addressed by the Intergovernmental commission for monitoring the implementation of The Bilateral Slovenian-Croatian Agreement [3] on the Krško NPP at its 10th session in July 2015. The commission decided that the construction of a SFDS at reactor site until the cessation of the NPP's operation is part of a joint solution for spent fuel disposal and in accordance with point seven of Article 10 of The Bilateral Slovenian-Croatian Agreement on the Krško NPP [2]. Operation of the SFDS beyond 2043 at NPP Krško site is subject of additional negotiation and potential further agreement between Slovenian and Croatian government [4].

3.1.2. Description of facility

Historically first dry storage applications were developed for at-reactor storage for gas cooled reactors already more than 40 years ago. Through the years of experience, these first systems developed significantly for light water reactor fuels and specifically for PWR SF. These developments included concrete and metal casks, fuel baskets and variants from this original design.

Dry storage is a flexible solution, which can easily be adapted to a larger inventory [3]. It is sensitive to changes in fuel characteristics. This system is not easily adapted for significant changes in fuel type and it is hard to adapt to accept fuel from different reactor types (if not planned before). These disadvantages are not critical for the SFDS at NEK, as the reactor type of NEK and fuel type are well defined, commonly used and well know.

3.1.2.1. Description of Spent Fuel Dry Storage at NEK

Construction of dry storage facility for spent fuel at the NEK site for a minimal operational life of 60 years with the possibility of extending its operation is included in

2016 national policy as action to be completed by NEK [5]. In addition to definition of SFDS as next storage step in National program the need for AR dry storage was identified also through in-depth safety reviews performed as stress tests and other safety analyses performed in 2011 and later [6].

SFDS facility is also significant safety upgrade that will with its passive nature and reduction of SF amount in the pool enhance nuclear safety. SFDS is passive system as there is no need for active systems, structures or components to guaranty safety of long-term SF storage. In this respect, dry storage increases safety of AR SF storage under the same environmental and radiological limits. SFDS facility will be built to allow for additional storage space for spent fuel in the pool and increase safety of spent fuel storage system.

New storage system will contain a new Dry Storage Building (DSB) within NEK yard. The SFDS at NEK is based upon Holtec lnternational's HI-STORM FW Dry Storage System (HI-STORM) for the dry storage of spent fuel. In this system spent fuel is stored in an MPC and placed within a Hl-STORM over pack. The Hl-STORM FW over pack is then transported to and stored on a concrete pad. At Krško NPP site concrete pad for storing HI-STORM over packs is located inside of the Dry Storage Building (DSB).

Holtec International HI-STORM dry storage system is in principle steel lined concrete other protective containers with inner sealed closed metal casks. HI-STORM FW is designed to provide physical protection of the spent fuel, radiation shielding, and passive heat removal with enabling efficient cooling through natural convection during interim storage.

The concrete pad in DSB at Krško NPP can store up to 70 HI-STORM over packs, each of which can hold up to 37 fuel assemblies, with a maximum capacity of 2590 fuel assemblies. Currently only 62 canisters are needed for the planned number of spent fuels. Additional capacity is considered for potential fuel management or operating changes in the future and for potential interim storage of generated.

The concrete pad in DSB is an approximately 47 by 69 meter slab of reinforced concrete with a thickness of roughly 1,75 meter. The main function of the concrete pad in DSB is to store the HI-STORM over packs in a seismically stable and isolated area that can withstand all of the applicable structural and seismic loads associated with long term storage operations. DSB is a combined concrete and metal building. The lower part of the building is to be made of concrete for the purpose of flood protection. The building consists of a storage area, acceptance area and technical area as well as entry and egress areas for controlled radiological purposes. The DSB is designed to provide ventilation, and radiation protection for the loaded HI-STORM during long term storage. Acceptance area is an area inside DSB where acceptance and preparation of MPC for storage is performed and where transfer equipment is stored. The cask transfer facility (CTF) is lowered part of acceptance area in DSB where MPCs are transferred from HI-TRAC to

HI-STORM (or the other way around). Technical area is an area inside DSB that contains panels and equipment for DSB operation monitoring and is separated from the cask storage area by a concrete shield wall.

Figure 3.1-2: Location of Dry Storage Building (DSB) within the location of Nuclear Power Plant Krško [7]

Figure 3.1-3: Dry Storage Building (DSB) [7]

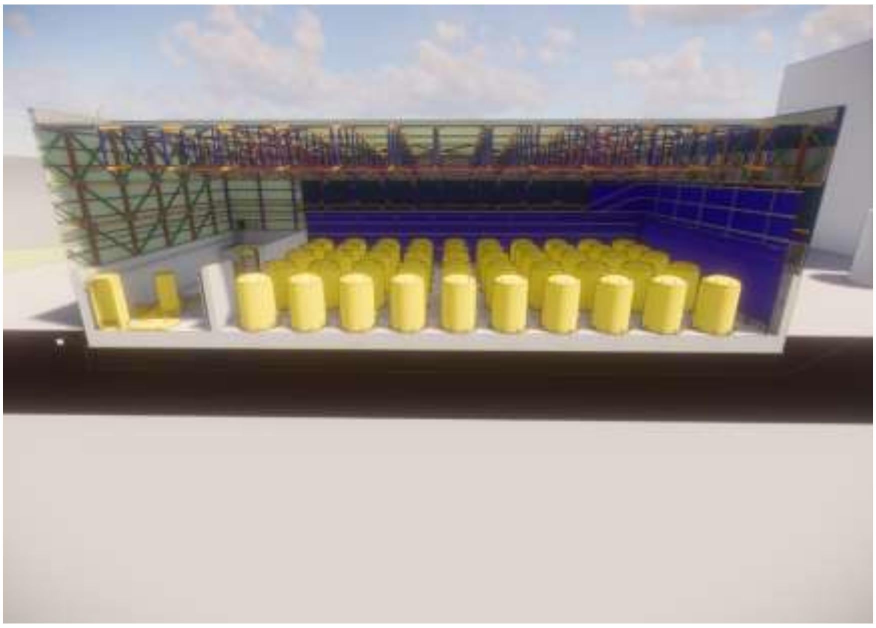


Figure 3.1-4: DSB Cross section I [7]

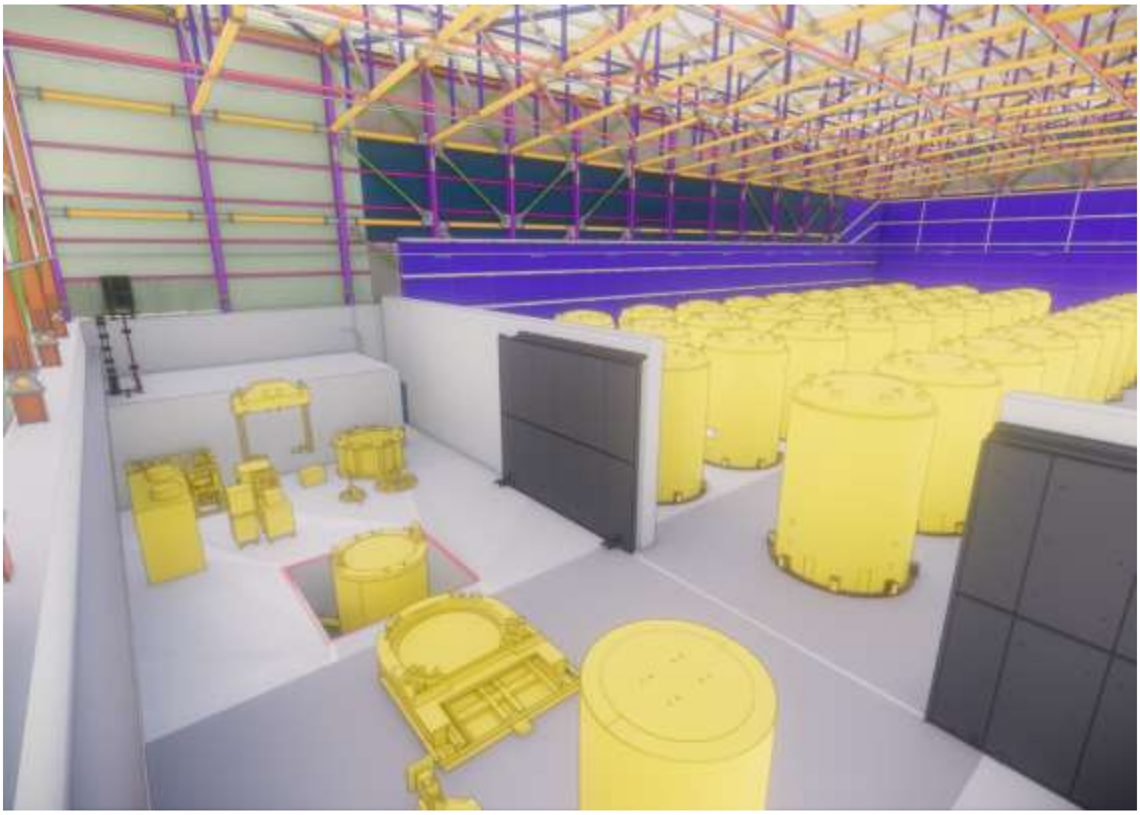


Figure 3.1-5: DSB Cross section II [7]

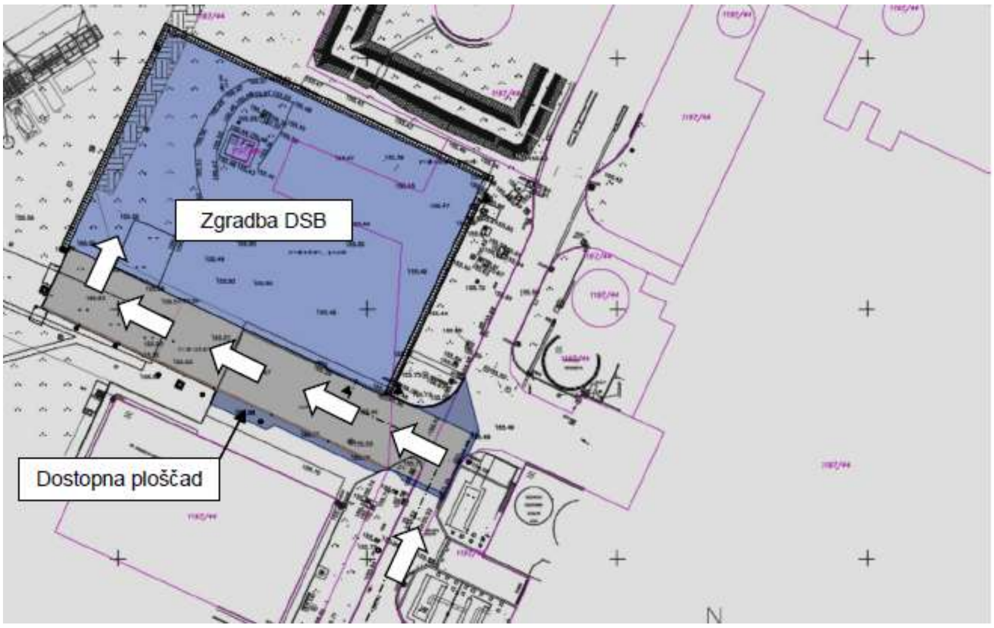


Figure 3.1-6: DSB situation [7]

The HI - STORM FW overpack is the main shielding and protective component of the dry storage system. The overpack consists of an inner and outer shell that are connected by radial ribs throughout the component. The shells are connected at the top and bottom by plates that create a cavity between the two shells. This cavity is then filled with high density concrete that forms a protective shell approximately 70 centimeters thick. The concrete provides radiation shielding along with compressive strength. The HI-STORM overpack is also equipped with four inlet vents at the base which allow for air to flow into the center and then up and around the outside of the MPC stored within before exiting through outlet vents located at the top of the overpack. This provides a passive form of cooling for the heat generated by the fuel.

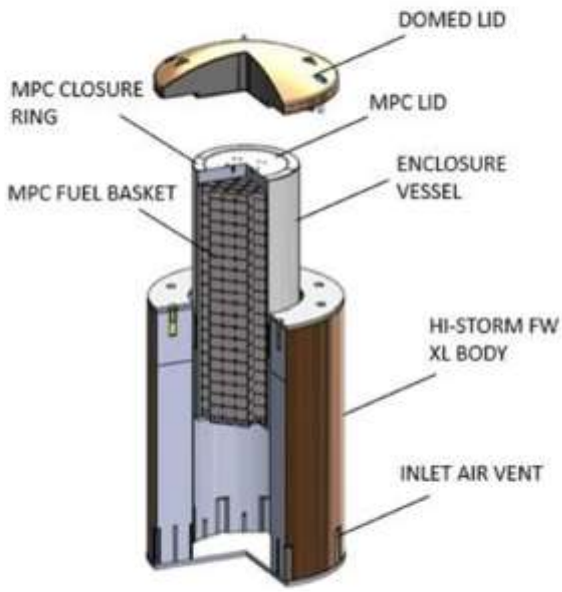


Figure 3.1-7: HI-STORM with MPC (MPC-37) Dry Storage System [8]

The Multi-Purpose Container (MPC) is the confinement system for the stored spent fuel. The MPC is a dried, welded, and helium back-filled cylindrical canister with a honeycomb basket, a baseplate, a lid, a closure ring and the canister shell. The MPC houses the fuel assemblies in a fuel basket that can hold up to 37 assemblies for transport and storage operations. The MPC shell is approximately 12 mm thick and is welded to a lid and baseplate. While the MPC does provide some shielding its main function is to maintain the configuration of the spent fuel and to be the confinement boundary between the stored spent nuclear fuel and the environment.

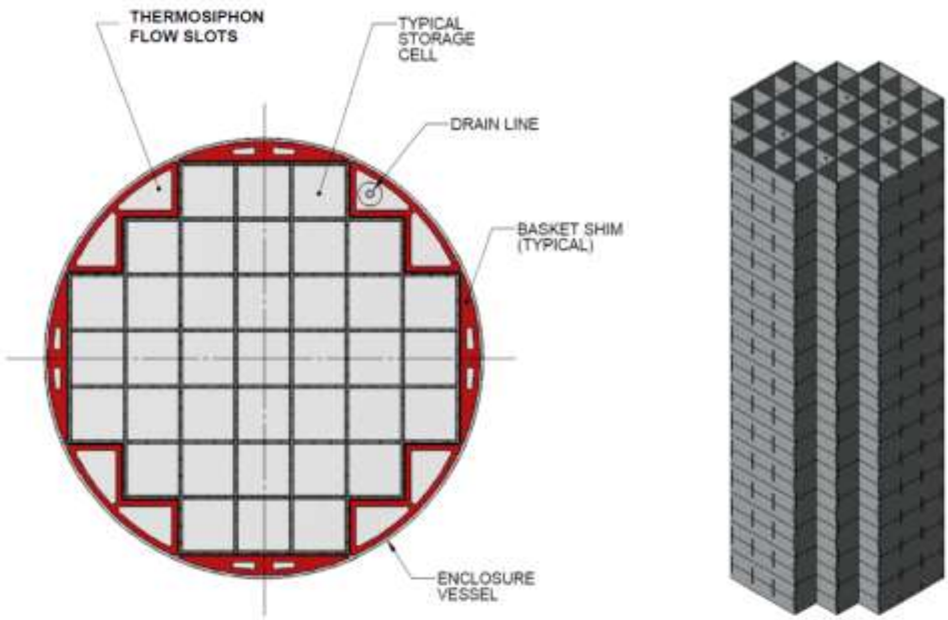


Figure 3.1-8: Multi-Purpose Canister for 37 PWR spent fuel elements (MPC-37) in cross section (on left) and MPC-37 PWR fuel basket (37 storage cells) in perspective view (on right) [8]

3.1.3. Inventory

3.1.3.1. General description

Globally the nuclear power plant operating environment has continued to move in the direction of higher fuel burnups. Such developments have reduced the amount of SF being produced but have put a greater burden on the SF storage system with higher decay heat. In the case of geological disposal, the fuel may have to be stored for long periods of time to ensure that thermal loading on the materials in the engineered and natural barriers systems will remain below thermal design limits. Under several expected scenarios, fuel cooled for 100 years or more may be required [9].

The reactor core at the Krško NPP comprises 121 fuel assemblies with external dimensions of 19,718 cm x 19,178 cm x 405,803 cm. A fuel element comprises 235 fuel rods filled with ceramic tablets of uranium dioxide and dressed in zirconium alloy cladding. Uranium enrichment is in the order of a few percent (between 2 and 5%). One fuel element comprises approximately 406 kg of uranium.

The higher fuel burnup is valid also for NEK, where longer fuel cycles and higher burnups have also resulted in increased operation efficiency.

3.1.3.2. Short operation history of NPP Krško (Fuel Cycles) and NEK SFP current inventory

NEK was operated in Cycles 1-3 with Westinghouse standard (STD) 16x16 fuel. 40 Kraftwerk Union (KWU) 16x16 fuel assemblies were loaded in the core in Cycle 4. A standard out-in fuel management was utilized in Cycles 1-4. A low-leakage fuel management was introduced into NEK in Cycle 5 and it was also used in subsequent cycles. A half of the fresh fuel reloaded in Cycle 7 was Westinghouse standard 16x16 fuel and a half of the fuel was Westinghouse 16x16 fuel with VANTAGE 5 design features. All fresh fuel assemblies (40) loaded in Cycle 8 were Westinghouse 16x16 fuel with VANTAGE 5 design features. The 16x16 fuel assembly with VANTAGE 5 design features is designed as a modification of the standard 16x16 fuel assembly design with the same outer dimensions but with additional features and extended burnup capability.

Beginning with Cycle 15 NEK introduced 24 Westinghouse 16x16 STD fuel assemblies with some VANTAGE + fuel design features. Westinghouse fuel with VANTAGE + design feature uses ZIRLO material as fuel tube cladding, guide thimbles and instrument tubes. Beginning with Cycle 28, NEK introduced another VANTAGE+ feature, zirconium dioxide protective coating on the bottom 7 inches of the ZIRLO fuel rod cladding material. Beginning with the Cycle 29 NEK introduced 56 fuel assemblies with modified VANTAGE+ design features. (modified VANTAGE + fuel design features) [10].

In 2004 (after Cycle 20) NEK introduced a longer fuel cycle in which fuel assemblies are changed once every 18 months. On average, 56 fuel assemblies are discharged from the core to SFP at the end of each cycle. At the end of 2017 there were 1,210 spent fuel assemblies stored in the pool for spent nuclear fuel at the Krško NPP site, taking into account two containers of fuel rods from the fuel reconstitution [11].

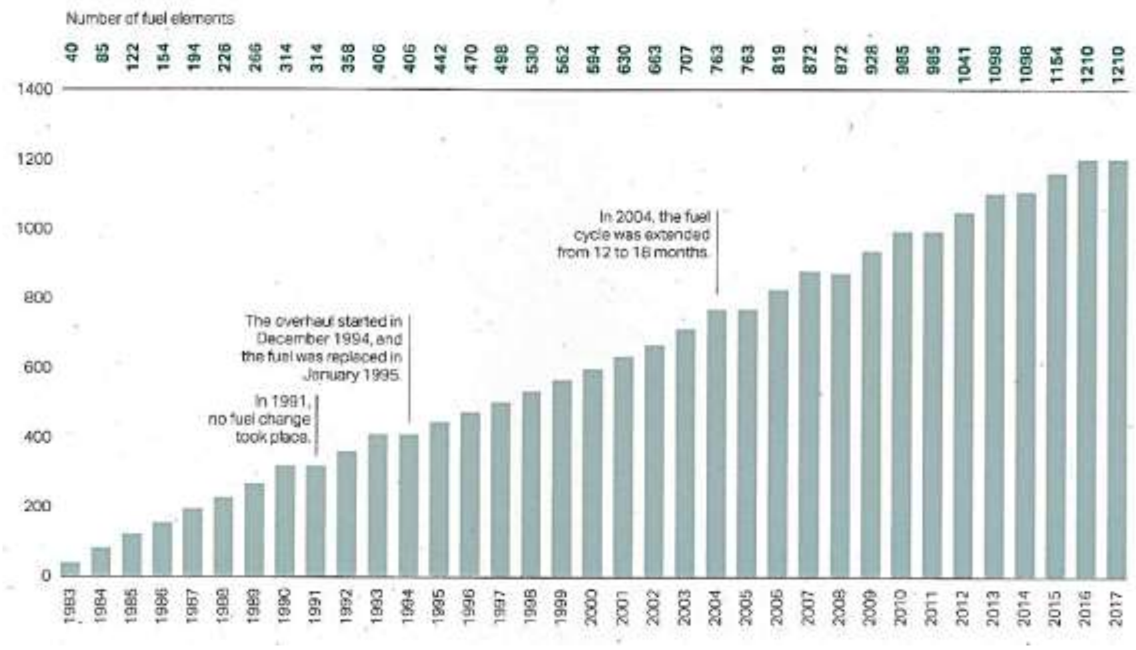


Figure 3.1-9: Inventory of spent fuel assemblies in NEK Spent Fuel Pool (SFP) – (wet storage) [11]

3.1.3.3. SFP Storage capacity and expected spent fuel inventory

Wet storage at NEK - Spent Fuel Pool (SFP) has 1,709 storage locations for spent fuel, of which 26 locations in the New racks are physically inaccessible and 56 locations in the Old racks are administratively prohibited cells. Since space for the entire reactor core must be ensured in the pool at any given moment, at least 121 locations must always be reserved for emergency core unload. The remaining 1,506 locations are physically available for the storage of spent fuel assemblies that can be stored in two out of four, three out of four and four out of four configurations depending on design parameters: initial enrichment, burnup and decay heat. The results of the performed stress tests in 2011 led to an increase in safety reserves and stricter criteria for the placement of fuel assemblies in the storage racks.

3.1.3.4. Planned spent fuel inventory in SFP and SFDS

Planned inventory in SFP and SFDS considering planned transfer phases is presented in Table 3.1-1. Three planned transfer campaigns are taken into account. First phase campaign in 2021, second in 2028 and final campaign envisioned 5 years after reactor core unloading in 2043 (phase three is envisioned in 2048). 60 years of NPP Krško is assumed with final unloading of reactor core before the end of 2043.

Before final unloading of the reactor core in 2043 there will be 1184 SF assemblies in SFDS and less than 1200 SF assemblies in the SF pool. After final unloading of the core there will be less than 1316 SF assemblies in the SF pool. Decay heat of 121 discharged

spent fuel assemblies from the last core 140 h after shutdown is less than 6.4 MW. Decay heat of spent fuel elements in one MPC will not exceed 42.5 kW. Average decay heat of one MPC during loading campaign will be between 26 and 32 kW. Average decay heat of one MPC after 5 years in SFDS will be below 26 kW.

Table 3.1-1: Planned and anticipated SF inventory in Spent Fuel Pool (SFP) and Spent Fuel Dry Storage (SFDS). Final shut down of NPP Krško reactor is foreseen in 2043. Conservative estimates for end of operation in 2048 are given in parenthesis.

Table 3.1-1: Krško NPP current and expected SF inventory

	Year	Total number of SF assemblies	No. SF in SFP	No. SF in SFDS	No. of MPC in SFDS
Phase I	2020	1323	731	592	16
Phase II	2028	1661	477	1184	32
Final shut down	2043	2282	1098	1184	32
5 years cooldown	2048	2282	1098	1184	32
Phase III	2048	2282 (< 2500)	0	2282 (< 2500)	62 (< 68)

Detailed SF inventory (historical and anticipated) is given in Annex 3.4.

3.1.3.5. HLW inventory from NEK decommissioning

During NEK decommissioning quantity of 82.1 t of HLW waste will be generated [4]. This HLW is represented by the activated material which mainly comes from In-Core Instrumentation System, Nuclear Instrumentation System and Rod Control and Position System. Total activity of HLW is assessed to be 2.46×10^{16} Bq. Dominant nuclides are Co-60 (from Baffle Plates, Core Barrel, Thermal Shield, Cladding Reactor Vessel, Insulation and Reactor Vessel) and Eu-152 (from Biological Shield). For packaging of all the reactor pressure vessel (RPV) internals and high activated components approx. 7 Holtec HI-SAFE containers are needed. The Holtec HI-SAFE containers are intended for packaging of the activated and high contaminated parts of the RPV.

Holtec's HI-SAFE storage system provides safe and cost-effective solution for on-site storage of radioactive waste generated from decommissioning of nuclear power plants including highly activated metal components. The waste Canister serves as the confinement enclosure for the waste and the steel-concrete-steel HI-SAFE overpack provides biological shield and physical protection. The HI-SAFE Storage System is allowing its users to utilize the same ancillary equipment as those used to load Holtec's HI-STORM used nuclear fuel dry storage system.

The main dimensions of the Holtec HI-SAFE containers which will be used for storing HLW generated during NEK decommissioning are described in [4] and total storage volume of 7 Holtec HI-SAFE containers is estimated to 237 m^3.

3.1.4. Construction

Most nuclear power plants in the USA were not originally designed with a pool storage capacity sufficient to accommodate the spent fuel generated over the operating life of the power plants. Utilities have developed independent spent fuel storage installations (Dry Storage Systems) as a means of expanding their on-site spent fuel storage capacity.

Sore examples of licensing experience in different IAEA member states is given in Table 3.1-2.

Table 3.1-2 Licensing experience and licensing conditions for Dry Storage Systems [9]

Member State	Initial licence period	Renewal period
Argentina	5 years	5 years
Germany	40 years	none
Hungary	10 years	10 years
Japan	Not limited	N/A
Spain	20 years	20 years
Switzerland	Not limited	N/A
United Kingdom	Not limited (covered under the reactor site licence)	N/A
USA	20 years	20 years

3.1.4.1. DSB construction in NEK

Part of the Krško NPP Safety Upgrade Program is also the construction of a dry storage, which would consequently improve nuclear safety due to its passive nature and by reducing the number of fuel assemblies in the pool. The relevant Krško NPP activities started in 2014 and the contract for the construction of a dry storage facility was signed at the beginning of 2017. The construction of a dry storage facility for spent fuel was addressed by the Intergovernmental Commission for monitoring the implementation of the bilateral Slovenian-Croatian Agreement on the Krško NPP at its 10th session in July 2015 [12]. The Intergovernmental Commission decided that the construction of a dry storage facility at the Krško NPP site to be used until the cessation of the NPP's operation is part of a joint solution for spent fuel disposal and in accordance with point seven of Article 10 of the bilateral Slovenian-Croatian Agreement on the Krško NPP. Costs for SFDS project that includes investment for construction, operation, spent fuel relocation

from wet storage pools to DSB and costs for spent fuel storage canisters until the cessation of the NPP should be covered and be part the Krško NPP operational costs. The construction of dry storage is scheduled for 2020. The first relocation Campaign of SF from the spent fuel pool to the dry storage facility within the Krško NPP is envisaged for 2021. The 3rd Revision of the NPP Krško Decommissioning Program strategy based on PDP rev.6 take into account that a SFDS is constructed on NPP Krško site and that it may be in operation for at least additional 60 years after the end of NPP Krško operation. Additionally, according to ReNPRRO16-25 the assumption that the fuel will remain on site in the SFDS until 2075 with the possibility of prolongation has to be taken into account [4][13][14].

As a consequence of the above two statements two Krško NPP decommissioning cases have been defined:

Base case: Transfer of spent fuel from the fuel handling building (FHB) to SFDS. All buildings and systems that are needed for SFDS operation remain operable until 2103 (end of SFDS operation). The so called "Green field" status decommissioning of the whole NPP Krško site including the SFDS is done after 2103 (removing all installations and building structures).

Sensitivity case: The "Green field" scenario with complete removal of the whole site (including SFDS) is done after 2075. That implies "Brown field" status for the period between releases of the above-mentioned building structures (see base case description) until the end of SFDS operation in 2075.

It is normal to construct SFDS in phases. The compatibility between the NEK FHB dimensions and capabilities and the dry storage facility will be assured with a good practice to utilize a transfer cask. The dry storage facility design will accommodate the transfer cask at CTF (cask transfer facility) within DSB [3].

The construction will include all necessary upgrades to existing structures including FHB Overhead Crane upgrade according to the design changes defined.

Preparatory work and DSB construction are done according to the Slovenian construction code. Preparatory works include ground excavation and relocation of some electrical and water installations within NEK boundary. Relocations as part of preparatory works include relocation of one transformer (TP6), light post, fire protection lines and water supply lines.

3.1.5. Operation

Spent Fuel Dry Storage operations consist of several well-defined steps [3] . These steps can be separated in few major groups:

- Selection of fuel

- Preparations prior to MPC canister loading (wet loading)
- Loading spent fuel into canisters (MPC fuel basket loading)
- Processing for storage (draining, drying and introducing cover helium gas)
- Storage
- Surveillance and monitoring in storage, maintenance

In NEK all these steps will be performed several times in separated Campaigns (Phase I, II and III).

3.1.5.1. Selection of fuel

Each fuel assembly stored in the HI-STORM FW system must satisfy the approved content parameters and storage requirements as defined in both HI-STORM FW MPC Storage System FSAR and HI-STAR 190 Package SAR. The loading procedure addresses the spent fuel specifications (e.g., burn-up, cooling time, heat generation, etc.).

Spent fuel accounting system will be implemented in accordance with the COMMISSION REGULATION (Euratom) No. 302/2005 [13].

3.1.5.2. Preparations prior to MPC canister loading (wet loading)

In order to ensure successful loadings cleanliness is important in order to avoid difficulties in securing effective leak tightness or avoiding contamination of supporting systems; for example, filters. It is essential to execute effective planning where special attention needs to be paid to check the compatibility of individual systems.

Before loading a canister, the operator has to demonstrate that all necessary technical tools are suitable and ready for use. Before any operation, a sequence plan (cask preparation, loading, handling, controls and tests, transfer to storage facility including arrival and emplacement) is established and agreed with the regulator. After loading the cask in the power station and before moving it to the storage facility the operator has to prove to the regulator that all conditions are met for the storage.

3.1.5.3. Loading spent fuel into canisters (MPC fuel basket loading)

Loading of spent fuel into storage canister will be performed using operating procedures provided by the cask manufacturer and will be revised to incorporate NEK specific items, such as fuel handling, a general listing of the major tools and equipment needed to support cask loading and storage operations.

The procedures and fuel handling equipment design ensure that the fuel will not be damaged during its transfer, which would otherwise compromise its integrity. Good practices which have been deployed during spent fuel loading into a cask include:

- Minimizing the number of times the spent fuel assembly is lifted;
- Reducing the height of each lift to its lowest possible value.

The empty MPC 37 is raised and inserted into the HI-TRAC VW at FHB Truck Bay area. HI-TRAC VW and MPC are than raised and lowered into the spent fuel pool cask loading area (CLA). Pre-selected assemblies are loaded into the MPC. HI-TRAC VW and loaded MPC are then moved to FHB Decontamination area (see Figure 3-10).

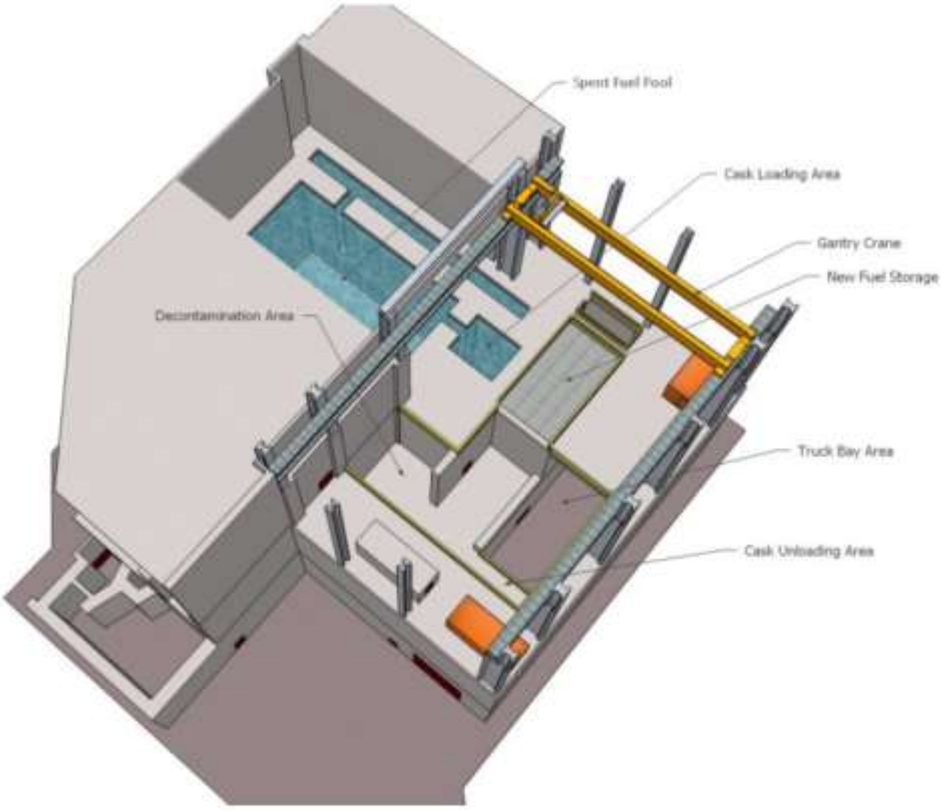


Figure 3.1-10: A 3D model of the FHB building within NEK where loading of the MPC will take place

3.1.5.4. Processing for transfer to DSB

The process steps involved in preparing the loaded HI TRAC and MPC system are defined in HI-STORM FSAR Technical Specifications [8]. Generic steps are: system decontamination, draining water and then drying of the spent fuel and system internals, backfilling of MPC with helium gas and sealing of MPC.

Loaded HI TRAC and MPC system is than lowered to Truck bay area ready for transfer to DSB.

3.1.5.5. Storage

Loaded MPC is transferred from HI-TRAC to HI-STORM in DSB Cask transfer facility (CTF). HI-STORM FW cask is than stored in Dry Storage Building Storage area on concrete pad that secures stability and within the building accommodating ventilation and radiation protection.

3.1.5.6. Surveillance and monitoring in storage, maintenance

Surveillance and monitoring of HI-STORM Dry Storage System during 60 years' service lifetime will be provided. The requirements for periodic inspection and maintenance of the storage overpack throughout the 60-year design life are defined in HI-STORM FSAR. These requirements include provisions for routine inspection of the storage overpack exterior and periodic visual verification that the ventilation flow paths of the storage overpack are free and clear of debris. In addition, the HI-STORM FW system is designed for easy retrieval of the MPC from the storage overpack should it become necessary to perform more detailed inspections and repairs on the storage overpack.

The inert helium atmosphere in the MPC provides a non-oxidizing environment for the SF cladding to assure its integrity during long-term storage. The preservation of the helium atmosphere in the MPC is assured by the robust design of the MPC Confinement Boundary. Maintaining an inert environment in the MPC mitigates conditions that might otherwise lead to SF cladding failures. The required mass quantity of helium backfilled into the canister at the time of closure and the associated fabrication and closure requirements for the canister are specifically set down to assure that an inert helium atmosphere is maintained in the canister throughout the 60-year design life. Reliance on spent fuel performance in dry storage is very much put on the integrity of the storage system itself, and that the spent fuel integrity is not changed with time. This approach was justified in several documents and experimentally justified in the 1990s; for example, see the technical underpinning given in IAEA document "Spent fuel storage operation: lessons learned" [3].

Access to spent fuel assemblies stored in dry storage facility is not as easy as in the storage pools. Like wet storage systems, ageing effects are monitored by strategically deploying corrosion coupons and seal samples which are inspected periodically.

Dry storage system is designed to remove heat using only natural convection without forced air cooling. Each HI-STORM Dry Storage System duct opening is equipped with a heavy duty insect barrier (screen). Routine inspection of the screens or temperature monitoring of the air exiting the outlet ducts is required to ensure that a blockage of the screens is detected and removed in a timely manner.

During surveillance and monitoring phase DSB building needs physical protection, monitoring of temperature and humidity, monitoring of radiation levels in the building

and lighting. All these needs electrical supply to power the systems. DSB building also needs communication connection to IAEA for safeguards purposes.

3.1.5.7. NEK SFDS operation periods

Table 3.1-3: Overview of important milestones in NEK SFDS operation

	Base scenario (Base case)	Alternative scenario (Sensitivity case)
Start o project (contract)	2018	2018
Start of construction	2019	2019
Construction end	2020	2020
Loading campaign - Phase I	2021	2021
Operation	2021-2027	2021-2027
Loading campaign - Phase II	2028	2028
Operation	2029-2048	2029-2048
Loading campaign - Phase III	2048	2048
Operation (Brown field)	2049-2103	2049-2075
SF/HLW transfer to disposal completed (transfer to DGR)	2103	2075
SFDS/DSB Dismantling and decommissioning	2104-2107	2076-2079
Green field	2107	2079

Site specific operation periods for base and sensitivity case are given in Table 3.1-3. The last relocation of SF from the pool to the dry storage facility for both cases is envisaged to take place 5 years after the Krško NPP has ceased to operate (2048, 5 years after NPP Krško reactor final shut down in 2043) and will last for 3 years ending in 2050.

After Phase III loading campaign SFDS facility will not receive new spent fuel elements. All SF and HLW from decommissioning will be stored and monitored in SFDS and not in other structures of NEK. SFP of NEK will be emptied and decontaminated and an alternative facility (dry or wet) will need to be constructed that will enable potential cask re-opening and emptying (or re-packaging) in case an exchange of the MPC is necessary. In this time other NEK structures, systems and components are in brown field state.

As an option (coming out of national policy on spent fuel and radioactive waste management) the SFDS storage can also be used to store (beside HLW generated during

decommissioning) solid and conditioned ILW and HLW coming from potential reprocessing of SF. HLW format following reprocessing has to be determined before storage. After SF reprocessing, most commonly utilized form of HLW are residues arising from reprocessing that are to be returned to the country of the SF owner, responsible for their final management. They consist in high and intermediate level waste (HLW and ILW):

- Vitrified HLW universal canisters (UC-V) containing the fission products – which represent approximately 4% of the initial mass of uranium and most of the SF activity,
- Compacted ILW universal canisters (UC-C), containing the metallic structure of the SF.

National plan for SF and RW management [1] requires from the license owner of the fuel (NEK) to examine the possibility of spent fuel processing until 2025. Residual HLW from SF reprocessing should be solid and packed in standard format for later storage in appropriate Dry Storage facility.

Activities related to SFDS facility in this phase of operation consist of surveillance and monitoring in storage, and potentially, according to need, some maintenance.

There are two different scenarios for the operation of SFDS after Phase III loading campaign. In base scenario, SFDS installation is operating between 2049 to 2102 in alternative scenario this operation period is between 2049 and 2074.

Before the end of this period (in 2103 or 2075 respectively) all inventory in SFDS facility will be transferred and transported to geological disposal facility. Deep geological repository (DGR) is internationally recognized safe long-term disposal solution of HLW and SF (if not reprocessed to HLW). According to national policy for HLW and SF management all inventory of HLW and SF inventory has to be transferred to national, or multinational deep geological facility (reference to Strategy no.5, page 40, [5]), [15].

3.1.6. SFDS Decommissioning

Dismantling and decommissioning of SFDS installation and DSB at NEK will take place after all inventory of SF and HLW stored in the facility will be transferred for final disposal to national, regional or multinational geologic disposal facility.

Dismantling and decommissioning activities will not commence before 2104 in base case scenario or not before 2076 in sensitivity case scenario [4].

The objective of decommissioning activities for the SFDS installation and DSB at the Krško Nuclear Power Plant is to verify that any potential radioactive contamination is below established release limits, and in the unlikely event of contamination, to identify

and remove radioactive contamination that is above the legal release limits, so that the site may be released for unrestricted use and the facility license terminated.

In principle the facility is expected to operate as a "clean" facility. All components of the facility including the transport casks and storage canisters are not expected to have surface contamination during operation. Periodic surveillances and surveys throughout the life of the facility will be performed to identify any possible contamination and to verify that the facility remains clean. Actual decommissioning and dismantling activities will depend on the operating history of the facility.

Residual radioactive contamination at the facility is expected to be minimal for several reasons:

- MPCs are surveyed and decontaminated prior to placement in storage to ensure the outer surfaces are clean.
- MPCs are welded shut and sealed to prevent leaks.
- Radiological activation of the HI-STORM overpacks and concrete pad materials is expected to be minimal, due to low neutron and dose rate.

The MPC units with 37 SF assemblies each are stored inside the HI-STORM overpacks. MPC units will be removed from HI-STORM and placed into HI-STAR casks and transported off site for final disposal in DGR. Once all of the MPCs have been shipped off-site and the decommissioning period begins, a site assessment will be performed to identify any areas that need decontaminations before all systems, structures and components of SFDS installation and DSB are free of contamination.

<u>Dry Storage Building with Concrete Pad</u>

No DSB components will become contaminated since these are not in contact with spent fuel pool water and the MPC is designed to leak tight criteria. It is not anticipated that any components of the DSB will become activated due to proximity to the loaded overpacks. All DSB components will be able to be decommissioning through normal commercial methods.

Due to the design of the HI-STORM system, no residual contamination is expected to be left behind on the concrete pad (floor below HI-STORM) in the DSB. The base pad and peripheral utility structures will require no decontamination or special handling after the last overpack is removed. No activation of the concrete or rebar above clearance levels is anticipated. Therefore, it may be dismantled using normal commercial methods or reused if desired.

<u>HI-STORM Overpack</u>

The HI-STORM overpack consists of steel and concrete. The overpack is expected to have no interior or exterior radioactive surface contamination. The only source of activity is through neutron activation. Any neutron activation of the steel and concrete is expected to be extremely small due to low neutron dose and is also minimized by the design of

the inner steel shell. The activated inner shell (approximately 1 cubic meter per one overpack) can be separated from the rest of the overpack during dismantling. Steel inner shell of HI-STORM is expected to be LILW waste stream.

Activation of concrete in the HI-STORM is expected to be below limits for unconditional free-release (limits taken form UV1 [16] and BSS [17]). HI-STORM overpack concrete has a level of activation which is below limits for free-release. Once removing the inner and outer shell, the concrete can be broken up and treated as normal construction waste.

Alternatively, the HI-STORM can be reused as a storage for another MPC if required by change of circumstances or different national policy direction.

<u>Multi-Purpose Canister (MPC)</u>

All MPCs from SFDS facility will be transported of the site in HI-STAR transportation casks. MPC loaded with spent fuel and closed is a self-contained “Waste Package”, no further handling of the spent fuel stored in the MPC is required prior to transport to a final repository. The MPC is engineered to be suitable as a waste package for permanent disposal in deep geological facility. The materials of construction permitted for the MPC are known to be highly resistant to severe environmental conditions. No carbon steel, paint, or coatings are used or permitted in the MPC.

Transport of the spent fuel to the repository is planned by road. For transport purposes, MPCs with FAs will be transferred in the dry storage building at NEK from HI-STORM storage casks to the HI-STAR transport casks. Fuel elements in MPCs will be conditioned for disposal by insertion into copper disposal casks. The encapsulation process, which will, in the basic scenarios, be carried out in an encapsulation plant at the site of the deep repository, is described in chapter 3.2 about geological disposal of HLW and SF.

Approximately 650 m^3 of long lived LILW and HLW waste from SF dry storage operation, loading and unloading campaigns, transfer of MPCs to final disposal and decommissioning is expected [17]. Amount of waste includes also waste MPCs in which SF fuel assemblies were emplaced for dry storage purposes and from which fuel assemblies are transferred into cooper canisters during encapsulation process. The containers with activated LILW from dry storage will be disposed of in the underground compartments of the service area of the geological repository after ceasing other disposal operations, while LL-LILW and HLW will be disposed of also in the service area or, alternatively, in a special repository space [18][19][20].

3.1.7. Costs

All costs given in this section are expressed in 2018 EUR.

The financing of the construction of a spent fuel dry storage (SFDS) facility are to be part of the Krško NPP operating costs. The operation of the SFDS facility during the operation

of NPP Krško are the part of Krško NPP operating costs [12]. Thus, all costs related to the SFDS until 2043 are financed solely through the price of electricity and are not given as cost in this chapter nor are included in the total storage costs for the purpose of costs assessment to be paid into the NEK decommissioning and disposal funds to collect the necessary assets for SF and RW management from Krško.

All other SFDS costs related to fuel transport from SFP to SFDS location, operation of SFDS after Krško NPP end of operation and SFDS decommissioning are based on 6th Revision of the Preliminary Decommissioning Plan NPP Krsko [21] and included and presented in Third revision of the NPP Krško Decommissioning Program [4] and are not given as cost in this chapter. These included and planned activities are:

- Purchase of 30 additional canisters (Holtec HI-STORM FW) for spent fuel (Phase III – for 1,098 spent fuel assemblies)
- Packaging of the remaining 1,098 SF assemblies (in Phase III) in Holtec containers and transportation to SFDS location
- Operation of the SFDS
    - Management/operational personnel (NEK) with 1 on-site manager and 2 technicians
    - Security service (NEK): 365 days per year, 24 h per day, 2 guards per shift, 5 shifts
    - Consumables and non-personnel costs (lump sum): 50,000 € per year
- Decommissioning of the SFDS
    - Dismantling of equipment and components
    - Dismantling and packaging of the concrete shielding of the Holtec HI-STORM and Holtec HI-SAFE casks
    - Measurements for release the building from nuclear constraints
    - Conventional demolition

Costs during SFDS regular operation are including costs for consumables, physical protection, electricity costs (lightning, temperature, humidity and radiation monitoring) and costs of communication connection are part of Third revision of the NPP Krško Decommissioning Program [4] and are in the order of 0.4 million € per year.

Transport of the SF in MPCs to DGR is assessed and included in the reference scenario for geological disposal facility [20]. Costs are therefore presented within chapter 3.2 about spent fuel disposal program and are covered by two Decommissioning Funds in Republic of Slovenia and Republic of Croatia (Sklad NEK and Fund).

<u>Cost of compensations paid to local communities</u>

The cost of compensation paid to local communities in accordance with Slovenian legislation for the storage of SF in SFDS. The radioactive waste storage facility in Slovenia

is obliged to pay compensation for restricted land use. Payment of compensation is pursuant to the Slovenian legislation and currently regulated by the Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas (Decree UV8) [22]. By the ZVISJV-1 [23] and the decree UV8 the entity liable to pay compensation is the operator of facility. Compensations fees are not paid twice if there are several facilities within one license holder premises [22][24].

Compensation for restricted land use on the basis of Decree on restricted land use [24] and Decree on compensation rates [22] was set in reference documentation [25] to 5.885 million € per annum and is based on actual payments of Sklad NEK for 2017 for LILW repository Vrbina Krško. For the purpose of cost estimates it is according to ICC decision from its 19th session [26], considered that the compensation is paid annually in the amount of 824,964 € from 2059 (end of Krško NPP decommissioning in 2058) throughout 2103 when SFDS operation ends. The total expected amount of compensations paid by two Decommissioning Funds in Republic of Slovenia and Republic of Croatia (Sklad NEK and Fund) based on annual payment of 824,964 € is estimated to 37.123 million €. In Table 3.1-4 all costs associated with HLW and SF storage operation of the spent fuel and its decommissioning after the final shutdown of the Krško NPP (2043) are presented.

As mentioned earlier in this subchapter all nominal and tax costs associated with SFDS storage operation of the spent fuel and its decommissioning are included in the Third revision of the NPP Krško Decommissioning Program [4]. Only SFDS costs due to compensation for restricted land use are part of Third Revision of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program and as such included in the total costs for RW and SF management in Chapter 8 of the 3rd revision document.

Table 3.1-4 Total costs for HLW&SF storage

In million EUR	**Nominal costs**[1]	**Tax**[2]	**Compensation costs**[3]	**Total**
HLW&SF storage costs	75.6	12.8	37.123	**125.523**

[1] Part of 3rd Revision of the NPP Krško Decommissioning Program [13].
[2] Part of 3rd Revision of the NPP Krško Decommissioning Program [13].
[3] VAT is not payable for compensation costs.

3.2. Krško NPP SF&HLW disposal

3.2.1. Introduction and background

The deep geological repository (DGR) is the only internationally accepted solution for long term and final SF and HLW management. It consists of underground facilities and a number of above ground facilities, which are indispensable for normal underground repository operation. The underground part has two areas: central service area and disposal area. It is connected to the surface part through access shafts and a waste transportation ramp. The ground facilities include several areas with different safety regime: unfenced area with visitor centre and utility supports, industrial area with office building and auxiliary workshops and technological area with possible encapsulation plant and service buildings.

3.2.1.1. Reference scenario for DGR from 2004

The assessments of technical and financial measures for establishment of deep geological repository for SF and HLW started with development of the Programme of NPP Krško Decommissioning and SF & LILW Disposal according to the Bilateral Agreement. In 2004, as part of the first Programme of NPP Krško Decommissioning and SF & LILW Disposal (DP Rev.1) [27] the disposal of SF was for the first time more thoroughly addressed. The main purpose was to propose key technical solutions for DGR according to international approaches and to assess costs of basic elements of the SF disposal to gain the insight into the future nuclear liabilities related to SF long term management. The result of this activity was to define the target values for both national decommissioning funds which collect the assets for SF and RW management from Krško NPP in Slovenia and Croatia.

As part of the DP Rev.1 two different spent fuel disposal options were investigated: the disposal of SF in one of the two countries and permanent export of SF. After evaluation of both options the disposal of SF in Slovenia or Croatia was accepted as more feasible option and developed as a reference disposal scenario in which dry storage was introduced and disposal started 45 years after NPP shutdown. The reference scenario was based on the Swedish concept of disposal in hard rock and was developed with the assistance of the international experts [28][29] and elaborated as Reference Scenario 2004 (RS 2004) in a study Spent Nuclear Fuel and High Level Waste Disposal in Slovenia

– Assessment of Spent Fuel Management Costs [30]. The RS 2004 was based on the following presumptions:

- The operating lifetime of the NPP Krško will end in 2023 after 40-year operation. No lifetime extension is taken into account.
- Only direct disposal of spent nuclear fuel is considered (no reprocessing).
- A joint single repository will be developed for SF and HLW from NPP Krško regardless of shared ownership of SF and HLW.
- The repository will be constructed in a hard rock environment at a depth of 500 m.
- The capacity of the repository must be planned to accommodate both the estimated spent fuel quantity at the end of the planned NPP Krško life time (620 tons of heavy metal), as well as a small quantity of HLW generated during NPP Krško decommissioning (~16 m^3).
- The operating schedule must be harmonized with the activities of decommissioning plan.
- Encapsulation plant is part of the reference disposal concept. Packaging of SF also follows the Swedish model. Fuel elements are inserted and sealed in massive copper canisters with cast iron inserts.
- Planned repository operation starts in 2065. After 7 years of operation it is planned to be closed. Total quantity of 420 canisters would be deposited within this period.

The total nominal cost for SF disposal was estimated to 567.7 million EUR in euro units from the year 2002. No taxation or cost for transport were included in the estimates which were based on expert judgments and without real technical data.

3.2.1.2. Developments between 2004 and 2009

Since 2004, several actions were taken to increase the specific knowledge on geological disposal and to make basic preparations for the new iteration of the reference scenario for SF disposal. Some of these activities were performed as part of the IAEA Technical cooperation programme with ARAO which allowed several expert missions on selected topics; others were performed on bilateral basis with foreign waste management organizations and on contractual arrangements with different national research institutes and engineering companies. The following inputs were provided for new revision of the Programme of NPP Krško Decommissioning and SF & LILW Disposal according to the Bilateral Agreement:

- **Novelation of Geological Disposal Programme:** including an outline of a geological repository development phases, explanation of the mutual links among particular elements of the project, indication of technical options to be considered during the repository development, and advice on managing the project, all provided through the IAEA expert mission [31];
- **Geological Data Acquisition**: with the assistance of foreign experts [32] more systematic approach has been taken to collect and assess the available existing data on geological environment of interest for geological disposal in Slovenia, which includes hard and sedimentary rock [33][34]. The further geological data acquisition proposal was developed taking into account very limited geological data at depth of several hundred meters [35].
- **PA/SA:** the first preliminary performance assessment of a reference geological repository in hard rock [36] was performed to demonstrate safety of the proposed disposal system, mainly based on expert judgments and estimations amended from literature or based on experience from other projects. For the source term estimations based on calculations of isotopic composition, activity and heat output of selected spent fuel assemblies [37] were taken. The work of the PA/SA team has been supported also by an IAEA expert mission [38] in which an expert advice and recommendations were given on different aspects relevant for further development of PA/SA of geological disposal.
- **Cost calculations:** Several expert missions were also organized to review the first cost assessment of the reference scenario, to provide recommendations on how to improve the costs estimates of spent fuel disposal including the uncertainties treatment of different cost items and evaluation of contingencies [39][40][41][42].
- **Optimization of canisters' utilization:** To optimize the utilization of canisters' capacity based on the total heat output and reduce the number of canisters needed to accommodate all spent fuel a special programme was developed based on heuristic approach to optimize the solution [43]. With this methodology the number of required canisters is optimized. The method can also be used to define the minimum cooling period at which the full capacity of all canisters can be optimally used.

3.2.1.3. Revised Reference Scenario for DGR from 2009

In 2009, a Revised Reference Scenario (RRS 2009) for a geological repository in hard rock with an estimate of costs relating to the scenario implementation [44] was developed and integrated in the Program of NPP Krško Decommissioning and SF & LILW Disposal, Revision 2 (DP Rev.2) . The revised scenario postulates two alternatives for NEK operation - operation till 2023 or till 2043, with a prior spent fuel storage period in each of the alternatives. The following assumptions were considered for RRS 2009:

- Only direct disposal of SF (no reprocessing);
- The repository will be constructed in hard rock environment at the depth of 500 m; the entire disposal system remains based on the Swedish KBS-3V concept, developed by Swedish Spent Fuel Management Agency (SKB);
- The repository development includes also the construction and operation of an under-ground testing facility at the site of future repository;
- Sufficient cooling period is required and taken prior the disposal to allow optimal utilization of canister capacity (4 SF elements per canister);
- Two main scenarios to be considered:
  - Scenario No. 1 – start of the NPP decommissioning in 2023, start of repository operation in the year 2068 after 50-year of SF storage, number of encapsulated copper canisters: 389 (+10 canisters for training),
  - Scenario No. 2 – start of the NPP decommissioning in 2043, start of repository operation in the year 2088 after 50-year of SF storage, number of encapsulated copper canisters: 571 (+10 canisters for training).
- All other HLW originating from NPP decommissioning and long-lived LILW from operation and decommissioning of nuclear facilities will be disposed in DGR.

The revised reference scenario for SF disposal in 2009 have been developed by using some presumptions the same as for the previous version and some of them being new. The deep geological repository consists of underground facilities and a number of above ground facilities, which are indispensable for normal underground repository operation. The underground part has two areas: central service area and disposal area. It is connected to the surface part through access shafts and a waste transportation ramp.

The disposal area at a depth of 500 meters consists of a number of disposal tunnels, conventionally excavated by means of drilling and blasting. From the bottom of each tunnel, vertical boreholes are drilled with due spacing regarding heat distribution around the canister. Canisters are lowered into the holes and surrounded by a layer of bentonite clay called a buffer, since it protects the canister against small movements in the rock and keeps it in place. The disposal tunnel is continuously backfilled with a mixture of crushed rock and bentonite in step with the progress of emplacement of the canisters. Encapsulation plant is part of the reference disposal concept. Packaging of SF

also follows the Swedish model. Fuel elements are inserted and sealed in massive copper canisters with cast iron inserts. Based on provisions of the reference scenario, canisters are procured by an outside supplier rather than being manufactured locally.

In sensitivity analysis different variants of technical solutions were investigated and costs assessed (different depth of repository's underground facilities, variation in boreholes spacing for SF emplacement, different composition of back-filling material, increased number of required boreholes due to possible unfavourable geological conditions, ramp access or vertical access to the underground facilities).

Costs in the RRS 2009 were calculated for both scenarios for price level of € in December 2008. In the first alternative considered (NEK operation till 2023, disposal of 1553 fuel elements in 389 canisters, 45 years of spent fuel storage prior to disposal), the total costs amounted to 1,116 million EUR. In the second alternative considered (NEK operation till 2043; disposal of 2281 fuel elements in 571 canisters, also 45 years of storage) they amounted to 1,311 million EUR. The total costs include beside all technical and administrative expenses also contingencies and Value Added Tax (VAT).

3.2.2. SF &HLW Inventory for disposal

The Krško NPP is equipped with a Westinghouse pressurized light water reactor, and started with trial operation in autumn 1981, and with commercial operation since 1983. It Prior to its steam generators being replaced in 2000 and a power up-rate, the generator output reached 664 MWe. At present, the generator output is 727 MWe; however, its net output is 696 MWe. The NPP originally operated in twelve-month fuel cycles (up to the cycle 19 in 2002/2003).

The NPP Krško reactor core is composed of 121 fuel elements. During the course of each refuelling, part of spent fuel assemblies is discharged and replaced by the fresh ones. With the exception of some fuel cycles in the late eighties and beginning of nineties the first two decades of its commercial operation the NPP Krško operated in twelve-months fuel cycles. After steam generators replacement, the NPP Krško extended its fuel cycles to fifteen-months and from the year 2004 it has been operating in eighteen-month fuel cycles.

The average number of replaced fuel assemblies (FA) during each refuelling in 12-months fuel cycle was 37 (the actual number varying from 28 to 48) and increased during refuelling after 2004 where 56 fuel elements are replaced with fresh fuel in 18-months fuel cycle. Spent fuel assemblies are kept under water in the spent fuel pool, where they are cooled.

Each fuel assembly is composed of 235 fuel rods, filled with ceramic uranium dioxide pellets. Fuel pellets are inside zircaloy-4 (ZIRLO) cladding. Outside dimensions of a fuel element or a fuel assembly are 20 cm x 20 cm x 376 cm (including support platform).

The uranium enrichment rate has increased from 2.1 % in the first core loading to app. 5 %. Fuel assembly burn-up rate of 36 GWd/tU has also increased to 50 GWd/tU as a result of extended fuel cycles.

Some technical data on the nuclear fuel:

- Number of Fuel Assemblies in the Core: 121
- Number of Fuel Rods per Assembly: 235
- Fuel Rod Array in Fuel Assembly: 16 x 16
- Fuel Rod Length: 3.658 m
- Clad Thickness: 0.0572 cm
- Clad Material: Zircaloy-4, ZIRLO
- Fuel Chemical Composition: UO_2
- Pellet Diameter: 8.192 mm
- Pellet Height: 9.8 mm
- Type Standard, Vantage V5/V+

3.2.2.1. Spent Fuel Inventory

The Krško NPP planning considers nuclear fuel cycles until the year 2043, with a total number of 2,282 fuel assemblies [45][20] . The average mass of heavy metal in fuel assemblies is about 406 kg. Enrichment has changed during operation from 2.1 w% in the first core load in the year 1983 to 4.95 w% in the year 2007. Accordingly, burn-up for different typical fuel assemblies is taken into consideration:

- 50,000 MWd/tU (4.95 % enrichment)
- 45,000 MWd/tU (4.3 % enrichment)
- 35,000 MWd/tU (3.6 % enrichment)
- 25,000 MWd/tU (2.6 % enrichment)
- 15,000 MWd/tU (2.1 % enrichment).

The decay heat of the Krško NPP fuel assemblies has been calculated for fuel cycles planned up to 2043 [46]. It has been calculated for each assembly stored in the spent fuel pool. For the planned fuel cycles (18-month refuelling) the decay heat has been calculated for each refuelling.

An optimization of the Krško NPP spent nuclear fuel loading in canisters according to the maximal allowed decay heat was performed. A computer code which combines spent fuel assemblies into groups (canisters) of up to 4 while minimizing the number of canisters has been developed [43]. Assuming a 1600 W decay heat limit per canister and an optimal loading of 4 fuel assemblies in all canisters, the study shows that, in the case of plant lifetime extension until 2043, all canisters could be loaded with 4 fuel elements

after the year 2050. Criticality analysis was also performed; emplacement of 4 fuel elements into each canister is potentially possible [47].

3.2.2.2. Data on Other Waste to be Disposed

Besides spent nuclear fuel other HLW originating from NPP decommissioning and long-lived LILW from operation and decommissioning of nuclear facilities and other nuclear applications will be disposed of in geological repository. The expected quantities are estimated to:

- decommissioning HLW from NEK, packed in 7 Holtec HI-SAFE containers with disposal volume of 237 m^3 of (PDP, Table 8-9) [45][20];
- 650 m^3 of SF dry storage operational and decommissioning waste [19][20] ;
- 172 m^3 of encapsulation facility operational and decommissioning waste [48]; and
- 3000 m^3 of repository operational and decommissioning waste; 5 % of waste are assessed to be LL-HLW [49].

The containers with short lived LILW from decommissioning of above ground facilities and activated LILW from dry storage will be disposed of in the underground compartments of the service area after ceasing other disposal operations, while LL-LILW and HLW will be disposed of also in the service area or, alternatively, in a special repository space. The same solution is proposed by Posiva, Finland. It is anticipated that at the time of closure of the geological repository, the LILW disposal facility will be already closed.

3.2.3. Transition from storage to disposal

The new dry SF storage which is under licencing for construction licence at Krško NPP will be used for storing of all SF and HLW generated at NPP until deep geological repository will be developed. The duration of the storage period is determined by considering cooling of SF and optimal loading of disposal canisters in two variants: a storage period of 60 years after NEK shut down until 2103 (an optimal solution) and a storage period of 32 years after NEK shut down until 2075 (an alternative solution).

Transport of the spent nuclear fuel to the repository is planned by road. For transport purposes, MPCs (Multi-Purpose Containers) with FAs will be moved in the dry SF storage building at NEK from HI-STORM storage casks to the HI-STAR transport casks.

Transport of spent nuclear fuel will begin after the start of regular operation of the repository. Transports will be carried out between the spent fuel storage facility at NEK

and the DG repository in case that encapsulation plant will be part of DGR. In case of spent fuel encapsulation at a regional encapsulation plant (abroad), transports will be carried out between the spent fuel storage facility at NEK and the encapsulation plant. Encapsulated spent fuel will be transported to the DG repository (either local or regional).

Transport activities will be carried out in accordance with the provisions of the Act on Transport of Dangerous Goods Act [50]. In article 3, the act stipulates that the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) with the appendixes A and B is to be used for the transport of dangerous goods by road. In accordance with these regulations a transport package, i.e. the HI-STAR cask has to be so designed that in normal use and in case of anticipated accidents it provides adequate radiological shielding and prevents the release of radioactive materials. According to the ADR regulation for transport of spent fuel type B packages are used.

It is conservatively assumed that the distance between the spent fuel storage facility at NEK and the repository is 200 km and that the distance between the spent fuel storage facility at NEK and a regional encapsulation plant or regional repository is 1000 km. Such assumption is introduced for transport costing purposes only. Additionally, encapsulation plant at NEK site is technically feasibility solution that together with encapsulation plant on DGR site present optimisation where less SF transports are needed. Only conservative cost estimate is included in the total disposal costs, noting that costs in case of optimisation can be easily obtained by deducting SF transport costs.

3.2.4. Reference scenario 2018 for geological disposal

The reference scenario 2018 (RS 2018) for deep geological repository (DGR) in hard rock with cost estimation for its implementation [20] includes new technical, technological, statutory and organizational developments and all other requirements to calculate new cost estimates for spent fuel (SF) disposal from NEK at a generic location in Slovenia or Croatia. Two basic scenarios, both with NEK operation until 2043 as was decided by responsible authorities, are examined as follows:

- Base case scenario (Scenario No. 1) – start of regular operation of the SF repository in 2093; 10 years of operation; dry storage facility needed until 2103;
- Sensitivity case scenario (Scenario No. 2) – start of regular operation of the SF repository in 2065; 10 years of operation; dry storage facility needed until 2075.

In addition, several options are assumed and evaluated for RS 2018 as alternative solutions:

  - Option 1: Post closure monitoring for 50 years (not part of basic scenarios);
  - Option 2: Encapsulation in regional encapsulation plant; and
  - Option 3: Disposal in multinational repository (dual-track approach).

The cost estimates for the scenarios considered are based on integrated list of all relevant activities from initial R&D to final disposal of SF and on revised technical solutions for SF disposal in a hard rock geological environment. The Swedish disposal concept KBS-3V is taken as a basis and has been improved and elaborated in detail up to the implementation level based on experience of the Olkiluoto SF repository (Posiva, Finland) for which construction started in 2016. The RS 2018 also includes information of the status and development of all available SF disposal methods, including disposal in sedimentary rock formation. Prior to the start of the geological disposal program, the reference scenario will be revised several times (every 5 years for decommissioning fees purposes). An alternative disposal method will be introduced, if found more appropriate and mature.

The revised cost estimates will be part of the basis for determination of a special (radwaste management) fee which is charged to power utilities and for the relevant funds to be paid into the NEK decommissioning and disposal funds in Slovenia and Croatia.

3.2.4.1. Requirements and presumptions

The following basic requirements are considered in the reference scenario 2018 for DGR:

- In total 2282 SF elements will be disposed of.
- SF will be stored at the NEK site prior to disposal. The duration of the storage period is defined by considering cooling of the SF and the optimal filling of the disposal canisters. A storage period of at least 32 years after the NEK shut down in 2043 is achievable, assuming repository operation from 2065 to 2075 in accordance with ReNPRRO16-25 [5]; this is labelled as early storage duration; however, a storage period of at least 50 years after the NEK shut down (i.e. till the start of repository operation in 2093) is assumed as an optimal one.
- An Underground Testing Facility (UTF) shall be constructed as the first phase of the disposal facility.
- The generic site of the shared repository is in a hard rock formation in Slovenia or Croatia.
- In the pre-activation stage before adoption of a chosen repository concept, RS 2018 includes also monitoring of the status and development of all available SF disposal methods, including disposal in sedimentary rock formation. In this stage maintenance and periodic revision of the deep geological disposal programme, RD&D, international cooperation and project administration will be carried out.

- In the base case scenario, the site selection program begins in 2055, the final site for which spatial planning commences is chosen in 2065 and its designation in 2069; confirmation of the site is in 2086 and construction begins in 2087,
- The site of the repository is 200 km from the SF storage facility at the NEK site.
- Four assemblies of SF are encapsulated into each copper canister for disposal. In the basic scenarios (No.1 and No. 2), the encapsulation plant is part of the above-ground repository facilities. As an alternative, encapsulation at a shared regional encapsulation plant 1000 km away from the SF store at the NEK site is considered.
- The disposal area is located at a depth of 500 m; an alternative depth of 800 m is also evaluated.
- The disposal area is accessed by way of an access ramp. Alternatively, access via an access shaft is also considered.
- Disposal boreholes are vertically oriented and lie 9 m apart. Distances of 8 and 10 m and space requirements for an additional 20 % of boreholes are also considered.
- In addition to SF, long-lived LILW and HLW as well as operational and decommissioning LILW from the dry storage and the encapsulation/repository facilities will be disposed of in the geological repository. Disposal of this waste is anticipated to take place in the abandoned underground service compartments or, as an alternative, in a special underground compartment.
- As an alternative to the basic scenarios which assume that SF disposal is in a shared bilateral repository in Slovenia or Croatia, a multinational option for disposal is considered. A multinational / shared regional repository, including an encapsulation plant, 1000 km from the SF storage at the NEK site is considered.
- Costs of items and activities are specified in fixed costs for June 2018. VAT is defined in accordance with the Slovenian and Croatian tax regulations in force in 2018. Compensation costs are presented separately and defined in accordance with the Slovenian regulation [22] and in accordance to decision of the ICC [26].
- Regarding the spatial planning, construction, public investments and nuclear safety requirements, relevant Slovenian legislation and corresponding procedures are considered.

3.2.4.2. Host rock properties

The geological disposal facility will be sited at a location within the Slovenian or Croatian national borders in an appropriate hard rock geological formation. The site selection process will consist of four stages, i.e. concept and planning stage, area survey stage, site characterization stage and site confirmation stage according to the IAEA recommendations. Reference data for Swedish Kristallin-I and Äspö hard rock geological conditions are assumed to be sufficiently representative for the current phase of the Slovenian/Croatian program.

Geology - general: The host rock is a natural barrier, which should enable several safety functions of the repository, like mechanical and chemical confinement for the disposal system with low transport of radionuclides. "Crystalline rock" refers to an igneous and or metamorphic hard rock, which implies that the rock has favourable mechanical properties for construction of underground structures (high strength, mainly elastic deformation) and that the rock at the chosen depth does not behave plastically (no creep, no long-term deformation). The rock is brittle which means that, locally, zones of cracks and faults with practically no self-sealing properties are to be expected. These zones have very different hydro-geological and mechanical properties from the undisturbed rock mass and will be therefore minimized.

Hydro-geological properties: It is assumed that the permeability of the potential unfractured magmatic and metamorphic rocks will range from 10^{-8} m/s to approximately 10^{-12} m/s. The permeability coefficient of a weathered layer closer to the surface may lie between 10^{-6} and 10^{-8} m/s. Due to the complex tectonically induced structure of the area, the rocks express pronounced foliation and brittle fracturing. Therefore, the fracture permeability may be "high", and locally "very high". It is also estimated that the unsaturated zone is shallow, being limited to topmost horizon of the weathered rock. The unweathered rock mass is assumed to be in saturated conditions. Groundwater flow is governed by faults and fracture networks.

Thermal properties of the rock: The expected depth of the high-level radioactive waste repository is approximately 500 m. Higher rock temperatures are expected at this level than near to surface. Temperatures at these depths in areas with igneous and metamorphic rocks in Slovenian and Croatian geological regions are estimated up to 30^0 C, which is somewhat higher than what is observed in Sweden (11^0 to 14^0 C). The canister and tunnel spacing will have to be recalculated accordingly in the next phases of the project. Estimates of heat conductivity of magmatic and metamorphic rocks in Slovenia were made and values from 2.5 (tuff) to 3.4 W/mK (gneiss). The data are not essentially different from the ones of the Scandinavian rocks in which the concept of KBS-3 repository was analysed (2.91 W/(mK) - Posiva and 3,6 W/(mK) – SKB).

Hydraulic parameters: Since the site has not been selected yet, some hydraulic rock parameters from the literature for a similar type of rock have been collected (parameter values for Kristallin-I and Äspö rock type) and serve as first reference for values.

Geotechnical rock mass quality: Mechanical parameter estimates are given on the basis of the existing data from rock investigations for typical potential igneous and metamorphic rock formations in the Slovenia/Croatia region. Geotechnical rock quality is expected to be for the largest part of the repository "very good" to "exceptionally good" where normally no support is required for a span of 10 m of the underground openings. In minor parts of repository worse rock conditions can be expected with classes from "fair" to "good". In the access gallery and in the shafts, in the upper, weathered parts and in some major fault zones, some even worse conditions could be expected in gneiss or in phyllite. This means that some more support would be required (e.g. shotcrete with wire mesh, systematic rock bolting, and steel ribs); generally, no tunnel lining is expected to be necessary.

The following rock parameters could be assumed in the majority of the rock:

- Unconfined compressive strength: 100 MPa
- Unit weight: 27kN/m^3
- Poisson's coefficient: 0.23
- E- module 40 GPa
- E_{dyn}: 100 GPa

For the fractured rock at 500 m depth:

- Unconfined compressive strength: 18 MPa
- Unit weight: 26 kN/m^3
- Poisson's coefficient: 0.28
- E- module 2 GPa
- E_{dyn}: 10 GPa

The given values are chosen to be rather pessimistic. In the primary rock stress field, some anisotropy can be expected, due to the nearby alpine orogenesis.

3.2.4.3. Disposal Concept and Development of Scenarios

The disposal concept [49] includes only those elements which are directly connected to the disposal activities and are needed for establishment of DGR. It does not address either pre-disposal spent fuel management or, in basic scenarios, off-site infrastructure. The geological disposal program is consistent with the preliminary decommissioning plan for the NPP Krško after final shut down in 2043, as described in the PDP [21]. The main milestone, i.e. start of operation of the geological repository, is set based on the chosen dry storage period. Two basic scenarios - Base case scenario No. 1 and Sensitivity

case scenario No. 2 - foresee the NPP operation until 2043 and differ in the start of DGR operation. In the first scenario the disposal of SF starts after 50-year period of storage in 2093 and in the second scenario after shorter storage period in 2065. In both cases all activities necessary for DGR would be the same, operation would last for 10 years only.

The disposal concept for both scenarios follows the SKB KBS-3V model of disposal and includes at the repository site all structures, systems and components needed for the repository to operate as an independent nuclear facility. Because of operating requirements and of necessary physical protection measures, the entire repository area will be divided into four areas: unfenced area with support buildings and systems, industrial area with fences due to industrial security (including offices, production buildings and workshops), technological above ground area with fences due to radiological and nuclear safety (with encapsulation plant, service buildings and auxiliary systems) and underground facilities (access ramp and tunnels, service area and disposal tunnels with disposal boreholes)

3.2.4.3.1. Encapsulation of spent fuel

The encapsulation plant is part of the disposal concept in both basic scenarios. Encapsulation plant (EP) is located at the repository site. The plant will contain units for acceptance of transport containers with SF, for encapsulation of SF in copper canisters including handling area, for dispatching and transportation of canisters to underground disposal facilities, unit for treatment and packaging of LILW, office building, store and auxiliary facilities and systems.

In the proposed concept the encapsulation plant has an annual production capacity to encapsulate 60 copper canisters per year which allows sufficient capacities for all SF in operational period. After the encapsulation is completed, the plant shall be decommissioned, and radioactive decommissioning waste shall be transported to the repository. The operation period for encapsulation plant is 10 years in both basic scenarios after 1 year of trial operation. Its operation ceases simultaneously with the repository operation.

Description of encapsulation process is described in more detail in the RS 2018 [20].

3.2.4.3.2. Canisters

Spent fuel will be encapsulated according to the Swedish concept. Fuel assemblies will be inserted and sealed into massive copper canisters. Their main function is to isolate spent fuel assemblies from their environment. Canister is approximately a 1 m-diameter and 4.7 m-high cylinder with 5 cm-thick anticorrosion overpack of copper. From the

inside it is reinforced by cast iron insert which can accept four PWR fuel assemblies. The insert also serves as a pressure-bearing component. After inserting the spent fuel assemblies into the canister, the lid of the canister is sealed by an electron beam welding machine. The weight of canister filled with SF is about 25 t.

The maximum temperature on the canister surface is limited to the design temperature of 100°C. However, due to the uncertainties of thermal analysis, the allowable maximum canister temperature is set to 90°C causing a safety margin of 10°C. Namely, the rock thermal diffusivity is low, and the heat released from the canisters is spread into the surrounding rock volume quite slowly causing a thermal gradient in the rock close to canisters. Consequently, the canister temperature is increased remarkably. The layout of copper canister in given in Figure 3-11.

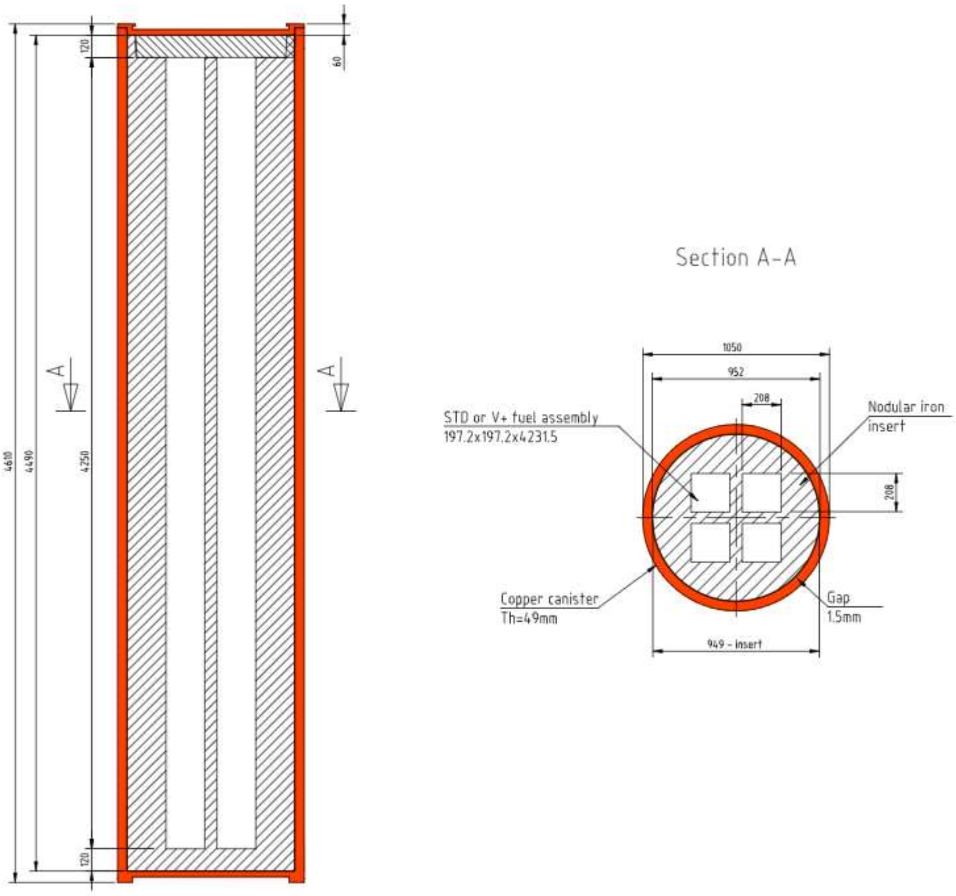


Figure 3.2-1: Copper Canister with Cast Iron Insert

In both scenarios it is assumed that copper canisters will either be bought from a producer or else manufactured in a dedicated Slovenian facility, following agreements for technology transfer. The cost assessment for both possibilities is almost the same [33].

The quantity requirements for canisters are based upon residual heat data of the spent fuel assemblies from previous cycles and upon estimated residual heat data of spent

fuel assemblies from future cycles. Based on the thermal analysis performed by SKB [29] for Aberg site the maximal thermal output of 1,600 W per canister is used as the limit to calculate minimum number of canisters for SF encapsulation [43]. The minimum required number of canisters for both basic scenarios is 571, based on the calculated number of SF elements of 2,282 produced by the end of NPP operation in 2043. All canisters are maximally utilized and entirely filled in with 4 SF assemblies. Several canisters in addition to the required number will be purchased for testing purposes (to test and train welding technology), therefore the annual capacity in encapsulation plant is 60 canisters.

3.2.4.3.3. Repository description

Deep geological repository (Figure 3-12) consists of underground facilities and a number of above ground facilities, which are indispensable for normal underground repository operation. In terms of operating requirements and requirements of physical protection, the entire repository area is divided into four areas: unfenced area, accessible also to visitors, fenced industrial area under industrial security regime, fenced technological above-ground area under nuclear security and radiological control and underground area. The surface part is connected with the underground part with access and disposal tunnels through access ramp or alternatively access shaft, through service and ventilation shaft. Functions of the access ramp (or alternatively access shaft) will be used for transport of excavated rock to the surface and for all transport requirements during operation, decommissioning and closure activities.

It is assumed that the construction of the repository will start with construction of an underground testing facility (UTF) as part of the site investigation and characterization process.

Underground Test Facility

The UTF will be used to obtain further information to plan the repository in detail and to assess safety and construction engineering solutions. The UTF will also enable final disposal technology to be tested under actual conditions. The UTF is not intended solely for research activities but will also be designed to serve as an access route to the repository when constructed. The UTF is also so designed that at a later stage it can be used as a part of the repository.

The UTF will be constructed at a level of -500 m (or -800 m as an alternative) and will consist of the following underground rooms:

- access ramp (alternatively, shaft),
- service shaft,
- service drift with auxiliary compartments for water collection,

- vault for testing and demonstration (which could be later used as a vehicle vault),
- technical vault (which could be later used as a utility vault), and
- characterization tunnel (which could be later used as an access tunnel).

Establishment of the UTF will necessitate construction of some above ground structures, like utility networks, research/geology building, service building, repository access building (entrance to access ramp), spent water management facilities and rock spoil heaps.

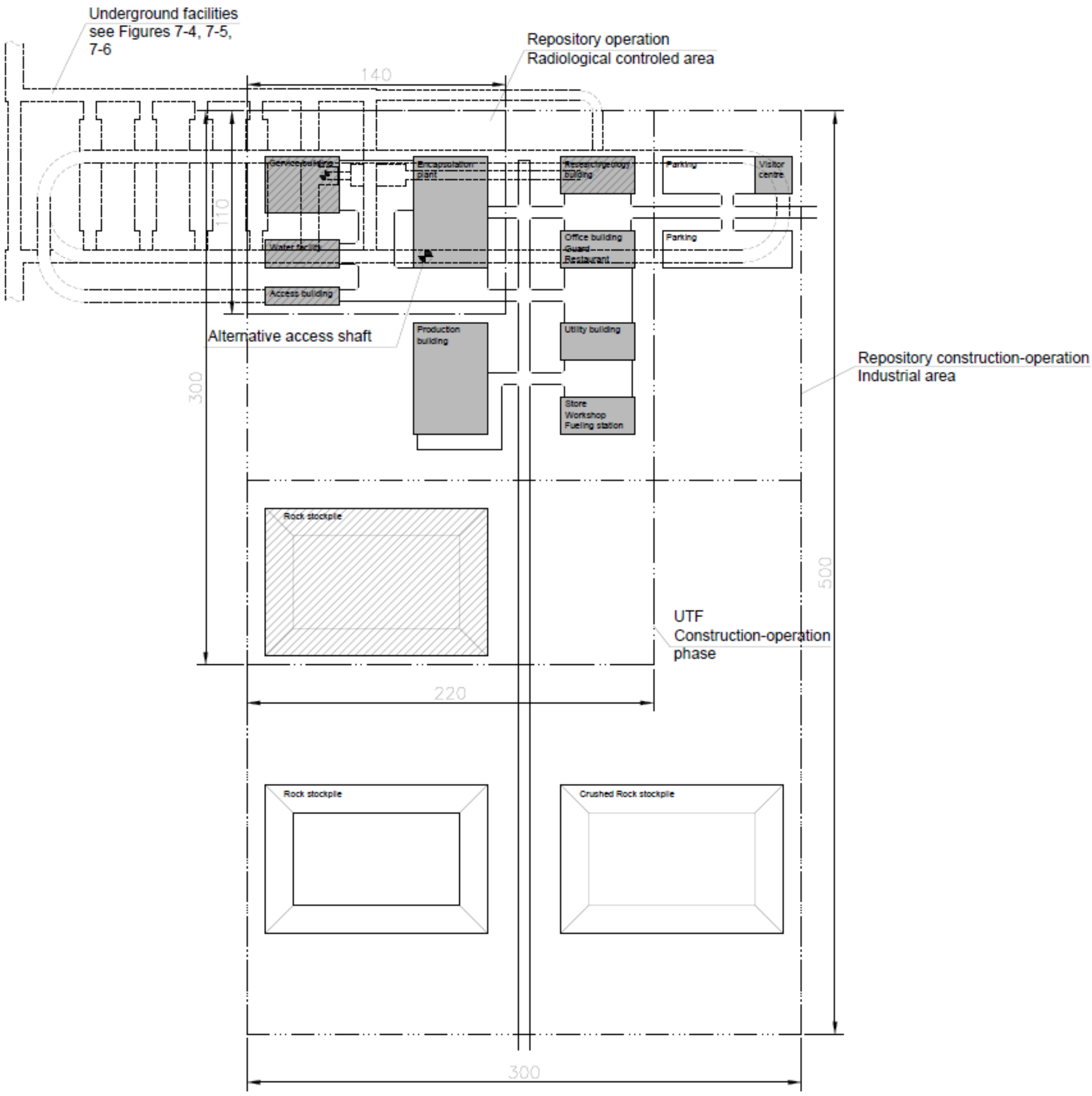


Figure 3.2-2: Deep geological repository lay-out with indicated UTF area and final repository area

Facilities above ground

The surface part of the repository consists of a number of buildings, systems and components Including the structures and facilities constructed already as part of the UTF, the above ground part of the repository includes:

- Unfenced area
    - visitors center (incl. parking areas);
    - utility networks; and
    - rock spoil heaps;
- Industrial area (fenced – industrial security)
    - office building (including guard center and restaurant);
    - research/geology building;
    - production building;
    - utility building; and
    - store and workshop building;
- Technological above ground area (fenced – nuclear security, radiological control)
    - encapsulation plant;
    - reception building (part of encapsulation plant, if constructed on the disposal site);
    - service building;
    - repository access building (giving access to ramp);
    - spent water management facilities; and
    - ventilation building (above exhaust ventilation shaft).

These facilities and systems are necessary for the development and normal operation of underground part of the repository. Part of the above ground facilities are also access to underground facilities.

Facilities under ground

The underground part of the repository (Figure 3-13) is situated at a depth of 500 m below the ground surface. Alternatively, the depth of 800 m is also considered. It consists of two areas: central service area and disposal area. The underground level can be reached in several ways: for personnel through service shaft, for waste and other cargo through spiral ramp (with at least 15 m curve radius to enable access by long vehicles and 10% slope) or alternatively through access vertical shaft with 8.0 m clear diameter. The ramp is 5 km (alternatively 8 km) long, 7m wide and 7m high. Service shaft has 5m of clear diameter. It contains two elevators (cages). The main cage shall be used

for transportation of personnel and light equipment. The small cage shall be used in case of emergency for personnel rescue. Both cages may be used for shaft inspection. Service shaft is also used as part of ventilation system (air intake). The repository is supplied with a 3 m wide ventilation shaft which can serve as an emergency exit as well.

The horizontal tunnel development is designed as a double loop system. The first loop consists of a large-size haulage tunnel, designed to provide good accessibility to waste transport vehicles. This loop serves the disposal tunnels and is connected to the access ramp station. The second loop surrounds the service area and is connected to the service shaft and access ramp stations. The size of haulage and disposal tunnels is determined by considerations on the transport and handling of spent fuel canisters placed in radiation-shielding cask.

Access shafts lead towards central service area located directly below the operations area on the surface. The area covers about 320 m by 100 m. Beside shaft station, a large-sized excavation (80 m long, 10 m wide and up to 10 m high) located at the level of the main horizontal development underground, there are four 60 m long, 12 m wide and 10 m high underground halls: also a workshop vault intended for maintenance and repairing of underground facilities and equipment, vehicle vault, storage vault and utility vault. The 30 m long drainage vault is located at a lower level beneath the service area. Central service area contains equipment for unloading of canisters, their transportation to disposal tunnels; it is equipped for acceptance, storage and transportation of bentonite blocks and other items.

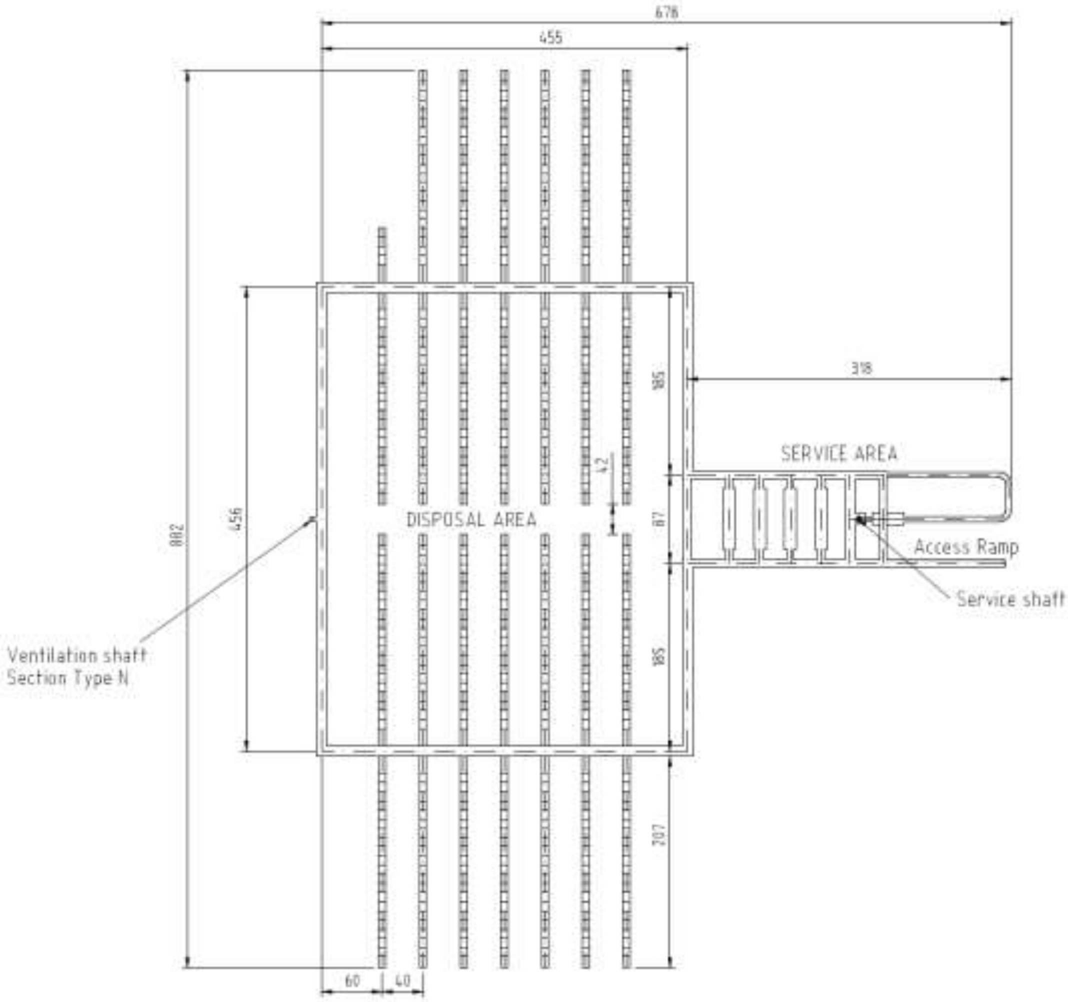


Figure 3.2-3: The disposal area of deep geological repository (571 canisters, 9 m borehole distance) with repository data

Central service area is connected to the disposal area which consists of two sections of parallel disposal tunnels. The tunnel length is 207 m and the tunnel spacing is 40 m. The disposal area for the basic scenarios consists of 28 disposal tunnels, grouped on either side of the main access tunnel. The disposal area is dimensioned for 583 disposal boreholes (one disposal tunnel serves 21 boreholes). Vertical boreholes are drilled in the bottom of the disposal tunnels. Each hole is approximately 7.6 m deep and has a diameter of 1.80 m (Figure 3-14). Each borehole holds one spent fuel canister, surrounded by a minimum of 34 cm of compacted bentonite.

Out of the 571 disposal boreholes required to accommodate all the fuel canisters, only a few tens are required to start the operation. The rest will be drilled as required for waste emplacement activities.

When all of the disposal tunnels have been backfilled and sealed with concrete plugs, the operation is complete. The backfilling of the main drifts is carried out as a part of the total backfilling during the closure/decommissioning phase.

The complete underground area including shafts and ramps will be declared as a radiological controlled area during operation.

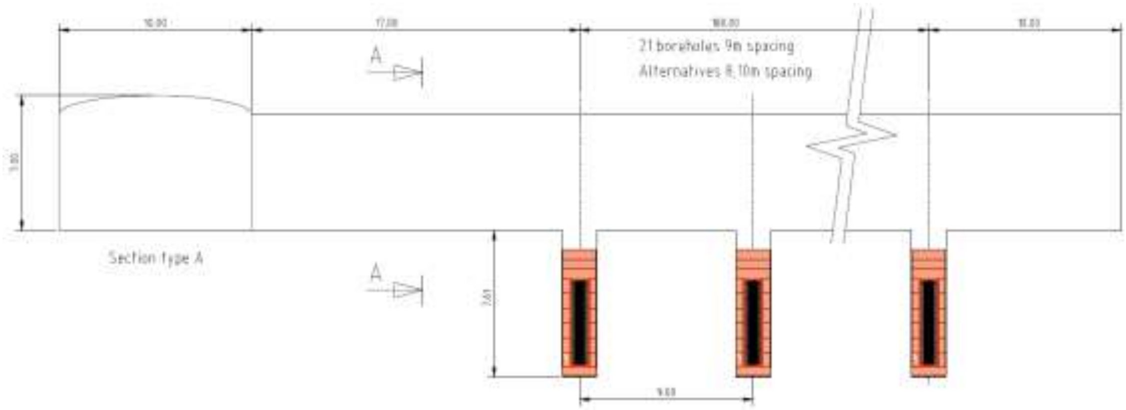


Figure 3.2-4: Canister Disposal in Tunnel Boreholes

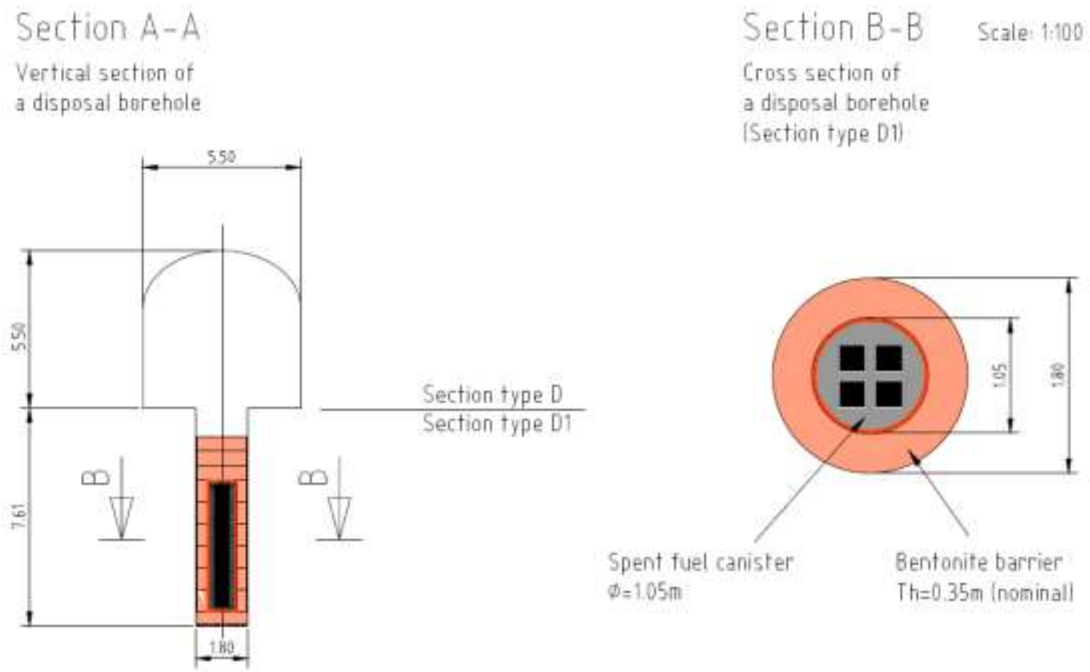


Figure 3.2-5: Vertical and cross section of a disposal borehole

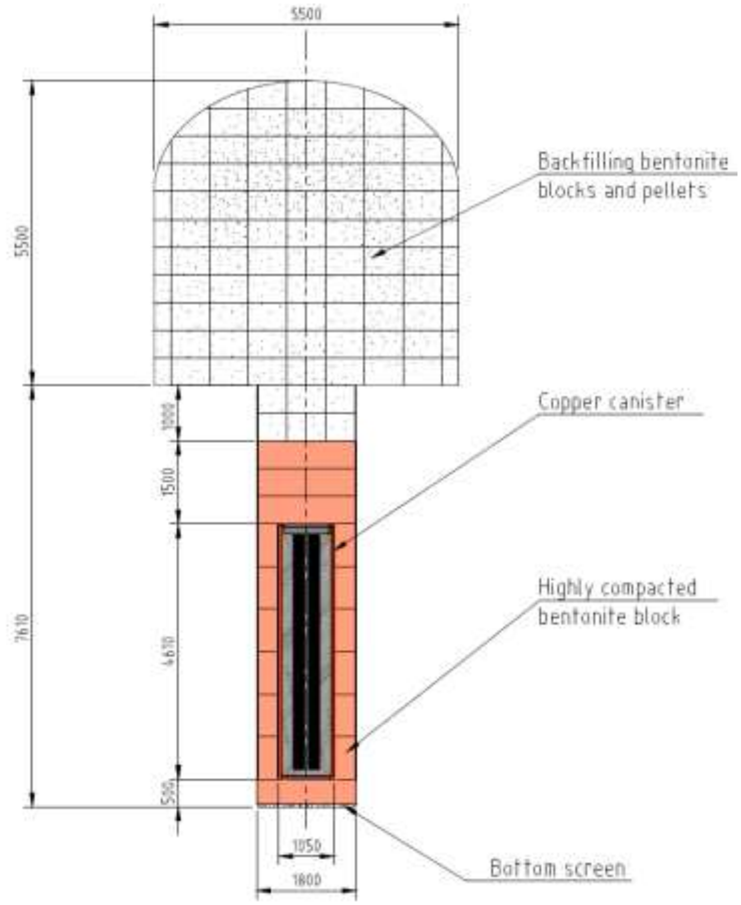


Figure 3.2-6: Vertical cross section of a disposal borehole with copper canister disposal in bentonite block backfilled with bentonite

Long lived institutional LILW, decommissioning HLW and long lived LILW from Krško NPP, HLW and other RW from SFDS decommissioning, long lived LILW and eventually HLW from operation and decommissioning of geological disposal facility and encapsulation plant will be disposed of in one of the abandoned vaults of the service area. Alternatively, a special repository room will be excavated approximately 70 m above transverse drift.

Decommissioning of the facilities can begin when all of the spent fuel has been deposited. Closure of the geological repository starts with backfilling of the underground tunnels and disposal areas. The disposal tunnels will be sealed with a concrete plug of 6 m thickness. It is assumed that the decommissioning stage will last for 5 years and the closure stage will last for 2 years.

3.2.4.3.4. Time Schedules

For the identified activities of the geological disposal program, a time schedule has been constructed, taking into account sequencing of activities in each group and sequencing of activities among other groups of activities. The following groups of activities are considered:

- project administration;
- site selection;
- site investigations and monitoring;
- design;
- safety of the repository;
- spatial planning;
- investment;
- construction;
- operation;
- decommissioning and closure; and
- long-term institutional control.

Time schedules for the Base Case scenario (Scenario No. 1) and the Sensitivity Case scenario (Scenario No. 2) are similar, basic difference is that they are just shifted in a way that the Scenario No. 2 starts with activation of geological program already in 2025 to be prepared for operation in 2065, whereas the Scenario No. 1 starts geological program in 2053 to be prepare for operation in 2093.

The basis for base case and sensitivity case scenario determination are as follows:

a. Scenarios (cases) are in accordance to the technical specification for revision of NPP Krško Decommissioning Plan [4] and 6th Revision of the PDP document [21]: cases are in general in compliance with the SF disposal scenario defined in Slovenian ReNPRRO16-25 (sensitivity case), as well as with scenario in document Croatian National program for application of strategy of radioactive waste, disused sources and spent nuclear fuel management – NP - (base case).

b. Activities (in general) are as in Revised Reference Scenario for Geological Disposal Facility in Hard Rock and Cost Estimation for its Implementation (RRS 2009) . The duration of activities is checked and adjusted considering available data on SKB and Posiva repository projects;[44]

c. Active institutional control and maintenance of the repository after closure are normally not required for SF repository (e.g. SKB and Posiva repository projects). However, this is anticipated by ZVISJV-1 and ReNPRRO16-25 and is therefore considered as an option 1.

In order to start with regular operation at a fixed time, it is assumed that site selection stage must begin 38 years earlier for both base case and sensitivity case scenarios as advanced in guidance [51][52]. In the last part of the site selection stage, i.e. site confirmation, construction of the underground research laboratory is foreseen. Construction of the laboratory will last for 4 years. Construction of the laboratory will be carried out on the basis of a separate design documentation and construction permit. After the end of construction, site investigations in the underground laboratory will start. The site investigations in the laboratory will last for 4 years when the final site

confirmation will be achieved. The overview of main activities and their duration is given in Table 3.2-1.

Table 3.2-1: Start and duration of the main activities of the geological disposal program

Activity/case	**Base case (year/years)**	**Sensitivity case (year/years)**	**Explanation - argumentation**
Dry storage facility in operation (start in 2020)	83	55	see item a. above
Activation of geological program	2053	2025	see item b. above
Start of the site selection process	2055	2027	see item b. above
Start of construction of the UTF	2079	2051	see item b. above
Start of site investigations in the UTF	2083	2055	see item b. above
Confirmation of the final site	2086	2058	see item b. above
Start of the repository construction	2087	2059	see item b. above
Start of trial operation (repository/ encapsulation)	2092	2064	see item b. above
Start of regular operation/disposal	2093	2065	see item b. above
Last transport from dry storage to repository – cease of dry storage and repository operation	2103	2075	see item a. above
Start of decommissioning	2104	2076	see item b. above
Start of closure	2108	2080	see item b. above
End of closure	2110	2082	see item b. above
Active institutional control and maintenance	/ (2111)	/ (2083)	50 years, elaborated as an Option 1, see item c. above

Construction of the geological repository will start 6 years prior to the start of regular operation. It will begin with construction of auxiliary aboveground structures. Then, construction of the encapsulation plant and of the underground structures will begin. Construction of these structures will last for 5 years. It is assumed that the encapsulation plant will be a part of the repository. Construction of the repository will be carried out on the basis of a separate design documentation and construction permit. In case of construction of the encapsulation plant as a standalone facility an additional construction permit will be required. It is foreseen that investigations in the underground laboratory may continue during construction of the repository.

After the end of construction, a 1-year trial operation of the repository will commence. It is assumed that trial operation of the encapsulation plant and of the other structures of the repository will start at the same time. The regular operation of the repository will

last for 10 years in both scenarios. It is assumed that the length of regular operation of the encapsulation plant and of the other structures of the repository is the same.

Decommissioning and closing activities will start after all spent fuel has been disposed of. However, a part of decommissioning and closure activities, i.e. backfilling and sealing of disposal vaults will begin already during operation of the repository. The activities will be carried out on the basis of a separate design documentation and construction permit. It is assumed that decommissioning of aboveground and closure of underground structures will be carried out in the same time period. Decommissioning activities will last for 5 years, while closure activities will last for 2 years. After the closure, the repository might be transferred into long term institutional control (option 1).

3.2.5. SF&HLW disposal costs estimate

All costs for two basic scenarios are based on price level of June 2018. The base estimates for establishment of DGR ware made already in RRS in 2009 [44], therefore the historic prices were updated, using the following indexes for different costs from January 2009 until June 2018:

- construction costs (or producer prices) index (EUROSTAT, EU28) in the value of 13.68 %,
- service producer prices (architectural and engineering activities, technical testing and analysis) index (EUROSTAT, EU28) in the value of 7.75 %,
- producer prices in industry (Capital goods) index (EUROSTAT, EU28) in the value of 7.73 %,
- service producer prices (land transport and transport via pipeline) index (EUROSTAT, SI) in the value of 4.92 % and
- harmonized index of consumer prices (EUROSTAT, EU28) in the value of 3.69 %.

The cost estimate covers all costs in the period from 2018 until the closure of the repository. The cost estimate covers two basic scenarios:

- Base case scenario (Scenario No. 1) – regular operation starts in the year 2093; and
- Sensitivity case scenario (Scenario No. 2) – regular operation starts in the year 2065.

Total costs of geological disposal were calculated in two steps. In the first step, costs per activities, without any contingencies, were estimated. The activities included project administration and R&D, site selection, site investigations and monitoring, construction of encapsulation plant (part of basic scenario), surface facilities and equipment, underground facilities and equipment, activities related to offsite infrastructure, operation, transport of SF from dry storage to DGR, decommissioning, closure and compensation. Calculation of compensation costs to local communities is based on the

provisions of the Slovenian decree on the criteria for determining the compensation rate due to the restricted use of areas and intervention measures in nuclear facility areas [22]. The compensation costs are estimated for the period from adoption of the national spatial plan to the closure of the repository. Duration of this period is 42 years for both scenarios. The yearly compensation costs achieve 5,884,794 EUR for the period of 42 years. For base case scenario 841,546 EUR is used as annual compensation rate during research, development and repository construction (2069-2092), and 5,884,794 EUR for repository regular operation (2093-2103), decommissioning (2104-2107) and closure (2108-2110) [26]. Total estimated costs for compensation are estimated to 126,123,396.8 EUR.

In the second step of the cost estimation in RS 2018, contingencies for technological and projects uncertainties and VAT were estimated using the Monte Carlo simulation and added to the project costs. The Project and Technology contingency factors (P and T factors) used in the RS 2018 are the same as for costs calculations for RRS in 2009. Contingencies for technological and projects uncertainties (P and T-factors) are elaborated only after 2052 for base case scenario and only after 2024 for sensitivity case scenario by using FIS TOOL software [42]. Based on diverse international practice of contingency calculation and its application [53][54], and together with decisions of the intergovernmental commission and implementation coordination committee [55][56], it was decided to apply an uniform rate contingency of 30% (flat 30% margin on all cost figures) on the estimated costs for siting, project administration and R&D, site purchase, investment and construction, on-site disposal, investment and construction, encapsulation plant, operation and maintenance, disposal, operation and maintenance, above ground facilities, decommissioning and closure. Compensation costs and VAT costs were excluded from the contingency calculation cost based on international contingency practices and standards [53].

VAT (value added tax) is defined in accordance with the Slovenian and Croatian tax regulations [57][58], in force in 2018, and is in Slovenia a 22% tax rate and in Croatia 25% tax for all investment cost consider in this document.

So, the total costs of geological disposal consist of:

1. Cost estimate without contingencies,
2. Costs including contingencies and
3. Value added tax (VAT).

The total costs with contingencies and VAT are given in following tables by using mean value of total costs with contingencies and VAT: for base case scenario in Table 3.2-2 and for sensitivity case scenario in Table 3.2-3. There are different total costs due to differences in VAT in Slovenia (15.09 %) and Croatia (16.80 %) and they value for base scenario (start of operation in 2093) 1,136,879,898 EUR in case DGR would be

constructed in Slovenia and 1,160,270,663 EUR in case DGR would be constructed in Croatia. In case of sensitivity scenario with start of DGR operation in 2065, the total cost would be approximately 4.9 million EUR smaller due to shorter period of geological disposal programme.

Table 3.2-2: Total costs of geological disposal for base case scenario.

	COSTS in EUR (SI)	**Structure (SI)**	**COSTS in EUR (CRO)**	**Structure (CRO)**
Siting, project administration and R&D, site purchase	124,127,199	10.92%	124,127,199	10.70%
Investment and construction – On-site Disposal	202,631,694	17.82%	202,631,694	17.46%
Investment and construction – Encapsulation plant	35,332,052	3.11%	35,332,052	3.05%
Operation and maintenance – Disposal	93,436,497	8.22%	93,436,497	8.05%
Operation & Maintenance – Above ground facilities	147,050,428	12.93%	147,050,428	12.67%
Decommissioning and closure	42,979,223	3.78%	42,979,223	3.70%
Compensation costs	126,123,397	11.09%	126,123,397	10.87%
SUBTOTAL	**771,680,490**	**67.88%**	**771,680,490**	**66.51%**
Contingencies	193,667,128	17.03%	193,667,128	16.69%
TOTAL COSTS with contingencies	**965,347,618**	**84.91%**	**965,347,618**	**83.20%**
VAT	171,532,280	15.09%	194,923,045	16.80%
TOTAL COSTS INCLUDING VAT	**1,136,879,898**	**100.00%**	**1,160,270,663**	**100.00%**

The total costs of the base case scenario are estimated to 1,136,879,898 EUR in case DGR would be constructed in Slovenia and 1,160,270,663 EUR in case DGR would be constructed in Croatia.

Table 3.2-3: Total costs of geological disposal for sensitivity case scenario

	COSTS in EUR (SI)	**Structure (SI)**	**COSTS in EUR (CRO)**	**Structure (CRO)**
Siting, project administration and R&D, site purchase	121,030,190	10.69%	121,030,190	10.48%
Investment and construction – On-site Disposal	202,631,694	17.90%	202,631,694	17.54%
Investment and construction – Encapsulation plant	35,332,052	3.12%	35,332,052	3.06%
Operation and maintenance – Disposal	93,436,497	8.25%	93,436,497	8.09%
Operation & Maintenance – Above ground facilities	147,050,428	12.99%	147,050,428	12.73%

	COSTS in EUR (SI)	Structure (SI)	COSTS in EUR (CRO)	Structure (CRO)
Decommissioning and closure	42,979,223	3.80%	42,979,223	3.72%
Compensation costs	126,123,396	11.14%	126,123,396	10.92%
SUBTOTAL	**768,583,480**	**67.90%**	**768,583,480**	**66.53%**
Contingencies	192,738,025	17.02%	192,738,025	16.68%
TOTAL COSTS with contingencies	**961,321,505**	**84.92%**	**961,321,505**	**83.21%**
VAT	170,646,535	15.08%	193,916,517	16.79%
TOTAL COSTS INCLUDING VAT	**1,131,968,041**	**100.00%**	**1,155,238,023**	**100.00%**

In total, the contingencies due to the uncertainties contribute about 17 % and the VAT about 15.1 % (SI) or 16.8 % (CRO) to the total cost estimate.

Disposal cost distributions with inclusion of compensation, contingencies and VAT for both scenarios are shown in Figures 5 (base case scenario – left figure SI VAT, right figure CRO VAT) and 6 (sensitivity case scenario– left figure SI VAT, right figure CRO VAT).

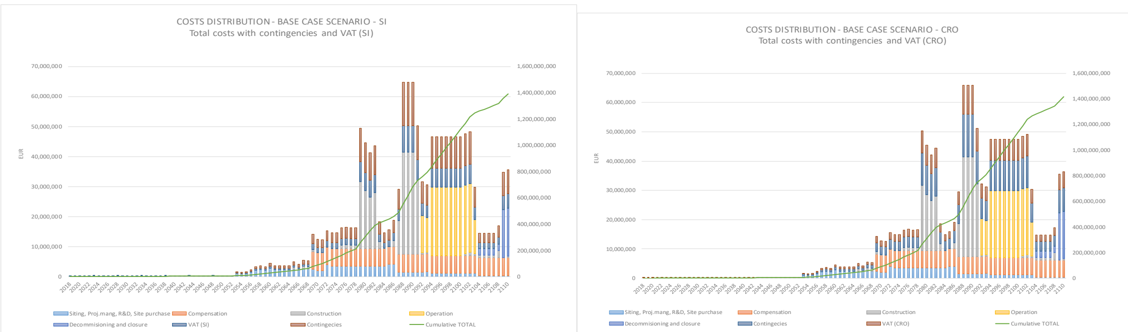


Figure 3.2-7: Cost Distribution – Base Case Scenario

A gradual increase of costs is registered from 2050 or 2080 respectively with start of site selection process. More significant increase of costs is noticed after 2080 and 2090 respectively when the construction works start, with two distinctive peaks, the first one defined by the construction of the UTF and the second one by the construction of the encapsulation plant and the repository construction. Still high but more steady cost is expected during the period of repository operation and then it is gradually decreasing during the closure and decommissioning of the facilities. The distribution of cots in sensitivity case scenario is similar but shifted for 28 years with start of geological programme in 2025 already.

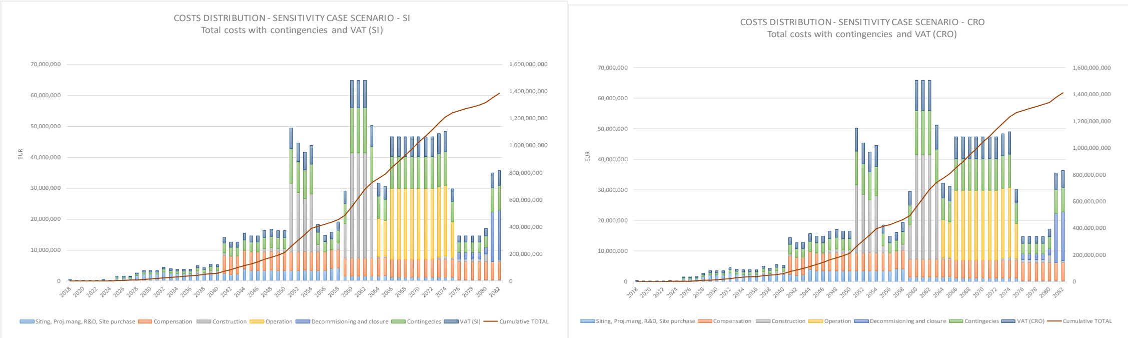


Figure 3.2-8: Cost Distribution – Sensitivity Case Scenario

3.2.6. Costs of options and alternative solutions

Costs of options and alternative solutions are also estimated to have a comparison how they impacted the total costs. Options, for which costs are estimated and which are not part of basic scenarios are as follows:

- Option 1: Post-closure monitoring for 50 years,
- Option 2: Encapsulation in regional encapsulation plant, and
- Option 3: Disposal in multinational repository.

In addition, also several alternatives to the basic design are evaluated in included in the comparison. Alternatives include changes to basic scenarios with different access, depth, distance between boreholes, additional boreholes and special underground compartment for HLW and long lived LILW [20].

3.2.6.1. Evaluation of options

3.2.6.1.1. Option 1 - Post-closure monitoring

At this stage it is not known yet, what the requirements might be for a long-term monitoring of the disposal site and over which time span they will extend. In the most advanced repository projects (e.g. Posiva, SKB) long term monitoring is not anticipated after closure and is therefore not included into costs of the basic and sensitivity case scenarios. Thus, monitoring activities after closure of the repository have been evaluated as an option (Option 1). In case of long-term monitoring activities as part of the institutional control after closure of the repository, they will be carried out in two stages, i.e. an active institutional control and a passive institutional control. The active post-closure monitoring can include measuring of radioactivity on the ground surface and in deep boreholes. Groundwater table levels, flow, chemistry, temperature, etc.,

are monitored in boreholes. The incidence of any seismic event can also be observed by geophysical measurements performed on the ground surface.

At the end of the active institutional control period, the repository is prepared for passive long-term surveillance. The preparation primarily includes removal of all equipment, closure of inspection wells and removal of fence and other structures. Passive long-term institutional control includes the data preservation and retaining the repository land ownership.

Post-closure monitoring costs are estimated using data on Slovene LILW disposal project and are revalorized with Service producer prices index (Architectural and engineering activities, technical testing and analysis) (EUROSTAT, EU28). For cost estimation purpose only, the active institutional control stage is taken into account. It is assumed that this stage lasts for 50 years. The total costs of active institutional control for 50 years are evaluated as option 1, are not included into costs of the basic and sensitivity case scenarios and are estimated to 2,693,665 EUR for both basic scenarios, recalculated from Slovenian LILW repository project (VAT is not included) [20].

3.2.6.1.2. Option 2 - Encapsulation in a regional encapsulation plant

For optimized operation of the facility it is advantageous to have encapsulation facilities for the preparation of the waste packages situated at the repository site. Nevertheless, investments in the encapsulation are significant and amount to 35.33 million EUR, i.e. 0.062 million EUR per each of 571 canisters or 0.038 million EUR/tHM.

It is conceivable that commercial encapsulation services as well as encapsulation services as a result of joint venture partnership investment could be available in the future. e.g., investment costs estimated in Sweden for a capable encapsulation plant (with operation rate of 200 canisters per year) are assessed to 484 million EUR. Unit investment cost for each of planned treated 6000 canisters is 0.081 million EUR [59]. If number of planned treated canisters in such an encapsulation plant is doubled (as a result of a partner or customer participation), the unit investment cost for each of 12,000 canisters decreases to 0.04 million EUR. A reception building instead of the encapsulation building would be constructed at the repository site. Investment, operational and decommissioning costs are assessed as 1/3 of costs for encapsulation plant. Also, SF would be delivered for encapsulation in MPC and HI-STAR casks in 62 transports, 1000 km each, with the assessed double cost in comparison with the basic scenarios - transport to the repository.

Comparing unit investment cost, it could be seen that the encapsulation joint venture partnership investment and services costs of larger encapsulation plants would be competitive and economically attractive when compared to the encapsulation costs for a smaller national encapsulation facility [20].

3.2.6.1.3. Option 3 – Disposal in a multinational repository

A geologic repository is an expensive enterprise with high fixed costs that are largely independent of the size of the repository. This makes a multinational repository (MNR) an interesting option for reducing overall costs for disposal. Two options are analysed: Service concept (Option 3.a) and Cooperation concept (Option 3.b). The Service concept involves a service provider country developing a geologic repository and accepting SF from several customer countries (e.g. South Australia approach [60]), while the Cooperation concept includes collaboration between partner countries in the joint venture project for development of disposal facility and construction of MNR in the host partner country [61].

To get rough and conservative cost estimation based on Option 3.b, costs are taken from Table 3.2.2. If we assume 5 partners (nations) decided to construct one joint repository, equally sharing of double investment costs of about 810 million EUR (conservative estimation) and compensation and double contingency costs (513.5 million EUR), where operational costs are variable and dependent on inventory (240,5 million EUR), then total costs for Republic of Slovenia and Republic of Croatia for the disposal of 926 tHM amount to 505.2 million EUR with unit disposal costs of 0.55 million EUR / tHM. This is significant saving compared to 965.4 million EUR (1.04 million EUR / tHM), VAT excluded. This is despite using double investment and contingency costs somewhat still optimistic estimation, therefore for more conservative estimate we need to consider other cost items that might arise due to any additional tasks needed to manage all aspects sensitive to the multinational context such as additional sitting costs, licensing, legal barriers, inventory harmonisation, higher work force costs, … . Such estimation is also in line with the economy of scale advantages and costs reduction for larger inventory programs presented in OECD/NEA report The Economics of the Back End of the Nuclear Fuel Cycle [62].

The option for disposal in a multinational repository seems a reasonable and in principle feasible solution. Especially Option 3.b, considering operation of at least medium scale MNR on a partnership basis seems an economically attractive solution. However, the realization of an MNR on the basis of either service or cooperation principles is not an available option at the present time. Assessment of unit disposal costs (with very high uncertainties) amounts from 0.55 million EUR / tHM for cooperation option (3.b) up to 1,28 million EUR per tHM for service option (3.a) - which indicates that the cooperative option at the time being could be more favourable [20].

3.2.6.2. Evaluation of alternative solutions

Several alternatives to the basic design are evaluated and included in the comparison. The main characteristics of the basic solution are [20]:

- 2282 SF assemblies in 571 canisters (21 boreholes in each of 27 disposal tunnels of uniform length plus 4 canisters in one shorter disposal tunnel),
- access to disposal area through access ramp,
- disposal area at level 500 m below ground,
- HLW/LLW disposal in service area.

The related costs for these activities: civil works 172,943,599 EUR, equipment 23,017,048 EUR and in total 195,960,647 EUR.

As alternatives following solutions were evaluated and are presented in Table 3.2-4 as total costs of one alternative solution and the difference in costs to basic solution which include construction and closure costs:

- **Access shaft**, instead of access ramp, which results in a decrease of total costs for 40.17 million EUR. Equipment (transfer lift, trolley and station) is enlarged with regard to the basic solution.
- **Deeper DGR:** repository is located at underground level of - 800 m instead of - 500 m. The change in the repository location results in an increase of costs for 36.17 million EUR due to additional construction costs.
- **Shorter distance between boreholes**: When the borehole distance is 8 m, costs decrease for 5.76 million EUR. Length of tunnel No. 28 amounts to 51 m and has 4 boreholes.
- **Larger boreholes distance**: the borehole distance of 10 m results in an increase of costs for 7.43 million EUR. Canisters are emplaced in 29 disposal tunnels (19 canisters in each) of basic length in 8 tunnel rows. Length of additional tunnel No. 30 amounts to 217 m and has 20 boreholes.
- **Additional boreholes**: if number of boreholes is increased for 20%, costs increase for 17.53 million EUR. 686 canisters are emplaced in 32 disposal tunnels (21 canisters in each) of basic length in 9 tunnel rows. Length of tunnel No. 33 amounts to 144 m and has 14 boreholes.
- **Unfavourable geological conditions**: in such case with combination of high rock conductivity more boreholes (686) would be dig 10 m apart of each other, which would lead to more tunnels. Total costs of underground civil works for this alternative amount to 197,957,358 EUR, that is 25,013,759 million EUR (14%) more than in case of basic solution.
- **Special compartment for HLW/LILW**: HLW/LLW disposal in a special underground compartment is supposed. The resulting difference in costs in comparison with the basic solution is 483,800 EUR.

Table 3.2-4: Total cost of alternative solutions and difference to basic solution [20]

Alternative solution	Cost (EUR)
Access shaft	**132,771,902**
Difference to basic solution	- 40,171,697
DGR at -800 m	**209,117,488**
Difference to basic solution	+ 36,173,889
Shorter boreholes distance	**167,178,082**
Difference to basic solution	- 5,765,517
Larger boreholes distance	**180,381,106**
Difference to basic solution	+ 7,437,507
Additional boreholes	**190,482,359**
Difference to basic solution	+ 17,538,761
Unfavourable geological conditions	**197,957,358**
Difference to basic solution	+ 25,013,759
Special compartment	**173,427,398**
Difference to basic solution	+ 483,800

3.2.7. Differences in strategy and costs between RRS 2009 and RS 2018

The RRS 2009 and RS 2018 for deep geological repository of SF are both made for a generic location in a hard rock media and also include encapsulation plant as part of disposal concept. Key differences between design basis for the RRS 2009 and RS 2018 are as follows:

- Only NEK operational period until 2043 is anticipated in RS 2018 (in RSS also NEK operation until 2023).
- In RS 2018 two scenarios with dry storage period of 50 and 22 years between the NEK and repository operational period are considered in accordance to the up-to-date decommissioning plan (in RSS 2009 storage periods of 45 and 100 years were considered).
- SF disposal in Slovenia and potential hard rock formation in Slovenia is considered in RSS. The bilateral repository in the generic site in Slovenia or Croatia is considered in RS 2018.
- In RS 2018 dual-track approach was introduced: SF disposal in a multinational repository is additionally considered as an option.
- Amendments and updates to the descriptions of the required licensing and permitting processes.

Therefore, the comparable options for DGR which could be taken into account are:

- RRS 2009: Scenario No. 2 – start of the NPP decommissioning in 2043, start of repository operation in the year 2088 after 50-year SF storage, 15 years of operation, No. of encapsulated copper canisters: 571 (+10 canisters for training);
- RS 2018: Base case scenario (Scenario No. 1) – start of NPP decommissioning in 2043, regular operation of the SF repository in 2093; 10 years of operation; dry storage facility needed until 2103; No. of encapsulated copper canisters: 571 (+ several canisters for testing).

The results of comparison of estimated costs for these two options of deep geological repository are provided in Table 3.2-5. Costs have been grouped from original calculations [20][44] for the following individual groups of activities: siting, project administration, R&D and site purchase, investment and construction for on-site disposal and encapsulation plant, operation and maintenance for disposal and above ground facilities and for decommissioning and closure. Additionally, also relevant costs of compensation and calculated contingencies are shown, individually and as a sum. For RRS 2009 two columns are given: first one in € from 2008 as in [63] and second one with recalculation for inflation (according to Statistical office of Republic of Slovenia between December 2008 and June 2018 the inflation rate was 13.0 % for retail prices of goods and services). The final sum is for all cases without VAT as the main purpose is to compare the individual groups to see where the biggest differences come in relation to cases and to understand the impacts of individual groups on total cost.

The biggest differences are in the following groups:

- siting, project administration, R&D and site purchase which is in case of RS 2018 decreased for app 57 million €,
- investment and construction of disposal with increase for app 42 million € in case of RS 2018,
- decommissioning and closure with increases for app 22 million € in case of RS 2018,
- compensation costs that have decreased in case of RS 2018 for 139.8 million €.

The rest of items are comparable and could be explained roughly with updates of prices based on the indexes presented in chapter 5.

Table 3.2-5: Comparison of cost estimates for RRS 2009 – Scenario 2 and RS 2018 – base case scenario

Activities	**RSS 2009: Scenario 2 (€ 2008)**	**RSS 2009: Scenario 2 (€ 2018)**	**RS 2018: Scenario 1 - Base case (€ 2018)**
Siting, project administration, R&D and site purchase	160,212,000 €	181,039,560 €	124,127,199 €
Investment and construction - on site disposal	142,382,000 €	160,891,660 €	202,631,694 €

Activities	**RSS 2009: Scenario 2 (€ 2008)**	**RSS 2009: Scenario 2 (€ 2018)**	**RS 2018: Scenario 1 - Base case (€ 2018)**
Investment and construction - encapsulation plant	32,160,000 €	36,340,800 €	35,332,052 €
Operation and maintenance - disposal	70,569,000 €	79,742,970 €	93,436,497 €
Operation and maintenance - above ground facilities	133,298,000 €	150,626,740 €	147,050,428 €
Decommissioning and closure	17,877,000 €	20,201,010 €	42,979,223 €
Subtotal	**556,498,000 €**	**628,842,740 €**	**645,557,093 €**
Compensation costs	265,900,000 €	300,467,000 €	126,123,397 €
Subtotal with compensation	**822,398,000 €**	**929,309,740 €**	**771,680,490 €**
Contingency	222,594,000,00 €	251,531,220 €	193,667,127 €
Total (no VAT)	**1,044,992,000 €**	**1,180,840,960 €**	**965,347,618 €**

It can be also seen that cost for compensation is decreased significantly for case of RS 2018, as the operation period is 10 years instead of 15 years (RRS 2009) and due to decreased annual compensation rate during research, development and repository construction. The contingency costs also decreased as new uniform rate contingency of 30% have been assigned. However, in total without VAT, the estimated costs for RS 2018 is app 215.5 million € lower than in previous revalorised option and sum to app 965.4 million €.

3.3. References

[1] "Decision of Croatian Government on the adoption of the National Programme, Off Gazz of the RC, Nr.100/18]."

[2] *Treaty between the Gov. of the Republic of Slov. and the Gov. of the Republic of Cro. on the regulation of the status and other legal relations regarding investment, exploitation and decommissioning of the Krško NPP... BHRNEK, Off. Gaz. of the RS 23/2003*. .

[3] "'Spent fuel storage operation: lessons learned', IAEA TECDOC 1725, IAEA, Vienna, 2013."

[4] "3rd Revision of the NPP Krško Decommissioning Program, NIS Ingenieurgesellschaft mbH, Document No.: 4520 / CA / F 010640 5 / 07, June 2019."

[5] "Resolution on the National Programme for Managing Radioactive Waste and Spent Nuclear Fuel 2016-2025, Off. Gaz. of the RS, Nr. 31/16."

[6] "Odločba URSJV št. 3570-9/2011/2, Odločba o izvedbi izrednega občasnega varnostnega pregleda Nuklearne elektrarne Krško, z dne 30. 5. 2011."

[7] "'Nuklearna elektrarna Krško, Suho skladišče izrabljenega goriva'; Idejna Zasnova, NEKDSB-1V/01A, IBE, Ljubljana, 2018."

[8] "'Final Safety Analysis Report on the HI-STORM FW MPC Storage System'; Revision 5, HI-2114830, Holtec International, Camden, 2017."

[9] "'Spent fuel performance assessment and research (SPAR-III)', IAEA TECDOC 1771, IAEA Vienna, 2015."

[10] ""Nuclear Power Plant Krško Updated Safety Analysis Report"; Revision 24, Chapter 4 – Reactor, NEK, Krško, 2017."

[11] "'Annual Report 2017 on Radiation and Nuclear Safety in the Re public of Slovenia', SNSA, 2018."

[12] "Record of the 10th Intergovernmental Commission Meeting, Krško, July 2015."

[13] "Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards - Council/Commission statement."

[14] "Terms of REFERENCE (ToR) for the THIRD REVISION OF THE KRŠKO NPP DECOMMISSIONING PROGRAM, Krško NPP, ARAO, Fond NEK, 2107."

[15] "National Programme for RW, DS and SF management (Programme to 2025 with a vision to 2060), (Decision of Croatian Government on the adoption of the National Programme, Official Gazette No 100/18), Zagreb, 2018."

[16] *Uredba o sevalnih dejavnostih (UV1)*. (Uradni list RS, št. 19/18).

[17] *Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom a*. Official Journal of the EU, Volume 57, january

2014.

[18] "'Decommissioning Plan for Krsko DSB'; HI-2188105, Holtec International, Camden, 2018."

[19] "Program razgradnje (suhega skladišča) – SFDS Decommissioning plan, NEKDSB-5P/04B", IBE, Dec. 2018."

[20] "'Reference Scenario for Geological Disposal Facility in Hard Rock with Cost Estimation for its Implementation', IBE d.d., February 2019."

[21] "6th Revision of the Preliminary Decommissioning Plan (PDP) for NPP Krško, NIS Siempelkamp, document No.: 4520/CA/F 010420 7 / 01, June 2019."

[22] "'Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas', UV8, Off. Gaz. RS 92/14, 46/15 and 76/17 – ZVISJV-1."

[23] *Zakon o varstvu pred ionizirajočimi sevanji in jedrski varnosti (ZVISJV-1)*. (Uradni list RS, št. 76/17, in 26/19).

[24] "'Decree amending the Decree on areas of restricted use due to nuclear facili-ties and on the conditions for construction in these areas (UV3)'; Official Gazete of the RS, nr. 36/04, 103/06, 92/14, and 76/17-ZVISJV-1."

[25] "Letno poročilo Sklada za financiranje razgradnje Nuklearne elektrarne Krško in za odlaganje radioaktivnih odpadkov iz Nuklearne elektrarne Krško za leto 2017, Sklad NEK, junij 2018."

[26] "Record of 19th session of the implementation coordination committee for monitoring the progress of preparation of the Third Revision of the Krško NPP Decommissioning Program and the Third Revision of the Krško NPP RW and SF Disposal Program, 21.05.2019."

[27] "Program of Krško NPP Decommissioning and SF & LILW Disposal (Program razgradnje NEK in odlaganja NSRAO in IJG), ARAO, T-1123/03, Ljubljana, 2004, APO Ltd., Environmental Services, 25-04-1348/06, Zagreb, 2004."

[28] "Costs for management of the radioactive waste products from nuclear power production, Plan 2003, Technical Report TR-03-11, SKB, 2003."

[29] "Lars Ageskog, Patrik Jansson, Heat propagation in and around the deep repository, SKB TR-99-02, January 1999."

[30] "Spent Nuclear Fuel and High Level Waste Disposal in Slovenia – Assessment of Spent Fuel Management Costs, IBE, May 2004."

[31] "Lumir Nachmilner, Developing a ToR for a New Revision of the SNF Disposal Concept in Hard Rock, IAEA Expert Mission under SLO 3003, June 2008."

[32] "Cooperation between ARAO and ONDRAF/NIRAS in 2005 - 2006 (Laurent Wouters and Pierre Manfroy consultancy on geological environment for spent fuel disposal)."

[33] "Overview of Geological Data for Deep Repository for Radioactive Waste in Argillaceous Formations in Slovenia, GeoZS – Geological Survey of Slovenia, Ljublja-na, 2005."

[34] “Geological data and the preliminary catalogue of argillaceous formations for geological disposal of radioactive waste, GeoZS – Geological Survey of Slovenia, Ljubljana, 2007.”

[35] “Neil Chapman, Slovenian geological repository programme in sedimentary formations, IAEA Expert Mission under SLO-3003, October 2008.”

[36] “Preliminary Stage of PA/SA for HLW & SF Slovenian reference case: Generic Repository in Hard Rock (project No. 03-00-014-004), ZAG and GeoZS, Ljubljana, 2009.”

[37] “M. Ravnik, L. Snoj, G. Žerovnik, M. Kromar, Izračun izotopske sestave in sproščene toplote iz IJG iz NEK (Calculation of isotope composition and decay heat for SF from NEK), IJS-DP-9841, 2008.”

[38] “Paul Smith, Safety assessment of a KBS-3H repository in crystalline host rock at the Olkiluoto site in Finland, IAEA Expert Mission under SLO-3003, March 2008.”

[39] “Pierre Kunsch, IAEA Expert Mission Report on Task Number SLO 3003 02 Evaluation of the existing methodology and spent fuel disposal estimate, Ljubljana, July 2007.”

[40] “Pierre Kunsch, IAEA Expert Mission Report on Task Number SLO 3003 03 Recommendations for improved cost estimates of spent fuel disposal, Ljubljana, July 2007.”

[41] “Pierre Kunsch, IAEA Report Task Number SL0 3003 9003 Workshop on cost methodologies and cost calculation, 24 to 28 March 2008, Ljubljana.”

[42] “Pierre Kunsch, IAEA Report Task Number SLO 3003 07 Software code for cost calculations, Drafting of an analysis file for re-programming, March 2008.”

[43] “Optimization of canisters filling with spent fuel from Krško NPP regarding the highest allowed thermal power, IJS-DP-10075, IJS, Ljubljana, March 2009.”

[44] “Revised Reference Scenario for Geological Disposal Facility in Hard Rock with Cost Estimation for its Implementation, ARAO-03-00-014-004-2, IBE, Ljubljana, December 2009.”

[45] “Recommendations and input data update for the development of the study RS, ARAO, 20. 11. 2018; NEK note to ARAO nr. ING.DOV-148.16, April 2018; ToR for RS2018.”

[46] “Total decay heat in SFP (Skupna zakasnela toplota v SFP), ING.GOR-040.09/MB, NEK, 2009 (Enclosures 1 to 4), 2018.”

[47] “Criticality safety analysis of the NPP Krško spent fuel in the disposal facility at nominal conditions (Analiza kritičnosti v odlagališču za izrabljeno jedrsko gorivo iz NEK pri normalnih pogojih), IJS-DP-10839, Ljubljana, januar 2012.”

[48] “Waste management of the encapsulation plant, Working report 2015-51, Posiva, January 2016.”

[49] “Preliminary Design of the Repository; Stage 2, Posiva, 2006.”

[50] “Zakon o prevozu nevarnega blaga, Transport of Dangerous Goods Act, Off. Gaz. RS 33/06, 41/09, 97/10, 56/15.”

[51] "Management of spent nuclear fuel and its waste, EASAC policy report no. 23, JRC Reference Report, July 2014."

[52] "RD&D Planning Towards Geological Disposal of Radioactive Waste DELIVERABLE (D-No: 2.3), Guidance for less-advanced Programmes, IGD-TP, 2015."

[53] "»Costing methods and Funding Schemes for Radioactive Waste Disposal Programmes«, final draft, IAEA, 2018."

[54] "Guidelines for comparing cost assessments for geological repository projects, EDRAM, 2012."

[55] "Record of the 12th session of the intergovernmental commission for monitoring the implementation of The Bilateral Slovenian-Croatian Agreement [BRHNEK] on the Krško NPP, January 2019."

[56] "Record of the 18th session of the implementation coordination committee for monitoring the progress of preparation of the Third Revision of the Krško NPP Decommissioning Program and the Third Revision of the Krško NPP RW and SF Disposal Program."

[57] "Value Added Tax Act, Off. Gaz. RS 13/11, 18/11, 78/11, 38/12, 83/12, 86/14, 90/15."

[58] "Value Added Tax Act, Off. Gaz. RC 73/13, 99/13, 148/13, 153/13, 143/14, 115/16."

[59] "Plan 2016, Costs from and including 2018 for the radioactive residual products from nuclear power, Basis for fees and guarantees for the period 2018–2020, SKB TR-17-02, April 2017."

[60] "Radioactive Waste Storage and Disposal Facilities in South Australia – Quantitative Costs Analysis and Business Case, Report V2, Jacobs-MCM, 20 April 2016."

[61] "Framework and Challenges for Initiating Multinational Cooperation for a Radioactive Waste Repository, IAEA Nuclear Energy Series No. NW-T-1.5, Vienna 2016."

[62] OECD/NEA, "The Economics of the Back End of the Nuclear Fuel Cycle," 2013.

[63] "Program of NPP Krško Decommissioning and SF & LILW Disposal, Revision 2, text version 1, ARAO, APO, June 2010."

3.4. Annex 1- Detailed Krško NPP SF inventory

Year	Cycle number (after)	SF pool inven-tory	SF trans-fered to MPC	SF in SFDS	No. of MPC	Total SF inven-tory	No. of SF discharged from core
1983	0	0				0	
1984	1	40				40	40
1985	2	85				85	45
1986	3	122				122	37
1987	4	154				154	32
1988	5	194				194	40
1989	6	226				226	32
1990	7	266				266	40
1991	8	314				314	48
1992	8	314				314	0
1993	9	358				358	44
1994	10	406				406	48
1995	11	442				442	36
1996	12	470				470	28
1997	13	498				498	28
1998	14	530				530	32
1999	15	562				562	32
2000	16	594				594	32
2001	17	630				630	36
2002	18	663				663	33
2003	19	707				707	44
2004	20	763				763	56
2005	20	763				763	0
2006	21	819				819	56
2007	22	872				872	53
2008	22	872				872	0
2009	23	928				928	56
2010	24	985				985	57
2011	24	985				985	0
2012	25	1041				1041	56
2013	26	1098				1098	57
2014	26	1098				1098	0
2015	27	1154				1154	56
2016	28	1210				1210	56
2017	28	1210				1210	0

Year	Cycle number (after)	SF pool inven-tory	SF trans-fered to MPC	SF in SFDS	No. of MPC	Total SF inven-tory	No. of SF discharged from core
2018	29	1266				1266	56
2019	30	1322				1322	56
2020	30	730	592	592	16	1322	0
2021	31	786	0	592	16	1378	56
2022	32	842	0	592	16	1434	56
2023	32	842	0	592	16	1434	0
2024	33	898	0	592	16	1490	56
2025	34	954	0	592	16	1546	56
2026	34	954	0	592	16	1546	0
2027	35	1010	0	592	16	1602	56
2028	36	474	592	1184	32	1658	56
2029	36	474	0	1184	32	1658	0
2030	37	530	0	1184	32	1714	56
2031	38	586	0	1184	32	1770	56
2032	38	586	0	1184	32	1770	0
2033	39	642	0	1184	32	1826	56
2034	40	698	0	1184	32	1882	56
2035	40	698	0	1184	32	1882	0
2036	41	754	0	1184	32	1938	56
2037	42	810	0	1184	32	1994	56
2038	42	810	0	1184	32	1994	0
2039	43	866	0	1184	32	2050	56
2040	44	922	0	1184	32	2106	56
2041	44	922	0	1184	32	2106	0
2042	45	977	0	1184	32	2161	55
2043	46	1098	0	1184	32	2282	121
2044	n/a	1098	0	1184	32	2282	0
2045		1098	0	1184	32	2282	0
2046		1098	0	1184	32	2282	0
2047		1098	0	1184	32	2282	0
2048		1098	0	1184	32	2282	0
2049		0	1098	2282	62	2282	0

4. LILW Inventory

This chapter is based on a studies: *Proposal for Division and Takeover of operational LILW* created in September 2018 by ENCONET d.o.o. and EKONERG d.o.o., *Proposal for Division and Takeover of decommissioning LILW* created in October 2018 by ENCONET d.o.o. and EKONERG d.o.o and *6th Revision of the Preliminary Decommissioning Plan for NPP Krško* by *Siempelkamp NIS Ingenieurgesellschaft mbH* for the purpose of drafting this revision.

Abbreviations

A	Ash (incineration product)
ACC	Supercompacted Charcoal (pellets)
ARAO	Agency for Radwaste Management (Agencija za radioaktivne odpadke)
BR	Dried blow-down Resins (IDDS product)
BRHUT	Boron Recycle Hold-up Tank
CF	Filter Cartridges in Cemented Matrix

CPW	Compressible Waste
CS	Carbon Steel
CSF	Central Storage Facility
CW	Compressible Waste
CWC	Supercompacted Compressible Waste (pellets)
DB	Decontamination Building
DC	Dried Concentrates (IDDS products)
DGR	Deep Geological Repository
DMN	Difficult to Measure Nuclides
DS	Dried Sludges (IDDS products)
EB	Evaporator Bottom Solidified in Vermiculite-Cemented Matrix
EBC	Supercompacted Evaporator Bottom (pellets)
EC	Evaporator Concentrates and Tank Sludges
EU	European Union
FDT	Floor Drain Tank
Fond	Fund for financing the decommissioning of the Krško NPP and the disposal of Krško NPP radioactive waste and spent nuclear fuel
FWP	Final Waste Package (in this document it refers to final package for storage)
HF	Compacted Filter Debris
HLW	High Level Waste
I	Ingots (melting product)
IAEA	International Atomic Energy Agency
IDDS	In Drum Drying System
ILW	Intermediate Level Waste
JV7	Slovenian rules on radioactive waste and spent fuel management
LILW	Low and Intermediate Level Waste
LL	Long Lived
LLW	Low Level Waste
NCW	Non-compressible Waste
NEK	Nuclear Power Plant Krško (Nuklearna elektrarna Krško)
NPP	Nuclear Power Plant
O	Solidified Non-compressible Waste
OC	Other Supercompacted Compressible Waste (pellets)
PDP	Preliminary Decommissioning Plan
PE	Polyethylene
PR	Dried Primary Resins (IDDS product)
PVC	Polyvinyl Chloride
RCC	Reinforced Concrete Container
RW	Radioactive Waste
SF	Spent Filters
SFDS	Spent Fuel Dry Storage
SIR	Spent Ion Resins
SNF	Spent Nuclear Fuel
SNSA	Slovenian Nuclear Safety Administration (URJSV)
SR	Spent Resins Solidified in Vermiculite-Cemented Matrix
SRPA	Slovenian Radiation Protection Administration (URSVS)

SRSF	Solid Radwaste Storage Facility
SS	Stainless Steel
SW	Specific Waste
T1, T2	Types of Tube Type Containers
ToR	Terms of Reference
USAR	Updated Safety Analyses Report
WAC	Waste Acceptance Criteria
WHT	Waste Hold-up Tank
WP	Waste Package
WPs	Waste Packages
WPS	Waste Package Specification

4.1. Introduction

This chapter analyses quantities of operational and decommissioning waste to be safely disposed half by each Croatian and Slovenian side as defined by Intergovernmental agreement.

Krško NPP have been producing low and intermediate level radioactive waste (LILW) during operation, maintenance and refueling. LILW will still be produced until the end of planned plant life in 2043. LILW produced during Krško NPP operation is stored in Solid Radwaste Storage Facility (SRSF). Some radioactive waste inventory is also produced during Krško NPP maintenance and replacement of major parts and this material is stored in Decontamination Building (DB) on Krško NPP site.

Apart from operational LILW another type of LILW will be generated in the future. This is decommissioning LILW which will arise during decommissioning activities after the end of operational lifetime of Krško NPP. Types and quantities of decommissioning LILW are estimated by using NPP Krško site specific data based upon site specific decommissioning plan. This was done in *6th Revision of the Preliminary Decommissioning Plan for NPP Krško.*

The majority of radioactive waste generated by operation and decommissioning is LILW: short lived radioactive waste with its half-life period shorter than 30 years (specific activity of alpha emitters with half-life longer than 30 year is limited to 4.000 Bq/g/package and to average value of 400 Bq/g in total LILW mass). LILW will be after treatment and conditioning disposed in the LILW repositories planned by Croatian and Slovenian side. Long lived radioactive waste with its half-life period longer than 30 years will be disposed together with the spent fuel in HLW repository when the permanent solution for the spent fuel repository will be provided.

4.2. Description of operational LILW

This chapter deals with the waste streams, waste forms, waste containers and resulting waste packages that are being generated and are currently stored at Krško NPP. Also it deals with RW that will be generated up to the end of extended lifetime of Krško NPP (2043).The part related to waste packages gives the total number of the waste packages that are the subject of LILW division.

4.2.1. Waste streams

Waste stream is defined as the complete flow of RW starting from its source, through to treatment and conditioning, up to the final disposal. Waste streams usually assume the waste categories with roughly constant and unchanging radiological, chemical, physical, mechanical, thermal and biological properties. Taking into account different sources of

radioactive wastes in Krško NPP the following six waste streams of the operational LILW have been recognized:

1) EC - Evaporator Concentrates and Tank Sludges,
2) SIR - Spent Ion Resins,
3) SF - Spent Filters,
4) CPW - Compressible Waste,
5) NCW - Non-compressible waste and
6) SW - Specific waste.

4.2.2. Waste forms

Waste form is defined as the physical and chemical form of RW after treatment and/or conditioning, resulting in a solid product prior to packaging. The following table summarizes the waste streams and the corresponding operational LILW waste forms resulting from usual waste management practices at Krško NPP.

Table 4-1: Waste streams and corresponding waste forms.

Waste Streams	Waste Forms	Short Description
EC	EB	Evaporator bottom solidified in vermiculite-cemented matrix
	EBC	Supercompacted EB (pellets)
	DC	Dried concentrates (IDDS product)
	DS	Dried sludges (IDDS product)
SIR	SR	Spent resins solidified in vermiculite-cemented matrix
	BR	Dried blow-down resins (IDDS product)
	PR	Dried primary resins (IDDS product)
SF	CF	Filter cartridges in cemented matrix
CPW	CWC	Supercompacted compressible waste (pellets)
	OC	Supercompacted other compressible waste (pellets)
NCW	A	Ash (incineration product)
	I	Ingots (melting product)
	O	Solid non-compressible waste
SW	ACC	Supercompacted charcoal (pellets)

4.2.3. Waste containers

Table 4-2 shows the main characteristics of ten container types that are used for storage of the operational LILW at Krško NPP.

Containers labeled as D6, T1 and T2 are the overpacks. T1 and T2 containers may contain pellets or the waste placed into containers of smaller dimension (3 containers in the T1 or T2). D6 container contains pellets. Container D1 is the overpack just for A waste form

which is originally placed into D2 container. Containers labeled as D1, D2, D3, D4, D5, H1 and H2 are so-called basic containers for different types of waste forms.

Table 4-2: Waste containers used for storage of the operational LILW

Label	Volume/ Useful Volume (l)	Material(1)	Wall Thickness (mm)	Mass of Empty Drum (kg)	Usage (waste forms)
D1	208	CS	1	23	A, CW(2) and O(2)
D2	113	SS	1	10	A
D3	208/32	CS	1	400	CF
D4	208/80	CS	1	190	SR
D5	208/110	CS	1	180	EB
D6	320	CS	1.6	37	CWC, EBC and OC
H1	200	SS	1.5	65	BR, DC, DS
H2	200/150	SS	30	450	CF, PR
H3(3)	200	CS	1.5	60	-
T1	864	CS	2	117	ACC, CF, CWC, EB, EBC, OC and SR
T2	869	CS	2	135	A, ACC, BR, CWC, DC, DS, EBC, OC and PR

(1) CS – Carbon Steel, SS – Stainless Steel

(2) CW and O are abbreviations for transitional waste forms, i.e. waste forms that will be additionally treated. CW stands for compressible waste which will be supercompacted, O stands for other waste forms which may be supercompacted, incinerated, melted, cut, grinded or just placed into appropriate container.

(3) Still not in use

Table 4-3 provides a summary overview of all waste forms, streams and containers with modes of processing and conditioning of operational LILW in Krško NPP.

4.2.4. Waste packages

Waste container into which the corresponding waste form is placed makes the waste package. In other words, container and waste form are the components of the waste package. These two components are basic barriers for radionuclide migration in accordance with Slovenian rules on radioactive waste and spent fuel management that define waste package as packaging complete with internal barriers or absorption material, radioactive waste or spent fuel [1].

According to the Krško NPP operational LILW inventory [2] the waste packages that are currently stored in SRSF are shown in Table 4-4.

Waste packages formed by the overpacks D6, T1 and T2 are considered as final waste packages for storage [3]. These packages (2,788 packages) are the subject of division and takeover. The same applies for ingots (80 freestanding metal blocks).

Table 4-3: Operational LILW waste streams, treatment and conditioning methods, waste forms and types of containers [4]

No.	Waste Stream	Raw Waste	Treatment and Conditioning	Waste form	Container
1.	Evaporator Concentrates and sludges (EC)	1) Process fluid from WHT, FDT and BRHUT 2) Evaporator bottom 3) Sludges from tanks and sumps	1) Evaporation 2) Solidification 3) Supercompaction 4) In-drum drying	1) Solidified evaporator bottom in vermiculite-cemented matrix (EB) 2) Supercompacted solidified evaporator bottom in vermiculite-cemented matrix (EBC) 3) Dried concentrate (DC) 4) Dried sludge (DS)	D5 D6 H1 H3 T1 T2
2.	Spent ion resins (SIR)	1) Primary wet spent ion resins 2) Blow-down spent ion resins	1) Solidification 2) In-drum drying 3) Incineration (planned)	1) Primary resins solidified in vermiculite-cemented matrix (SR) 2) Dried primary resins (PR) 3) Dried blow-down resins (BR)	D4 H1 H2 H3 T1 T2 RL
3.	Spent filters (SF)	1) Spent filter cartridges	1) Immobilization (cement) 2) Manual filling	1) Filter cartridges in cemented matrix (CF)	D3 T1 T2
4.	Compressible Waste (CW)	1) Dry waste: a. Contaminated protective clothing, footwear and other protective gear b. Contaminated plastic (PVC, PE) c. Contaminated paper and textile waste 2) Wet waste: a. Wet waste I b. Wet waste II	1) Segregation 2) Dismantling 3) Compaction 4) Supercompaction 5) Drying 6) Incineration 7) Immobilization (cement)	1) Compacted waste (CW) 2) Supercompacted waste (CWC) 3) Incineration products (A)	D1 D2/D1 D6 T1
5.	Non-compressible Waste (NCW)	1) Contaminated wood 2) Contaminated metal equipment, structures and debris 3) Contaminated concrete 4) HEPA filters	1) Segregation 2) Compaction 3) Supercompaction 4) Incineration 5) Immobilization (cement) 6) Melting	1) Solid non-compressible waste (O) 2) Compacted filter debris (HF) 3) Supercompacted waste (OC) 4) Incineration products (A) 5) Melting products (I)	D1 D2/D1 D6 T1
6.	Specific Waste (SW)	1) Corundum powder 2) Charcoal 3) Contaminated oils, solvents and emulsions 4) Steam generators 5) Steam generator insulation 6) Dismantled spent fuel racks 7) Replaced equipment	Case by case	-	D1 D1 D1 - KCC-20 - KM

Table 4-4: Waste packages currently stored in SRFS (December 31, 2017)

Waste Stream	Waste Form	Waste Containers								
		D1	D3	D4	D5	D6	H1	H2	T1	T2
EC	EB				2(1)				12	
	EBC					7			1,457	1
	DC									86
	DS									5
Total		-	-	-	2	7	-	-	1,469	92
SIR	SR			689(1)					106	
	BR						54(2)			14
	PR									70
Total		-	-	689	-	-	54	-	106	84
SF	CF		113(1)					4(1)	23	
Total		-	113	-	-	-	-	4	23	-
CPW	CW	358(2)								
	CWC					515			226	18
	OC					95			15	115
Total		358	-	-	-	610	-	-	241	133
NCW	A	95(3)								11
	I	Ingots - melting products. Freestanding blocks. 80 ingots are stored in DB.								
	O	64(4)								
Total		159	-	-	-	-	-	-	-	11
SW	ACC								11	1
Total		-	-	-	-	-	-	-	11	1
Grand Total		517	113	689	2	617	54	4	1,850	321

(1) Waste packages that will be placed into T2 containers
(2) Waste packages will be additionally treated (incineration) and incinerated products will be placed into T2 containers
(3) Waste packages of D2D1 type that will be placed into T2 containers
(4) Waste packages will be additionally processed (supercompaction, incineration and/or just placement into T2 containers)

Waste packages such as EBD5 (2 packages), SRD4 (689), CFD3 (113), CFH2 (4) and AD2D1 (95), although packed into 200 l drums, are considered as final according to agreement reached between ARAO, Fond and Krško NPP. These waste packages (903 packages) are subject of division and takeover.

There are 476 waste packages waiting for additional processing. These packages are BRH1 (54 packages), CWD1 (358) and OD1 (64). Foreseen treatment technologies are supercompaction, incineration, melting, cutting, grinding and final placement into T2 containers. Taking into consideration the foreseen processing the resulting number of waste packages was estimated based on data and information given in *Technical Report on Radioactive Waste Management in Krško NPP* [5]. The results are shown in Table 4-5. Number of waste packages shown in the table (right column) is the subject of

division but not takeover. In this case division will be performed on the informative level only.

Table 4-5: Waste packages waiting for foreseen processing

<table>
<tr><th>Waste Stream</th><th>Waste Package</th><th>Current WP No.</th><th>Foreseen Treatment</th><th>Final Waste Package</th><th>WP No. after Treatment(1)</th></tr>
<tr><td>SIR</td><td>BRH1</td><td>54</td><td rowspan="3">Incineration</td><td rowspan="3">AD2D1T2</td><td rowspan="3">14(2)</td></tr>
<tr><td>CPW</td><td>CWD1</td><td>358</td></tr>
<tr><td>NCW</td><td>OD1</td><td>1</td></tr>
<tr><td>CPW</td><td>OD1</td><td>56</td><td>Supercompaction</td><td>OCT2</td><td>10(3)</td></tr>
<tr><td>NCW</td><td>OD1</td><td>7</td><td>Placement into T2</td><td>OD1T2</td><td>3(4)</td></tr>
<tr><td colspan="5">Total</td><td>27</td></tr>
</table>

(1) The calculated number of T2 packages is conservatively rounded up to the nearest integer.

(2) It was assumed that reduction factor for incineration is 10 [6] and that 3 D2 drums can be fitted in one T2

(3) For supercompaction following formula was used to calculate number of T2 packages: No. of OD1/ 6, where 6 is the number of supercompacted pellets that can be placed into one T2 [6].

(4) 3 D1 drums can be placed into one T2.

Thus, it is expected that additional treatment of 476 waste packages will result with 27 waste packages of type T2. It should be noted that by placing OD1 packages in T2 containers a new waste package will be produced – OD1T2 waste package. This type of waste package was not generated so far in Krško NPP. Mentioned waste package type assumes non-compressible and nonflammable type of waste that will be placed into D1 container and overpacked into T2 container afterwards.

Based on predictions of waste generation given in *Technical Report on Radioactive Waste Management in Krško NPP* (94 waste packages of T2 type over three years) the projected number of waste packages that will be generated for the time period 2018–2024 was calculated and is shown in the Table 4-6. Expected number of waste packages shown in the table is the subject of division but not takeover. In this case division will be performed on the informative level only.

Table 4-6: Projection of WPs that will be generated in time period 2018-2023

<table>
<tr><th>Waste Stream</th><th>Waste Form</th><th>No. of T2 Packages</th></tr>
<tr><td rowspan="2">EC</td><td>DC</td><td rowspan="2">50</td></tr>
<tr><td>DS</td></tr>
<tr><td>SIR</td><td>PR</td><td>50</td></tr>
<tr><td>SF</td><td>CF</td><td>20</td></tr>
<tr><td rowspan="2">CPW</td><td>CWC</td><td>16</td></tr>
<tr><td>OC</td><td>18</td></tr>
<tr><td rowspan="2">NCW</td><td>A</td><td>16</td></tr>
<tr><td>O</td><td>18</td></tr>
<tr><td colspan="2">Total</td><td>188</td></tr>
</table>

By applying the same assumptions as above the number of waste packages of type T2 that will be generated in the time period 2024–2043 is calculated and shown in the Table 4-7. Number of waste packages shown in the table is the subject of division but not takeover. In this case division will be performed on the informative level only.

Table 4-7: Projection of WPs that will be generated in time period 2024–2043

Waste Stream	Waste Form	No. of T2 Packages
EC	DC	167
	DS	
SIR	PR	167
SF	CF	67
CPW	CWC	54
	OC	60
NCW	A	54
	O	60
Total		**629**

4.3. Operational LILW inventory

The aim of this chapter is to set up the inventory of the operational LILW that is the subject of division and afterwards of takeover. Data and information on waste packages given here correspond with data and information given in the subchapter 4.2.4.

Table 4-8 summarizes the results of analysis performed in this chapter. It presents the numbers of waste packages that should be considered in the process of division of the operational LILW.

Table 4-8: Total number of waste packages

WP Number	WP Type	Remark
2,788	D6, T1 and T2	***Final waste packages.*** Subject of division and takeover
80	Ingots	***Final waste packages.*** Subject of division and takeover
903	EBD5, SRD4, CFD3, CFH2 and AD2D1	***Final waste packages in 200 l drums.*** Subject of division and takeover.
27	AD2D1T2, OCT2 and OD1T2	***Estimated WPs after foreseen treatment.*** Packages estimated to be generated after foreseen treatment and conditioning of BRH1, CWD1 and OD1 packages. Not considered as final packages. Subject of the informative division.

WP Number	WP Type	Remark
188	T2 containing various waste forms	***Projection of WPs for period 2018–2023*** Packages anticipated to be generated in the time period 2018–2023. Not considered as the final packages. Subject of the informative division.
629	T2 containing various waste forms	***Projection of WPs for period 2024–2043*** Packages anticipated to be generated in the time period 2024–2043. Not considered as the final packages. Subject of the informative division.
4,615	**Total number of waste packages considered in the report**	

As already stated above the inventory includes following waste packages:

- Already produced and stored final waste packages,
- Final waste packages which are already produced and stored in 200 l drums
- Estimated number of waste packages that will be generated after foreseen processing of existing WPs and
- Projection of waste package to be generated in time periods 2018–2023 and 2024–2043.

4.3.1. Final waste packages

Table 4-9 provides main inventory data on final packages that are currently stored in SRSF. It counts 2,788 packages of D6, T1 and T2 types and 80 ingots (temporary stored in DB building). Data on waste packages mass, volume and total activity is taken from [6]. It should be noted here that masses of the waste packages include masses of empty containers, i.e. they present gross mass. These packages are considered as the subject of the operational LILW division and takeover.

Table 4-9: Inventory data on the final WPs

Waste Stream	Waste Package	WP Number	Mass (t)	Volume (m^3)	Total Activity(1) (Bq)
EC	EBCD6	7	4.9	2.2	8.00×10^{8}
	EBCT1	1,457	3,164.8	1,258.8	1.32×10^{12}
	EBD5T1	12	15.1	10.4	7.85×10^{9}
	EBCT2	1	2.3	0.9	1.09×10^{9}
	DCH1T2	86	89.4	74.7	3.13×10^{11}
	DSH1T2	5	4.8	4.3	8.04×10^{10}
Total		**1,568**	**3,281.3**	**1,351.3**	$\mathbf{1.72\times10^{12}}$
SIR	SRD4T1	106	170.3	91.6	2.13×10^{13}
	BRH1T2	14	11,0	12.2	4.28×10^{10}
	PRH2T2	70	127.2	60.8	1.92×10^{13}

Waste Stream	Waste Package	WP Number	Mass (t)	Volume (m^3)	Total Activity(1) (Bq)
Total		**190**	**308.5**	**164.6**	**4.05×10^{13}**
SF	CFD3T1	23	56.0	19.9	1.71×10^{11}
Total		**23**	**56.0**	**19.9**	**1.71×10^{11}**
CPW	CWCD6	515	202.4	164.8	1.30×10^{11}
	OCD6	95	43.1	30.4	1.70×10^{10}
	CWCT1	226	213.0	195.3	1.15×10^{11}
	OCT1	15	14.0	13.0	1.01×10^{10}
	CWCT2	18	16.1	15.6	2.88×10^{9}
	OCT2	115	158.2	99.9	7.05×10^{10}
Total		**984**	**646.8**	**519.0**	**3.46×10^{11}**
NCW	AD2D1T2	11	20.0	9.6	1.34×10^{9}
	I	80	49.6	8.8	2.22×10^{8}
Total		**91**	**69.6**	**18.4**	**1.56×10^{9}**
SW	ACCT1	11	9.0	9.5	4.29×10^{6}
	ACCT2	1	0.9	0.9	1.22×10^{6}
Total		**12**	**9.9**	**10.4**	**5.51×10^{6}**
Grand Total		**2,868**	**4,372.1**	**2,083.6**	**4.27×10^{13}**

(1) Activity values are taken from LILW inventory [2] and they do not include radioactive decay.

4.3.2. Final Waste Packages in 200 l Drums

Table 4-10 provides inventory data on 903 waste packages in 200 l drums. Masses given in the table include masses of the empty containers. These packages are considered as the subject of the operational LILW division and takeover

Table 4-10: Inventory data on WPs waiting to be placed into T2 containers

Waste Stream	Waste Package	WP Number	Mass (t)	Volume (m^3)	Total Activity* (Bq)
EC	EBD5	2	0.7	0.4	7.94×10^{8}
SIR	SRD4	689	329.4	143.3	1.61×10^{13}
SF	CFD3	113	87.2	23.5	7.21×10^{11}
	CFH2	4	4.2	0,8	3.08×10^{11}
NCW	AD2D1	95	48.6	19.8	1.25×10^{10}
Total		**903**	**470.1**	**187.8**	**1.71×10^{13}**

* Activity values are taken from LILW inventory [2] and they do not include radioactive decay.

4.3.3. Estimated waste packages after foreseen processing

Table 4-11 provides inventory data on 27 waste packages assumed to be generated from foreseen processing of 476 waste packages (BRH1, CWD1 and OD1 types of packages, Table 4-5).

Table 4-11: Inventory data on WPs resulting from foreseen processing

Waste Stream	Waste Package	WP Number	Mass (t)	Volume (m^3)	Total Activity* (Bq)
CPW	OCT2	10	8.2	8.7	3.46×10^{10}
NCW	AD2D1T2	14	25.5	12.2	1.71×10^{9}
	OD1T2	3	1.5	2.6	5.45×10^{9}
Total		**27**	**35.2**	**23.5**	$\mathbf{4.17\times10^{10}}$

* Activity values do not include radioactive decay.

Masses and Activity given in the table were calculated as follows:

- OCT2 and OD1T2 – total mass and activity is the sum of masses and activities of WPs BRH1, CWD1 and OD1 which will form OCT2 and OD1T2 packages as foreseen processing will not reduce mass or activity, plus the mass of empty T2 containers
- AD2D1T2 – mass and activity were calculated based on the average values of already existing packages of same sort, which already include mass of T2 container [2].

Masses given in the table include masses of empty T2 containers, i.e. they present gross mass. These waste packages can only be subject of informative division as the foreseen treatment will significantly reduce volume and number of waste packages, and the characteristics of new waste packages cannot be determined in advance, nor could the identification number of final T2 package be defined. The division on informative level for aforementioned WPs includes division of estimated number of packages with associated total mass and activity per group of WPs.

4.3.4. Projection of waste packages for time periods 2018–2023 and 2024–2043

Table 4-12 and Table 4-13 provide inventory data on waste packages that will be generated in the time period 2018–2023 and 2024–2043 respectively.

Table 4-12: Projection of inventory data on WPs 2018–2023

Waste Stream	Waste Package	WP Number	Mass (t)	Volume (m^3)	Total Activity (Bq)
EC	DCH1T2	50	49.9	43.5	4.93×10^{11}
	DSH1T2				
SIR	PRH2T2	50	90.8	43.5	1.37×10^{13}
SF	CFH2T2	20	48.7	17.4	1.50×10^{11}
CPW	CWCT2	16	14.3	13.9	2.56×10^{9}
	OCT2	18	23.8	15.6	1.13×10^{10}
NCW	AD2D1T2	16	29.1	13.9	1.95×10^{9}
	OD1T2	18	7.4	15.6	5.03×10^{10}
Total		**188**	**264.0**	**163.4**	$\mathbf{1.44\times10^{13}}$

Masses and activity given in the table were calculated based on the average values of

already existing packages of the same kind [2]. Masses given in the tables include masses of empty T2 containers, i.e. they present gross mass. Although presented here as final waste packages the projection of number of WPs can only be subject of informative division, as the exact characteristics of waste packages cannot be determined. The division on informative level for aforementioned WPs includes division of assessed number of packages with associated total mass and activity per group of waste packages.

Table 4-13: Projection of inventory data on WPs 2024–2043

Waste Stream	Waste Package	WP Number	Mass (t)	Volume (m^3)	Total Activity (Bq)
EC	DCH1T2	167	166.6	145.1	1.65×10^{12}
	DSH1T2				
SIR	PRH2T2	167	303.4	145.1	4.59×10^{13}
SF	CFH2T2	67	163.0	58.2	4.99×10^{11}
CPW	CWCT2	54	48.2	46.9	8.64×10^{9}
	OCT2	60	79.5	52.1	1.68×10^{11}
NCW	AD2D1T2	54	98.3	46.9	6.60×10^{9}
	OD1T2	60	24.7	52.1	1.68×10^{11}
Total		**629**	**883.7**	**546.6**	$\mathbf{4.83\times10^{13}}$

4.3.5. Summary of operational waste

Table 4-14 presents summary data on complete LILW inventory at Krško NPP (existing, estimated and projections). This table corresponds with Table 4-8.

Table 4-14: Summary data on LILW operational inventory

WPs	WP Type	WP Number	Mass (t)	Volume (m^3)	Total Activity* (Bq)
FWPs	D6, T1 and T2	2,788	4,322.5	2,074.8	$4{,}27\times10^{13}$
FWPs	Ingots	80	49.6	8.8	$2{,}22\times10^{8}$
FWPs in 200 l drums	EBD5, SRD4, CFD3, CFH2 and AD2D1	903	470.1	187.8	$1{,}71\times10^{13}$
Estimated WPs after foreseen treatment	AD2D1T2, OCT2 and OD1T2	27	35.2	23.5	$4{,}17\times10^{10}$
Projection of WPs period 2018–2023	T2 containing various waste forms	188	264.0	163.4	$1{,}44\times10^{13}$
Projection of WPs period 2024–2043	T2 containing various waste forms	629	883.7	546.6	$4{,}83\times10^{13}$
Total		**4,615**	**6,025.1**	**3,004.9**	$\mathbf{1{,}23\times10^{14}}$

* Activity values do not include radioactive decay.

Current Krško NPP LILW database was used in the preparation of this review. Analysis of presented data indicate that overall knowledge of the operational LILW characteristics is insufficient. Just division, takeover and removal of LILW to long term storage or repositories cannot be guaranteed in absence of a full inventory which is must for proper verification of the storage or repository WACs.

LILW was characterized earlier but last operational LILW characterization project has been undertaken some 10 years ago. Presently, database on operational LILW in Krško NPP requires updating since it does not contain data on some long lived (LL) nuclides. These nuclides belong to the difficult to measure group of nuclides (DMN) which rely on indirect data used in conjunction with correlation (scaling) factors. Those radionuclides are important for post-closure safety assessment and decision on the LILW disposal options.

Quantifying the radionuclide inventory of the DMNs is a significant future challenge for Krško NPP. The estimation method should be frequently reviewed with a view to confirming the adequacy of the Scaling Factors. It is suggested to perform sampling on the existing waste (resins and filters, which gathers the main part of the activity), and perform precise gamma analysis and radiochemical analysis for determining the key DMNs, in order to improve the robustness of the inventory. Detailed sampling and laboratory analysis allows the development of more reliable correlations (Scaling Factors) and helps better estimation of the critical (for long term safety point of view) nuclides.

In conclusion, prior to division and takeover additional and improved operational LILW characterization is needed necessitating preparation and adequate equipment.

4.4. Description of decommissioning waste

Detailed description of waste generated by decommissioning can be found in *Preliminary Decommissioning Plan for Krško NPP*, Rev.6 developed by Siempelkamp (PDP Rev.6 Chapter 8).

4.5. Decommissioning LILW inventory

Assessment of quantities of decommissioning LILW is based on Preliminary Decommissioning Plan for Krško NPP, Rev.6 developed by Siempelkamp (PDP Rev.6). It is important to note that PDP Rev. 6 deals with decommissioning of two facilities. These are Krško NPP for which decommissioning will be performed in the period 2043–2058 and Spent Fuel Dry Storage facility (SFDS) for which decommissioning will be performed in the period 2103–2106. Two different times of decommissioning dictate time of takeover for decommissioning LILW.

Estimated masses of complete material that will be generated during decommissioning of two facilities (Krško NPP and SFDS facility) could be divided in five main categories.

Furthermore, decommissioning material that will be produced by decontamination, dismantling and treatment of the components and structures will be coming from three different parts of facilities: controlled area, monitored area and from the area inside fence of Krško NPP. Decommissioning material balance of all the estimated waste quantities to be generated after decontamination, dismantling and consecutive treatment is presented in Table 4-15.

Table 4-15 Decommissioning material balance

Decommissioning material category	Mass (t)
1. Conventional waste (no treatment)	444,089.2
2. Released material (before treatment)	15,632.0
3. Toxic non-radioactive material (before treatment)	115.0
4. HLW (no treatment)	82.1
5. LILW (before treatment)	6,115.6

Decommissioning implies decontamination, dismantling and treatment of the components and as a result primary and secondary LILW is generated. Dismantled components are primary waste and clothes, tools and other consumables used during the decommissioning work including waste water are the so called secondary waste. Out of the masses of all primary and secondary waste only waste that could be qualified as LILW is within the scope of interest of this *Krško NPP Radioactive Waste and Spent Fuel Disposal Program*.

Total quantity of primary and secondary decommissioning LILW prior to treatment is assessed to be 6,115.6 t (PDP Rev.6 Table 8-6). After treatment this mass will be reduced almost to half, due to the significant quantity of contaminated waste water and water rinsing from decontamination which will be treated by evaporation. The mass of LILW that will be packed into appropriate containers (N2d and RCC) after treatment is 3,252.0 t. Mass of all contaminated material (including old steam generators which is stored in DB building presently) is included in the total decommissioning LILW mass.

This mass of LILW will be further treated and conditioned and finally packed into appropriate containers (N2d containers or RCC depending on the disposal technology) to be disposed of in LILW repositories. Total activity of the whole LILW mass is assessed to be 5.60×10^{12} Bq. Regarding the origin decommissioning LILW could be divided in the 3 categories (Table 4-16).

Table 4-16 Decommissioning LILW Inventory

LILW category	Mass to be disposed (t)
LILW from controlled area	2,000.0
LILW from monitored area	744.0
Secondary LILW	508.0
Total	**3,252.0**

Therefore, mass of 3,252.0 t of decommissioning LILW is the subject of division and takeover.

Present analysis indicate that there are some inconsistencies regarding quantities of decommissioning LILW in PDP, Rev.6.

Presented inventory is generic and nonspecific but at this point in time estimates are useful for capacity developments. Project aimed at characterization of the decommissioning LILW should be established as soon as possible for two reasons: (1) this waste stream represents half of the volume and approximately 30% of the mass destined for the repository and (2) the post-closure SAs already performed indicate that the radionuclide with the highest calculated dose (^{59}Ni) arises from the decommissioning wastes. Decommissioning LILW characterization project should include direct measurement on the wastes such as previously replaced steam generators and heat exchangers or theoretical calculations, such as neutron activation of core components. The characterization estimates need to be specific to Krško NPP and should not be based only on generic literature values.

4.6. Overall quantities of LILW to be divided by Croatian and Slovenian side

After analyzing inventory of Krško NPP storage and assessments of future generation of LILW through operation of Krško NPP and decommissioning of facility, overall quantities of LILW to be divided by Croatian and Slovenian side are presented in the Table 4-17. RW generated by decommissioning of SFDS facility will be disposed in joint Deep Geological (DGR) repository since both national LILW repositories will be already closed at the time of decommissioning.

Table 4-17 Overall quantities(1) of LILW to be divided by Croatian and Slovenian side

Period of LILW generation	Type of LILW	Source of data	Mass (t)	Volume (m^3)	Activity(2) (Bq)	Management after division and takeover.
1983–2018	Operational	Inventory	4,877.4	2,294.9	5.98×10^{13}	No WMF on site. Croatian half: Transport and treatment with conditioning in RCC in the third country. Slovenian half: Transport and treatment with conditioning in N2d containers in Slovenia.
2018–2023		Assessm ent	264.0	163.4	1.44×10^{13}	

Period of LILW generation	Type of LILW	Source of data	Mass (t)	Volume (m³)	Activity(2) (Bq)	Management after division and takeover.
2024–2043			883.7	546.6	4.33×10^{13}	No WMF on site[1]. [7] Croatian half: Transport and treatment with conditioning in RCC in the third country. Slovenian half: Transport and treatment with conditioning in N2d containers in Slovenia.
2043–2058	Decommissioning		2,860.0	2,842.0	4.93×10^{12}	WMF on site (3). Treatment and conditioning in N2d containers and RCC. Transport in corresponding LILW repositories in Croatia and Slovenia after 2050.
2103–2106	Decommissioning		392.0	407.4	6.7×10^{11}	WMF on site (3). Treatment and conditioning on Krško NPP site. This LILW will be disposed in HLW repository.
Total			**9,277.1**	**6,254.3**	**$1,23\times10^{14}$**	

(1) Presented here are quantities in the Krško NPP storages or projections of quantities to be generated by operation after 2023 and by decommissioning of Krško NPP. Quantities to be disposed will be adopted from this quantities and adjusted for each side depending on the disposal containers types.
(2) Activity presented here is nominal activity. This is activity of the LILW in the time of placing LILW in the vessels for storage or for further treatment and conditioning. Since most of the radionuclides in LILW are shortlived (half-life under 30 years) activity will be quite different in the time of their disposal in the repository.
(3) This is suggested and assumed by PDP Rev.6.

[1] Currently there is no on-site capacity for treatment and conditioning of operational LILW in Krško NPP. Such a facility was planned and construction permit was obtained (construction permit nr. 35105-25/2014/5-01031383 TŠ, GB; 16. 6. 2014) but investment into such facility was not yet approved by the supervisory board of the Krško NPP.

4.8. References

1 JV7, Pravilnik o ravnanju z radioaktivnimi odpadki in izrabljenim gorivom, Ur. l. RS 49/2006

2 Stanje inventarja odpadkov v skladišču NSRAO NEK na dan 31.12.2017, NEK, 2018

3 Throughout this document term final waste package refers only to final waste packages for storage.

4 Krško NPP Radioactive Waste Characterization Project, Enconet, 2006

5 Gospodarenje z radioaktivnimi odpadki v NE Krško, NEK ESD-TR-03/97, Rev.9, NEK,2018

6 IAEA, Regulations for the Safe Transport of Radioactive Material, Specific Safety Requirements, No. SSR-6, Rev. 1, 2018

7 Opredelitev NEK do možnosti priprave NSRAO na odlaganje v NEK, dopis št. ING.DOV-319.18/6243, September 2018.

5. Krško NPP RW (half of amount) management/disposal in the RS with nominal costs which include compensations to the local community

Contents

ABBREVATIONS

ARAO	Agency for Radwaste Management from Slovenia
BRHNEK	Bilateral Agreement Between RH and RS on NEK
CSF	Central Storage Facility for Radioactive Waste in Brinje
DP Rev.1	"Program of Krško NPP Decommissioning and SF & LILW Disposal (Program razgradnje NPP Krško in odlaganja NSRAO in IJG), ARAO, T-1123/03, Ljubljana, 2004, APO Ltd., Environ-mental Services, 25-04-1348/06, Zagreb, 2004.
DUM	Decree on the uniform methodology for the preparation and treatment of investment documentation in the field of public finance
Fond NEK	Croatian Fund for Financing the Decommissioning of the Krško NPP and the Disposal of NPP Krško Radioactive Waste and Spent Nuclear Fuel, Zagreb, Croatia
HLW	High-Level Waste
IAEA	International Atomic Energy Agency
ICC	Project Implementation Coordination Committee
LILW	Low and Intermediate Radioactive Waste
NEK	Krško NPP
NSP	National Spatial Plan
RC	Republic of Croatia
ReNPRRO16-25	Resolution on the National Programme for Managing Radioactive Waste and Spent Nuclear Fuel 2016-2025, Off. Gaz. of the RS, Nr. 31/16
RS	Republic of Slovenia
SF	Spent Fuel
Sklad NEK	Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Radioactive Waste from the Krško NPP, Krško, Slovenia
ToR	Terms of Reference
Triga RR	TRIGA Mark II Research Reactor in Brinje operated by the Jožef Stefan Institute
URSJV	Slovenian nuclear safety administration (SNSA)
VAT	Value Added Tax
WAC	Waste Acceptance Criteria
WMF	Waste Management Facility
ZVISJV-1	Ionizing Radiation Protection and Nuclear Safety Act, Off. Gaz. of the RS, Nr. 76/17

5.1. Introduction

This chapter is prepared for the purpose of costs assessment for the LILW repository in Slovenia on the basis of technical study Investicijski program za odlagališče NSRAO, Vrbina Krško (Investment Program) that was confirmed in July 2014 by the Ministry competent for energy and revised in 2017 and 2019 [1][2]. Repository technological part description and disposal solution is presented on the basis of technical documentation for the preparation of the draft safety report for the Vrbina LILW repository [3][4][5]. The investment program preparation and its required content is regulated with Decree on the uniform methodology for the preparation and treatment of investment documentation in the field of public finance (DUM) [6]. With its technical, technological and economic part, the investment program is a basis for an investment decision. Prepared investment program includes mandatory content as required by the DUM such as investment objectives, expert and technological basis, a brief description of the variants considered and the rationale for choosing the optimal variant, presentation of the estimated investment costs and the anticipated financial structure with the defined share of the co-financing and a summary presentation of the results of the calculations and the justification for the eligibility of the investment project.

This chapter considers technically and technologically wise the management and disposal of the half of total quantity of RW from the operation and decommissioning of Krško NPP in the RS. All cost estimates are presented in June 2018 Euro (€) prices as nominal costs. Cost estimate are in accordance with Slovenian VAT regulations and include contingency and the cost of compensations to the local community.

Costs of compensations, taxes (VAT) and contingencies are calculated separately and are separately presented in summary tables.

This chapter contains a timeline of activities scheduled according to Slovenian National Programme for managing RW and SF (ReNPRRO16-25) [7] and to the boundary conditions for the Third Revision of the Krško NPP Decommissioning Program and the Third Revision of the Krško NPP RW and SF Disposal Program (Third revision) as defined in ToR [8][9]. Main milestones of the repository development, its construction, operation and closure are according to the national program, modified and updated in accordance with the current status and past and future project development.

With the overall goal of the Third revision, to provide the necessary costs estimates and to provide the necessary funds for RW and SF management, the focus in this chapter is more on the LILW repository costs assessment, technological solutions, repository location and less on waste disposal inventory and other because this is more detailed elaborated in other chapters of Third revision document and its supporting studies.

5.2. National Strategy and Program

With the adoption of the Decree on the National Spatial Plan for a LILW Repository [10], the location and type of repository were confirmed. The selected type of repository envisages the disposal of radioactive waste in a near-surface silo [7]. The Investment Programme for the LILW Repository Vrbina, Krško, envisages two scenarios: the baseline scenario allowing for disposal of half of the waste generated in Krško NPP, and the extended scenario, which, in accordance with The Bilateral Slovenian-Croatian Agreement on the Krško NPP, provides for the disposal of all LILW waste from the Krško NPP.

Under the baseline scenario, the repository is to accommodate half of the LILW from the Krško NPP and the entire Slovenian LILW not originating from the Krško NPP, whereas its construction is envisaged to take place between 2017 and 2019. As per today there is around 2 years of delay with start of repository construction.

The start of trial operation is scheduled for 2020. All "Slovenian" operating waste is to be disposed of by 2025, when the repository enters temporary standby phase[1] until re-operation in 2050. During the re-start of operation, the remaining "Slovenian" operating waste generated in the Krško NPP and the waste generated during the decommissioning of the NPP until 2061 will be disposed in the repository. After the disposal of all the waste, the silo and the entire repository will be closed, and the long-term monitoring and maintenance of the repository will commence [7].

The Vrbina repository has to accommodate in the basic scenario half of all LILW waste from the Krško NPP (i.e. LILW generated during the operation and decommissioning of the Krško NPP and also other LILW, such as replaced or removed equipment). In addition to the aforementioned, the repository has to also accommodate LILW from the CSF in Brinje, LILW generated during the decommissioning of the CSF and the TRIGA Research Reactor, as well as LILW generated during the operation and closure of the repository [7].

The repository must be designed with a capacity allowing the disposal of any kind of LILW generated in Slovenia, with the exceptions of small quantities of long-lived or other waste, which would require disproportionately complicated and costly conditioning for disposal. The disposal thereof will be addressed subsequently when considering solutions for HLW and spent fuel disposal. The criteria for the acceptance of LILW at the repository must be drawn up accordingly [7].

---

[1] Standby phase is the operational condition of the repository which corresponds to a longer interruption of operation and during which no disposal or other more extensive work is carried out at the repository. Preparation of the repository for the standby phase will last for one year. After finishing the activities to prepare the repository for the standby phase, the repository will enter the standby phase.

The conditioning of all LILW for disposal is to be carried out in the Krško NPP [7][11][1].

5.2.1. National strategy

National strategy for construction and operation of the LILW repository is defined in the ReNPRRO16-25 [7] under strategy nr. 4 and provides the construction of the LILW repository and the disposal of the current LILW inventory in the repository as soon as possible. The disposal is envisaged in 2 phases: The first phase of disposal of the stored waste from the Krško NPP and other sources will run from 2020 to 2025 and the second phase of disposal is envisaged after the NPP has ceased to operate between 2050 and 2061 when the final closure of the repository is planned. From 2025 onwards the repository will be in temporary standby phase until re-operation in 2050. The repository is to be constructed in 3 years following 2 years of trial operation.

Without an agreement on joint LILW disposal solution with the Republic of Croatia, the baseline scenario where the repository is to accommodate half of the LILW from the Krško NPP and the entire Slovenian portion of LILW from other sources, main milestones of the repository are as follows:

1. Regular operation of the repository in the period between 2022 and 2025, during which the repository is to accommodate half of all LILW from the Krško NPP and the waste from the CSF.
2. Temporary standby period of the repository until 2050, during which operational storage of LILW in the Krško NPP and the CSF, or at the LILW repository site, will be carried out appropriately and when required (in accordance with the results of the eligibility study concerning the further operation of the CSF under Strategy 8).
3. In 2050, the repository re-start of operation is planned to accommodate the remaining radioactive waste from the Krško NPP operation and decommissioning, CSF and from the decommissioning of the TRIGA Research Reactor.
4. The repository is to operate until 2061.
5. According to the analysis results of the need for further disposal, the operation of the repository is to continue after 2061, otherwise the repository will be closed down in 2062, and long-term monitoring and maintenance will begin.

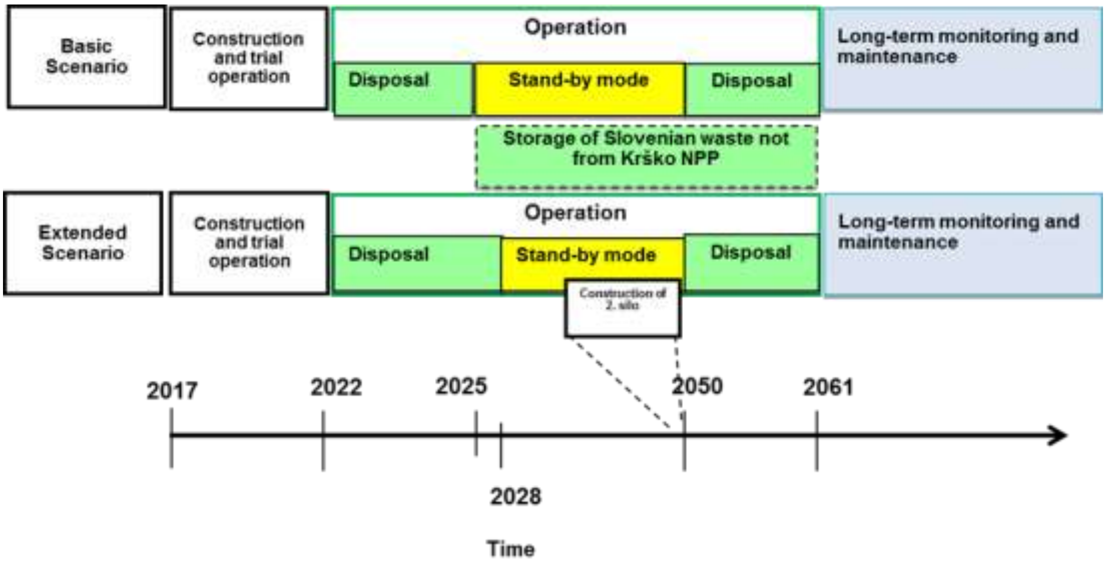


Figure 5-1 Schematic presentation of the main milestones of Strategy 4 from ReNPRRO16-25 [7].

5.3. Inventory

General description

Chapter 4 of Third revision document presents the properties and overall quantities of LILW generated by operation and decommissioning of Krško NPP. Table 4-17 summarizes quantities of LILW to be divided equally by Croatian and Slovenian side in compliance with Bilateral Agreement [12].

Table 5-1 Slovenian half of LILW from Krško.

Period of LILW generation	Type of LILW	Source of data	Mass (t)	Volume (m^3)	Activity(1) (Bq)	Management after division and takeover.
1983 - 2018	Operational	Inventory	2,438.7	1,147.45	2.99×10^{13}	Treatment and conditioning of final waste packages in Krško NPP before transport to Vrbina disposal facility. Vrbina trial operation starting in 2023.
2018 - 2023		Assessment	132.0	81.7	7.2×10^{12}	
2024 - 2043			441.85	273.3	2.17×10^{13}	Treatment and conditioning of final waste packages in Krško NPP, transport and disposal in Vrbina disposal facility with operation until 2027, standby phase starting in 2028.

Period of LILW generation	Type of LILW	Source of data	Mass (t)	Volume (m^3)	Activity(1) (Bq)	Management after division and takeover.
2043 - 2058	Decommissioning		1,430.0	1,421.0	2.47×10^{12}	WMF on Krško NPP site (2). Treatment and conditioning in N2d container. Transport and disposal in Vrbina LILW repository after 2050.
2103 - 2106	Decommissioning		196.0	203.7	3.35×10^{11}	Treatment and conditioning on site. This LILW will be disposed in HLW and SF repository(3).
		Total	**4,635.55**	**3,127.15**	**$6{,}15\times10^{15}$**	

(1) Activity presented here is nominal activity. This is activity of the LILW in the time of placing LILW in the packages for storage or for further treatment and conditioning. Since most of the radionuclides in LILW are short-lived (half-life under 30 years) activity will be quite different in the time of their disposal in the repository.

(2) This is suggested and assumed by PDP Rev.6.

(3) See corresponding chapter 3 and reference documentation "Reference Scenario for Geological Disposal Facility in Hard Rock with Cost Estimation for its Implementation", IBE d.d., February 2019.

In the Table 5-1 Slovenian half of LILW from Krško half of those quantities are presented, respectively the quantity of LILW RS is responsible for and which RS must dispose.

After division and takeover this is the inventory that will be managed by Slovenian side. All the estimates of capacities and expenses for processing, conditioning, transport and disposal of LILW further in this chapter are based on the quantities presented in Table 5-1 and with recalculation including adjustment to number of disposal containers based on results of the PDP Rev.6 [13], 3rd Revision of the NPP Krško Decommissioning Program [14] and documentation for repository draft Safety Report [3].

The Krško NPP LILW that will need to be disposed of in the Vrbina repository is as follows:

- LILW generated from Krško NPP operation and decommissioning, including replaced and removed equipment from operation;
- LILW that will be generated in the Krško NPP during the conditioning of the LILW for disposal and during decommissioning of facility for conditioning and;
- LILW that will be generated from the operation and decommissioning of the repository itself.

With the LILW conditioning activities in the Krško NPP and with the dismantling and decontamination of facilities for conditioning, as well as the operation and decommissioning of the repository, approximately 52.2 t of LILW will be generated,

which will be prepared and conditioned for disposal in the Krško NPP as well as other waste [15][1].

In addition to the above-mentioned, the repository will also accommodate LILW that meets the waste acceptance criteria for disposal from the Central Storage Facility for Radioactive Waste (CSF) in Brinje and its decommissioning (40 N2d containers - 24 disposed until 2027 and 16 after 2050) and the LILW from TRIGA Research Reactor decommissioning (36 N2d containers disposed after 2050) [15][3]. This LILW is according to ToR for the Third revison of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program [8] not subject of this revision and is therefore not presented nor further elaborated in this document.

Table 5-2 Estimate of N2d disposal containers for disposal of LILW from Krško NPP in Vrbina repository from different sources with division for number of containers by repository mode of operation.

LILW	**Number of disposal containers N2d**	**Number of disposed containers: until 2027 / after 2027**
A. LILW from Krško NPP		
Krško NPP operational LILW	585[2]	468 / 117[3]
Krško NPP decommissioning LILW	177	0 / 177
LILW from conditioning process, repository operation and decommissioning	15[4]	1 / 14
Total	**777**	**467 / 308**

5.4. Technological solutions

The repository at the site Vrbina in the municipality of Krško is a nuclear facility designed for permanent disposal of low and intermediate level radioactive waste generated in the republic of Slovenia (nuclear power plant, industry, hospitals, research institutions,

---

[2] The number of N2d containers is based on results of the 3rd Revision of the NPP Krško Decommissioning Program , Appendix 4: Disposal of “Operational waste” [14].

[3] Based on the Third Revision of the Krško NPP Decommissioning Program (Attachment 4: Disposal of “Operational waste”) 80% of total mass of operational LILW will be disposed of in the years 2023 until 2025 (2027) and the remaining 20% of total mass will be disposed of in the years after 2043 [14].

[4] The quantity covers 6 containers total from the LILW conditioning activities in the Krško NPP (4 containers) and the operation of the repository (2 containers), and 9 total containers from the decommissioning of facilities for conditioning in the Krško NPP (8 containers) and the decommissioning of the repository (1 container) [15][1].

etc.). When ensuring the disposal of LILW, it has been taken into account the generally accepted principles that radioactive waste should be managed in a way that ensures the protection of human health and the environment, does not burden the future generations in any way, and where the control of the safety of facilities and activities related to radioactive waste is ensured by the proper inclusion of independent administrative authorities. In December 2009, Decree on the National Spatial Plan (NSP) for a LILW Repository in Vrbina in the Municipality of Krško [10] was adopted by the Government of Republic of Slovenia. With adoption of the Decree on the NSP, disposal concept has been determined with waste disposal in disposal silos, which are built from the surface, but placed in low permeability silt layers in a saturated zone under groundwater. The concept combines the properties of surface type repositories (disposal from the surface) and properties of underground repositories (the placement of disposal units in low permeable saturated geological formations) [3].

The location and design of the repository enable extension with additional silos. According to Decree on the NSP, in the NSP area, the design and arrangement of a repository with a disposal capacity of 9.400 m^3 of radioactive waste generated in RS is planned. The LILW repository includes all structures, systems and components required for its operation as an independent nuclear facility and disposal of LILW [10].

Safety Assessment results from 2016 have proven that the combination of location and disposal concept is favorable, and the impact of such a repository on the human and the environment is negligible [16][5][3][17].

The concept of the Vrbina Krško repository is based on a multi barrier system and system, when the individual components of the repository perform several safety functions. In the case of the Vrbina Krško repository, an important part of the waste isolation role is based on properly treated and conditioned waste, final disposal packages (units) and the engineered barrier system of the repository [3].

Short description of the site

The location of the LILW repository is in Vrbina, in the municipality of Krško, in the gravel plain area, with individual depressions resulting from the former course of the Sava River. The nearest town is Krško, which is 2.5 km away from the site, the town Brežice is 5 km away. The site is located approximately 13 km from the border with Croatia, and approximately 40 km from the city of Zagreb. Approximately 300 m from the western edge of the site, the Krško Nuclear Power Plant is situated. Approximately 400 m north-east of the site lies the settlement Spodnji Stari Grad. The plain on the southern side of the site is limited by the riverbed of the Sava River. To the south of the planned activity (approx. 600 m), the construction of a reservoir of the Brežice hydro power plant was finished in 2017 (start of trial operation in September 2017). In the north, the plane extends towards the hill Libna. In the east, the site is limited by the local road leading

from the settlement Vrbina towards south-east, i.e. towards the bank of the Sava River. The wider area of the site is in agricultural use and is designated as the best agricultural land. At the site itself, there are landscaped fields, and on the far western edge of the site, a plantation orchard is arranged (Figure 5-2) [18].

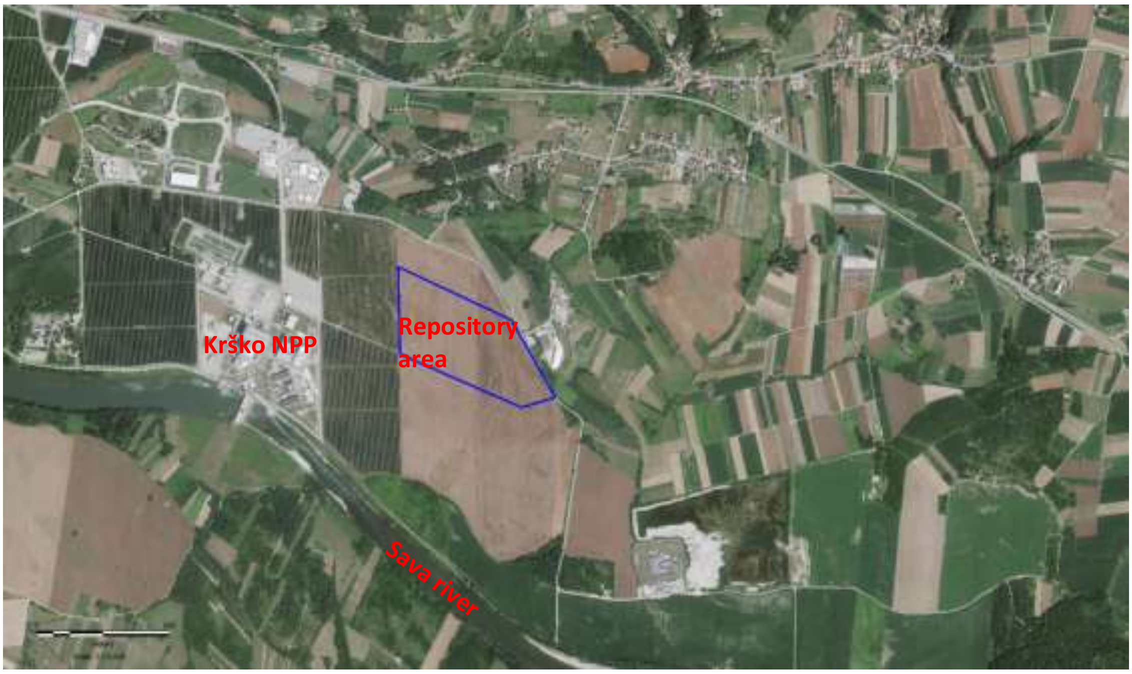


Figure 5-2 Illustration of the location, placing of the planned arrangement, with the surroundings on the satellite image.

Based on the impact of high flow rates of the Sava River, the maximum possible elevation in the area of the LILW site is determined at 152.73 m above the sea level. For the impact of extreme hinterland water, additional analyses have shown that, under the conservative assumption of zero percolation, the elevation of the hinterland water near the repository cannot exceed 154.17 m above the sea level. Due to greater uncertainty of determining the relevant elevation of the hinterland water, it has been proposed that the safety height should be 1 m; the unified elevation of the platform of the LILW repository is thus determined at the height of 155.20 m above sea level [19].

Development and current status of the Vrbina repository project

Project and other documentation are being prepared since the adoption of the Decree on the NSP. Project solutions and its development are inputs for preparation of documentation needed for procedures related to environmental impact assessment and obtaining a building permit.

The main field research confirmed the preliminary results and provided the necessary input data for repository design and for safety analysis. Most of the main field research was carried out on the micro location of the first disposal silo. For the purpose of the

repository construction with its necessary infrastructure, land that is now in the management of ARAO has been purchased. The landowner is the Republic of Slovenia.

Safety analyses were harmonized with the development of project solutions. Conceptual design documentation [20] was prepared in 2016 based on the design documentation for obtaining a building permit and optimization of the project solutions (introduction of the standby phase, disposal technology optimization, treatment and conditioning optimization) and is an integral part of application for obtaining an environmental approval. Basic design project documentation, which is in the final phase of revision, is also being prepared. The Project bases for the repository in the environmental impact assessment phase [21] have been developed, as required by the Rules on Radiation and Nuclear Safety Factors [22]. The reference documentation for the draft Safety Report has been finalized in accordance with the guidance from the SNSA Practical Guidelines [23].

In April 2019 preliminary approval for the radiation and nuclear safety of nuclear facility was issued by the SNSA in the procedure issuing of an environmental protection approval [17].

In order to obtain a building permit for the construction of the LILW repository, the design project documentation will be completed and finalized on the basis of the external expert review required by the ZVISJV-1 [24], the process of cross-border environmental impact assessment and process of environmental approval should be completed.

5.4.1. Description of the concept of the repository

The basic concept of LILW disposal at the Vrbina site represents the disposal of properly prepared and packaged low and intermediate level radioactive waste into the disposal units, i.e. silos, located below the groundwater level on the site itself. The disposal is carried out from the surface.

The basic purpose of the LILW repository is to prevent the migration of radionuclides into the environment by means of a series of consecutive natural and artificial barriers; it is designed as a complex technological unit. The multi-barrier system of the silo thus consists of the following main barriers: properly prepared waste, metal drum, concrete container, concrete silo, and geology/surroundings of the repository site [3].

Waste will be prepared for disposal at the Krško NPP, where it will be packed in the so-called final package units (containers). Curently there is no on-site capacity for treatment and conditioning of operational LILW in Krško NPP. Such a capacity was planned but not yet approved by the supervisory board of the Krško NPP [25]. However, according to 3rd Revision of the NPP Krško Decommissioning Program [14] (Chapter 7.3.3. Packaging concept) the cementation of waste into the N2d containers is

performed on the site of the Krško NPP. If necessary, the cementation can also be done on the repository site. Procedures to do this on site are under investigation and should be possible too.

The only LILW disposed in the repository silo will be solid, not explosive or flammable, it will be chemically stable, poorly soluble in water and will contain an extremely small proportion of organic matter. Any waste not meeting the waste acceptance criteria for disposal will be treated and conditioned at the Krško NPP. Inserting waste packages into disposal containers or preparation for disposal will be implemented at the Krško NPP. Supervision of the process of filling disposal containers, grouting and checking the compliance of filled final package units (containers) with acceptance criteria for disposal will be carried out by ARAO at the Krško NPP in accordance with the written procedures [18].

Waste will be disposed of in metal drums which will be inserted into concrete containers and be top-filled with mortar that shall fill up all free space in the container [26].

Transportation of containers to the LILW repository will be provided by the Krško NPP [7]. The transportation will be carried out on the local road or on the section of the future regional road from Krško to Brežice and local road and access road to the LILW repository. The entire trip is approximately 1200 m long. A final package (container) ready for disposal will be transported from the facility for final conditioning of waste to repository site by means of semi-trailer which will ensure the proper fixation of the container during transport, and the height of the transport platform will not exceed 1m. The vehicle will transport one container at a time. Entry and waste reception procedure will be performed at the repository site entry control point, where formal compliance of the disposal package with WAC for disposal will be checked, including visual control, measurement of surface radiation, and checking of supporting documentation and labeling. If all requirements are fulfilled, transport will continue to the hall above the silo where each individual container is disposed with a portal crane to a predetermined position in the disposal silo [26][18].

The LILW repository has been designed with facilities that will enable the implementation of all activities necessary for its operation and permanent disposal of LILW waste.

The repository is spatially divided in the following sections:

- entrance section with free external surfaces (outside the fence of the narrow area),
- narrow area of the repository.

In the entrance section of the repository, there is an access driveway from the local road arranged outside the fence of the narrow area. The free external surfaces of the

repository are planted with trees to represent a green barrier between the repository and its surroundings.

The narrow area of the repository is intended for administration and service activities, waste reception and disposal, and for provision of physical security of the repository. It has a rectangular floor plan, with dimensions 318.50 m x 184.50 m (surface area of approx. 58,763.25 m^2) [18].

In this area, the following premises are located:

- Administration and service facility,
- Technological facility,
- Disposal facility - silo with the associated hall above it:
  - 1st silo (planned construction by the year 2022, in case of confirming the scenario whereonly the Slovenian half of the waste will be disposed in the repository)
- Control shaft

Figure 5-3 Display of spatial placement of individual repository facilities: 1 Administration and service facility, 2 Technological facility, 3 Hall above silo [18].

The narrow area of the repository is fenced in and comprises a platform and a surface at the elevation height of the natural terrain, and is divided into [18]:

a) **fenced physical security-controlled area**, at the elevation height of 155.20 m, with the administration and service facility (USO). The site of the repository is enclosed in fence and physically protected. The area also includes an inner peripheral service road at the elevation height of 153.60 m and the area with control wells for monitoring;

b) **radiation protection-controlled area**, on a platform with an elevation height of 155.20 m, which protects the area from the probable maximum flood (PMF). The area represents the core of the controlled area. The project solutions enable the controlled area to cover the entire area of the technological section of the technological facility (TF) and the hall with the disposal silo, which is enclosed with an additional, inner protective fence. The latter is connected to the technological facility at both ends.

Both areas are connected by the main communication through the entire complex of the repository, from the local road to the disposal facility - the silo.

In the entrance section of narrow area of the repository**,** the administration and service facility (ASF) is located which is intended for the repository management activities and related service and administrative activities, the activities of controlling the entry to the site and the physical protection of the repository [18].

The core of the narrow, radiation-controlled area of the repository is made up of the technological facility (TF) and a disposal silo with a hall. TF is intended for the temporary storage and repair of any damaged waste containers, basic laboratory research, control of technological processes, and the remaining necessary technological and service functions of the repository as well as functions for the provision of nuclear and radiation safety. Capacities for temporary storage and possible repair of damaged containers will be built if the need for such a space arises during the operation of the repository. In the meantime, this activity will be carried out in the hall above the silo if necessary. (Figure 5-4) [18].

Figure 5-4 Spatial placement of individual repository facilities [18].

5.4.2. Presentation of the most important units of the repository: silo and container

Silo

The silo is designed as reinforced concrete cylindrical construction with internal diameter of 27.3 m. The composition of the silo wall comprises a primary lining of 1.2 m and a secondary lining; their total thickness is 2.2 m. In the silo, the disposal of the first level of containers is arranged at the depth of 49.2 m. Inside the silo, there is a vertical communication tract in the form of a shaft. The central part of the communication tract consists of stairs and elevator, and the side parts are intended for the installation lines. The communication tract ends as an entry facility within the hall above the silo Figure 5-5.

The net floor area of the silo allows the arrangement of 99 containers at each level. The height and location of the facility is adapted so that 10 levels of containers and the planned sealing layer, i.e. a reinforced concrete slab and a part of the clay layer, are situated below the level of the existing aquifer, and the entire clay layer extends nearly to the surface. For the vertical communication tract, temporary exits to the interior of the silo are planned along its height, which will facilitate access to working levels during the exploitation of the repository. As the filling of the silo will progress, these exits will gradually be put out of use/filled with concrete Figure 5-5.

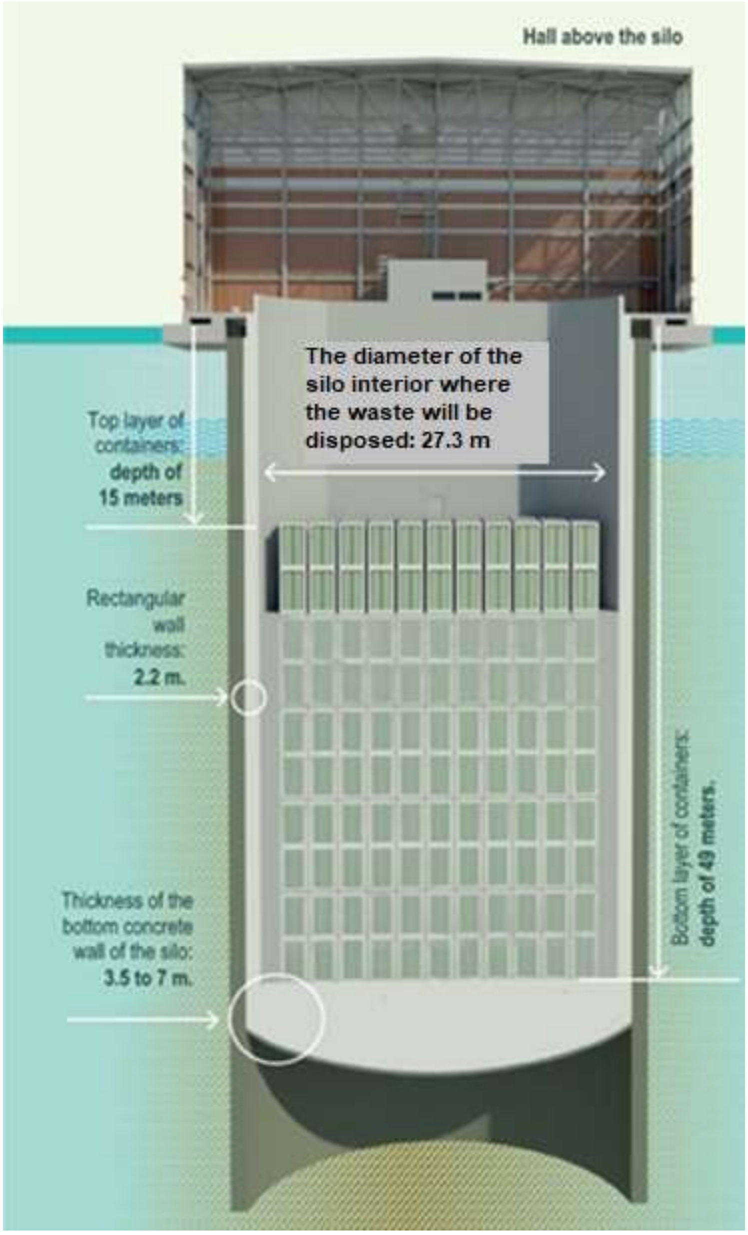


Figure 5-5 Presentation of the concept of the silo design [18].

The silo is intended for the following:

1. to provide storage space in an appropriately solid building in relation to the anticipated project events and the required durability of the structure;
2. to limit access of water to the deposited waste and spreading of contamination to the environment by limiting the flow of groundwater and by favourable sorption effects;
3. to collect and retain water potentially penetrating the silo wall;
4. to provide a biological shield;
5. to provide an engineering barrier that limits water penetration after closure of the repository.

In safety analyses, the silo is considered as one of the engineering barriers (besides the container and the primary LILW package) [5].

Container

The N2d container is a reinforced concrete container designed for waste disposal in LILW repository. According to the repository design it is the only container to be used for production of disposal packages. N2d has obtained in RS STS (Slovenian Technical Consent). Next stage licensing is planned in the process of obtaining repository construction permit and in the repository safety report approval.

Empty disposal containers will be transported from the manufacturing plant to facility for final conditioning of waste or directly to specific waste storage location, where they will be filled with packed or not packed LILW.

The N2d container concept covers the following components [26]:

- reinforced concrete container body (bottom slab and walls) formed to represent monolith reinforced concrete structure with grooves made in the four corners bottom of the container for container handling by means of specially designed gripping device with turning hoist feet;
- reinforced concrete lid with built-in elements for lifting and void filling inside the container, which extends over the entire container and equipped with anchoring system comprised of pre-inserted anchor elements in the corners of the container and the sockets in the corners of the lid. The fixing is carried out by screwing bolts;
- expanding/swelling material for sealing the gap between lid and container walls and filling-in openings.

While not directly considered as structural component of the container however of high importance in production of disposal package is mortar for filling the voids inside the container.

The geometry, dimensions and other important characteristics of the disposal container N2d are given in sub-sections below and Table 5-3, based on information from [27].

The N2d container is proposed to be available in basic design only. The fabricated containers shall meet the design requirements ref.[19]. In its final position in the silo, the container provides 300-year protection of the environment against the hazards posed by contained LILW. This is to be ensured by the use of durable materials, observing the design requirements at technological level in manufacturing process and

the regular implementation of quality control of manufactured container and materials used.

Table 5-3 N2d dimensions and weights [27].

Dimensions (mm)	
Width x length x height Outside: Inside: bottom/top height before/after lid placement	1950 x 1950 x 3300 1490/1490 x 1550/1550 3070/2870
Bottom slab thickness	230
Wall thickness (bottom/top)	230/220
Thickness of lid	200
Volume of the container	
Gross volume – outer dimensions	12.28 m^3
Net volume – after lid placement	6.31 m^3
Weight	
Empty container with lid	14.92 t
Lid	1.36 t
Maximum allowable weight of container	40 t

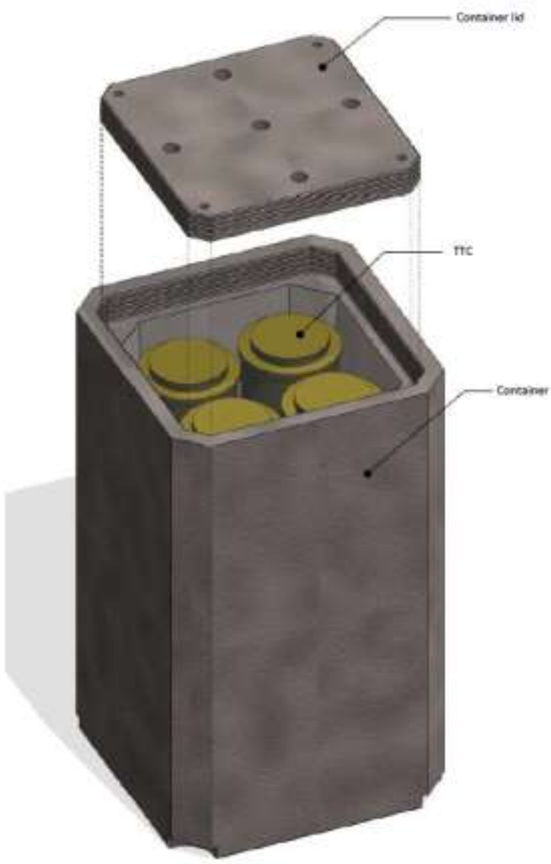


Figure 5-6 3-D view of disposal container [26].

The N2d disposal container is designed for the following combinations of primary and secondary waste packages [26]:

- 4 pcs of Tube Type Containers (TTC) with a total gross weight of maximum 31.97 tonnes positioned on the bottom slab of the container in a 2 x 2 pattern in an upright position
- 12 pcs of 200-litre or 320-litre drums to be calculated depending on combination positioned on the bottom slab of the container in a 2 x 3 x 2 pattern with in an upright position
- a combination of TTCs and 200-litre and/or 320-litre drums maximum total gross weight to be calculated depending on combination
- LILW forms unpacked

Maximum total gross weight to be calculated depending on combination and shall not exceed 40 tones (averaged density of the container content, waste and grout considered, shall not exceed 3974 kg/m^3).

5.4.3. Pre-disposal and Disposal procedures of Slovenian half of Krško NPP LILW management

Treatment and Conditioning

The radioactive waste in Krško NPP is conditioned in a number of different types of containers (drums and Tube Type Containers (TTCs)), as required by the waste stream specific waste package specification (see reference documentation [28], chapter 4), to form radioactive waste package suitable for next steps in management.

Final conditioning of LILW aims to produce disposal package meeting WAC for disposal. It will be performed in a dedicated facility to be designed and built at Krsko NPP site.

After incoming inspection, the preconditioned waste in primary packages and overpacks will be loaded into disposal container according to procedures to be deployed at facility for final conditioning. Following that the container lid will be mounted on top of the container. It will be fixed to the container body by means of special anchored elements and screws (bolted). The remaining free space inside the disposal container will be grouted using the grouting openings in the lid and the gap between the container body and lid will be filled with expansion/swelling [27].

A reinforced concrete container was designed as one of the elements of future LILW repository and is fully compatible with other technological elements of the future repository. Besides the functions of the disposal container as a component of the multiple barrier system, it will also perform certain functions in predisposal management, to enable safe handling, storage and transport, as follows:

- containment of hazardous materials;
- biological shielding;
- physical protection of hazardous content;
- mechanical stability/strength.

According to latest design the disposal container will meet the requirements for the IP-2 package [27].

Disposal Package Handling Within the Repository Site

Entry procedure will be performed at the repository site entry control point, where formal compliance of the disposal package with WAC for disposal will be checked.

The normal handling of the waste within the repository site will mainly consist of unloading of well characterised disposal package from semi-trailer and its emplacement into the silo, which will be performed by means of crane of 40 t lifting capacity that to be available inside the Hall above the silo. In case of any abnormal situation further actions can be done in the Technological Facility, where disposal package can be unloaded from semi-trailer for temporary storage and repairing.

Disposal packages can be handled without shielding unless the surface dose rate is higher then 2 mSv/h, which can only happen in exceptional cases under exclusive use or special arrangement [26].

Lifting of waste packages should be avoided, unless it is a part of technological process and lifting height shall be limited as far as possible.

Placement of Disposal Packages into the Silo

The disposal containers will be placed inside the silo by a crane. It is anticipated that crane will mainly be operated remotely from control panel in Technological Facility [26].

The capacity of one silo is 990 N2d disposal containers (99 disposal containers in 10 layers) which corresponds to the disposal volume of 12.157 m^3 (disposal capacity calculation is based on disposal of 990 N2d containers x 12.28 m^3 which is 1 disposal container gross volume). Containers in each layer will be positioned so that a 200 mm gap will be left between each container. These gaps enable container handling with special gripping device with turning legs. A layer of concrete of 100 mm to 300 mm thick will be emplaced on top of every second layer of containers in the silo in order to eliminate unevenness, caused during the container placement process [26].

5.5. Time schedule with scenario for disposal of Slovenian half of Krško NPP LILW

Time-frames of the repository periods were taken from the investment program for LILW repository [1] and from adjusted conceptual design documentation for LILW repository [20]. They take into account the NPP Krško lifetime extension until 2043 and new decommissioning time schedule according to PDP rev.6 [13] where it is planned that Krško NPP decommissioning will end in 2058. Repository time schedule is originally based on study for impact on cost estimation due to standby phase introduction during operation as well as on adjusted study on development of solutions for disposal technologies where temporary operation mode was implemented in 2010 with standby phase for 27 years in order to reduce the operational costs [29][30].

The operation of the repository with the standby phase is also foreseen in ReNPRRO16-25 [7]. The characteristics of phase operation are the following:

- after the construction of the repository, all the existing LILW generated in Krško NPP will be disposed if in compliance with WAC for disposal;

- after first phase of disposal, the repository is put into the standby phase (when the existing storage facility in Krško NPP is used for temporary storage);
- the standby phase ends when the storage capacities in the Krško NPP are filled and the second phase of LILW disposal starts; the disposal phase lasts until the disposal of all stored LILW in Krško NPP generated from NPP operation during standby phase of the repository and all LILW which are generated during the decommissioning of the Krško NPP.

In the phase operation mode, the repository will be in a state of "cold stop" during standby phase. Even though no LILW reception and disposal will take place, all the activities that a nuclear facility must perform as required by the national legislation will be provided and the status of the repository as a nuclear facility will be preserved.

According to the basic scenario (the scenario involves the construction of one silo for disposal of Slovenian half of Krško NPP LILW and all other LILW generated in RS outside NPP), a three-year construction of the repository is envisaged after obtaining a building permit; during this period, one disposal silo, all technological and other facilities and the associated infrastructure will be built. Then, a maximum two-year trial operation will begin when a permit for trial operation, which is a condition for the reception of radioactive waste, will be obtained. According to JV5 rules [22], for radioactive waste repository, the consent for the facility's trial operation shall be construed as permit for disposal of radioactive waste while the possibility to remove waste from the disposal facility and to recover the facility's original state has to be ensured. During trial operation tests and experiments of the constructed and operation ready repository will be carried out in order to verify and define the compliance of the repository operation and SSC (System Structure and Components) with approved design solutions and the required design conditions [3].

At the end of the trial operation, an operating permit will be obtained, and on the basis of this permit, the repository will be put into regular operation. The repository is expected to begin trial operation in 2023 with regular operation starting before 2025 and continue to operate until the year 2027, when all »Slovenian« operating waste will have been disposed of; in 2028, the repository will enter the standby phase until re-entering the operation in 2050.

During the renewed operation, the remaining "Slovenian" operating waste generated in the Krško NPP will be deposited in the repository, as well as the waste generated during the decommissioning of the Krško NPP until the year 2058. After the disposal of all the waste and the decommissioning of the repository (2058), the silo and the entire repository are closed in 2059 and the long-term monitoring, control and maintenance of the repository is initiated [1][31].

After closing the repository, it will enter the period of post-closure monitoring and maintenance. During the period of active long-term monitoring, the operator will

predominantly take care of the implementation of technical monitoring of the closed repository, regular maintenance work, physical protection of the facility etc. After the end of active long-term monitoring, the repository will pass into the phase of passive long-term monitoring. The above-ground facilities of the repository not intended for active monitoring will be removed or submitted to unlimited use after the closure of the repository.

It is assumed that the earth-filled platform of the repository will continue to remain at the site in the phase of passive long-term monitoring.

After the end of passive monitoring, the surface of the repository area will pass to unlimited use, i.e. the use that will not endanger the protective functions of the repository [18][3].

Table 5-4 Time schedule for repository basic scenario with number of annual disposed containers [1].

Year – before start of Krško NPP decommissioning	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Construction																							
Trial operation				10																			
[5]Operation – filling of the 1st silo, phase 1				5	10	160	160	134															
Interruption of disposal – standby phase																							
Silo occupancy with LILW from NEK (%)				0,5	1,5	18	34	40	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Year – after start of Krško NPP decommissioning	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059						
Repository decomissioning																							
Repository closure																							
[6]Operation – filling of the 1st silo, phase 2								20	30	40	40	40	40	40	40	18							
Interruption of disposal – standby phase																							
Silo occupancy with LILW from NEK (%)	47	47	47	47	47	47	47	49	52	56	61	65	69	73	77	79	/						

[5] Only LILW from Krško NPP and from repository operation and decommissioning is included and presented, CSF and Triga RR LILW is therefore not included.

[6] Only LILW from Krško NPP and from repository operation and decommissioning is included and presented, CSF and Triga RR LILW is therefore not included.

In accordance with the revised construction dynamics, the repository will be built by the end of 2022 with maximum 2 years trial operation starting in 2023 when 10 disposal containers will be used but not disposed. 3 years of full regular operation will start in 2025 and will last until 2027. For the purpose of estimating LILW annual disposal quantities from Krško NPP, it is assumed that in the first phase of operation, disposal of those LILW will occur that were generated before the start of standby phase. For operational waste from the Krško NPP, this is the default amount of LILW which would be generated if the Krško NPP was to be operated by the end of 2023. By the end of 2027, 80% of Slovenia's share of operational and other waste from the Krško NPP will be disposed. Other Krško NPP operational waste and all waste from the decommissioning of the Krško NPP will be disposed after the re-start of the repository operation in 2050 [1]. During the temporary standby phase of the repository (until 2050) radioactive waste generated from the operation of the Krško NPP is to be stored in the Krško NPP [7].

1 disposal container will be disposed until the start of the standby phase containing LILW generated during the conditioning and packaging for disposal (in the Krško NPP) together with the LILW from operation of the repository. The rest of the LILW that will be generated later will be disposed in the second phase of the repository operation.

In line with the number of containers from [15] and adjusted as a result of PDP rev.6 [13] 777 N2d containers (Table 5-2) with LILW from Krško NPP are to be disposed of in one disposal silo, with a design capacity of 990 containers. The project reserve is 137 disposal containers or approximately 14% of the disposal capacity where disposal of 76 containers from CSF and Triga RR is included. It is planned that by the end of 2027, 469 containers, or 80% of Slovenian share of LILW from the Krško NPP, 59% of CSRAO waste and 1 container from the conditioning for disposal in the Krško NPP will be disposed and the repository in 2028 enters into the standby phase - Table 5-4.

5.6. Cost estimates and repository financing

All costs given in this section are expressed in 2018 EUR. The costs were taken from investment program documentation [1] and have been adjusted in operation to address the PDP activities [13] and modified and reduced for number of disposal containers and all related expenses. The construction costs for silo, administration, service and technological facility and all other costs associated with repository operation such as costs for site maintenance, monitoring, work, municipal services, compensation for restricted land use, … were not reduced due to reduced number of containers and remains the same as in the documentation. Also costs of filling material (concrete) to eliminate unevenness of each 2 disposal layers are left unchanged. The cost of filling material for one layer of disposed containers is approximately 97,000 EUR (excluding VAT) and as such its total costs changes due to adjusted number of containers in comparison to total costs of the repository is negligible.

The construction and operation of the repository will be financed from the Slovenian Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Radioactive Waste from the Krško NPP (Sklad NEK) and the state budget for the portion of radioactive waste not originating from the Krško NPP [7][1].

The key for the distribution between both sources of financing is the disposal volume of waste from the Krško NPP and the volume of waste from other sources [7]. The volume of LILW from the Krško NPP is assessed to 91.58% and the volume of other waste is assessed to 8.42% [1]. The final division of costs between the Sklad NEK and the state budget will be made on the basis of the actual disposed volume of the radioactive waste [7][1]. Not to prevent the overall overview of the estimated and already invested funds, included cost items for the repository are based and presented as total investment costs irrespective of the source of funding (Sklad NEK, state budget). The division into the share of the source of funding is presented and commented in the total investment and operating costs chapters. For the purpose of discounting and annuity payment calculations only share of the source of funding from Sklad NEK in Republic of Slovenia is used in other chapters of the Third Revision of the Krško NPP Radioactive Waste and Spent Fuel Disposal Program.

The value of the investment also includes already invested funds from previous years. The costs of treatment and conditioning for disposal, including transportation to the repository, shall be entirely borne by the producer [7]. However, the costs of treatment and conditioning of LILW for disposal are considered as part of total disposal costs, although there is no definitive decision on where these procedures will actually be implemented. All costs associated with the conditioning and preparation for disposal (cementation) and transport are presented as addition to total investment and operating costs in chapter 5.6.3. Depending on the final decision of Krško NPP owners and IC, these costs will be later charged to the waste generators or financed from the Sklad NEK.

Costs of active long-term monitoring and maintenance (50 years) are estimated to 6 million EUR and are mainly related to monitoring activities, other measurements and maintenance (4,5 Milllion EUR) and work costs (1,5 million EUR). Costs of passive long-term monitoring and maintenance are estimated to 4 million EUR (repository data and records keeping, control over land ownership and control of limited land use).

Costs for phase of active and passive long-term monitoring and site maintenance will be financed from the state budget as required by ZVISJV-1 [24] and planned in the reference documentation for the Safety Report preparation [31] and are therefore not taken into account as total costs of the Third revision.

Repository total estimated costs are divided into two principal parts [1]:

- Investment costs for repository construction and closure, engineering, equipment, project and investment documentation, location and building site acquisition, compensation costs for restricted land use, trial operation costs, …
- Operating costs directly connected to disposal operation such as work costs, insurance costs, monitoring costs, ...

5.6.1. Investment costs

The estimation of investment costs includes costs directly related to repository construction and closure and other costs. All costs are based on constant prices (nominal costs) for June 2018 and excluding value added tax (VAT).

The costs of repository construction and closure cover, in addition to the costs of construction and closing the storage silo, also the costs of decommissioning the nuclear part of non-disposal facilities (administration, service and technological facility). Based on plan that the conditioning with final packaging will be performed by Krško NPP, it is assumed that the decommissioning activities include in particular the decontamination and dismantling of equipment [1].

The presented costs of decommissioning do not include the costs of decommissioning of technological installations and facilities that will be provided for the conditioning in the Krško NPP.

Repository construction and closure costs

A summary of the construction and closure works of the repository are divided into several costs items and given in the Table 5-5.

Table 5-5 Total costs of repository construction and closure works.

Cost item (cost in 000 EUR without **VAT**, Constant prices, June 2018)	Construction and closure costs	Assessment of the share of contingency	Total with contingency	Proportion of total costs %
Platform	1,105	0.10	1,154	2.86%
Infrastructure connections	1,419	0.10	1,561	3.87%
Non-disposal facilities	9,663	0.10	10,629	26.32%
Disposal facilities	12,331	0.10	13,564	33.59%
Mechanical systems	3,212	0.10	3,533	8.75%
Electrical systems and telecommunications	1,965	0.10	2,161	5.35%
Technical security systems	549	0.10	604	1.50%
Transport devices	2,901	0.10	3,191	7.90%
Radiology	712	0.10	784	1.94%
External arrangement	2,239	0.10	2,463	6.10%
Landscape architecture	674	0.10	741	1.83%
TOTAL	**36,769**	**0.10**	**40,385**	100.00%

According to relatively detailed available data from basic design documentation, is in line with the international practice [32][33] assumed that contingency costs amount to 10%. Costs by individual costs items are estimated with a uniform contingency rate of 10% (flat 10% margin on all cost items). In the case of a platform construction, unforeseen costs are charged only for the non-built part of the platform.

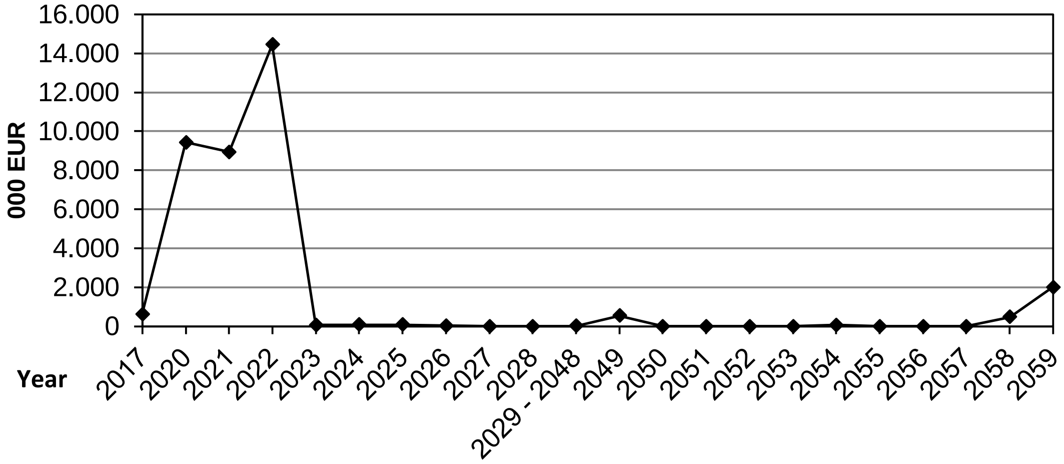


Figure 5-7 Dynamics of construction and closure costs, excluding VAT and contingency costs [1].

Total costs of construction, equipment and silo closure for basic scenario including contingency are 40.128 Million EUR (VAT excluded).

Other investment costs

Other investment costs include [1]:

- location and building site acquisition which cover the costs for site selection process, field investigations, research and monitoring and repository site location purchase,
- costs of cooperation with local communities and communication activities,
- costs of project and investment documentation, engineering, ARAO costs acting as investment agent, repository operation procedures costs, PA/SA analysis costs and
- cost of compensation due to restricted land use.

Costs for evaluation of the areas suitable for disposal location

Expenses for the evaluation of the suitable areas include costs:

- determining the baseline potential areas for the construction of the repository and other activities and base documentation for the preparation and launch of national detailed site plan and
- preparation of the preliminary comparative study.

The total cost of evaluating the suitable areas amounts to 2.580 Million EUR with VAT and has already been invested in previous years.

Location and building site acquisition

Total costs for location and building site acquisition are 8.584 Million EUR (VAT included).
Field investigation, research and monitoring costs are divided into 5 parts:

- field investigation program
- geological and hydrological location site assessment implementation
- potential location biosphere, socioeconomics and demographic data acquisition,
- geological and hydrological location site confirmation implementation,
- non geological research for repository site confirmation.

The total cost for field investigation, research and monitoring is estimated at 4.125 million EUR with VAT, of which 3.767 million EUR with VAT has already been invested by 30 June 2018.

Repository site location purchase

The land acquisition was carried out in the size of the area within the limits of the potential location of Vrbina. The purchased area amounts to 34,718 m^2 and by 30 June 2018, 1.039 Million EUR was spent on land acquisition. For the acquisition of land for road infrastructure and servitude, 65,878 thousand EUR will have to be invested and 681,384 thousand EUR for the land use change. In addition, 92,916 thousand EUR will be required for reimbursement due to damages during construction.
Thus, the cost of land acquisition, servitude and costs of land use change is estimated to 1.879 Million EUR.

Costs of cooperation with local communities and communication activities

Costs of cooperation and communication activities include mediation, promotion, protocols, communication with local stakeholders, support for independent research, standard communication activities such as public surveys, cooperation with media and others.

The total cost of cooperation with local communities and communication activities and protocols (costs of damages and investments in local infrastructure) is estimated at 8.695 Million EUR with VAT. Out of the total amount, 5.185 million EUR with VAT is estimated on costs for communication activities and cooperation with local communities and the costs of damages and investments to local infrastructure (protocols) amount to 3.510 million EUR with VAT. By June 30, 2019, 4.436 million EUR with VAT was already invested [1].

Costs of project and investment documentation, engineering, ARAO costs acting as investment agent, repository operation procedures costs, PA/SA analysis costs

They include following costs[1] :

- planning (technical, project and investment documentation),
- obtaining permits,
- ARAO costs acting as investment agent
- PA/SA and RW inventory analysis,
- environmental impact assessment (EIA),
- working procedures documentation, engineering
- experimental operation testing, measurements, disposal container development

The costs of documentation, engineering, investment and analysis are estimated at 33.196 million EUR with VAT. Up to 30 June 2018, 19.109 million EUR with VAT was invested from the total value.

After 30 June 2018, the cost of materials and container research will amount to 2.874 million EUR with VAT and the cost of the ARAO acting as investment agent will amount to 4.220 million EUR. After 30 June 2018, the costs of the project and technical documentation will amount to 2.746 million EUR with VAT, the costs of safety assessment and other analyzes, and the EIA 3.254 million EUR with VAT.

After June 30, 2018, the cost of engineering will amount to 0.994 million EUR with VAT. The cost of engineering in nuclear facilities is relatively high and can account for a significant proportion of equipment and work costs.

Costs of compensation for restricted land use

From 2004 until 2015 different compensation rates and different organizations subject to payment of compensations were used based upon previous decrees. Compensation for limited land use is value added tax excluded. In accordance with Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas [34] adopted in 2015, annual compensation based on actual payments from Sklad NEK, acting as organization liable to pay compensation, for 2017 is 5.885 million EUR [35].
The annual cost of the compensation is fixed and does not depend on the amount of LILW disposed, it is corrected only for the value of annual inflation in the EU [34].

ICC has provided ARAO and Fond NEK with presentation "Optimisation of compensation expenses". Upon decision of the ICC from its 19th meeting and provided presentation, compensation rates and payments should take into account that there should be no increase of compensation due to inflation, no duplication of compensation for co-existing nuclear facilities inside area of limited use of areas and reduced compensations for nuclear power plant under construction, decommissioning or storage of RW and SF on the premises of the NPP. Compensation amount should be reduced also for independent storage of RW and SF and for repositories during research, development, construction and standby phase. All novelated cost of compensation are prepared according to this presentation and may be subject of later changes if or when the novelation of the Decree will be approved by the Government of Republic of Slovenia.

In 2019, up to 2022, a payment of total 6.0 million EUR is foreseen each year. In 2023 and onwards, the cost of compensation is included in the operating costs. In 2059, however, the cost of compensation is again part of the investment costs. The cost of compensation for the time of construction by the end of 2022 (6.0 million EUR annually) together with the already paid amounts of compensation in previous years (49.465 million EUR) and the compensation in the year of closure of the repository (2059) that are included as investment costs, amounts to total 82.394 million EUR for investment costs.

In June 2019, Government of Republic of Slovenia in its 36th session confirmed report of the inter-ministerial working group that has examined the system of compensation payments for restricted land use of space for LILW repository. In line with government material, Ministry of the Environment and Spatial Planning should prepare novelation of the Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas [34] and submit it for confirmation to the Government of Republic of Slovenia.

Total repository investment costs

When calculating investment costs constant prices for June 2018 were considered. The entire investment period ranges from 1998 to 2059 (except for the intermediate period 2023-2058). The investment value also includes funds already invested from previous years (from 1998 to 30. 06. 2018). Investment costs are shown with value added tax separated, except for compensation costs, land acquisition costs and costs related to ARAO acting as investment agent which are VAT excluded [1]. More detailed invested costs per year are, given in Annex 1.

The total value of the investment at constant prices in June 2018 amounts to 184.734 million EUR with VAT included and is estimated to 168.180 million EUR (91.58 %, VAT included) for the investment share that is funded from Sklad NEK and to 15.555 million EUR (8.42 %, VAT included) for the share that is funded from state budget. The investment value at constant prices is presented for the main cost items in the Table 5-6

Table 5-6 Total repository investment costs with presentation of Sklad NEK investment share based on [1].

Constant prices in 000 EUR	**Total Investment**	**Total Investment share %**	**Sklad NEK total Investment**[7]	**Sklad NEK total Investment share %**
1. Location and building site acquisition	7,223	3.91%	6,615	3.58%
2. Cooperation with local communities and communication activities	7,127	3.86%	6,527	3.53%
3. Project and investment documentation, engineering, ARAO costs acting as investment agent, repository operation procedures costs, PA/SA analysis costs	28,712	15.54%	26,295	14.23%
4. Construction and equipment	36,769	19.90%	33,673	18.23%
5. Compensation for restricted land use	82,394	44.60%	75,457	40.85%
6. Contingency	6,072	3.29%	5,561	3.01%
7. VAT	16,435	8.90%	15,051	8.15%
TOTAL	**184,158**	**100.00%**	**169,180**	**91.58%**

The highest costs item in the total value of the investment is the cost of compensation, which amounts to 82.394 million EUR and accounts for 44.60% of the total investment costs. The second largest item are costs for construction and equipment with 36.769 million EUR (no VAT included) and represents 19.90% of total investment costs.

It is evident that more than half of the total investment costs consist of costs that are not directly related to the construction, technical, engineering or other conditions for disposal.

[7] The key for the investment costs distribution between both sources of financing is the currently estimated volume of waste from the Krško NPP and the volume of waste from other sources. The volume of LILW from the Krško NPP is assessed to 91.58% and the volume of other waste is assessed to 8.42%.

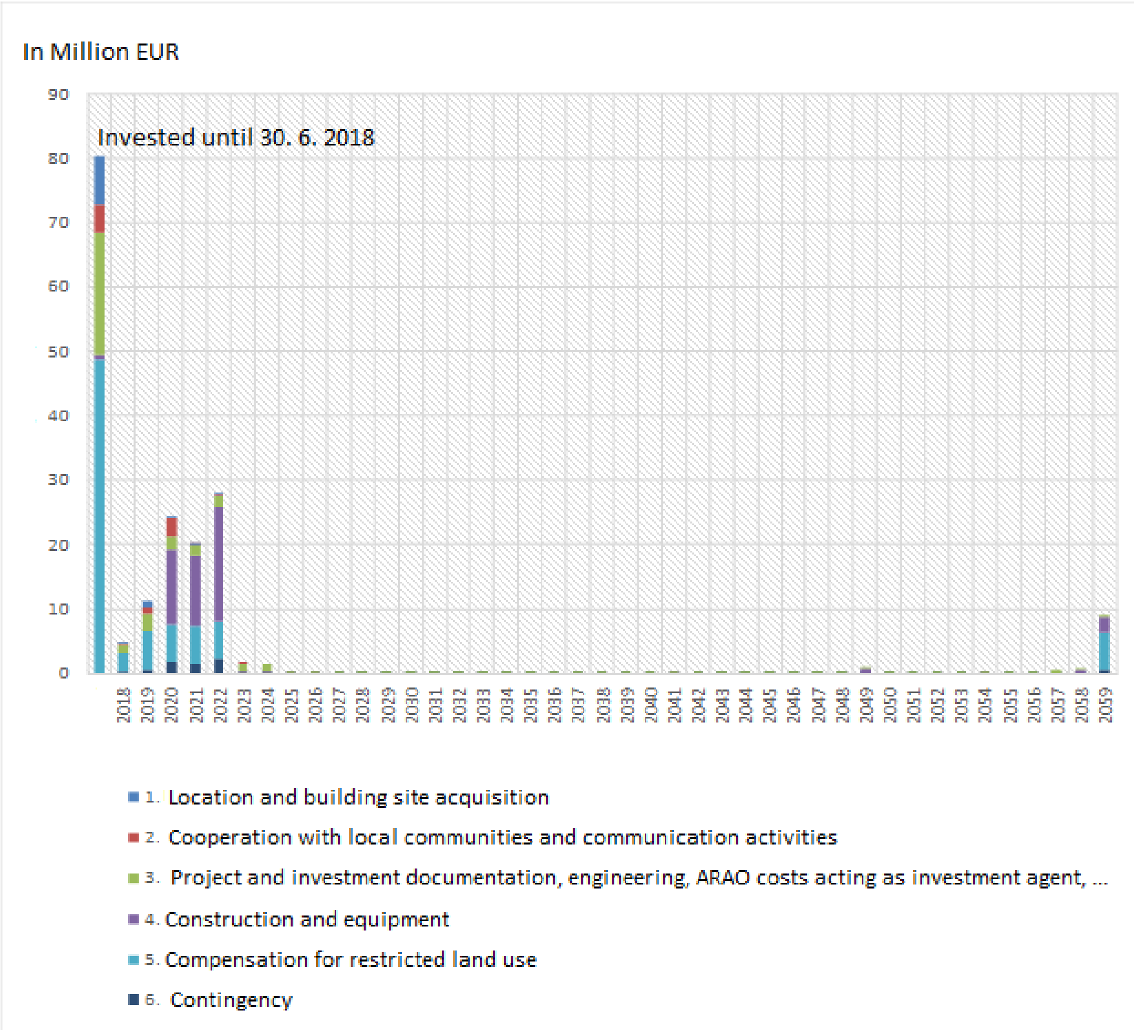


Figure 5-8 Dynamics of investments at constant prices for June 2018, VAT included [1].

In the Figure 5-8 investments dynamics is shown for all repository investment costs. The first period includes investments until the beginning of regular operation. The second set covers a period of regular operation and subsequent standby phase in the period from 2025 to 2057. The last period includes the decommissioning and closure of the silo that takes place in 2058 and 2059.

5.6.2. Operating costs

Operating costs are directly connected to disposal operation and associated with the implementation of the operation activities as well as activities during the standby phase. The operating costs for the LILW repository are estimated by individual cost groups for the operating and standby phase. They are [1]:

- Costs of disposal activities,
- Work costs,
- Insurance costs,
- Municipal services and energetic costs,

- Site maintenance and material costs,
- Costs of monitoring and radiological and other measurements,
- Compensation for restricted land use,
- Other costs.

Descriptions and assumptions for individual types of operating costs are given below.

Costs of disposal activities

In line with ReNPRRO16-25 [7], investment documentation [1] and repository Safety Report documentation [3] it is assumed that the repository accepts containers that are already conditioned and prepared in the Krško NPP for direct disposal into the disposal silo.

At the time of the start-up tests, 10 containers (but not disposed) will be used, and costs will amount to 231 thousand EUR (excluding VAT) or 23.1 thousand EUR per container.

The voids around containers in the silo will be filled with filling material (concrete). The cost of filling material for one layer of disposal containers is approximately 97 thousand EUR (excluding VAT). During the years of intensive disposal (>100 containers annually) will be disposed, so that two fillings of voids each two completed layers will be required.

At standby phase, these costs do not occur. More detailed costs of disposal activities per year are given in Annex 1. The contingency costs for experimental containers and filling of voids is 10%, so the cost of 10 experimental containers is 310 thousand EUR with VAT and contingency costs and costs of filling material is 130 thousand EUR with VAT and contingency costs [1].

The cost per disposal container is 10,943 EUR. The price includes the price of the container with the lid and the material costs of the filling material to fill the voids in the container and the sealing material to seal the lid.

During operation, state budget financing, through ARAO, will be used to cover the costs of disposing of 80 containers with LILW that is generated outside the Krško NPP as a result of CSF, Triga RR and repository operational LILW disposal and disposal of LILW from repository decommissioning activities (chapter 5.3) and as such are not included in the total costs estimate that should be financed from the Sklad NEK [1][7].

As regards the costs of preparing for disposal, the default estimate was that the cost of constructing facility for the conditioning and preparation of disposal containers to be provided at the Krško NPP would amount to approximately 6.52 million EUR and that these costs would be distributed equally to 1819 containers [1][15], which is the number of containers required to dispose all LILW generated in NEK and outside NEK (CSF, Triga RR, repository operation and decommissioning). Operating costs for conditioning and packaging LILW in NEK are costs related to N2d trial and disposal containers costs that

include also the transport costs to the repository location and were in total estimated to 12.47 million EUR [1][36].

In total, investment costs for facility construction, costs for LILW conditioning and packaging in Krško NPP, including N2d production and transportation, were estimated to 20.99 million EUR. This does not include VAT costs that could be deducted as the Krško NPP performs a taxable activity and has the possibility to deduct VAT for the purchased goods and services.

However, in the 3rd Revision of the NPP Krško Decommissioning Program [14] the number of required N2d containers for disposal of operating waste was reduced to 585 N2d containers and number of containers with decommissioning LILW, has been estimated to 205 N2d containers, where 177 N2d containers, generated during Krško NPP decommissioning, will be disposed in Vrbina repository and the remaining 28 N2d containers from SFDS operation and decommissioning will be disposed later together with HLW and SF as taken into account in chapter 3 of this Third revision document and in [37]. Costs of waste processing and treatment for all decommissioning waste including conditioning of waste (without cementation) and containers (e.g. drums, Holtec HI-SAFE, N2d container, RCC) is already included in 3rd Revision of the NPP Krško Decommissioning Program [14] under WPS project 15. Therefore, in costs estimates that are included in this Third Revision Disposal Program, costs of investment to conditioning facility, costs for cementation material and equipment and personnel costs for 177 N2d containers of Krško NPP decommissioning waste are included as presented in attachment 3 from [14] despite the fact that is not finally decided, if this work will be carried out at the NPP Krško site or at the final disposal facilities in Slovenia and Croatia.

Total costs for Slovenian share of operational waste for planning and engineering activities, preparation works, packaging/re-packaging of stored waste into repository containers and costs for N2d containers (WBS project 03, attachment 4) is estimated to 8.75 Million EUR including VAT [14]. Investment costs to new treatment and conditioning facility, together with material, equipment and personnel costs for share of Slovenian operational waste are estimated to 5.42 million EUR [14].

Other operating costs

Work costs

It is assumed that 12 people will be employed for operational work and related activities. The workplaces are to be filled by 5 ARAO employees from ARAO organizational unit for disposal and 7 workers by external contractors or workers from other ARAO organizational units. Expected annual work costs during operation will be 605,278 EUR. In the standby phase work force reduction for 20% is foreseen thus the costs will be proportionally reduced. In total, work costs are estimated to 8.070 million EUR and represent 2.82 % of all operating costs.

Insurance costs

Annual insurance costs were estimated as 1.0% of all construction and equipment investment costs without value added tax. Insurance services are value added tax excluded, but 8.5% tax payment for insurance transactions is needed [38]. Total annual insurance costs (VAT excluded) are 0.368 million € (50% in the standby phase - 0.184 Million EUR). In total these costs amount to 9.560 million EUR.

Municipal services and energetic costs

Municipal services and energy annual costs are 44,795 € (VAT excluded) and include costs of electricity, water, fuel oil and municipal services [1]. In total this cost amount to 0.896 million EUR (VAT excluded). Consumption of energy and the costs of municipal services will be significantly reduced during the standby phase where only a smaller share (20%) of these costs will occur.

Site maintenance and material costs

Annual site maintenance and materials costs for operation are estimated as:

- 2.0% of the value of radiation protection equipment,
- 1.5% of the value of other equipment,
- 1,0% of the value of the disposal and non-disposal facilities and
- 0.5% of the value of infrastructure connections, platform, repository outer layout and landscape architecture.

Annual site maintenance and material costs are estimated to 492,809 EUR (VAT included) and in total this cost amounts to 9.429 million EUR. Costs will be significantly reduced during the standby phase where only a smaller share (16%) of these costs will occur.

Costs for monitoring and radiological and other measurements

The total cost of monitoring and radiological and measurements during operation are estimated to 294,042 EUR (VAT excluded). During the standby phase, these costs are reduced accordingly and amount to approximately 39% of the total costs for monitoring and radiological and other measurements during operation. In total, monitoring and measurements costs amounts to 7.030 million EUR (VAT excluded) [1].

Compensation for restricted land use

In accordance with Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas [34]

annual compensation to local municipality Krško paid in 2017 was 5.885 million EUR[8] [35]. Compensation costs are not subject to value added tax. The beneficiary municipality has the right to receive this compensation for all years of operation of the repository, as well as during the period of the standby phase.

Costs for compensation during full (regular) operating period are 84,0 million EUR and for standby phase 13,2 million EUR. Therefore, total costs for compensation during operating period are 97,2 million EUR.

Other costs

Other operational costs (include services costs, administrative costs, costs of cooperation with local communities and communication activities and other) are estimated as 0.50% of all investment costs (without value added tax), plus 10% of work costs and costs of cooperation with local communities in time of repository operation.

Costs of services also include physical security costs. Physical security will be carried out by external contracting company.

All together 1.207 million EUR is foreseen per year and 25.649 million EUR during whole operating period (all VAT excluded). In the years of standby phase, when for the repository activities external contractors inclusion is not foreseen, these costs account for around 26% of the costs in the year of full operation [1].

Table 5-7 Annual costs estimate with VAT for other operating costs in time of full and standby phase operation

Cost item (000EUR / year), VAT included	**Repository in full operation**	**Share of costs in standby operation phase**	**Repository in standby operation phase**
Work costs	252,199	0,80	201,759
Insurance costs	398,948	0,50	199,474
Municipal services and energetic costs	54,650	0,20	10,930
Site maintenance and material costs	599,809	0,16	95,347
Costs for monitoring and radiological and other measurements	359,042	0,39	141,581
Other costs	1,467,570	0,26	384,888
Total (no compensation)	**3,132,217**	**0,33**	**1,033,979**
Compensation costs[9]	6,000,000	0,10	600,000
Total	**9,132,217**	**0,18**	**1,633,979**

8 Revalorization factor HICP for EU28 (01.06.2014-31.05.2018) EUROSTAT with value 1,36864 is used.

9 If compensation costs are based on draft novelation of the Decree [34], 6.0 million € compensation costs should be paid during full operational phase and 0.6 million for standby phase.

The highest annual costs item in the value of other operating costs is the cost of compensation, which amounts to 6.0 million EUR and accounts for 65.70% of the total annual other operating costs. The second largest item are other costs with 1.468 Million EUR and represents 16.07% of other operating costs.

It is evident that more than 2/3 of other operating costs consist of costs that are not directly related to the LILW disposal activities in operation period of the repository.

Total operating costs

Table 5-8 Total operating costs for disposal of all Slovenian LILW and only for 1/2 of LILW from Krško NPP (financed from Sklad NEK)

Operating costs 000 EUR	**Disposal of all Slovenian LILW**		**1/2 of LILW from Krško NPP (financed from Sklad NEK)**	
	Operating costs (2023-2058)	Share %	Operating costs financed from Sklad NEK (2023-2058)	Total costs share %
Costs of ARAO LILW disposal containers including filling material	2,687	1.57%	2,461	1,44%
Municipal services and energetic costs	896	0.52%	820	0,48%
Site maintenance and material costs	9,429	5.50%	8,635	5,04%
Insurance costs	9,560	5.58%	8,755	5,11%
Costs for monitoring and radiological and other measurements	7,030	4.10%	6,438	3,76%
Work costs	8,070	4.71%	7,391	4,31%
Compensation costs[10]	97,200	56.71%	89,016	51,94%
Other costs	25,649	14.97%	23,490	13,71%
Total without VAT	**160,522**	**93.66%**	**147,006**	**85.77%**
VAT	10,865	6.34%	9,950	5,81%
Total with VAT	**171,387**	**100.00%**	**261,955**	**91.58%**

The total operating costs with VAT for the period from 2023 to 2058 inclusive are 171.387 million EUR in the case where all Slovenian LILW is disposed in line with basic scenario and EUR 156.956 million € for the share of LILW that is financed from Sklad NEK.

The amount of operating costs varies by year. The annual costs depend on operation mode if repository is fully operational or is in a standby phase. The average amount of annual costs in the standby phase is 1.827 million EUR. Of this, 0.600 million EUR is

[10] Compensation costs are based on draft novelation of the Decree [34] and decision of the ICC from session 19. Total operating costs are estimated to 97.2 million EUR, where 89.016 million EUR should be financed from Sklad NEK.

payment of compensation and around 1.227 million EUR for all other operating costs. The annual costs in years of full operation do not depend much on the annual quantity of disposed containers. In the years when 40 containers are disposed (second full operational phase after 2050), the cost is estimated to around average 9.52 million EUR. In 2025 and 2026, when around 160 containers will be disposed, the annual costs are estimated to about 9.66 million EUR.

5.6.3. Total investment and operating costs

Table 5-9 shows that the total nominal costs for LILW disposal with regular operation starting in 2025 until 2028, when the repository enters the so-called standby phase where the repository is still in operation, but no disposal activities are planned. The repository second phase of full operation starts in 2050 and ends in 2058 with repository closure in 2059. Consequently, the operating period of Slovenian LILW repository is very long due to extended NPP Krško lifetime until 2043, and decommissioning activities which last for 15 additional years [14]. This results in rather high operating and high compensation costs.

The results for all grouped costs items are presented in Table 5-9 where also their share is given. Construction and operational cost individually do not represent the biggest part of nominal costs. For investment and operation phase of the repository compensations to local communities represent the majority of nominal costs.

The cost of disposal of LILW per m^3 of disposal volume is calculated as the sum of the total costs (356.121 million EUR) and divided by the amount of disposal volume (9,541.56 m^3)[11]. Currently the price of disposal per m^3 of RW is approximately 37,323.14 EUR.

In addition to investment and operating costs, costs of LILW division and takeover in Krško NPP are estimated to 117,000.0 EUR [28]. These costs are included in the overall costs of the Third revision together with all other RW and SF management costs that are used for calculation of annual payments to Sklad NEK.

[11] In the calculation estimated number of N2d disposal container from Table 5-2 was multiplied by the gross volume of 1 N2d container (12.28 m^3).

Table 5-9: Total costs for investment and repository operation with share of costs that need to be financed from Sklad NEK.

Nominal costs in 000 EUR	Total	Share %	Total financed from Sklad NEK	Share of total financed from Sklad NEK
Total investment	**184,734**	**100.00%**	**169,180**	**91.58%**
1. Location and building site acquisition	7,223	3.91%	6,615	3.58%
2. Cooperation with local communities and communication activities	7,127	3.86%	6,527	3.53%
3. Project and investment documentation, engineering, ARAO costs acting as investment agent, repository operation procedures costs, PA/SA analysis costs	28,712	15.54%	26,295	14.23%
4. Construction and equipment	36,769	19.90%	33,673	18.23%
5. Compensation for restricted land use	82,394	44.60%	75,457	40.85%
6. Contingency	6,072	3.29%	5,561	3.01%
7. VAT	16,435	8.90%	15,051	8.15%
Operating costs	**171,387**	**100.00%**	**156,956**	**91.58%**
1. Costs of ARAO LILW disposal containers including filling material	2,687	1.52%	2,461	1.44%
2. Municipal services and energetic costs	896	0.52%	820	0.48%
3. Site maintenance and material costs	9,429	5.50%	8,635	5.04%
4. Insurance costs	9,560	5.58%	8,755	5.11%
5. Costs for monitoring and radiological and other measurements	7,030	4.10%	6,438	3.76%
6. Work costs	8,070	4.71%	7,391	4.31%
7. Compensation costs	97,200	56.71%	89,016	51.94%
8. Other costs	25,649	14.97%	23,490	13.71%
9. VAT	10,865	6.34%	9,950	5.81%
Total for investment and operation	**356,121**	**100.00%**	**326,136**	**91.58%**
Total for investment and operation with waste preparation, division and takeover	**370,408**	**104.01%**	**340,423**	**91.90%**

5.7. Sensitivity analysis

In the sensitivity analysis several factors were investigated which could have influence on nominal costs for LILW repository. They were decided based on available results in different studies and documentations as well as on the expert judgment of possible developments in LILW repository project. They are:

- the amount of investment costs,
- the extent of compensation costs (change in compensation throughout the estimated period and change in compensation during the standstill phase)
- Influence of LILW volumes and related expenses on the nominal costs,

The results of sensitivity analysis for the amount of investment costs and the extent of compensation costs are presented in Table 5-10, Table 5-11 and Table 5-12. In all tables disposal price in EUR/m^3 is presented as an orientation value of changes for different parameters. If we decrease/increase the investment amount for 40%, the decrease/increase percentage for total disposal price EUR/m^3 is much lower (around 20%). This is somehow expected as most of the investment (44.60%) and operating costs (56.71%) is related to compensation costs. All other investment costs related to construction, land purchase, project and investment documentation, engineering, … were already successfully optimized throughout the Vrbina project development.

Table 5-10 Sensitivity analysis on the amount of investment costs

Data change %	Investment in 000 EUR	Disposal price EUR/m^3
-40%	110,840	29,579
-30%	129,314	31,515
-20%	147,787	33,451
-10%	166,261	35,387
0%	**184,734**	**37,323**
10%	203,207	39,259
20%	221,681	41,195
30%	240,154	43,131
40%	258,628	45,068

Table 5-11 Sensitivity analysis on the amount of compensation for the total repository time period, no reduction in the standby phase

Data change %	Compensation in 000 EUR	Disposal price EUR/m^3
-90%	600	26,570
-80%	1,200	29,148
-70%	1,800	31,727
-60%	2,400	34,305
-50%	3,000	36,883
-40%	3,600	39,461
-30%	4,200	42,039
-20%	4,800	44,618
-10%	5,400	47,198

Data change %	Compensation in 000 EUR	Disposal price EUR/m³
0%	**6,000**	**49,208**
10%	6,600	52,352
20%	7,200	54,930
30%	7,800	57,509
40%	8,400	60,087
50%	9,000	62,665

Table 5-12 Sensitivity analysis on the amount of compensation in standby phase

Data change %	Compensation in 000 EUR	Disposal price EUR/m³
-100%	0	35,940
-90%	600	37,323
-75%	1,500	39,398
-50%	3,000	42,857
-25%	4,500	46,315
0%	**6,000**	**49,208**

Sensitivity analysis on the amount of compensation in total repository period Table 5-11 and only in standby period Table 5-12, shows compensation amount significance and its impact on disposal price. As most of the investment (44.60%) and operating costs (56.71%) is related to compensation costs, the impact of compensation changes is very high, therefore total repository costs reduction/increase could be significant due to compensation amount changes and in requirement that revalorization of compensation costs is needed [34]. Proposed compensation changes, based on ICC decision and decision of the Government of RS to prepare a novelation of the Decree [34], have a significant influence on total repository costs. These are lower for 114.077 million EUR due to proposed compensation rate changes, especially in the repository standby phase where costs reduction of 114.653 million EUR is estimated.

In addition to financial, also time parameters (project dynamics) have significant influence on the investment. In particular, the duration of the period in which the repository has the status of the nuclear disposal facility, the duration of the period of (full) and standby operation and the time when the construction and operation of the repository starts. Variation of these parameters cannot be carried out in the same way as for financial parameters analysis, but a scenario approach is needed. Practically, all feasible and available scenarios have been verified in the previous stages of the project.

The scenario used and presented in this document that is based on the considered boundary conditions, is therefore the optimal scenario [17][1].

Influence of LILW volumes changes

Cost analyses for presented scenario as quoted in Table 5-9 are given for adjusted project numbers of containers and respective volumes of LILW to be disposed. Current waste volumes are very low compared to the waste volumes in previous revision of the Program of NPP Krško Decommissioning and SF and LILW Disposal (DP Rev.1) from 2004 [39], PDP Rev.5 from 2010 [40], repository capacity based on NSP [10] and also to some other studies [41] which already incorporated clearance levels into the estimations. Therefore, the biggest possible influence of LILW volumes changes have been investigated as presented in Table 5-13. The comparison was done for equivalent costs items where the effect of bigger LILW volume changes has been analyzed by comparing variant of construction of only 1 silo with capacity of 990 containers (basic scenario) and 2 silos with capacity of 1.980 containers (possible extended scenario).

Table 5-13 Nominal costs for basic and extended scenario with cost increase percentage.

Nominal costs in 000 EUR	**Total for basic scenario (950 N2d)**	**Total for extended scenario (1819 N2d) [1]**	**Cost change %**
Total investment	**184,158**	**209,073**	**113.5%**
1. Location and building site acquisition	7,223	7,223	100.0%
2. Cooperation with local communities and communication activities	7,127	7,127	100.0%
3. Project and investment documentation, engineering, ARAO costs acting as investment agent, repository operation procedures costs, PA/SA analysis costs	28,712	32,127	111.9%
4. Construction and equipment	36,769	52,343	142.4%
5. Compensation for restricted land use	82,394	82,394	100.0%
6. Contingency	6,072	7,801	128.5%
7. VAT	16,435	20,634	125.5%
Operating costs	**286,039**	**295,669**	**103.4%**
1. Costs of ARAO LILW disposal containers including filling material	2,687	3,545	131.9%
2. Municipal services and energetic costs	896	860	96.0%
3. Site maintenance and material costs	9,429	12,036	127.6%
4. Insurance costs	9,560	13,347	139.6%
5. Costs for monitoring and radiological and other measurements	7,030	6,851	97.5%
6. Work costs	8,070	8,020	99.4%
7. Compensation costs	97,200	97,200	100.0%

8. Other costs	25,649	26,965	105.1%
9. VAT	10,865	12,191	112.2%
Total for investment and operation	**356,121**	**390,665**	**109.7%**

There is not significantly bigger effect on costs even in the case when the number of containers is increased dramatically from 950 in basic scenario to 1819 in extended scenario which include also the construction of 1 additional silo with all related expenses. Investment costs increase is observed mainly for construction and equipment associated costs and related costs of contingency and VAT for additional silo construction. Other investment costs changes are small or zero as location acquisition costs are fix and the location is allowing construction of 4 silos if needed. Project and investment documentation, engineering, … and other costs increase is small as the majority if these costs is fix and does not depend on the LILW inventory. Operating costs increase, as consequence of operating 2 disposal silos, are higher for costs items where purchase of increased number of containers is needed (but small in nominal value) or where more services, materials, energy consumption and insurance costs is foreseen.

Despite an almost double increase in inventory, the total investment and operating cost increase is only 9.7% and even this is directly related to construction and operation of 1 additional silo. The reason for this is quite simple as the majority of costs is associated with fix costs for compensations, taxes and location and as such have the biggest influence on cost changes (see table Table 5-11 and Table 5-12).

5.8. Risk management

Risks occur in all phases of the repository project: in the phase of preparation, implementation and operation of the project or investment. Risks is therefore constantly monitored throughout the preparation and implementation of the investment to the Vrbina repository. For all stages of the investment, detailed identification of risks and the establishment of mechanisms that allow effective control and limitation of risks is being implemented.

The preparation of a risk set including risk assessment is carried out at regular workshops involving all key stakeholders in the project. The overall quantified assessment of the risk level for a particular risk or risk factor is made as a product of estimates of the severity level of the consequences and the likelihood of risk occurrence. For each risk, and in particular for the risks with the highest estimates, measures are taken to eliminate and mitigate the risk [1].

The results of the risk assessment in Table 5-14 show that currently the biggest risks are related to possible additional requirements of neighboring countries in process of cross-border impacts assessment, uncertainty and changes in regulations, obtaining the consent of the owners of Krško NPP on the conditioning and final preparation of LILW

for disposal in the Krško NPP and to annual delays in approval of ARAO work and financial plan. Delays to ARAO work and financial plan approval lead to delays in signing a contract with Sklad NEK that represents precondition for annual financing of investment activities for Vrbina LILW repository.

The likelihood of occurrence (LO) and the severity of the consequences (SC) that form the product "level of risk" were defined in the expert decision-making process, taking into account the evaluation guidelines. The likelihood of occurrence is valued as 1 (unlikely), 2 (uncertain), 4 (probably), 6 (very likely), and 10 (almost certainly). The degree of severity of the consequences is scored with score points (1, 2, 4, 6, 10) whose value is based on impacts of risk to costs, project milestones (deadlines) achieved, project results specifications and nuclear safety and impact on the satisfaction of key stakeholders. Maximum number of score for level of risk is 100. In addition to the risk management results in Table 5-14, other less significant risks were identified whose overall result did not exceed 60 points.

Table 5-14 Presentation of the most important risks in the project preparation phase [1].

	Description of the risk	**Description of the consequence**	**Likelihood of occurrence (LO)**	**The degree of severity of the consequences (SC)**	**Level of risk (=LOxSC)**	**Possible risk mitigation measures**
1	Possible additional requirements of neighboring countries in process of cross-border impacts assessment	Delay of the project, costs increase	10	8	80	The inclusion of potentially interested countries as soon as possible with correct presentation of the project
2	Uncertainty and changes in regulations	Delay of the project	8	8	64	Include the ministries responsible for energy and the environment, the SNSA in monitoring the implementation of the project. Active participation in legislative changes, with analysis of potential consequences.
3	Consent of the owners of Krško NPP on the conditioning and final preparation of LILW for disposal is not yet acquired	Delay in providing technology and facilities for conditioning of LILW	10	6.25	62.5	Obtaining consent as soon as possible.

	Description of the risk	Description of the consequence	Likelihood of occurrence (LO)	The degree of severity of the consequences (SC)	Level of risk (=LOxSC)	Possible risk mitigation measures
4	Delays to ARAO work and financial plan approval, delays in signing contract with Sklad NEK	Delay of the project, implementation of the project is slowed down, ARAO financial problems	10	6.25	62.5	Timely adoption of the ARAO work and financial plan, temporary financing of the project, prior harmonization with financiers, multi-year work programs

5.9. Comparison with DP Rev.1

Comparison of costs for basic scenario were prepared with revalorized expenses from corresponding SID 45 scenario from DP Rev.1 [39] for LILW repository in EUR 2018 (Table 5-15). Recalculation for inflation (according to Statistical office of Republic of Slovenia) between June 2003 and June 2018 was used where the inflation rate was 34.9 % for retail prices of goods and services. The costs are divided into individual components for construction, for compensation during construction and for operational costs per year. In operational costs also compensation to local communities are separately identified to enable corresponding comparison. No contingencies and VAT were considered.

Table 5-15 Costs comparison of basic scenario with previous revision SID-45 from DP Rev.1

Costs	SID 45 (million EUR, 2018)	Basic scenario (million EUR, 2018)
1. Location and building site acquisition	8.62	7.223
2. Cooperation with local communities and communication activities	6.67	7.127
3. Project and investment documentation, engineering, repository operation procedures, PA/SA analysis	4.44	28.712
4. Construction and equipment	91.94	36.769
5. Compensation for restricted land use[12]	5.61	82.394
6. Trial operation	5.44	0.393
7. Decommissioning and closure	10.75	2.548

[12] All costs due to compensation for restricted land use (2007-2016). Amount is sum of costs between old (31.12.2003-31.12.2008) and new (1.1.2009-) compensation decree with al amendments [42], [43], [34].

Costs	SID 45 (million EUR, 2018)	Basic scenario (million EUR, 2018)
8. Operating costs/year	4.65 (2.90⇒CLC, other 1.75)	4.63[13]
Total costs for construction, no compensations	**126.32**	**79.832**
Total costs for construction and operation, no compensations	**173.64**	**142.154**
Compensations	**82.98**	**179.594**[14]
Total costs for construction and operation with compensations included	**256.62**	**356.121**

Total nominal SID 45 LILW repository costs represent 72.1 % of total nominal costs for Vrbina LILW repository in basic scenario if the compensation costs are included. Comparison of all investment and operating costs in SID 45 without compensations represents 122.2 % of the present basic scenario costs. Construction and equipment costs for basic scenario due to several project optimizations are lower than in the case of SID-45 scenario, but on the other hand operating costs for repository basic scenario are higher and longer in duration. The compensation increases the costs for 38.8 % in basic Vrbina scenario compared to SID-45 scenario. It is also evident that pure technical costs for construction without compensation costs decreased for 22.2 % in basic scenario versus revalorized SID-45 scenario.

Detail comparison between group of cost items shows that the biggest differences in new expenses arise due to increases of construction and material costs (for factor 2,5), and increase in project and investment documentation, engineering, repository operation procedures and PA/SA analysis (for factor 6,5). The largest increase in costs can be observed for compensation costs. For compensations in investment phase the increase is enormous (more than 1000%) and in total more than 200%. The reasons for such dramatical increase are changes in decree for compensation for restricted land use with annual nominal value increase and investment and operating dynamics of the repository where 49.7 million EUR was already invested for compensations to Vrbina repository until June 2018. The operation of the repository was also extended from 27 years of operation for SID-45 scenario to 37 years for Vrbina basic scenario.

Costs connected with construction and equipment for Vrbina basic scenario (1 silo construction) present 40% of the SID-45 corresponding costs. Such costs ratio is expected as has to be remembered that SID-45 deals with much bigger LILW volumes (4 silo construction planned for 17,600 m^3) versus smaller volume in Vrbina basic scenario

---

[13] Total operating costs are calculated as sum of operating costs and compensations and no contingency or VAT. Because of 37 years of repository operation this value is divided with 37 to calculate annual operating costs.

[14] Compensation costs based on ICC decision and draft novelation of the Decree [34].

(777 N2d containers, 1 silo construction for 9,542 m^3). In sensitivity analyses it was already proven that the radioactive waste volume does not influence significantly the total prices.

5.10. References

[1] "Odlagališče NSRAO Vrbina, Krško, Investicijski program, Rev. E, IBE d.d., 2019."

[2] *Sklep o potrditvi Investicijskega programa za odlagališče NSRAO Vrbina v občini Krško, št. 360 - 54/2014/31, 8.7.2014, Ministrstvo za infrastrukturo in prostor, Direktorat za energijo*. .

[3] "'osnutek Varnostnega poročila za odlagališče NSRAO Vrbina, Krško', ARAO, Revizija 5, 2019."

[4] *SAFETY ANALYSIS AND WASTE ACCEPTANCE CRITERIA PREPARATION FOR LOW AND INTERMEDIATE LEVEL WASTE REPOSITORY IN SLOVENIA Phase II and III, Revised Operational Safety Assessment, ARAO, EISFI-TR-(15)-37 Vol. 1, NSRAO2-PCS-019-01-eng*. Konzorcij EISFI (ENCO, INTERA, STUDSVIK, FACILIA, IRGO), 2016.

[5] Consortium EISFI, *Safety Analysis and Waste Acceptance Criteria Preparation for Low and Intermediate Level Waste Repository in Slovenia, Inventory report, Technical Report ARAO, EISFI-TR-(11)-12 Vol.1, Rev.4*. Konzorcij EISFI (ENCO, INTERA, STUDSVIK, FACILIA, IRGO), 2014.

[6] *Uredba o enotni metodologiji za pripravo in obravnavo investicijske dokumentacije na področju javnih financ*. (Uradni list RS, št. 60/06, 54/10 in 27/16).

[7] "Resolution on the National Programme for Managing Radioactive Waste and Spent Nuclear Fuel 2016-2025, Off. Gaz. of the RS, Nr. 31/16."

[8] "Terms of REFERENCE (ToR) for THIRD REVISION OF THE KRŠKO NPP RW AND SF DISPOSAL PROGRAM, ARAO, Fond NEK, 2017."

[9] "Terms of REFERENCE (ToR) for the THIRD REVISION OF THE KRŠKO NPP DECOMMISSIONING PROGRAM, Krško NPP, ARAO, Fond NEK, 2107."

[10] "Decree on the National Spatial Plan for a LILW Repository (Official Gazette of the Republic of Slovenia, Nr. 114/09 and 50/12)."

[11] *Odlagališče NSRAO Vrbina, Krško, Investicijski program, Rev. C,*. IBE, d.d., 2013.

[12] *Treaty between the Gov. of the Republic of Slov. and the Gov. of the Republic of Cro. on the regulation of the status and other legal relations regarding investment, exploitation and decommissioning of the Krško NPP... BHRNEK, Off. Gaz. of the RS 23/2003*. .

[13] "6 th Revision of the Preliminary Decommissioning Plan (PDP) for NPP Krško, NIS Siempelkamp, document No.: 4520/CA/F 010420 7 / 01, June 2019."

[14] "3rd Revision of the NPP Krško Decommissioning Program, NIS Ingenieurgesellschaft mbH, Document No.: 4520 / CA / F 010640 5 / 07, June 2019."

[15] *Safety Analysis and Waste Acceptance Criteria Preparation for Low and Intermediate Level Waste Repository in Slovenia, Inventory report, Technical*

Report ARAO, EISFI-TR-(11)-12 Vol.1, Rev.5. Konzorcij EISFI (ENCO, INTERA, STUDSVIK, FACILIA, IRGO), 2016.

[16] *Safety Analysis and Waste Acceptance Criteria Preparation for Low and Intermediate Level Waste Repository in Slovenia - General overview of Safety Assessmnet Report*. Konzorcij EISFI (ENCO, INTERA, STUDSVIK, FACILIA, IRGO), 2012.

[17] "Osnutek predhodnega soglasja o jedrski in sevalni varnosti, URSJV, št. 354-1/2017/21, april 2019."

[18] "Abstract of the Cross-Border Environmental Impact Assessment Report, Phase of environmental impact assessment - EIA, November 2018."

[19] "LILW Repository Vrbina, Krško / Elevation points and access roads, IBE d.d., August 2015."

[20] *Odlagališče NSRAO Vrbina, Krško, Idejna zasnova Rev.C*. 2016.

[21] "Projektne osnove za odlagališče NSRAO Vrbina, Krško - faza presoje vplivov na okolje, Revizija 4 02-08-011-004/NSRAO2-POR-013-01, ARAO, 2019."

[22] *Rules On Radiation And Nuclear Safety Factors (JV5). Unofficial Translation of the original published in Slovene language in the Official Gazette of the Republic of Slovenia, No. 92/2009. Prepared in February 2011*. .

[23] *Praktične smernice - Vsebina varnostnega poročila za odlagališče nizko in srednje radioaktivnih odpadkov*. 2012.

[24] *Zakon o varstvu pred ionizirajočimi sevanji in jedrski varnosti (ZVISJV-1)*. (Uradni list RS, št. 76/17, in 26/19).

[25] "Opredelitev NEK do možnosti priprave NSRAO na odlaganje v NEK, dopis št. ING.DOV-319.18/6243, september 2018."

[26] "WPS at the phases of obtaining building consent and construction permit, Technical Report ARAO, EISFI-TR-(17)-02, Del.3.5 Revision 1, January 2019."

[27] "Projekt za pridobitev gradbenega dovoljenja, Rev.C. Načrt gradbenih konstrukcij in drugi gradbeni načrti. Odlagalni zabojnik. NRVB - 5G16C. IBE Consulting Engineers, Ljubljana, 2017."

[28] "Analysis of Potential Division and Takeover of Operational and Decommissioning RW from Krško NPP, Enconet d.o.o. and Ekonerg, Zagreb, February 2019."

[29] "Prekinitev obratovanja odlagališča NSRAO in vplivi na oceno stroškov, IBE, marec 2010."

[30] "Razvoj rešitev tehnologije odlaganja, rev.A, Odlagališče NSRAO Vrbina, Krško, IBE, Ljubljana, December 2010."

[31] *Načrt dolgoročnega nadzora in vzdrževanja po zaprtju odlagališča NSRAO, referenčna dokumentacija za osnVP, NSRAO2-POR-008-00 02-08-011-003*. ARAO, 2016.

[32] “»Costing methods and Funding Schemes for Radioactive Waste Disposal Programmes«, final draft, IAEA, 2018.”

[33] “»European Commission, Guide to Cost-Benefit Analysis of Investment Projects Economic appraisal tool for Cohesion Policy 2014-2020«, December 2014.”

[34] “‘Decree on the Criteria for Determining the Compensation Rate due to the Restricted Use of Areas and Intervention Measures in Nuclear Facility Areas’, UV8, Off. Gaz. RS 92/14, 46/15 and 76/17 – ZVISJV-1.”

[35] “Letno poročilo Sklada za financiranje razgradnje Nuklearne elektrarne Krško in za odlaganje radioaktivnih odpadkov iz Nuklearne elektrarne Krško za leto 2017, Sklad NEK, junij 2018.”

[36] “Analiza scenarijev SA.4 in SA.5, IBE d.d., NRVB---4X/02, 2017.”

[37] “‘Reference Scenario for Geological Disposal Facility in Hard Rock with Cost Estimation for its Implementation’, IBE d.d., February 2019.”

[38] “Zakon o davku od prometa zavarovalnih poslov (Uradni list RS, št. 96/05 – uradno prečiščeno besedilo in 90/14).”

[39] “Program of Krško NPP Decommissioning and SF & LILW Disposal (Program razgradnje NPP Krško in odlaganja NSRAO in IJG), ARAO, T-1123/03, Ljubljana, 2004, APO Ltd., Environ-mental Services, 25-04-1348/06, Zagreb, 2004.”

[40] *Preliminary Decommissioning Plan (PDP) for NPP Krško, Revision 5*. 2010.

[41] ARAO, “Assistance in Development of Conceptual Design for LILW Repository in Slovenia, PHARE 2003/5812.08.01,” 2006.

[42] “Uredba o merilih za določitev višine nadomestila zaradi omejene rabe prostora na območju jedrskega objekta, Uradni list RS št.134/2003.”

[43] “Uredba o spremembah in dopolnitvah Uredbe o merilih za določitev višine nadomestila zaradi omejene rabe prostora na območju jedrskega objekta, Uradni list RS št. 100/2008.”

5.11. Annex 1

Cost item, waste from Table 5-2 included with addition to all slovenian institutional waste)	Repository costs per construction and operation phases (in 000 EUR, constant prices June 2018, no VAT)																					
	Preparatory work	Construction			Trial operation		Full operation			Preparation for standby phase	Standby phase	Preparation for full operation	Full operation								Decommissioning	Repository closure
A. COSTS FOR CONSTRUCTION AND CLOSURE	2017	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029 - 2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059
Platform	611	0	0	494	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Infrastructure connections	0	473	473	473	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-disposal facilities	0	1871	2806	4677	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	310	0
Disposal facilities	0	6352	2117	2117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1745
Mechanical systems	0	134	1962	795	0	0	0	0	0	0	0	202	0	0	0	0	0	0	0	0	77	41
Electrical systems and telecommunications	0	324	648	648	60	60	84	0	0	0	7	28	0	0	0	0	0	0	0	0	58	46
Technical security systems	0	60	119	119	0	24	0	34	0	0	4	66	0	0	0	0	66	0	0	0	23	35
Transport devices	0	0	0	2901	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Radiation protection (Radiology)	0	0	0	475	0	0	0	0	0	0	0	237	0	0	0	0	0	0	0	0	0	0
External arrangement	0	217	759	1192	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71
Landscape architecture	0	0	62	555	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58
TOTAL A	**587**	**9430**	**8946**	**14446**	**60**	**84**	**84**	**34**	**0**	**0**	**11**	**533**	**0**	**0**	**0**	**0**	**66**	**0**	**0**	**0**	**468**	**1997**
B. OPERATING COSTS																						
Trial containers / filling material (concrete)	0	0	0	0	231	0	0	195	195	0	0	0	0	97	0	97	97	0	97	97	0	0
TOTAL B	**0**	**0**	**0**	**0**	**231**	**0**	**0**	**195**	**195**	**0**	**0**	**0**	**0**	**97**	**0**	**97**	**97**	**0**	**97**	**97**	**0**	**0**
C. ARAO LILW DISPOSAL																						
Containers/ treatent&conditioning in NEK / transport	0	0	0	0	0	17	150	150	67	0	0	0	50	117	117	117	117	117	117	117	84	0
TOTAL C	**0**	**0**	**0**	**0**	**0**	**17**	**150**	**150**	**67**	**0**	**0**	**0**	**50**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**84**	**0**
TOTAL A + B + C	**587**	**9430**	**8946**	**14446**	**292**	**101**	**234**	**379**	**262**	**0**	**11**	**533**	**50**	**214**	**117**	**214**	**280**	**117**	**214**	**214**	**551**	**1997**
Number of trial containers	**0**	**0**	**0**	**0**	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total number of disposal containers	**0**	**0**	**0**	**0**	**5**	**10**	**160**	**160**	**134**	**0**	**0**	**0**	**20**	**30**	**40**	**40**	**40**	**40**	**40**	**40**	**18**	**0**
Number of ARAO disposal containers	**0**	**0**	**0**	**0**	**0**	**1**	**9**	**9**	**4**	**0**	**0**	**0**	**3**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**5**	**0**

6. RW Management in RC

This chapter is based on a study *Razrada koncepta zbrinjavanja RAO u RH s novom procjenom troškova* created in February 2019. by EKOTEH d.o.o. for the purpose of drafting this revision.

Abbreviations

CNSF	Central National Storage Facility
DP Rev 1.	1st revision of the Program of NPP Krško Decommissioning and SF & LILW Disposal
DP Rev 2.	2nd revision of the Program of NPP Krško Decommissioning and SF &

	LILW Disposal
DP Rev.3	3rd Revision of the NPP Krško Decommissioning Program
DS	Disused sources
EIA	Environmental Impact Assessment
Fund	Fund for the Financing of the Decommissioning and Disposal of Radioactive Waste and Spent Nuclear Fuel from the Krško Nuclear Power Plant
IC	The Intergovernmental Commission
IRW	Institutional Radioactive Waste
Joint Convention	Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management
LILW	Low and Intermediate Level Waste
National Programme	National Programme for the Implementation of the Strategy for the Management of Radioactive Waste, Disused Sources and Spent Nuclear Fuel (Programme for the period up to 2025 with a view to 2060)
NORM	Naturally Occurring Radioactive Material
RC	Republic of Croatia
RCC	Reinforced Concrete Containers
RS	Republic of Slovenia
RW	Radioactive Waste
RWM Centre	The Radioactive Waste Management Centre
SAR	Safety Analysis Report
SEA	Strategic Environmental Impact Assessment
SF	Spent Nuclear Fuel
SNSA	Slovenian Nuclear Safety Administration (URJSV)
SORNS	State Office for Radiological and Nuclear Safety
SRSF	Solid Radwaste Storage Facility
Strategy	Croatian Strategy for the Management of Radioactive Waste, Disused Sources and Spent Nuclear Fuel
TTC	Tube Type Containers
WAC	Waste acceptance criteria
WMF	Waste management facility
WPS	Waste Package Specification

6.1. Introduction

This chapter contains updated information on matters covered in the first RW and SF disposal program approved by both sides in 2004 entitled *1st revision of the Program of NPP Krško Decommissioning and SF & LILW Disposal* (DP Rev.1). DP Rev.1. was joint document integrating RW and SF disposal program with decommissioning program in single text. Intergovernmental Agreement requires revision of RW and SF disposal program every five years.

2nd revision of the Program of NPP Krško Decommissioning and SF & LILW Disposal (DP Rev 2.) was initiated in 2009 but work was halted by IC on the 10th session held on July 20, 2015. Hence, present or third revision follows previously approved or valid revision (1st revision) after 14 years. Pursuant to the provisions of Article 10, paragraph 3 and paragraph 5 of the Intergovernmental Agreement three revisions should had been prepared in a meantime.

Following are major developments regarding RW management since D&DP Rev.1., previous valid revision:

- In 2007 the *Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Krško NPP Radioactive Waste and Spent Nuclear Fuel* (Fund) was established [1] to fulfill obligations undertaken by RC in the Intergovernmental Agreement. The Fund's founder is RC, which is liable for contractual obligations of the Fund. The Fund is accountable in respect of its work to the central state administration body in charge of energy affairs, i.e. presently to the Ministry of Environment and Energy. The Act establishing the Fund [1] came into effect on October 27, 2007. Croatian Government appointed the Management Board and Director on February 7, 2008; in September 2008 the Fund began operations.
- In 2012 a Decree for license extension to Krško NPP for additional period of 20 years, till January 14, 2043 had been issued by Slovenian Nuclear Safety Administration (SNSA) [2].
- On July 1, 2013 RC became a full member of the European Union (EU), and on that date the Treaty of Accession of RC to the European Union entered into force [3]. Prior to that by signing the Stabilization and Association Agreement in 2001, RC has taken on the obligation of harmonizing national legislation with the *acquis communautaire*, the implementation of the *acquis communautaire* and the harmonization of the entire corpus of rights and obligations connecting the EU Member States.
- In 2014 Croatian Parliament adopted *Strategy for the Management of Radioactive Waste, Disused Sources and Spent Nuclear Fuel* (Strategy) [4].
- On the 10th session of IC on July 20, 2015 IC supported lifetime extension of Krško NPP (Minutes of the Meeting, conclusions No. 1.2 and 2.1)

- In 2017 Croatian *Act on Radiological and Nuclear Safety* [5] was fully aligned with relevant EU directives, international conventions and IAEA recommendations .
- On the 11th session of IC on November 21, 2017 Croatian side had informed Slovenian side that after consideration of the *Investment project for the LILW Vrbina repository (Rev. C)* it was decided that proposed offer as presented is unacceptable for Croatian side.
- In 2017 Amendment was added to Croatian *Law on radiation protection and nuclear safety* introducing Radioactive Waste Management Centre (RWM Centre) as organizational unit within the Fund comprising facilities for institutional radioactive waste (IRW), LILW and SF management [5].
- In 2018 new *Ordinance on management of radioactive waste and disused sources* [6] was adopted that takes in the consideration all safety requirements set forth in the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* (Joint Convention), Council Directive 2013/59/Euratom of December 5, 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom (BSS Directive) and in the IAEA safety requirements and guidelines.
- On November 18, 2018 Croatian Government adopted *National Programme for the Implementation of the Strategy for the Management of Radioactive Waste, Disused Sources and Spent Nuclear Fuel (Programme for the period up to 2025 with a view to 2060)* (National Programme) [7] under the Council Directive 2011/70/Euratom.
- From January 1, 2019 Ministry of the Interior – Civil Protection Directorate replaces the former State Office for Radiological and Nuclear Safety as the national radiological and nuclear safety authority.

Aforementioned developments strongly influence Croatian present position regarding RW management.

Also, reviews of DP Rev.1 and halted DP Rev 2. found that both documents did not address two particularly important issues that under Article 10, paragraph 3 of the Intergovernmental Agreement had to be elaborated in Disposal Program. These are: (1) Proposal of the possible division and takeover of LILW and SF and (2) Waste acceptance criteria (WAC) for disposal. These two topics are directly related to the physical removal of RW and SF from the Krško NPP location.

It is also rather important to note that during period 1991 – 1995 site selection process for the location of national LILW repository was undertaken in Croatia [8]. Selection was done using elimination criteria set by Croatian Government [9]. Process demonstrated that more than 30 suitable locations could be identified in Croatia satisfying all set safety criteria in lowly inhabited areas and with favorable geological properties. Site selection

process proved that there are locations in Croatia where near surface LILW vault type repository could be built and operated, repository similar to several LILW repositories already built and operated in some EU countries. At the end of the site selection process in 1999 location on Trgovska gora was included in the *Republic of Croatia Spatial Planning Program* as location reserved for LILW repository [10]. The *Republic of Croatia Spatial Planning Program* specifies that Trgovska gora is the location on which further investigations will be conducted, and that partnership with local community will be developed ensuring, among other things, "*possible forms of compensations to the local community*" [10]. In 2017 new *Republic of Croatia Spatial Development Strategy* [11] was adopted by Croatian Parliament with the reference to the *Republic of Croatia Spatial Planning Program* and the Strategy.

6.2. National Strategy and Program

6.2.1. Strategy for the Management of Radioactive waste, Disused Sources and Spent Nuclear Fuel

Strategy for the Management of Radioactive waste, Disused Sources and Spent Nuclear Fuel (Strategy) was adopted by Croatian Parliament on October 17, 2014. The Strategy is based on requirements given under the Articles 54, 55, 56 and 95 of the Croatian *Act on Radiological and Nuclear Safety*. Also, the Strategy is developed in accordance with requirements given in the Articles 10 and 11 of the Intergovernmental Agreement as well as requirements in the Article 4 of the Directive 2011/70/Euratom [12].

The Strategy defines basic objectives and guidelines for the management of institutional radioactive waste (IRW) produced in RC, disused sources (DS), LILW and SF from Krško NPP as well as for the remediation of locations with naturally occurring radioactive material (NORM).

The Strategy defines short-term (2 years), mid-term (10 years) and long term objectives (for the period longer than 10 years). In a nutshell the Strategy could be presented with a Table 6.1.

In this chapter, the Strategy will be presented only partially with the focus on RW and LILW management.

Short-term objectives related to RW management are: Development of the National Programme for the Implementation of the Strategy for the Management of Radioactive Waste, Disused sources and Spent Nuclear Fuel; and Development of research program to establish long term RW storage for Krško NPP LILW.

Mid-term objectives related to RW management are: Implementation of a research program to establish long term RW storage for Krško NPP LILW and Development of

research program to establish repository for institutional RW, DS and LILW from Krško NPP.

Long term objective related to RW management is: Implementation of the program to establish repository for institutional RW, DS and LILW from Krško NPP.

The objectives set out in the Strategy include establishment of a long term storage and then repository for IRW, DS and LILW from Krško NPP. In order to fulfil the objectives mentioned above the Strategy sets up general guidelines regarding the legislative framework, responsibilities, funding, human resources and public participation.

In order to organize RW and DS management efficaciously the Strategy anticipates establishment of special RWM Centre. The RWM Centre will encompass all the facilities needed for safe storage of IRW and DS as well as long term storage of LILW from Krško NPP. The choice of one location for all the RW management facilities is in line with the 1999 *Republic of Croatia Spatial Planning Program*, which states that RC should address the disposal of LILW at a single location by applying state-of-the-art technology and procedures to ensure management and disposal in a safe manner [10] and with the *Republic of Croatia Spatial Development Strategy* [11]

Regarding RW management the Strategy offers official interpretation of the key LILW and SF Disposal Articles in Intergovernmental Agreement (Articles 10 and 11).

By Intergovernmental Agreement RC assumed responsibility for the disposal of half of LILW and SF from Krško NPP. Responsibility mostly implies reaching agreement between RC and RS on a joint solution for the disposal of LILW and SF (Article 10, paragraph 2 of the Intergovernmental Agreement). In the event of not reaching agreement on a joint solution until the end of regular Krško NPP lifetime (2023) RC and RS commit to complete the takeover of LILW and SF from Krško NPP location within two years, each by half (Article 10, paragraph 7 of the Intergovernmental Agreement). The dynamics of further physical takeover of the decommissioning LILW and the remaining SF will be carried out in accordance with the Krško NPP Decommissioning Program and LILW and SF Disposal Program at least every five years, unless otherwise specified in the approved programs (Article 10, paragraph 7 of the Intergovernmental Agreement).

The interpretation of the provisions of Article 10, paragraphs 6 and 7 of the Intergovernmental Agreement warns that regardless of whether RC and RS within regular lifetime (2023) reach joint solution for the disposal of LILW and SF or not, RC and RS will have to physically takeover and remove from the Krško NPP location operating LILW, half each of them after 2023, anyway. The difference between joint solution and separate solutions is that in the case of a failure to reach agreement on a joint solution, the dynamics of physical take over is obvious (Article 10, paragraph 7), while in the case of reaching a joint solution this dynamic remains undefined (Article 10, paragraph 6). Such an interpretation of the provisions of Article 10, paragraphs 6 and 7, derives from the standpoint of Article 5 (2), according to which the term "lifetime" implies a "regular

lifetime" of Krško NPP. Also, if the parties agree on a joint solution for the disposal of LILW and SF, these costs will be financed in equal parts. If such an agreement is not reached, the Contracting Parties shall bear the costs by themselves of all those activities of the implementation of the LILW and SF Disposal Program which are not of common interest (Article 11, Paragraph 2 of the Intergovernmental Agreement).

Table 6-1 Croatian Overview Matrix of IRW, DS, LILW and SF Management as presented in the 6th National Report of RC in accordance with the Joint Convention [13]

	Long term management policy	**Funding of Liabilities**	**Current Practices/ Facilities**	**Planned Facilities**
Spent Fuel	Dry storage at Krško NPP site (joint programme with Slovenia) followed by disposal.	Krško NPP up to final shutdown. National Fund after shutdown.	Wet storage at Krško NPP	Dry storage at Krško NPP site
Nuclear Fuel Cycle Waste	Long term storage (40 years) followed by near surface disposal.	Croatian Fund	Storage at Krško NPP site	Long term storage facility
Non-Power Radioactive Waste	Long term storage followed by disposal.	Users	Two temporary storage facilities (closed)	Central National Storage Facility
Decommissioning	Immediate dismantling of Krško NPP (joint programme with Slovenia). Deferred dismantling for other facilities.	National funds, users and State for non-power waste facilities	No facilities in decommissioning	No planed facilities
Disused Sealed Sources	Reuse, repatriation and long term storage.	Users	Reuse, repatriation and two temporary storage facilities (closed).	Central National Storage Facility

6.2.2. National Programme for the Implementation of the Strategy (Programme for the period up to 2025 with a view to 2060)

After the adoption of the Strategy the National Programme for the Implementation of the Strategy (Programme for the period up to 2025 with a view to 2060) was drafted. Drafting was coordinated by Croatian State Office for Radiological and Nuclear Safety (SORNS) in 2015-2016 in accordance with the requirements given under the Articles 57, 58, 59 and 95 of the Croatian *Act on radiation safety and nuclear security*, with requirements given in the Articles 10 and 11 of the Intergovernmental Agreement and

in accordance with Articles 5, 11, 12 of the Directive 2011/70/Euratom.

On November 18, 2018 Croatian Government adopted the National Programme.

SORNS carried out pursuant to Article 67, paragraph 2 of the *Croatian Environmental Protection Act* [14] and Article 15, paragraph 1 of the *Decree on Strategic Environmental Impact Assessment of Plans and Programmes* [15] Strategic Environmental Impact Assessment (SEA) for the Draft of National Programme. SEA for Draft National Programme was prepared in January 2016. A public hearing pursuant to Articles 16 and 17 of the *Regulation on Information and Participation of the Public and Public Concerned in Environmental Matters* [16] was held for SEA during February-May 2016. During hearing public was given insight into the SEA, Non-technical Summary of SEA and the Draft National Programme. After the public hearing the opinions, comments and proposals received from the public hearing were built into the final Draft of the National Programme. Prior to the SEA procedure, Ministry of Environmental Protection and Nature, pursuant to Article 48 paragraph 5, in conjunction with Article 26, paragraph 2 of the *Nature Protection Act* [17] issued on March 3, 2015 the Decision stating that the Draft National Program is acceptable to Croatia’s Ecological Network.

The National Programme, in accordance with the objectives of the Strategy, sets out a series of activities in terms of strengthening regulatory framework and establishment of necessary infrastructure for the timely and harmonized operation of the competent authorities in order to fulfil its obligation under the Intergovernmental Agreement and to take over and safely manage half of LILW from Krško NPP.

The National Programme states that there were already considerable changes in legal and regulatory framework after approval of the Strategy in terms of alignment with EU regulations, international standards and practice in EU member states to ensure safe disposal of LILW, IRW, DS and SF e.g. the Fund was named as operational organization for RW management by amendment to Croatian *Act on Radiological and Nuclear Safety* and 22 new ordinances regarding radiological and nuclear safety were issued. The ordinances focused on safety of nuclear installations prescribe: validation of location for nuclear installations, approval of commissioning, operation and decommissioning, approval of nuclear activities, safety analysis report, Quality Assurance Programme and certification of expert organizations in the field of nuclear safety. The ordinances focused on radiological protection prescribe: notification, registration, approvals and transport of ionizing radiation sources, conditions and measures for the protection against the ionizing radiation, education necessary for handling ionizing radiation sources, monitoring state of radioactivity in the environment, dose limits, recommended dose constraints and assessment of individual doses, remediation planes and radioactive waste and disused sources management.

The National Programme sets out dates for two objectives stated in the Strategy for the period up to year 2025: establishment of the Central National Storage Facility (CNSF) for

IRW and DS and construction with commissioning of long term storage facility for LILW from Krško NPP.

Planned duration of long term storage for LILW from Krško NPP is 40 years. Since a long term storage facility for LILW is foreseen to be established in 2023, the establishment of repository for LILW is not required before 2051. Therefore, activities regarding the site selection, site characterization and confirmation for repository are not planned to start in the next 10 years, within the span of this National Programme.

The National Programme also underlines obligations that have been taken by RC regarding RW and SF management under the respective conventions, bilateral agreements, directives, and laws.

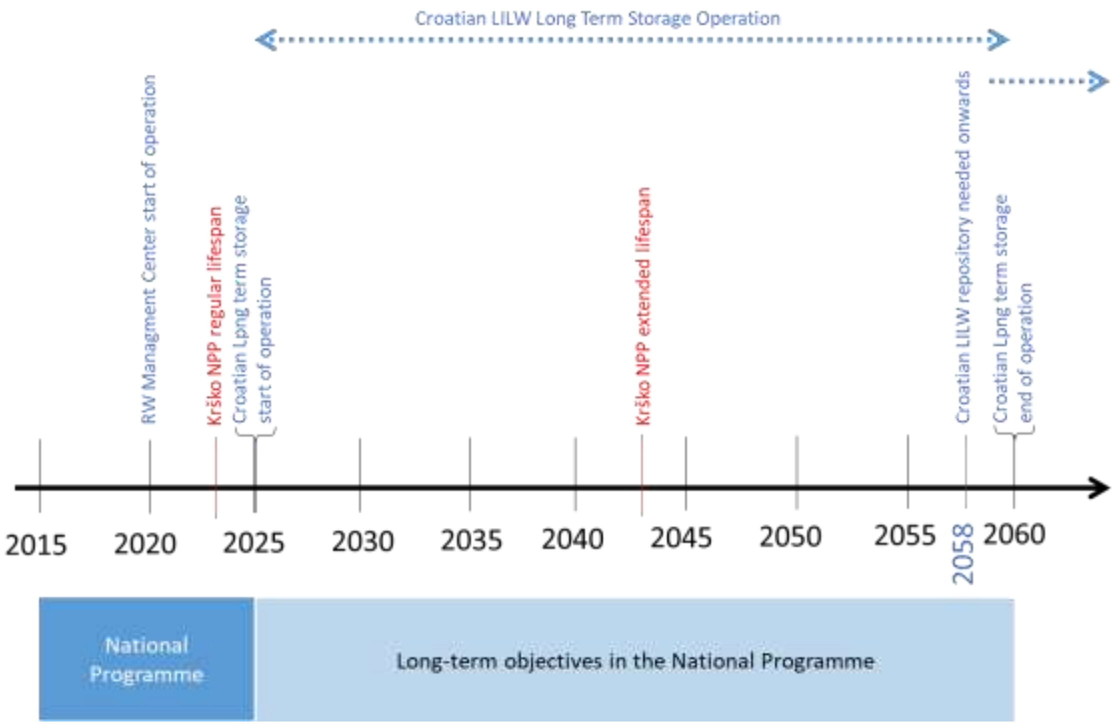


Figure 6-1 Overview graphic of dates proposed for management of IRW, DS and LILW from Krško NPP in the National Programme

Regarding the LILW generated in Krško NPP the Intergovernmental Agreement (Articles 10 and 11) favors development of a joint solution for disposal of LILW from Krško NPP. Since RC and RS have not achieved mutually satisfactory joint solution in the time of approval of present National Programme, RC in line with the objectives of the Strategy plans in National Programme a series of activities to establish national long term storage facility for LILW from Krško NPP within the RWM Centre.

For management of the RW and DS that originate from medicine, industry, science, education and the past public use of radioactive sources the National Programme plans the establishment of the CNSF within the RWM Centre. The preferred location for the RWM Centre is Čerkezovac, the location of the military logistic complex without

perspective for future use by army. Čerkezovac is located in Dvor Municipality on the southern slopes of the Trgovska gora massif. RWM Centre would also be focal point for public information and education regarding RW.

The process of confirmation of location Čerkezovac will include participation of public in decision-making, spatial planning, the environmental impact assessment process including the assessment of RWM Centre's trans-boundary impact.

As already stated, according to the Intergovernmental Agreement if there is no agreement on a joint solution by the end of regular lifetime of the Krško NPP (2023) the parties have to take over LILW and SF from the Krško NPP. In order to be prepared for such a scenario, the long term storage facility for LILW from Krško NPP has to be established and operational on the Čerkezovac location at the beginning of 2023.

Financing of management for LILW from Krško NPP will be provided in accordance with the Intergovernmental Agreement (Article 11).

6.3. Inventory

Chapter 4 of this document presents the properties and overall quantities of LILW generated by operation and decommissioning of Krško NPP. Table 4-17 summarizes quantities of LILW to be divided equally by Croatian and Slovenian side in compliance with Intergovernmental Agreement.

Table 6-2 Croatian half of LILW from Krško

Period of LILW generation	Type of LILW	Source of data	Mass (t)	Volume (m^3)	Activity (1) (Bq)	Management after division and takeover.
1983 - 2018	Operational	Inventory	2,438.7	1,147.45	2.99×10^{13}	No WMF on site. Transport and treatment with conditioning in RCC in the third country.
2018 - 2023		Assessment	132.0	81.7	7.2×10^{12}	
2024 - 2043			441.85	273.3	2.17×10^{13}	No WMF on site. (3) [18] Transport and Treatment with conditioning in RCC in the third county.
2043 - 2058	Decommissioning		1,430.0	1,421.0	2.47×10^{12}	WMF on site (2). Treatment and conditioning in RCC. Transport in corresponding LILW repositories in Croatia after 2050.

Period of LILW generation	**Type of LILW**	**Source of data**	**Mass (t)**	**Volume (m^3)**	**Activity(1) (Bq)**	**Management after division and takeover.**
2103 - 2106			196.0	203.7	3.35×10^{11}	Treatment and conditioning on site. This LILW will be disposed in HLW repository.
		Total	**4,635.55**	**3,127.15**	$\mathbf{6.15\times10^{13}}$	

(1) Activity presented here is nominal activity. This is activity of the LILW in the time of placing LILW in the vessels for storage or for further treatment and conditioning. Since most of the radionuclides in LILW are shortlived (half-life under 30 years) activity will be quite different in the time of their disposal in the repository.
(2) This is assumed by *3rd Revision of the NPP Krško Decommissioning Program* (DP Rev.3.) [19]
(3) Currently there is no on-site capacity for treatment and conditioning of operational LILW in Krško NPP. Such a facility was planned and construction permit was obtained (construction permit nr. 35105-25/2014/5-01031383 TŠ, GB; 16. 6. 2014) but investment into such facility was not yet approved by the supervisory board of the Krško NPP.

In the Table 6-2 half of those quantities are presented, respectively the quantity of LILW RC is responsible for and which RC must dispose.

After division and takeover this is the inventory that will be managed by Croatian side. All the estimates of capacities and expenses for processing, conditioning, transport, storage and disposal of LILW further in this chapter are based on the quantities presented in Table 6-2.

6.4. Krško NPP LILW management scenario

Based on the Strategy and National Programme scenario for Krško NPP LILW management was developed and financially optimized having in mind Croatian regulation, best safety practices and international recommendations. Scenario describes all the activities, facilities to be established and procedures needed in order to manage safely the Croatian half of LILW from Krško NPP within foreseen time framework.

After being taken over from storage in Krško NPP, LILW will be treated and conditioned into a form suitable for subsequent operations such as handling, transport, storage and disposal. Treatment and conditioning procedures will be carried out in a dedicated waste management facility. Croatian half of LILW will be conditioned by packaging into concrete containers. Containers will be stored in long term storage that will be established in Croatia (operational in 2023) and later disposed in the appropriate LILW repository also in Croatia (operational in 2051).

Since there will be no waste management facility on site in Krško NPP, possibly not

earlier then beginning of Krško NPP decommissioning, scenario assumes that Croatian part of operational LILW will be treated and conditioned in appropriate facility in the third country and subsequently transported to Croatia. However, since *3rd Revision of the NPP Krško Decommissioning Program* [19] (Chapter 7.3.3. Packaging concept) assumes treatment and conditioning facility will be operating during Krško NPP decommissioning process, LILW management scenario assumes that Croatian part of decommissioning LILW will be treated and conditioned on site and then transported to Croatia.

Presented approach to division, takeover, treatment, conditioning, transport, long term storage and disposal of operational and decommissioning LILW within the time schedule foreseen by the National Programme represents baseline scenario for the management of Croatian half of Krško NPP LILW.

6.5. Technical and technological solutions

In the following subchapter technical and technological solutions used in treatment and conditioning, transport, storage and disposal of Croatian half of Krško NPP LILW will be described. Description is based on several supporting studies [20], [21], [22].

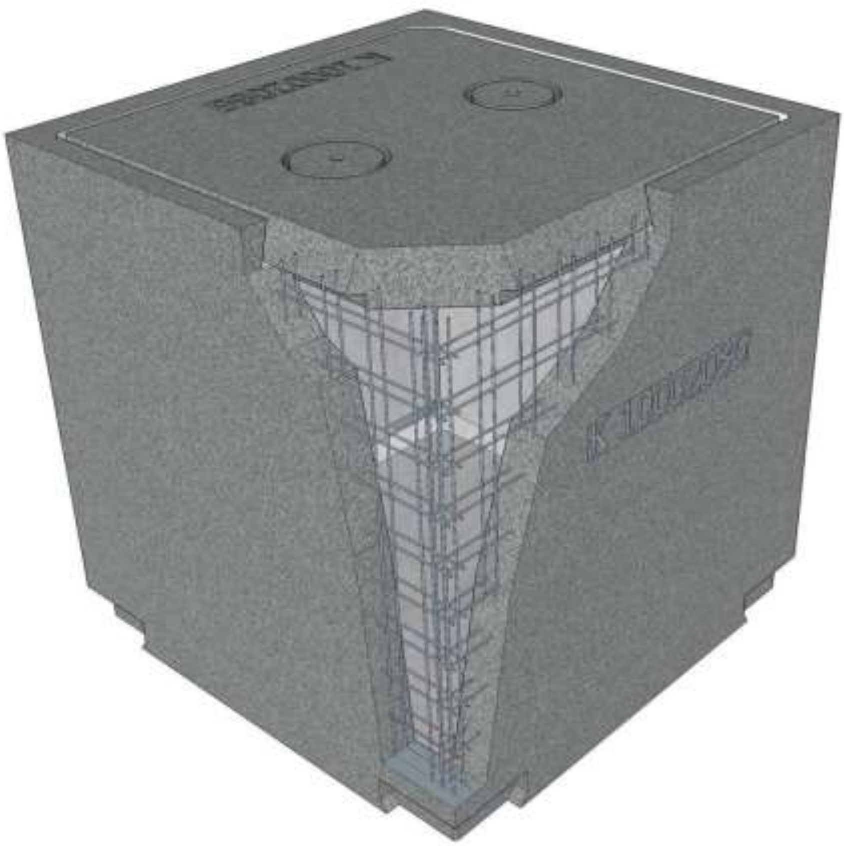


Figure 6-2: Model of iron reinforced concrete container (RCC)

6.5.1. Iron Reinforced Concrete Containers

For transport, storage and for disposal of Croatian half of Krško NPP LILW Iron Reinforced Concrete Containers (RCC) will be used. RCC is a new generation of containers. The RCC consists of a body, a lid and two plugs. Model of RCC is presented in Figure 6-2. The basic technical data on RCC are listed in Table 6-3.

Table 6-3: Basic technical data and properties of RCC

Parameter	Value / Characteristics
Shape and outer dimensions	Cube, 1.7 x 1.7 x 1.7 m
Internal dimensions	1.43 x 1.45 x 1.45 m
Mass of LLW that could be placed in container	~ 5000 kg
Mass of concrete container	Up to 7,500 kg
The maximum mass of IRCCs loaded with waste	15,000 kg
Useful volume	2.85 m^3
Durability	300 years
Reinforcement	Steel armor
Stackability	3 layers
Transportation	Suitable for transport

Volume of the LILW listed in the Table 6-2 could be recalculated in the number of RCCs after treatment and conditioning of waste. Number of RCCs to be managed and eventually disposed in Croatia is presented in the Table 6-4. Apart from operational and decommissioning LILW generated in Krško NPP estimated number of RCCs that will be also disposed in Croatian LILW repository with IRW and DS is also presented.

Table 6-4 Anticipated number of RCCs to be disposed in the Croatian LILW repository

	Number of RCC with LILW
Operational LILW generated up to 2023	685
Operational LILW generated from 2024 – 2043	240
Decommissioning LILW	475
IRW and DS that could be placed in surface LILW repository and LILW generated by decommissioning of long term storage	100
TOTAL	**1500**

The calculation of RCC number was taken from the studies "Razrada koncepta zbrinjavanja RAO u RH s novom procjenom troškova, Ekoteh, Enconet, 2019" [19] and "Analiza osjetljivosti i registar rizika zbrinjavanja RAO u RH, Enconet, 2019 [28]. The calculation was made based on the analysis in pre-feasibility studies [20], [21].

6.5.2. Treatment, conditioning and transport

It is considered that several waste forms and LILW packages that are now in the LILW interim storage in Krško NPP (Solid Radwaste Storage Facility, SRSF) do not meet the

preliminary WAC for accepting LILW in the long term storage of the Croatian RWM Centre or LILW repository. An overview of types of unstable forms and packages as well as appropriate preliminary WAC that must be satisfied before placing them in the RWM Centre are given in the Table 6-5. LILW that does not satisfy WAC needs to be treated before conditioning. Treatment includes all those operations intended to enhance the safety and/or lower disposal costs by changing the characteristics of RW.

Table 6-5: Forms and LILW packages that do not meet the WAC

Form/package LILW	**Unwanted characteristics**	**Preliminary WAC**
IDDS products that are result of treatment of concentrates and precipitates in reservoirs.	Waste form is very corrosive due to the content of boric acid.	The corrosivity of LILW must be reduced to the lowest level practically achievable. For the pH value of the LILW form, the range 4 ≤ pH ≤ 9 is suggested. The content of corrosive substances it is suggested should not exceed 1% of the mass of the package.
IDDS products deriving from the treatment of primary and secondary ionic resins.	Waste form is hygroscopic and in the presence of moisture increases volume (waste forms is bursting) resulting in internal pressure inside repository.	Creating internal pressure inside LILW repository is undesirable, so this process needs to be reduced to the lowest level practically achievable.
LILW packages containing filters, pucks and 200-liter containers.	Packages contain voids, i.e. LILW is non-homogeneous. High void content disturbs mechanical strength, allows accumulation of gases, accelerates radionuclide migration from the repository, etc.	LILW must be evenly distributed in a metal and concrete containers. The amount of gaps in LILW form should be reduced as low as practically achievable. It is suggested that the void fraction should be less than 0.5% of the package mass.

Presently there is no on site capacity for treatment and conditioning of operational LILW in Krško NPP and such a capacity is not planned in near future. According to *3rd Revision of the NPP Krško Decommissioning Program* [19] decommissioning waste will be packaged in RCCs and cemented (conditioned) on site.

In this circumstances, in order to fulfill obligations defined by International Agreement, RC will take over Croatian half of operational LILW after division, in a packages LILW is currently in SRSF. Operational LILW will be then transported to third country where it would be treated and conditioned in RCCs in dedicated waste management facility. The required treatment and conditioning of LILW is described in detail in a supporting study [21]. Operational LILW will be divided in two consignments: LILW generated up to 2023 will be transported after 2023 to third country where it will be treated and conditioned in RCCs; LILW generated from 2024 to 2043 will be also transported after 2050 to third country where it will be treated and conditioned in RCCs. However, first batch of RCC

with LILW will be transported to long term storage facility in RWM Centre in Croatia, waiting opening of LILW repository, while second batch of RCC with LILW will be transported directly to LILW repository in Croatia that will be operational since 2051.

After takeover decommissioning LILW will be conditioned on site in Krško NPP. Decommissioning LILW will be placed in RCC and properly cemented. First waste packages with decommissioning LILW will be prepared in 2050. RCC with Croatian half of decommissioning LILW from Krško NPP will then be transported directly to LILW repository in Croatia.

Transport campaigns from Krško NPP to third country and from third country to RWM Centre in Croatia are described in supporting study [22]. Estimated number of transports for operational and decommissioning LILW are shown in the Table 6-6.

Table 6-6: Estimated number of transports

	Number of packages	**Number of transports**
Krško NPP – LILW treatment and conditioning facility		
Operational LILW generated before 2023	1344 eqiv. TTC 309 D6	129
Operational LILW generated from 2024 – 2043	314 TTC	23
LILW treatment and conditioning facility – Čerkezovac(1)		
Operational LILW generated before 2023	685 RCC	343
Operational LILW generated from 2024 – 2043	240 RCC	120
Krško NPP-Čerkezovac		
Decommissioning LILW	475 RCC	238

(1) Number of RCC and number of transports may vary depending on the tretamnet and conditioning facility to be chosen by future public procurement.

6.5.3. Long term storage

On November 18, 2018 Croatian Government adopted the National Programme which sets up Čerkezovac as the location for RWM Centre. Long term storage for Croatian half of Krško NPP LILW generated by operation of Krško NPP will be located within the RWM Centre.

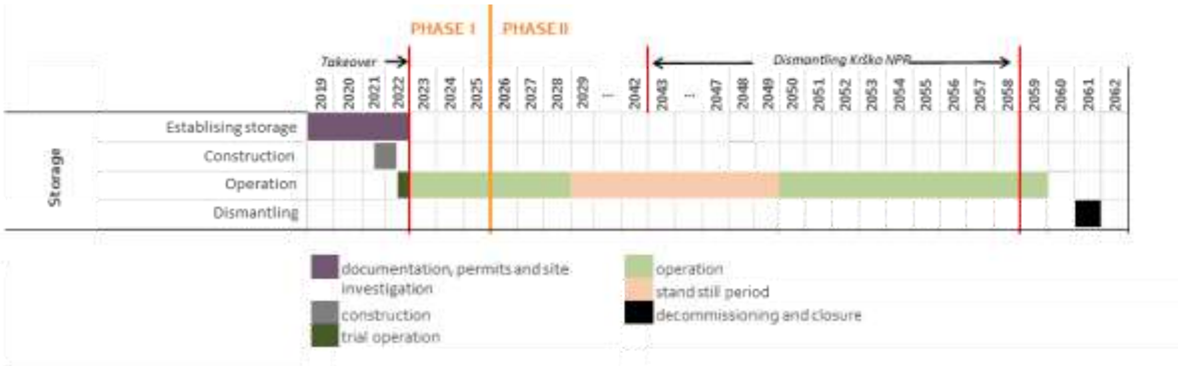
Krško NPP LILW management scenario assumes that long term storage facility will accommodate operational LILW generated up to 2023. After division and takeover, LILW will be transported to third country to be treated and conditioned in RCCs. According to current estimates (Table 6-4) operational LILW generated up to 2023 will be placed in a 685 RCCs.

The establishment of the RWM Centre and establishment, operation and decommissioning of the long term storage are based on the timeline depicted in the

Figure 6-3. Documentation will be prepared, site investigated and all necessary permits will be provided until 2022. One year is planned for a construction that will be followed with test period ending in 2022. Operation of long term storage could be divided into three periods: from 2023 to 2028 long term storage receives RCCs from treatment and conditioning facility; from 2029 to 2049 long term storage is in idle phase; from 2050 to 2059 long term storage is emptied by transferring stored RCCs to Croatian repository that will be opened in 2050. In 2061 long term storage is decommissioned.

Croatian half of operational LILW generated after 2024 as well as decommissioning LILW will be taken over from Krško NPP site after 2050 together with Slovenian side as foreseen in the Investment Program for the Vrbina repository [23]. Operational LILW (240 RCCs conditioned in the third country) and decommissioning LILW (475 RCCs conditioned on Krško NPP site) will be transported directly to Croatian repository that will be operational after 2051.

Figure 6-3: Long term storage timeline. PHASE I of LILW management ends in 2025 with the finished takeover of operational LILW generated up to 2023.



Plans for storage facility design are shown in Figure 6-4 and Figure 6-5. Floor space of storage facility will be 1,643 m^2 measuring 62.7 x 26.2 m, with 12 m height inside the hall. It will be possible to store 230 RCCs in single layer with a spacing of 0.3 m between containers, or overall 690 containers in 3 layers. 373 m^2 of storage space will be reserved for container inspections and for fire access. Empty space around the containers allows easier positioning and inspection of containers with a video camera. The storage also has 396 m^2 space for manipulation with RCCs. This space will be used for placing the controls for the bridge crane, air-dehumidifying equipment and fire-fighting equipment. Part of the space will be reserved for RCC acceptance inspection or as a spare storage space.

The storage facility will be designed in accordance with requirements for Čerkezovac earthquake zone. The basic construction is made of reinforced concrete elements. Roof (horizontal) and facade (vertical) panels are filled with expanded polyester. Floor and walls up to 1 m height will be fitted with a three layer epoxy coating. The siphons will be connected to the floor drainage system so that all the water inside storage will be collected and controlled. The foundation plates must withstand the maximum pressure

of 15.6 t/m^2 which is to be expected when RCC are stacked in 3 layers.

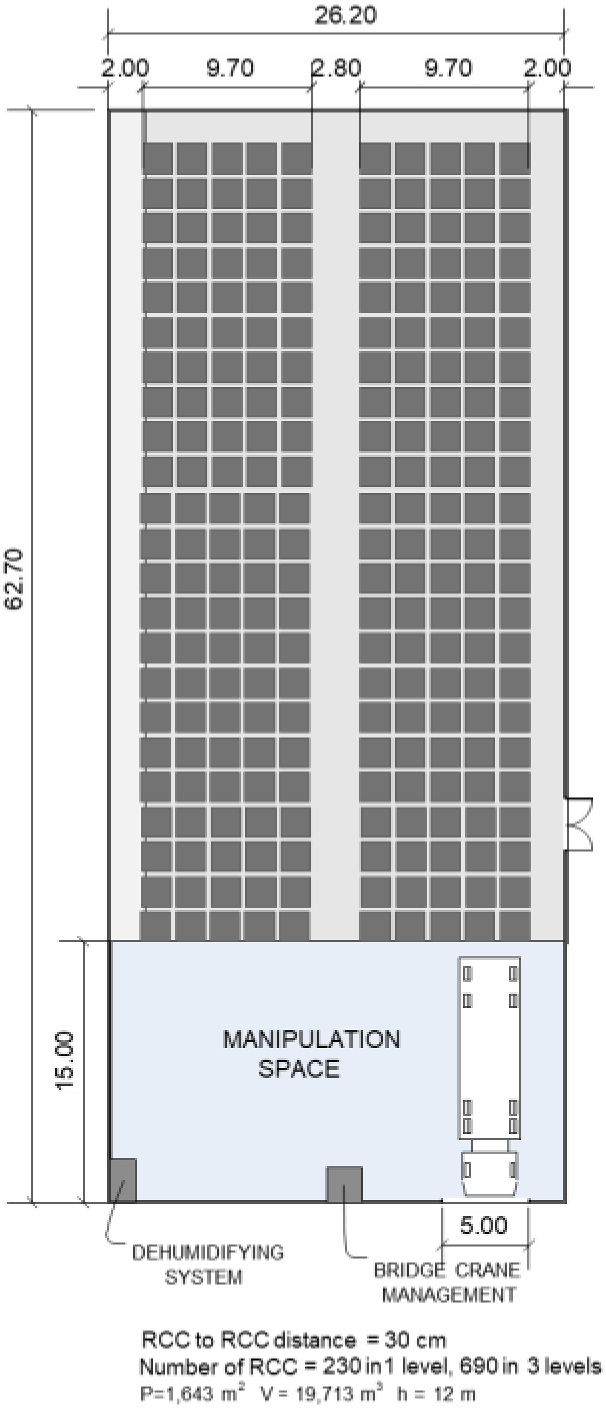


Figure 6-4: Proposed long term storage solution – ground plan

At the height of 10.5 m crane tracks will be mounted for the bridge crane system which will cover the entire storage area. The system will consist of 20 t bridge crane connecting 26 m wide corridor that is 55 m long. The crane will have an electric drive, with a control system for precise positioning and a soft start/stop.

The storage facility will be passively ventilated, without heating and with 8 cm insulation from expanded polystyrene in the facade and roof panels. Because of the climatic

conditions of the site it is necessary to install the fixed dehumidifying system in the storage due to the large volume of storage (19,860 m^3).

The storage will be equipped with a drainage system that is connected with a collecting basin where waste water radioactivity will be measured and controlled and kept in retention if needed.

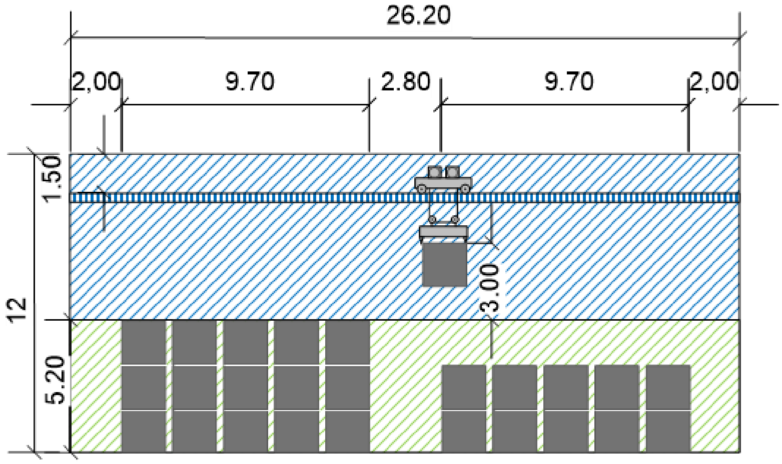


Figure 6-5: Proposed long term storage solution – side view

The entire RWM Centre complex will encompass a single system of physical and technical protection. Physical protection will be provided by 4 security guards (one of them will be fireman) in 3 shifts for 24-hour monitoring, during regular operation of storage when RCCs are received in storage and 3 security guards at long term storage stand still period. The guards would supervise the technical protection systems and carry out patrols. The technical protection system will include a video monitoring, motion detectors (with alarms) and a fire alarm. In addition to the passive fire protection measures, an active fire protection system is also planned, which will also be realized for the whole complex of RWM Centre.

RWM Centre joint radiological monitoring system will monitor radiation dose rates within the long term storage and in the immediate vicinity of the facility. Also there will be special station for measuring the radiation dose rate in a wider environment intended for control of possible radionuclide emissions into air, water and soil.

For an entire RWM Centre complex, an administrative object will be provided. It could be adapted from one of the Čerkezovac existing facilities. Administrative object will be equipped for a permanent use (e.g. with a suitable heating system).

The operation of the storage will be supported by auxiliary systems (electricity, water, sewage system for rain water and standard sewage system for administrative building, telecommunication system and lightning protection system).

Reception of RCCs will be carried out within the storage area since there will be reserved space that can receive trailers with containers. After the RCC has been unloaded by a

bridge crane, a visual inspection, dose rate measurement on the RCC surface and surface contamination detection will be performed. Sender's documentation will also be checked. If the Waste Package Specification (WPS) of the RCC meets the WAC storage criteria, RCC will be positioned in the storage (preliminary WACs for Croatian storage and repository are presented in chapter 7). The location of the RCC will be recorded and stored together with the sender's documentation.

During the operation of the long term storage, periodic inspections of containers could be carried out: visually, using a camera or by selection of a specific RCC that could be removed from the storage place via the bridge crane and then inspected for e.g. integrity.

During a trial operation of long term storage, a small number of empty RCCs will be used (5 – 10). This will enable testing and validation of processes related to reception of the RCCs and its manipulation in the storage.

For the long term storage facility 5 workers are foreseen for 17.5 years (acceptance period for RCCs transported from treatment and conditioning plus an additional 5 years for the accommodation, recording and manipulation). For the rest of the storage period (21 years), 30% lower employee engagement is anticipated.

The decommissioning of the long term LILW storage is planned for 2061. The decommissioning will last for a year if building will be standard industrial storage of reinforced concrete and assuming that the facility will not be significantly contaminated. In the case that contaminated building materials will be detected during decommissioning material will be separated, conditioned in RCC and disposed of in the LILW repository.

6.5.4. LILW repository

This section provides information on the LILW repository to be established on the still undefined micro-location on the Trgovska Gora. Following are description of the process of establishing LILW repository, its operation, closure of the repository and institutional control of the location to be implemented after the closure of repository. The establishment of the LILW repository is based on the timeline depicted in the Figure 6-6.

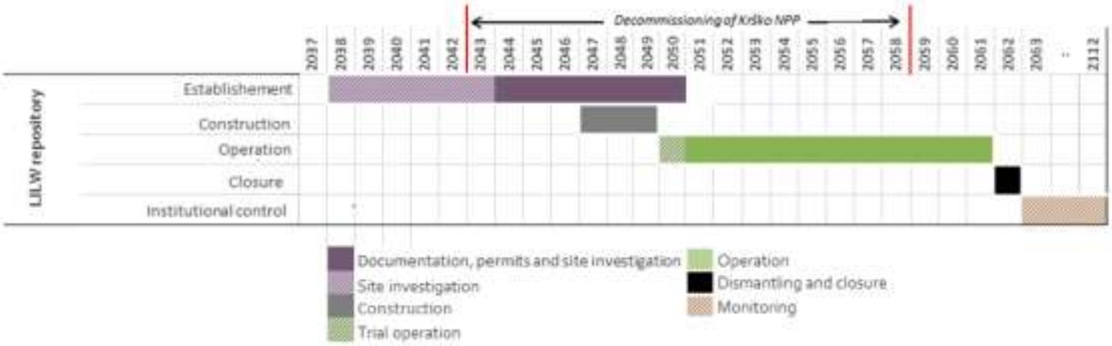


Figure 6-6 Repository timeline for Croatian half of Krško NPP LILW

Establishing the LILW repository for Croatian half of Krško NPP will start in 2038 with site investigation and launch of the different processes to obtain necessary permits in accordance with regulations, starting with the location permit. The location permit would be issued by 2044 and by the end of 2046 a building permit would be issued. The permit for trial work would be awarded in 2050, with regular repository work starting in 2051. The LILW repository would be in operation for next 11 years after which time its closure is planned. The processes of obtaining different permits during the progression of repository establishment will be similar to one for long term storage.

Preliminary site investigations will be carried out during the first phase of a project and throughout the process of obtaining a location permit. Aim of those site investigations will be to locate micro location for the repository within wider repository site and to create geological and hydrogeological databases of necessary parameters to model the groundwater flow and groundwater velocity needed to determine possible underground transport of radionuclides by a migration and a diffusion.

Preliminary site investigations will cover an area of approximately 10 km^2 in the neighborhood of the preferred LILW repository location. In the second phase detailed exploratory works (covering 1 km^2 around chosen repository location) will be undertaken in order to verify all features and results obtained by preliminary research. Main purpose of the second phase of site investigations is analyzing long term safety of repository. Detailed research of the second phase is directed to specific micro-location where future LILW repository will be placed. The end of second phase investigations would coincide with the end of process of obtaining LILW repository building permit.

For the purpose of obtaining a location permit, a preliminary safety analysis study and report on safety study will be prepared in accordance with the present regulation [24]. The final safety analysis study and the report on the safety study will be drawn up upon completion of repository construction in a support of obtaining trial and regular operation permits. Regulatory body would review safety documents and issue approvals for trial and regular operations of LILW repository based on the Safety Analysis Reports (SAR) for each stage of LILW repository development.

After approval of the final SAR a permit will be obtained for the regular operation of LILW repository. It could be assumed that trial operation of LILW repository will be approved in January 2050 and that trial operation will last one year. Regular operation of the LILW repository will start in January 2051.

Throughout the lifetime of the repository, constant environmental monitoring as well as monitoring of the radiation levels inside repository and in the vicinity of the facility will be carried out in order to protect the employees and the population living nearby. Operational monitoring starts with repository trial operation [25,26].

LILW repository will be of near surface type utilizing reinforced concrete cassettes for the placement of RCC with LILW. For the purpose of this analysis original design by

ELETROPROJEKT from Zagreb in the form of conceptual design [27] was adapted to the dimensions of the RCC.

Number of RCC to be disposed in the Croatian LILW repository is presented in Table 6-4.

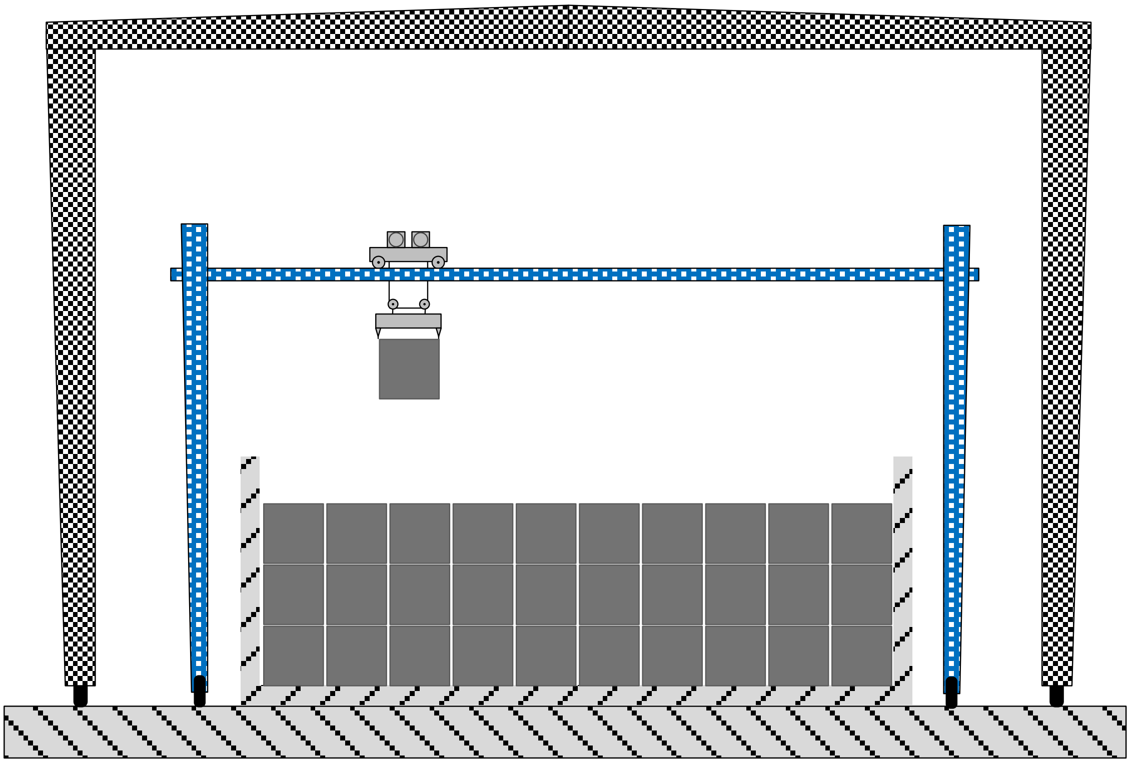


Figure 6-7 Disposal technology in single unit of LILW repository -- side view

Single concrete cassette or cell or unit with dimensions 19 x 24 x 7 m (w x d x h) could accommodate 390 RCC concrete containers placed within cell in the 10 x 13 x 3 structure. 4 repository cells are needed for placement of Croatian half of Krško NPP LILW, IRW and DS. Most of the RCC will be with Krško NPP LILW but place for additional 98 containers with IRW and RW as well for RW generated by decommissioning of long term storage is reserved. 4 cassettes with RCC will occupy an area approximately 50 x 70 m.

Cassettes or units in repository will be constructed using reinforced concrete. Unit consists of a base plate and four side walls. Top surface of the base plate is built with a tilt to the drainage exits. The thickness of the walls and base plate will depend on the measured characteristics of the location and the results of the safety analysis. On the top of the operational unit in the process of filling in with RCC will be a protective structure in the form of slide roof on the rails. Roof structure will be moved to the next unit after previous unit would be full (Figure 6-7). Full unit is closed with reinforced concrete slab and protective coating.

It is assumed that forklift could be placed inside the unit and under protective moving

structure to transport the RCC within the unit. Precise placing of the RCC is achieved with 20 t load capacity portal crane housed inside the protective structure. Maximum weight of the full RCC will be 15 tons.

Below the disposal unit the drainage system will be built as an additional protection measure. The drainage system collects all the leachate within the storage unit before and after the permanent concrete cover is placed on the top of the unit. The drainage system will be connected to the 100 m^3 tank which will collect liquid from all the units. The tank will be supplied with a measuring device for leachate radioactivity and the liquid level sensor enabling control over leachate that could be retained or released from regulatory control.

Precipitation sewerage system is designed in such a way that rain water is collected in special basin. Dimensions of the basin will be sufficient for collection of whole annual precipitation on the LILW repository location. After radiological control, rainwater will be discharged into the communal sewage system if the criteria for discharge would be met [24].

During the regular LILW repository operation systematic surveillance of the repository location and its surrounding is envisaged. Foreseen are systems of physical and technical protection, the fire protection system and the radiological monitoring system.

The disposal process will begin with the transport of RCC from the long term storage by a forklift truck with 18 to 20 t capacity to the disposal unit in the LILW repository. The truck with the RCC will be placed below the protective structure and by means of the portal crane the container will be lifted from truck and positioned in the unit.

Before RCC is permanently placed into the unit the surface dose and possible contamination of the container are measured. The data obtained is entered into the database and stored together with the exact storage location within the unit.

For the purpose of trial operation few empty RCC (5 – 10) will be used. They will be utilized for simulation of entire process of transport from long term storage to LILW repository and placement of containers in the units of repository. The aim of the test operation is to check systems and to demonstrate that the transport process is carried out in accordance with regulatory requirements and prescribed operating procedures and in accordance with the safety and radiation protection measures.

For the regular operation of LILW repository 10 employees altogether will be needed of the following profiles: 1 worker with university education, 2 workers with applied sciences diploma, 5 workers with technical school and 2 unqualified workers. 100% engagement is anticipated during the trial operation, regular operation and closing phase of the repository (6 years). By 2057 that means 5 additional workers more than it would be already employed as workforce in long term storage.

Once all units in the repository are fully filled with RCC, enclosed with an armored

concrete slab and protected with watertight synthetic materials so that regular operation of the repository is completed, closure of repository starts. Disposal units are covered with layers of natural materials that form an additional engineering barrier. Pebbly and sandy materials, as well as various types of clay, are the most often used. The structure of the repository cover depends on the results of geological environment and other characteristics of the repository site. The cover should be designed as to limit the penetration of water to the repository concrete structures in order to prevent possible rinsing and migration of radionuclides. The cover is formed by alternating layers of impermeable materials and materials that allow good drainage.

After repository closure systematic monitoring of the LILW repository and the environment should be continued in accordance with regulations. An active institutional control is required, including repository inspections, data collection and its management and reporting to the regulatory body in order to obtain approval for final repository closure and release from regulatory control. After that passive institutional control period begins.

Active institutional control is planned to last 150 years after the repository closure. Aim of active institutional control is to observe that repository acts as it is designed i.e. that disposed LILW is isolated from the biosphere. When this is achieved and it is evident that repository will not pose significant risk to human health regulatory control could be substituted with passive institutional monitoring period.

Passive institutional supervision must ensure preservation of repository records and documents including: repository site location, detailed repository content information, in particular inventory and characteristics of repository, repository project and project revision, closure plan, test results, repository operational records, regulatory documents, general information related to public discussion. It must be ensured that LILW repository information is an integral part of state and local spatial plans. The main aim is to keep complete records on the content of repository, project and construction of the repository, and on the closure process so that data is accessible and understandable to future generations.

6.6. Time schedule for management of Croatian half of Krško NPP LILW

Time schedule for management of Croatian half of Krško NPP LILW activities is based on the National Programme for the Implementation of the Strategy (Programme for the period up to 2025 with a view to 2060), Intergovernmental Agreement and two documents by EKONERG Ltd. and ENCONET Ltd. [28,29].

Time schedule recognizes two phases: Phase I – from 2019 to 2025 and Phase II – from 2026 onwards. Phases are elaborated in corresponding tables: Table 6-7 and Table 6-8.

All the activities are graphically displayed in Figure 6-8.

Table 6-7: Time Schedule for main activities in Phase I: 2019 – 2025

Phase I: 2019 – 2025		
Start	**End**	**Activity**
1.1.2019.	31.12.2022.	**Establishment of the RWM Centre** • resolution of property and legal issues • spatial planning documentation • preliminary site investigation • safety analysis • design • Environmental Impact Assessment, Environmental Impact Assessment Report • location, building and operation permit
20.10.2021.	20.10.2022.	**Construction of the long term storage for LILW**
20.11.2022.	31.12.2028.	**Operation of the long term storage for LILW** • trial operation (20.10.-20.11.2022.) • regular operation (beginning 01.01.2023 until 31.12.2028 when a period of rest starts when LILW packages are not received any more but only prescribed operating conditions of the storage are kept)
01.01.2022.	31.12.2025.	**Division and takeover of LILW from Krško NPP** • division • takeover It is assumed that work on the documents of the final division starts one year before takeover, while takeover will be carried out in accordance with Intergovernmental agreement from 2023 to 2025
01.01.2023.	31.12.2025.	**Transport of LILW from Krško NPP to treatment and conditioning facility** Transport will be carried out in campaigns in accordance with the terms of contract with the processing and conditioning facility and the carrier.
01.01.2023.	31.12.2025.	**Treatment and conditioning of NPP Krško LILW** It will be conducted in accordance with contract conditions with the treatment and conditioning facility and according to the supporting feasibility study [21].
01.01.2024.	31.12.2026.	**Transport of LILW from treatment and conditioning facility to the location Čerkezovac** It is assumed that transport of conditioned RCC will start a year after transport of LILW from Krško NPP to treatment and conditioning facility.

Table 6-8: Time Schedule for main activities in Phase II: 2026 – onwards

Phase II: 2026 – onwards		
Start	**End**	**Activity**
01.01.2029.	31.12.2048.	**Stand still period**

Phase II: 2026 – onwards		
Start	**End**	**Activity**
		Period of rest starts when LILW packages are not received any more but only prescribed operating conditions of the storage are kept
01.01.2050.	31.12.2059.	**Normal operation of the long term storage facility** Emptying and closure of long term storage after all of RCC are placed in LILW repository.
01.01.2048.	31.12.2060.	**Division and takeover of Krško NPP LILW** It is assumed that work on the documents of the final division starts one year before takeover and that campaigns of takeover would have to be coordinated with takeover of LILW in Vrbina repository as well as with the final decommissioning plan.
01.01.2050.	31.12.2050.	**Transport of LILW from Krško NPP to treatment and conditioning facility in the third country** Transport will be carried out in campaigns in accordance with the terms of contract with the processing and conditioning facility and the carrier.
01.01.2050.	31.12.2051.	**Treatment and conditioning of Krško NPP operational LILW generated after 2023** It will be conducted in accordance with contract concluded with the treatment and conditioning facility.
01.06.2050.	31.12.2051.	**Transport of conditioned Krško NPP LILW from treatment and conditioning facility to the location of LILW repository** It is assumed that transport of conditioned RCC will start 6 months after transport of LILW from Krško NPP to treatment and conditioning facility.
01.01.2050.	31.12.2060.	**Transport of conditioned decommissioning Krško NPP LILW from Krško NPP to the location of LILW repository** It is assumed that transport of conditioned RCC will start in 2050.
01.01.2038.	31.12.2050.	**Establishment of LILW repository** • preliminary site (up to 31.12.2041) • final site investigation (up to 31.12.2043) • spatial planning documentation • safety analysis • design • Environmental Impact Assessment (EIA) • location, building and operation permit
01.01.2047.	31.12.2049.	**Construction of LILW repository**
01.01.2051.	31.12.2061.	**Regular operation of LILW repository** • trial operation (01.01.2050. – 31.12.2050) • regular operation (01.01.2051 – 31.12.2061)
01.01.2061.	31.12.2061.	**Decommissioning of long term storage for LILW**
01.01.2062.	31.12.2062.	**Closure of LILW repository**
01.01.2062.	31.12.2112.	**Institutional control of LILW repository** Assumed to last 50 years.

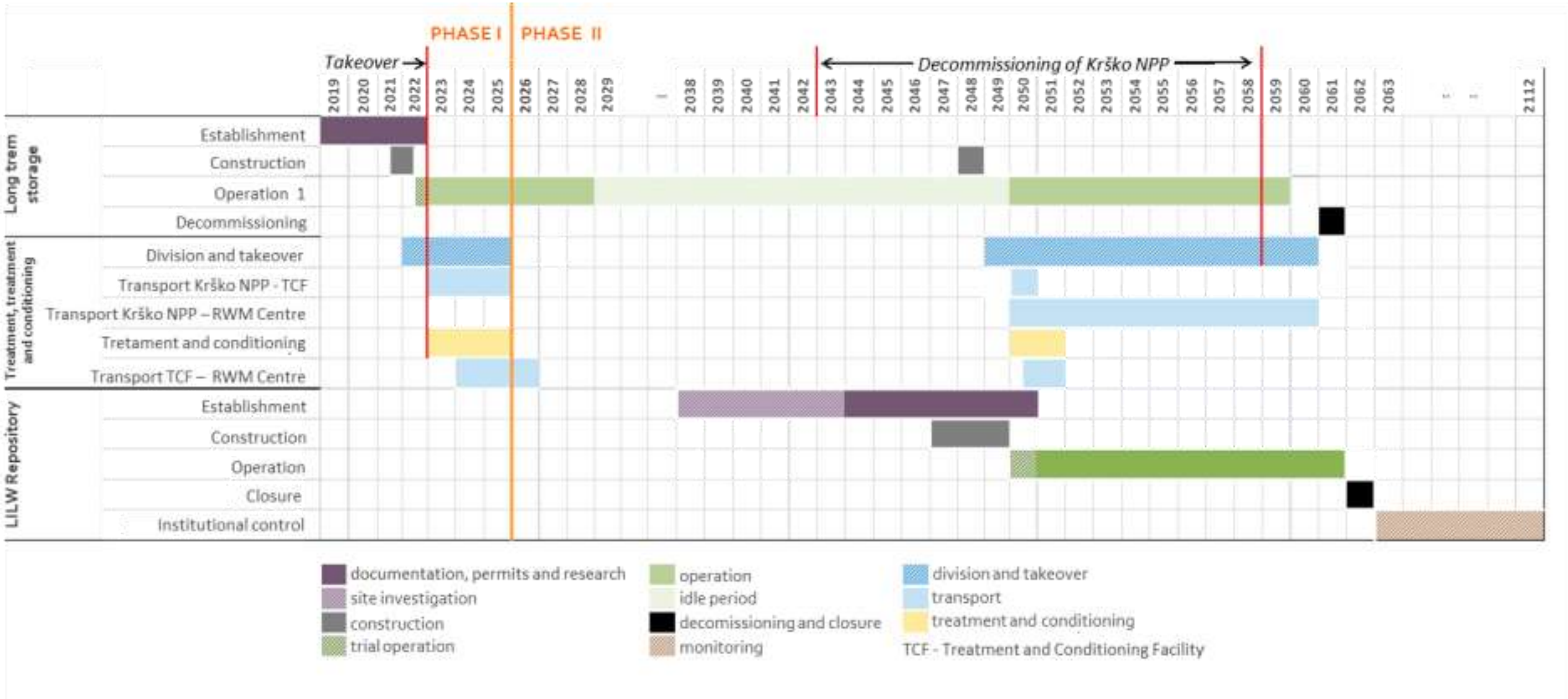


Figure 6-8 Time schedule of LILW management main activities

6.7. LILW Management cost estimates

Costs presented here are costs of optimized LILW management scenario presented in subchapter 6.4. They cover investments, LILW treatment, conditioning and transport, operation of management facilities as well as costs of public relations and compensation to the local community. Nominal cost estimates are based on the prices in euro (€) for year 2018. Cost estimates include following LILW management items:

1) Road transport of:

- TTCs with LILW from Krško NPP to treatment and conditioning plant in the third country (small quantity of LILW is in 200 l and 320 l barrels)
- RCCs with conditioned operational LILW from the treatment and conditioning facility to location Čerkezovac or LILW repository respectively
- RCCs with conditioned decommissioning LILW from NE Krško to location of LILW repository

2) Treatment and conditioning of LILW and the procurement of all needed RCCs (1500) in the contracted treatment and conditioning facility
3) Long term storage operation including preparatory works, construction and equipment, operation and decommissioning
4) LILW repository operation including preparatory works, construction and equipment, operation and closure
5) Public relations extending to closure of the LILW repository (2019–2062)
6) Compensation to the local community extending to closure of LILW repository (2019–2062).

Contingency is added to all estimated costs. Contingency represents costs of the activities which in this preliminary phase could not be determined. Contingencies are assessed respecting international recommendations [30,31,32,33]. Contingencies used in this cost estimate (planning and construction phase of infrastructure facilities) are of three categories: low (7%), medium (10%) and high (15%) of total investment costs.

For different cost items in this estimate following contingencies were used: road transport 10%; treatment and conditioning of LILW and the procurement of all needed RCCs 10%; preparatory works for long term storage and LILW repository 10%; long term storage construction and equipment 10%; LILW repository construction and equipment 15%; operation of long term storage and LILW repository 10%; decommissioning of long term storage 10%; LILW repository closure 15%; and public relation 10%.

Value added tax (VAT) was included in expenses according to Croatian law [34] and regulation.

Compensation to local community for the operation of long term storage is paid from the moment of signing the agreement with the local community (in this assessment assumed in 2019) until the beginning of the LILW repository operation (2050). In this estimate amount of

1 m€/year is anticipated. Similar amount of 1 m€/year is assumed as compensation to local community during the operational time of LILW repository (2050–2061) and the same amount will be paid during LILW repository closure period (1 year).

Public relation costs include establishment and operation of Public information and education center within RWM Center and other forms of communication with local community and students in Croatia. Road transport costs and treatment and conditioning costs as well as costs of RCCs are based on the supporting studies [21],[22]. Costs of services in these studies are subject of future public procurement in Croatia that could result in the choice of partner whose cost-based bid assuming Croatian WAC for LILW disposal and for long term storage in RWM Centre may be more eligible than the costs referred in the cited studies.

Cost estimates for long term storage operation including preparatory works, construction and equipment, operation and decommissioning and for LILW repository operation including preparatory works, construction and equipment, operation and closure are based on the supporting studies [20],[27].

Costs of management for Croatian half of Krško NPP LILW are presented in Table 6-9 by cost items.

Table 6-9: Costs by costs items for the management for Croatian half of Krško NPP LILW

Cost item	**Nominal costs (mil. €, 2018.)**
Road transport	9,291
Treatment and conditioning of LILW and the procurement of all needed RCCs	31,850
Long term storage operation including preparatory works, construction and equipment, operation and decommissioning	28,496
LILW repository operation including preparatory works, construction and equipment, operation and closure	46,199
Public relations costs	8,652
Contingencies	13,467
SUBTOTAL	**137,955**
VAT	24,295
SUBTOTAL+VAT	**162,250**
Compensation to local community	44,000
TOTAL OVERALL	**206,250**

Table 6-10 groups the costs presented in Table 6-9 in three categories: (1) investment costs, (2) costs of treatment, conditioning and transport and (3) operational costs for 2 waste management phases: PHASE I (2019–2025) and PHASE II (2026 onwards). Operational costs include 5 mil. € that will be used for location monitoring during institutional control (2063 – 2112).

Table 6-10: Costs by categories

	Cost item	Nominal costs (mil. €, 2018)		
		Time period		Total
		PHASE I 2019–2025	PHASE II 2026–2112*	
Investment costs	Long term storage	10,018	1,179	11,197
	LLW repository	0	33,255	33,255
	Public relations	2,657	5,996	8,652
	Contingency	1,267	4,811	6,079
	SUBTOTAL	**13,942**	**45,241**	**59,183**
	VAT	3,470	11,212	14,682
	Compensation to local community	4,000	3,000	7,000
	TOTAL investment costs	**21,412**	**59,453**	**80,865**
Treatment, conditioning and transport costs	Conditioning of operational LILW	20,300	8,700	29,000
	Conditioning of decommissioning LILW	0	2,850	2,850
	Transport	3,577	4,953	8,530
	Contingency	2,388	1,650	4,038
	SUBTOTAL	**26,264**	**18,154**	**44,418**
	VAT	0,984	1,362	2,346
	TOTAL treatment, conditioning and transport costs	**27,248**	**19,516**	**46,764**
Operational costs	Long term storage	2,511	15,549	18,060
	LILW repository	0	12,944	12,944
	Contingency	0,251	3,099	3,350
	SUBTOTAL	**2,762**	**31,593**	**34,355**
	VAT	0,601	6,666	7,267
	Compensation to local community	3,000	34,000	37,000
	TOTAL operational costs	**6,362**	**72,259**	**78,622**
	TOTAL OVERALL	**55,022**	**151,228**	**206,250**

* Year in which institutional control of LILW repository location stops.

Annual distribution of nominal costs is represented in Figure 6-9 where different investment cycles could be identified.

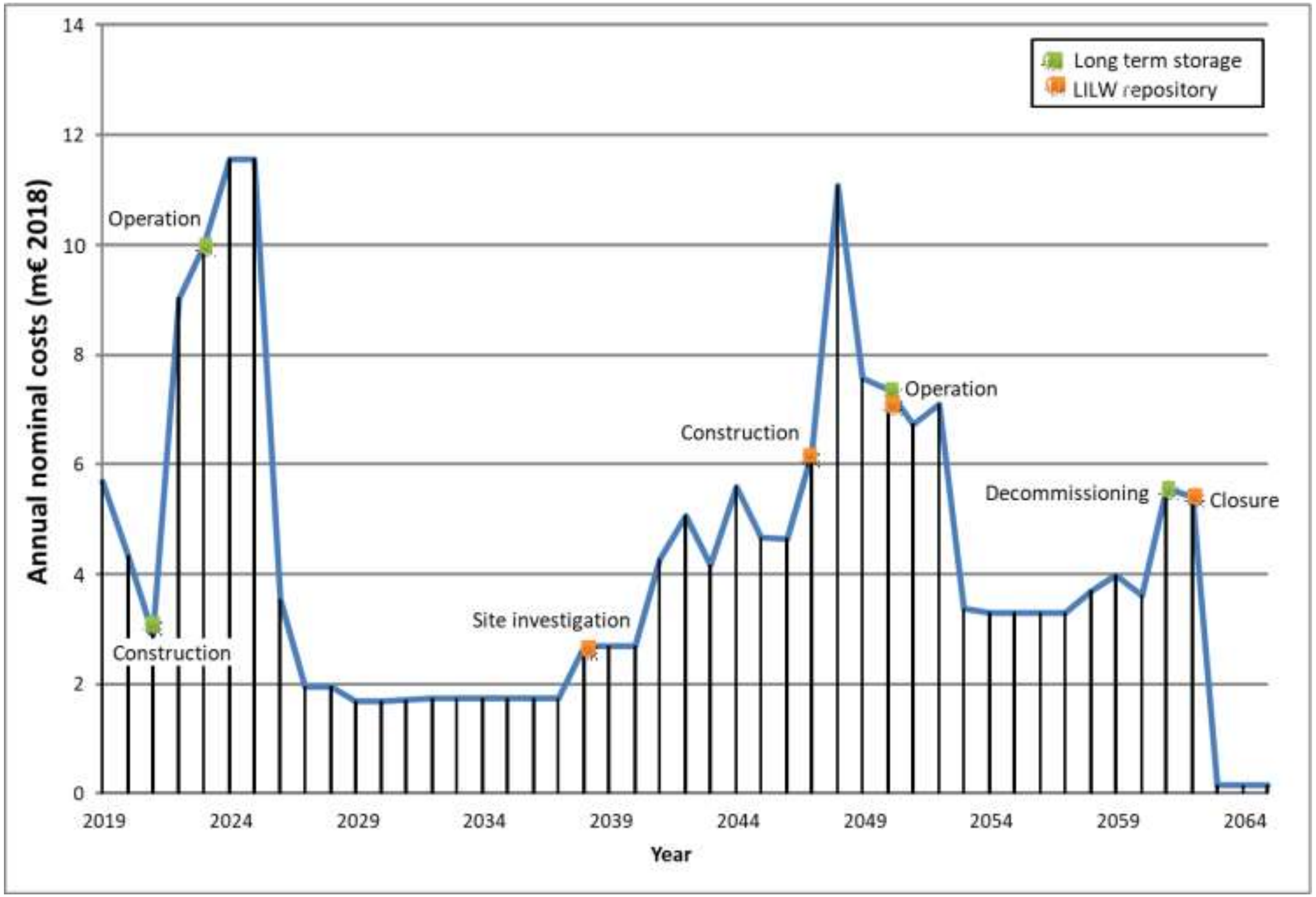


Figure 6-9: Annual distribution of nominal costs for Croatian half of Krško NPP LILW

6.8. Possibilities for optimization

The presented LILW management in RC and its associated costs are determined by the requirements set in Intergovernmental Agreement, time schedule defined in the National Program and limitations related to the lack of adequate capacities for LILW management in Krško NPP.

Presently, there is no free space SRSF and furthermore SRSF is replete. There is no space in Krško NPP suitable for division and takeover of operational LILW with appropriate buffer storage. It could be assessed that part of WPs in SRSF needs treatment in order to satisfy storage or repository WACs. In this moment there are no treatment and conditioning capacities in Krško NPP and furthermore such capacities are not foreseen during Krško NPP operation. PDP Rev.6 assumes only conditioning capacities later then 2043. Available treatment and conditioning facility nearest to future Croatian long term storage and LILW repository is almost 500 km away, assuming several border crossings.

Improvements in existing storage and manipulation capacities and development of new characterization as well as treatment and conditioning capacities inside Krško NPP could substantially optimize present LILW management scenarios both for RS and RC by improving long term safety of LILW disposal, simplifying procedures of division and takeover, cutting considerably transport distances for RC and ultimately lowering the costs of management presented in previous subchapters.

It is clear from the present analysis that characterization for the waste stored in SRSF is needed and that part of the waste requires treatment.

For that purpose WMB2 should be put in operation until 2023 and new facility for treatment and conditioning should be built. It is practical to entrust treatment and conditioning of Krško NPP operational LILW to the people familiar with the waste streams and waste packaging up to now and through Krško NPP lifespan. Capacity needed for characterization of LILW accumulated in SRSF up to now and treatment and conditioning capacity should be developed in Krško NPP until 2024 so that first conditioned N2d and RCC containers could be delivered to both sides in 2026 and then transported to Vrbina repository and to long term storage in RWM Centre Čerkezovac. This will be slight departure from the deadline set in Intergovernmental Agreement. But if both sides in the new circumstances (Krško NPP life extension) agree on the need for optimization of present scenario (undefined treatment and conditioning of LILW for Slovenian side and treatment and conditioning for LILW in the third country for Croatian side) in cooperation with Krško NPP new schedule could be set, and financing of facilities could be agreed upon.

6.9. Costs sensitivity analysis with risk registry

The total cost of LILW scenario depends on cost items. Cost items are calculated using a series of assumptions or parameters introduced in the scenario (e.g. number of waste management facilities, their size and period of operation, unit prices for labor, size of contingencies in total costs calculations, etc.). Influence of single assumption or parameter on the total overall costs is not simple: changes could influence several cost items and furthermore they are also reflected in different contingencies and in the VAT.

Sensitivity of total overall costs of LILW management scenario described in subchapter 6.4 on some of the parameters used and changes in number of long term storage facilities and periods of their operation was investigated [35]. The aim of the analysis was to call attention to assumptions and parameters influencing significantly total overall costs and also to investigate how and on what way changes in assumptions and parameters influence costs.

Following assumptions and parameters were investigated:

a) changes in the LILW inventory
b) absence of treatment and conditioning facility on Krško NPP site during decommissioning process
c) increase of radiological monitoring costs for long term storage, LILW repository and in the period of institutional control of repository
d) additional long term storage facility due to later opening of LILW repository needs to be built
e) changes in size of long term storage floor surface so that stacking of RCCs in storage is in 2 instead of 3 layers
f) increase in contingencies (road transport from 10% to 15%, tretment and conditioning from 10% to 15%, long term storage investment and operational cost from 10% to 15%, LILW repository investment and operational costs from 15% to 20%).

Analysis indicated that influence of changing assumptions and parameters was not significant (≤ 1% on total overall nominal costs) for all investigated assumptions and parameters apart from two: (1) increase of LILW quantities could influences costs 1.7% and (2) absence of treatment and conditioning facility on Krško NPP site during decommissioning could increase total overall costs for significant 4.7%. Increase of costs for adding another long storage facility are compensated by decrease of operational costs of repository which opens later and operates shorter (overall increase of costs 0.9%).

Same analysis [35] identifies and categorize risks for described optimal scenario in three categories: low risk ≤ 20%; medium risk 20–50%; and high risk > 50%.

Table 6-11: Description and category of risks related to costs of LILW management for optimal scenario

New parameter or assumption	Risk description	Risk category
Increase in LILW quantities	Increased quantities of operational LILW in a case of accident in Krško NPP. New revisions of Decommissioning Programme could estimate higher quantities of decommissioning LILW.	Medium risk
Absence of treatment and conditioning facility on Krško NPP site during decommissioning process	Owners of Krško NPP presently do not foresee treatment and conditioning facility on the site of Krško NPP. Treatment and conditioning facility is only suggested by Third revision of Decommissioning Program.	High risk
Long term storage is not operational in 2024 (in the time when first RCC containers should be received)	Problems with property and legal issues. Delay in site investigation or safety analysis. Exceeding the predicted time for location, building and operation permits.	Medium risk
Increase in long term storage monitoring costs	New regulation, public requests or results of environmental assessment studies could request lager scope of monitoring.	Medium risk
Increase in LILW repository monitoring costs	New regulation, public requests or results of environmental assessment studies could request lager scope of monitoring.	Medium risk
Increase in post closure institutional monitoring costs	New regulation, public requests or results of environmental assessment studies could request lager scope or longer period of monitoring.	High risk
Addition of second long term storage facility and later opening of LILW repository	Opening of LILW repository could be late due to longer period for site investigation of repository micro location or due to long lasting negotiations with local community.	Low risk
Storage of RCCs in 2 levels in long term storage facility	Seismic requirements could change present long term storage plans e.g. regulator could require that 3 levels stacking of RCCs should be replaced with 2 levels stacking with additional constructional solutions of the storage building, transport inside storage, etc.	Medium risk
Increase of contingency for road transport	Present costs estimates are for road transport many years in the future. For such a long period from now use of present costs of fuel and transport insurance is unreliable. Contingency used in present cost estimates could be insufficient to cover future increase of costs.	Medium risk
Increase of contingency for	Costs of treatment and conditioning could rise. In treatment and conditioning facility it could be revealed that more LILW needs treatment than it was	Medium risk

New parameter or assumption	Risk description	Risk category
treatment and conditioning	anticipated in present cost estimate or due to larger need for treatment and conditioning (more power plants in the process of decommissioning) prices could increase.	
Increase of contingency for long terms storage preparatory works, construction and for equipment	Costs for long term storage preparatory works could rise (inadequate present knowledge of location properties, property problems or demanding administrative process of issuing permits).	Medium risk
Increase of LILW repository contingency for preparatory works, construction and for equipment	Insufficient knowledge of potential micro locations in a case that LILW repository would not be on the location of RWM Center could increase expenses for site investigation or preparatory works. Location different then location of RWM Center requires new infrastructure already available in the Center. That will increase costs of construction and equipment. Another location with new local community could slow down and make more complex establishment of LILW repository.	High risk

Plans for mitigation of outcomes for itemized risks will be drafted in the process of preparation for the next revision of this document.

6.10. Comparison with DP Rev.1

Krško NPP LILW management was addressed in detail in DP Rev.1. Comparison with material presented in this chapter is rather complex and even dubious for several reasons connected with the fact that there are quite large formal differences in LILW management scenarios and boundary conditions. First, in DP Rev.1 LILW management was described and nominal costs were assessed (expressed in euros €2002) assuming one (or joint) LILW repository (located either in Slovenia or Croatia) of the subsurface (tunnel) type operational from 2013 compared to combination of long term storage and surface type of LILW repository in Croatia starting operation in 2050 presented in this chapter. Second, in the first revision it was assumed that Krško NPP will operate until 2023 (as compared to 2043) and quantity of operational and decommissioning LILW was assessed to be 17.500 m^3, considerably more than it was assessed in the present Third revision of Decommissioning Programme. Third, all the expenses were calculated without taxes; expenses for the repository post-closure institutional control were not taken into account; incentives to local community were included in LILW repository operational expenses; and all the expenses for LILW treatment and conditioning were treated as Krško NPP operational expenses (e.g. were not calculated at all as costs of

LILW management). Both costs estimates used comparable contingencies to cover for expenses not foreseen. LILW repository costs were estimated based on Slovenian supporting studies.

Due to significant differences (primarily in the disposal technologies) only costs of whole scenarios will be compared without comparison of different cost items e.g. costs of repository construction or operational cost.

D&DP Rev.1 singles out two optimized LILW management scenarios: SID-45 export and SID-45 disposal, costing 310.2 and 186.0 mil. €, respectively. First scenario is considerably more expensive then the second one because it assumes operational lifetime lasting 52 years compared to 19 years in the second scenario. In that respect being more similar to present scenario, costs of second scenario (SID-45 disposal) will be compared to scenario presented in this revision. In order to make very rough comparison of nominal costs of two scenarios corrections should be introduces.

Costs for SID-45 disposal are corrected for inflation in EU zone. Correction factor converting €2002 $\rightarrow$ €2018 was determined using industrial producer price index (PPI). For that purpose OECD data for EU (19 countries) was used [36]. Factor based on PPI using EU(19) index for period 2002 – 2018 is calculated to be 1.259. Corrected costs for SID-45 in €2018 prices are 234.174 mil €.

In order to be comparable, from the costs of present scenario (206.25 mil. €), costs for VAT (24.2 mil. €) and compensations or incentives to local community (44 mil. €) were subtracted. Corrected costs for present scenario are hence 138.05 mil €.

Comparison demonstrates that corrected nominal costs for present scenario as a whole are considerably lower than the costs for SID-45 with disposal, although this could be contested by comparing quantities of LILW to be disposed. But, sensitivity analysis in D&DP Rev.1 states that costs are quite insensitive on the quantities of disposed LILW as result of high initial preparation and construction costs of repositories.

6.11. References

1 Zakon o Fondu za financiranje razgradnje i zbrinjavanja radioaktivnog otpada i istrošenoga nuklearnog goriva Nuklearne elektrane Krško (NN 107/07)

2 3570-6/2009/32, SNSA License amendment dated 20. 06. 2012

3 Zakon o potvrđivanju Ugovora između Kraljevine Belgije, Republike Bugarske, Češke Republike, Kraljevine Danske, Savezne Republike Njemačke, Republike Estonije, Irske, Helenske Republike, Kraljevine Španjolske, Francuske Republike, Talijanske Republike, Republike Cipra, Republike Latvije, Republike Litve, Velikog Vojvodstva Luksemburga, Republike Mađarske, Republike Malte, Kraljevine Nizozemske, Republike Austrije, Republike Poljske, Portugalske Republike,

Rumunjske, Republike Slovenije, Slovačke Republike, Republike Finske, Kraljevine Švedske, Ujedinjene Kraljevine Velike Britanije i Sjeverne Irske (države članice Europske unije) i Republike Hrvatske o pristupanju Republike Hrvatske Europskoj uniji (NN MU 2/12)

4 Strategija zbrinjavanja radioaktivnog otpada, iskorištenih izvora i istrošenog nuklearnog goriva (NN 125/14)

5 Zakon o radiološkoj i nuklearnoj sigurnosti (NN 141/13), (NN 39/15) i (NN 130/17)

6 Pravilnik o zbrinjavanju radioaktivnog otpada i Iskorištenih Izvora (NN 12/18)

7 Odluka o donošenju Nacionalnog programa provedbe Strategije zbrinjavanja radioaktivnog otpada, iskorištenih izvora i istrošenog nuklearnog goriva (Program za razdoblje do 2025. godine s pogledom do 2060. godine) (NN 100/18)

8 Antun Schaller, Izbor mjesta odlagališta nisko i srednje radioaktivnog otpada u Republici Hrvatskoj, Posebno izdanje APO-novosti, 1997.

9 Kriteriji za izbor lokacija za termoelektrane i nuklearne objekte, Urbanistički institut Hrvatske, Zagreb, 1991.

Prostorno-planerske podloge, istraživanja i ocjena podobnosti lokacija za termoelektrane i nuklearne objekte na prostoru Hrvatske, Studija, Završni izvještaj, Urbanistički institut Hrvatske, Zagreb, 1991.

Zaključak o utvrđivanju kriterija za izbor lokacija za termoelektrane i nuklearne objekte (NN 78/92)

10 Odluka o donošenju Programa prostornog uređenja Republike Hrvatske (NN 50/99)
Program prostornog uređenja Republike Hrvatske, Ministarstvo prostornog uređenja, graditeljstva I stanovanja, Zavod za prostorno planiranje, Zagreb, 1999.

11 Strategija prostornog razvoja Republike Hrvatske (NN 106/17)

12 Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, Official Journal L 199 of 2 August 2011.

13 Table is presented in The 6th National Report of the Republic of Croatia in accordance with Article 32 of the Joint Convention on Safety of Spent Fuel Management and on Safety of Radioactive Waste Management, 2017.

14 Zakon o zaštiti okoliša (NN 80/13, NN 153/13 i NN 78/15)

15 Uredba o strateškoj procjeni utjecaja plana i programa na okoliš (NN 64/08)

16 Uredba o informiranju i sudjelovanju javnosti i zainteresirane javnosti u pitanjima zaštite okoliša (NN 64/08)

17 Zakon o zaštiti prirode (NN 80/13 i 15/18)

18 Opredelitev NEK do možnosti priprave NSRAO na odlaganje v NEK, dopis št. ING.DOV-319.18/6243, september 2018.

19 Slempelkamp, NIS Ingenieurgesellschaft mbH, 3rd Revision of the NPP Krsko Decommissioning Program, First Edition 23.11.2018

20 Ekoteh, Enconet: Razrada koncepta zbrinjavanja RAO u RH s novom procjenom troškova, 2019

21 Javys: Treatment and Conditioning of Radioactive Waste from Krsko NPP at The Javys Treatment Facilities. Feasibility Study, 2016

22 Javys: Study for the Transport of Radioactive Waste from Krško NPP. Feasibility Study, 2016

23 IBE: Investment Program for the LILW disposal facility Vrbina, Krško, Rev. D with appendices, 2017

24 Pravilnik o zbrinjavanju radioaktivnog otpada i Iskorištenih Izvora (NN 12/18)

25 International Atomic Energy Agency, Near surface disposal facilities for radioactive waste, (IAEA safety standards series, ISSN 1020–525X ; no. SSG-29), Vienna, 2014

26 International Atomic Energy Agency, Disposal of radioactive waste (IAEA safety standards series, ISSN 1020–525X ; no. SSR-5), Vienna, 2011

27 Elektroprojekt. Odlagalište nisko i srednje radioaktinog otpada - površinski tip. Idejno rješenje , Zagreb, studeni 1994

28 Ekonerg, Osnove Terminskog mrežnog plana, 2017

29 Enconet, Zbrinjavanje nisko i srednje radioaktivnog otpada iz NE Krško u Republici Hrvatskoj, 2016

30 AACE® International. Cost estimate classification system – As applied in engineering, procurement and construction for the process industries - Recommended Practice No. 18R-97. Morgantown, WV: Association for Advancement of Cost Engineers (AACE®) International, 2011

31 Project Management Institute. A guide to the project management body of knowledge (PMBOK®Guide) (5th ed.). Newtown Square, PA: Project Management Institute, 2013

32 England, K. & Moreci, J. Contingency—are you covered? Paper presented at PMI® Global Congress 2012—North America, Vancouver, British Columbia, Canada. Newtown Square, PA: Project Management Institute, 2012

33 RTA: Project Estimating. PMO-EST-UG001, 2008

34 Zakon o porezu na dodanu vrijednost (NN 115/16)

35 Enconet, Analiza osjetljivosti i registar rizika zbrinjavanja RAO u RH, 2019

36 OECD (2019), Producer price indices (PPI) (indicator). doi: 10.1787/a24f6fa9-en (Accessed on 10 April 2019)

7. Potential Division and Takeover of Operational and Decommissioning RW

This chapter is based on a studies *Proposal for Division and Takeover of operational LILW* created in September 2018 by ENCONET d.o.o. and EKONERG d.o.o. and *Proposal for Division and Takeover of decommissioning LILW* created in October 2018 by ENCONET d.o.o. and EKONERG d.o.o. for the purpose of drafting this revision.

Abbreviations

A	Ash (incineration product)
ACC	Supercompacted Charcoal (pellets)
ARAO	Agency for Radwaste Management (Agencija za radioaktivne odpadke)
BR	Dried blow-down Resins (IDDS product)
CF	Filter Cartridges in Cemented Matrix
CPW	Compressible Waste
CS	Carbon Steel
CW	Compressible Waste
CWC	Supercompacted Compressible Waste (pellets)
DB	Decontamination Building
DC	Dried Concentrates (IDDS products)
DS	Dried Sludges (IDDS products)
EB	Evaporator Bottom Solidified in Vermiculite-Cemented Matrix
EBC	Supercompacted Evaporator Bottom (pellets)
EC	Evaporator Concentrates and Tank Sludges
EU	European Union
Fond	Fund for financing the decommissioning of the Krško NPP and the disposal of Krško NPP radioactive waste and spent nuclear fuel
FWP	Final Waste Package (in this document it refers to final package for storage)
HLW	High Level Waste
I	Ingots (melting product)
IDDS	In Drum Drying System
JV7	Slovenian rules on radioactive waste and spent fuel management
LILW	Low and Intermediate Level Waste
NCW	Non-compressible Waste
NEK	Nuclear Power Plant Krško (Nuklearna elektrarna Krško)
NPP	Nuclear Power Plant
O	Solidified Non-compressible Waste
OC	Other Supercompacted Compressible Waste (pellets)
PDP Rev.6	Preliminary Decommissioning Plan Revision 6
PE	Polyethylene
PR	Dried Primary Resins (IDDS product)
RCA	Radiation-Controlled Area
RCC	Reinforced Concrete Container
RW	Radioactive Waste
RWM Centre	Radioactive Waste Management Centre
SDR	Surface Dose Rate

SF	Spent Filters
SFDS	Spent Fuel Dry Storage
SIR	Spent Ion Resins
SR	Spent Resins Solidified in Vermiculite-Cemented Matrix
SRSF	Solid Radwaste Storage Facility
SS	Stainless Steel
SW	Specific Waste
T1, T2	Types of Tube Type Containers
TTC	Tube Type Container
WAC	Waste Acceptance Criteria
WP	Waste Package
WPs	Waste Packages
WPS	Waste Package Specification

7.1. Introduction

This chapter addresses division and takeover of LILW generated by the operation during whole lifespan and decommissioning of Krško NPP by Croatian and Slovenian side. This chapter is requirement of Intergovernmental Agreement (Article 10, Paragraph 3).

7.2. Inventory of operational LILW

Proposal for Division of the Operational LILW deals with division of four waste package categories. These are:

1) Final waste packages which are already produced and stored.
2) Final waste packages which are already produced and stored in 200 l drums.
3) Estimated WPs that will be generated after foreseen processing of existing WPs.
4) Projection of WPs to be generated until end of extended lifetime (2043).

Table 7-1 presents summary data on complete LILW inventory at Krško NPP (existing, estimated and projections).

Table 7-1: Summary data on LILW inventory

WPs	WP Type	WP Number	Mass (t)	Volume (m^3)	Total Activity* (Bq)
FWPs	D6, T1 and T2	2,788	4,322.5	2,074.8	$4,27\times10^{13}$
FWPs	Ingots	80	49.6	8.8	$2,22\times10^{8}$
FWPs in 200 l drums	EBD5, SRD4, CFD3, CFH2 and AD2D1	903	470.1	187.8	$1,71\times10^{13}$
Estimated WPs after foreseen treatment	AD2D1T2, OCT2 and OD1T2	27	35.2	23.5	$4,17\times10^{10}$
Projection of WPs period 2018–2023	T2 containing various waste forms	188	264.0	163.4	$1,44\times10^{13}$
Projection of WPs period 2024–2043	T2 containing various waste forms	629	883.7	546.6	$4,83\times10^{13}$
Total		**4,615**	**6,025.1**	**3,004.9**	$\mathbf{1,23\times10^{14}}$

* Activity values do not include radioactive decay.

7.3. Proposal for division of the operational LILW

For division of operational LILW it is important to establish a set of criteria that will be used in the process of dividing the LILW in two parts. Multi-criteria approach was applied [1]. The set of division criteria is based on the following requirements:

1) Complete LILW inventory at Krško NPP listed in Table 7-1 is the subject of division.
2) LILW division will be performed in two groups for each waste stream separately.

3) The following waste package characteristics will be taken into account:

- Waste stream
- Number and type of waste packages
- Mass of waste packages
- Total activity of waste packages and
- Surface dose rate of waste packages.

4) Each group should contain approximately equal amount of LILW (number of waste packages, mass and total activity).
5) Each group will be associated with package (record) numbers of the corresponding waste packages.
6) For the waste packages that data on total activity are missing, this parameter will be assumed as an average value of the waste stream to which waste package belongs.
7) In case of even number of waste packages the difference between groups must be ≤ 1%. Criterion applies to the mass and total activity as well.
8) In case of odd number of waste packages the difference between groups must be ≤ 5%. Criterion applies to the mass and total activity as well.
9) Particular attention should be paid on the waste packages with surface dose rates above 2 mSv/h. As indicated in Chapter 4 there are 911 waste packages of this kind. Division of these waste packages must be performed in a way that surface dose rates should be approximately uniformly distributed over the groups.

WAC for Slovenian Vrbina disposal facility and Croatian RWM Centre long-term storage facility are not criteria for division but for final takeover of disposal containers (Preliminary WAC for storage and disposal in Croatia and WAC for disposal in Slovenia are in the Appendix of this document). The waste has to be divided as equally as possible regarding waste stream, mass, activity and dose rates.

The division, as stated in previous chapters, was performed separately for each waste stream and waste package type, and on different levels of detail depending on status of the waste package (final, estimated quantities, projected quantities). Tables below give summary of division results sorted in following categories:

- FWPs in T1 and T2 containers (Table 7-2)
- FWPs in D6 containers (Table 7-3)
- FWPs – ingots (Table 7-4)
- FWPs in 200 l drums (Table 7-5)
- Estimated WPs after foreseen treatment (Table 7-6)
- Projected WPs for period 2018-2023 (Table 7-7) and 2024-2043 (Table 7-8).

These summarized tables were made to demonstrate that the difference in total for all types of waste streams and waste packages meets the defined criteria and is well below 1% for both even and odd number of waste packages.

Table 7-9 presents division results per waste stream and waste package type, demonstrating that criteria are met for every waste stream and package type, as well as for even and odd number of WPs.

Table 7-10 shows that for total already produced and stored WPs one group will get one extra waste package, but the mass and activity difference could be considered negligible (below 0.015%). Division of projected waste packages that will be produced, after foreseen treatment and in period from 2018 until end of extended lifetime, gives equal number of WPs per group and the mass and activity difference are below 0.065%. Division results for total LILW inventory until 2043 (existing WPs and projected WPs) show difference in total mass and activity between groups below 0.015%, although one group will get one WP more.

Furthermore, it is important to emphasize that the division of waste streams spent ion resins and spent filters, which can be considered the most problematic waste with highest activities, is well below 1% for even, but also for odd number of waste packages.

Table 7-2: Division of FWPs in T1 and T2 Containers

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
EC	EBCT1/EBCT2	1,583,517.13	6.6172E+11	729	1,583,516.89	6.6172E+11	729
	EBD5T1	7,549.15	3.9276E+09	6	7,536.66	3.9241E+09	6
	DCH1T2	44,730.20	1.5634E+11	43	44,647.89	1.5634E+11	43
	DSH1T2	2,624.20	3.7641E+10	3	2,153.00	4.2802E+10	2
SIR	SRD4T1	85,151.00	1.0652E+13	53	85,136.45	1.0652E+13	53
	BRH1T2	5,503.30	2.1403E+10	7	5,488.70	2.1393E+10	7
	PRH2T2	63,591.70	9.6186E+12	35	63,576.50	9.6185E+12	35
SF	CFD3T1	28,063.00	8.5883E+10	12	27,897.00	8.5409E+10	11
CPW	CWCT1/CWCT2	114,530.06	5.9075E+10	122	114,542.89	5.9075E+10	122
	OCT1/OCT2	86,098.63	4.0978E+10	65	86,096.59	4.0977E+10	65
NCW	AD2D1T2	9,148.00	6.7150E+08	5	10,880.00	6.7244E+08	6
SW	ACCT1/ACCT2	5,030.01	2.7189E+06	6	4,859.05	2.7929E+06	6
	Total	**2,035,536.38**	**2.134E+13**	**1,086**	**2,036,331.62**	**2.1343E+13**	**1,085**
	Difference	**-795.24**	**-4.497E+09**	**1**			
	Difference (%)	**-0.010%**	**-0.005%**				

Table 7-3: Division of FWPs in D6 Containers

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
EC	EBCD6	2,263.20	4.2263E+08	3	2,646.50	3.7713E+08	4
CPW	CWCD6	101,148.90	6.4976E+10	258	101,228.00	6.4976E+10	257

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
	OCD6	21,578.60	8.5185E+09	47	21,549.00	8.5188E+09	48
Total		**124,990.70**	**7.3917E+10**	**308**	**125,423.50**	**7.3872E+10**	**309**
Difference		**-432.80**	**4.521E+07**	**-1**			
Difference (%)		**-0.086%**	**0.015%**				

Table 7-4: Division of FWPs - Ingots

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
NCW	I	24,799.00	1.1113E+08	40	24,789.00	1.1113E+08	40
Difference		**10.00**	**-1.0510E+03**	**-**			
Difference (%)		**0.010%**	**-0.0002%**				

Table 7-5: Division of FWPs in 200 l drums

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
EC	EBD5	338.00	3.7924E+08	1	383.00	4.1449E+08	1
SIR	SRD4	164,702.00	8.0646E+12	345	164,701.82	8.0647E+12	344
	CFD3	43,576.00	3.6503E+11	56	43,574.00	3.5598E+11	57
SF	CFH2	2,146.00	1.5236E+11	2	2,071.00	1.5582E+11	2
NCW	AD2D1	24,293.55	6.2724E+09	47	24,302.09	6.2719E+09	48
Total		**235,055.55**	**8.5887E+12**	**451**	**235,031.91**	**8.5832E+12**	**452**
Difference		**23.64**	**5.507E+09**	**-1**			
Difference (%)		**0.003%**	**0.016%**				

Table 7-6: Division of estimated WPs after foreseen treatment

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
CPW	OCT2	4,119	1.7275E+10	5	4,119	1.7275E+10	5
	AD2D1T2	12,745	8.5523E+08	7	12,745	8.5523E+08	7
NCW	OD1T2	582	2.3360E+09	1	867	3.1146E+09	2
Total		**17,446**	**2.0466E+10**	**13**	**17,731**	**2.1245E+10**	**14**
Difference		**-284**	**-7.79E+08**	**-1**			
Difference (%)		**0.404%**	**0.933%**				

Table 7-7: Division of projected WPs for period 2018-2023

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
EC	DCH1T2/DSH1T2	24,934	2.47E+11	25	24,934	2.47E+11	25
SIR	PRH2T2	45,417	6.87E+12	25	45,417	6.87E+12	25
SF	CFH2T2	24,330	7.45E+10	10	24,330	7.45E+10	10
CPW	CWCT2	7,143	1.28E+09	8	7,143	1.28E+09	8
	OCT2	11,921	5.67E+09	9	11,921	5.67E+09	9
NCW	AD2D1T2	14,566	9.77E+08	8	14,566	9.77E+08	8
	OD1T2	3,712	2.52E+10	9	3,712	2.52E+10	9
	Total	**132,024.20**	**7.2245E+12**	**94**	**132,024.20**	**7.2245E+12**	**94**
	Difference	**0.00**	**0.00E+00**	**-**			
	Difference (%)	**0.00%**	**0.00%**				

Table 7-8: Division of projected WPs for period 2024-2043

Waste Stream	Waste Package	Group 1			Group 2		
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs
EC	DCH1T2/DSH1T2	82,781	8.19E+11	83	83,778	8.28E+11	84
SIR	PRH2T2	152,602	2.4800E+11	84	150,785	2.5098E+11	83
SF	CFH2T2	80,290	2.46E+11	33	82,723	2.53E+11	34
CPW	CWCT2	24,109	4.32E+09	27	24,109	4.32E+09	27
	OCT2	39,737	1.89E+10	30	39,737	1.89E+10	30
NCW	AD2D1T2	49,160	3.30E+09	27	49,160	3.30E+09	27
	OD1T2	12,374	8.39E+10	30	12,374	8.39E+10	30
	Total	**441,053**	**1.4227E+12**	**314**	**442,667**	**1.4430E+12**	**315**
	Difference	**-1,614**	**-2.03E+10**	**-1**			
	Difference (%)	**-0.09%**	**-0.35%**				

Table 7-11 shows dose rate distribution for all final waste packages. The presented dose rate distribution can be considered almost uniformly distributed over the groups, considering the multiple criteria that had to be fulfilled and that the most WPs have dose rates lower or equal to 2mSv/h (Figure 7-1).

Table 7-9: Division of FWPs per waste stream

Waste Stream	Waste Package	Group 1			Group 2			Mass Difference (%)	Activity Difference (%)	Number of WPs Difference
		Mass (kg)	Activity (Bq)	No of WPs	Mass (kg)	Activity (Bq)	No of WPs			
EC	EC in T1 or T2	1,638,421	8.596E+11	781	1,637,854	8.648E+11	780	0.0086%	-0.1494%	1
	EC in D6	2,263	4.226E+08	3	2,647	3.771E+08	4	-3.9035%	2.8450%	-1
	EC in D5	338.00	3.7924E+08	1	383.00	4.1449E+08	1	-3.1207%	-2.2203%	0
SIR	SIR in T1 or T2	154,246	2.029E+13	95	154,202	2.029E+13	95	0.0072%	0.0002%	0
	SIR in D4	164,702.00	8.0646E+12	345	164,701.82	8.0647E+12	344	0.0000%	-0.0002%	1
SF	SF in T1	28,063	8.588E+10	12	27,897	8.541E+10	11	0.1483%	0.1383%	1
	SF in D3 and H2	45,722.00	5.1739E+11	58	45,645.00	5.1179E+11	59	0.0421%	0.2719%	-1
CPW	CPW in T1 or T2	200,629	1.001E+11	187	200,639	1.001E+11	187	-0.0013%	0.0002%	0
	CPW in D6	122,728	7.349E+10	305	122,777	7.349E+10	305	-0.0101%	-0.0001%	0
NCW	NCW in T1	9,148	6.715E+08	5	10,880	6.724E+08	6	-4.3239%	-0.0348%	-1
	NCW in D1	24,293.55	6.2724E+09	47	24,302.09	6.2719E+09	48	-0.0088%	0.0020%	-1
	NCW type I	24,799	1.111E+08	40	24,789	1.111E+08	40	0.0101%	-0.0002%	0
SW	SW in T1 or T2	5,030	2.719E+06	6	4,859	2.793E+06	6	0.8644%	-0.6709%	0
Total		**2,420,382**	**3.000E+13**	**1,885**	**2,421,576**	**3.000E+13**	**1,886**			

Table 7-10: Division results – Summary table

LILW Inventory until 2043		WPs	Group 1 Mass (kg)	Group 1 Activity (Bq)	Group 1 No of WPs	Group 2 Mass (kg)	Group 2 Activity (Bq)	Group 2 No of WPs
	Exisitng WPs	FWP in TTC	2,035,536	2.13E+13	1,086	2,036,332	2.13E+13	1,085
		FWP in D6	124,991	7.39E+10	308	125,424	7.39E+10	309
		I	24,799	1.11E+08	40	24,789	1.11E+08	40
		FWP in 200 l drums	235,056	8.59E+12	451	235,032	8.58E+12	452
		Total	**2,420,382**	**3.00E+13**	**1,885**	**2,421,576**	**3.00E+13**	**1,886**
		Difference betw. G1 & G2	-1,194	1.06E+09	-1			
		Difference (%)	-0.0123%	0.0009%				
	Projection	Estimation of TTC after treatment	16,637	2.05E+10	13	16,786	2.12E+10	14
		Projection for 2018-2023 (TTC)	132,024	7.22E+12	94	132,024	7.22E+12	94
		Projection for 2024-2043 (TTC)	442,667	1.44E+12	315	441,053	1.42E+12	314
		Total	**591,328**	**8.69E+12**	**422**	**589,863**	**8.67E+12**	**422**
		Difference betw. G1 & G2	1,464	1.95E+10	0			
		Difference (%)	0.0620%	0.0562%				
		Grand Total	**3,012,519**	**3.8689E+13**	**2,307**	**3,012,384**	**3.8668E+13**	**2,308**
		Difference betw. G1 & G2	135	2.06E+10	-1			
		Difference (%)	0.0011%	0.0133%				

Table 7-11: Dose rate distribution – summary table

Dose Rate (mSv/h)	Group1 No of WPs	Group2 No of WPs
150 ≤ Dose Rate ≤ 200	2	2
100 ≤ Dose Rate <150	3	3
50 ≤ Dose Rate < 100	31	30
20 ≤ Dose Rate < 50	103	107
2 < Dose Rate < 20	315	315
Total	**454**	**457**

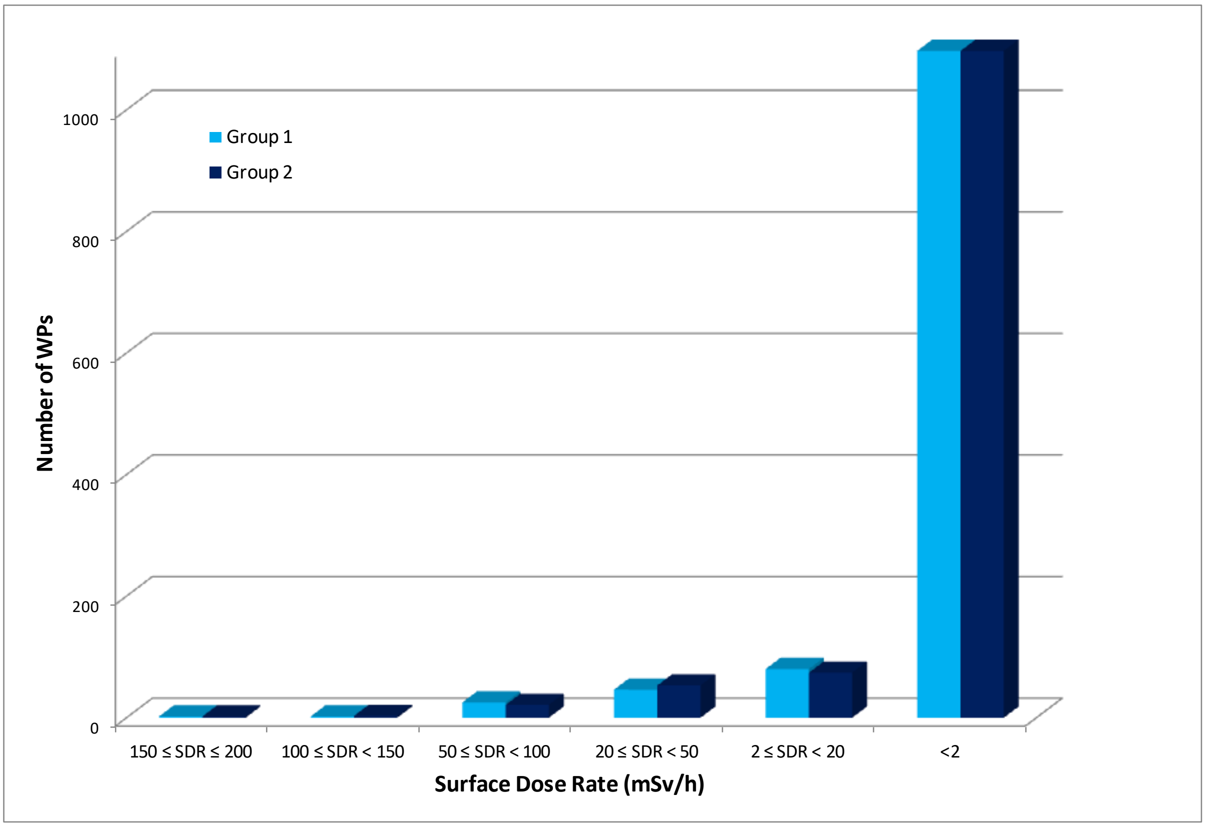


Figure 7-1: Dose rate distribution

7.4. Proposal for takeover of the operational LILW

In this subchapter proposal for takeover of final waste packages stored in SRSF and DB facilities is given. The described takeover process consists of two paths:

- ARAO - takeover of FWPs stored in SRSF and DB at radiation-controlled area (RCA) border for transport and

- Fond - takeover of FWPs stored in SRSF and DB at radiation-controlled area (RCA) border for transport to treatment facility.

First the proposed takeover process is described, following with the outline of responsibilities and documentation necessary for takeover. The final part of the chapter gives safety and environmental aspects of takeover process concluding with outline of predicted costs.

Actual takeover which will be performed in 2023 until 2025 has to be based on final division. The final division has to be performed before takeover starts taking into consideration latest data on LILW inventory and recalculated activities of all FWPs.

7.4.1. Takeover process

As a starting point for development of the takeover process the SRSF occupancy and major takeover preconditions were analyzed. Based on presented findings the takeover strategy was developed. Finally, important considerations that have to be taken into account were identified and are presented.

SRSF is almost fully occupied with different kind of WPs [2]. Necessary additional space will be provided with removal of supercompactor and other equipment to Waste Manipulation Building (WMB). Nevertheless, according to projections [2] by the year 2023, when takeover has to take place, the SRSF will be totally occupied with very little space for manipulation with waste packages.

It should be highlighted here that lack of room for WPs manipulation is the major limitation for the takeover process implementation. Adequate space for WPs manipulation during takeover process is necessary for:

- selection of WPs in accordance with division data
- grouping of WPs waiting for transport or removal to WMB and
- segregation of WPs with compromised integrity [3].

Furthermore, the operational LILW will continue to be generated meaning that room for storage in the near future is essential.

Such SRSF occupancy status practically determines strategy of the takeover process that can be applied. This takeover strategy can be figuratively named the Last In – First Out Strategy.

There are two major conditions that must be fulfilled prior to the takeover process implementation. These preconditions are:

1) ARAO should have confirmed solution for the conditioning of N2d containers. This precondition assumes that Vrbina disposal facility is in operation. ARAO should have also signed transport agreement with transport organisation.
2) Fond should have contract with a radioactive waste management company covering transport, treatment and conditioning of Krško NPP RW. This implies all necessary agreements and permits issued by responsible authorities and assumes that RWM Centre long-term storage facility is operational.

Proposed takeover strategy is based on the assumption that both major preconditions are met. In such circumstances we propose the takeover strategy that is composed of the following two consecutive campaigns:

1) First campaign – Emptying of entrance compartments in SRSF and FWPs from DB
2) Second campaign – Emptying of other Compartments in SRSF.

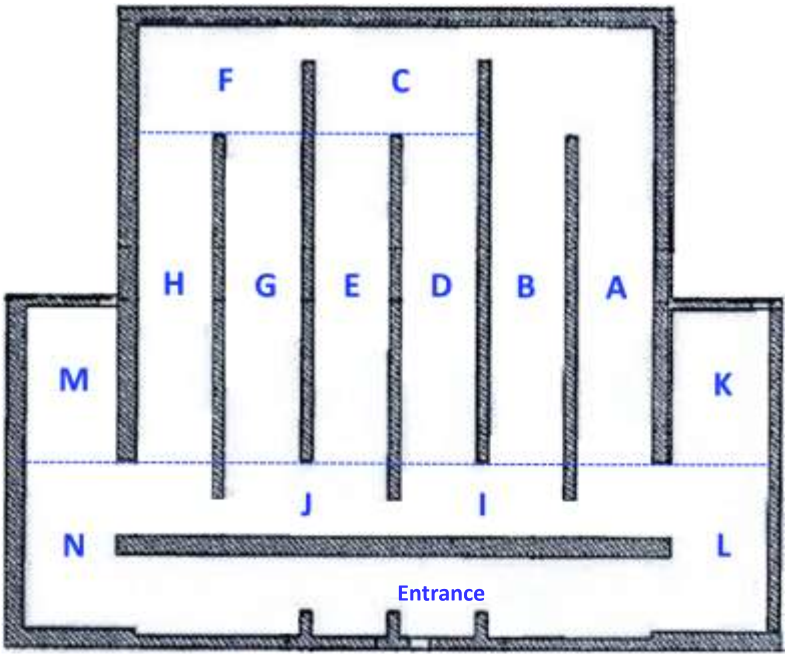


Figure 7-2: SRSF layout.

<u>First Campaign</u>

This campaign consists of emptying SRSF compartments I, J, K, L, M and N (Figure 7-2). In this way the necessary space for WPs handling and selection, for separation of potentially damaged WPs and space for storage of future WPs will be obtained.

As shown in the **Table** 7-12 there are 781 different FWPs currently stored in these compartments, not including the WPs waiting for foreseen processing.

Table 7-12: WPs currently stored in the entrance compartments

Waste Stream	Waste Package	SRSF Compartment												Total per WS
		I		J		K		L		M		N		
		G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	
EC	EBCT1/EBCT2									34	40			74
	EBD5T1									6	5			11
	EBCD6					3	4							7
	DCH1T2									0	2			2
CPW	CWCD6					228	234	23	18	7	5			515
	OCT1/OCT2									3	2			5

Waste Stream	Waste Package	SRSF Compartment												Total per WS
		I		J		K		L		M		N		
		G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	
	OCD6					46	47	1	1					95
NCW	AD2D1	36	20					3	13					72
Total per Group		**36**	**20**	**0**	**0**	**277**	**285**	**27**	**32**	**50**	**54**	**0**	**0**	**781**
Total per Compartment		**56**		**0**		**562**		**59**		**104**		**0**		

It is assumed that integrity of these FWPs is mainly preserved. Surface dose rate (SDR) is below 2 mSv/h for most of the FWPs (just 18 of them have SDR above 2 mSv/h, with maximal value being 25 mSv/h). The table also shows how many of FWPs per compartment are designated to specified group. By summing up Group 1 will receive 390 FWPs while Group 2 will receive 391 FWPs.

This campaign also includes takeover of all FWPs temporarily stored in DB building.

Second Campaign

This campaign consists of emptying remaining SRSF compartments A, B, C, D, E, F, G and H (Figure 7-2). According to Krško NPP operational LILW inventory [4] there are currently 2,797 WPs stored in compartments A - H in SRSF (not including the WPs waiting for further processing). Table 7-13 shows how many of FWPs per compartment are designated to specified group. By summing number of FWPs per each group, Group 1 will receive 1,397 FWPs while Group 2 will receive 1,400 FWPs.

Table 7-13: WPs currently stored in other compartments

WS	Waste Package	SRSF Compartment																Total per WS
		A		B		C		D		E		F		G		H		
		G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	
EC	EBCT1/ EBCT2			7	5	78	96	80	94	171	187	84	74	168	136	107	97	**1,384**
	EBD5T1							0	1									**1**
	EBD5	1	1															**2**
	DCH1T2	13	12	30	29													**84**
	DSH1T2	3	0	0	2													**5**
SIR	SRD4T1					1	0	0	2			5	8	28	20	19	23	**106**
	SRD4	2	7			74	82	269	255									**689**
	BRH1T2			7	7													**14**
	PRH2T2			35	35													**70**
SF	CFD3T1											1	1	3	0	8	10	**23**
	CFD3	4	22	3	7	21	11	28	17									**113**
	CFH2			2	2													**4**
CPW	CWCT1/ CWCT2			8	6	6	5	4	10	6	5	34	41	3	3	34	33	**198**

WS	Waste Package	SRSF Compartment																Total per WS
		A		B		C		D		E		F		G		H		
		G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	
	OCT1/ OCT2	18	14	15	19	1	0	3	2					0	1	3	2	**78**
NCW	AD2D1T2	5	6															**11**
	AD2D1	0	4															**4**
SW	ACCT1/ ACCT2													5	6			**11**
Total per Group		**46**	**66**	**107**	**112**	**181**	**194**	**384**	**381**	**177**	**192**	**124**	**124**	**207**	**166**	**171**	**165**	**2,797**
Total per Compartment		**112**		**219**		**375**		**765**		**369**		**248**		**373**		**336**		

It should be noted that Table 7-12 and Table 7-13 do not include all LILW inventory as they do not include 94 FWPs for which the data on exact location was not available. This refers to 47 OCT1/OCT2 and 46 CWCT1/CWCT2 packages and as well as to 1 ACCT2 package. Also the Tables do not include WPs temporarily located in DB building and WPs waiting for foreseen processing.

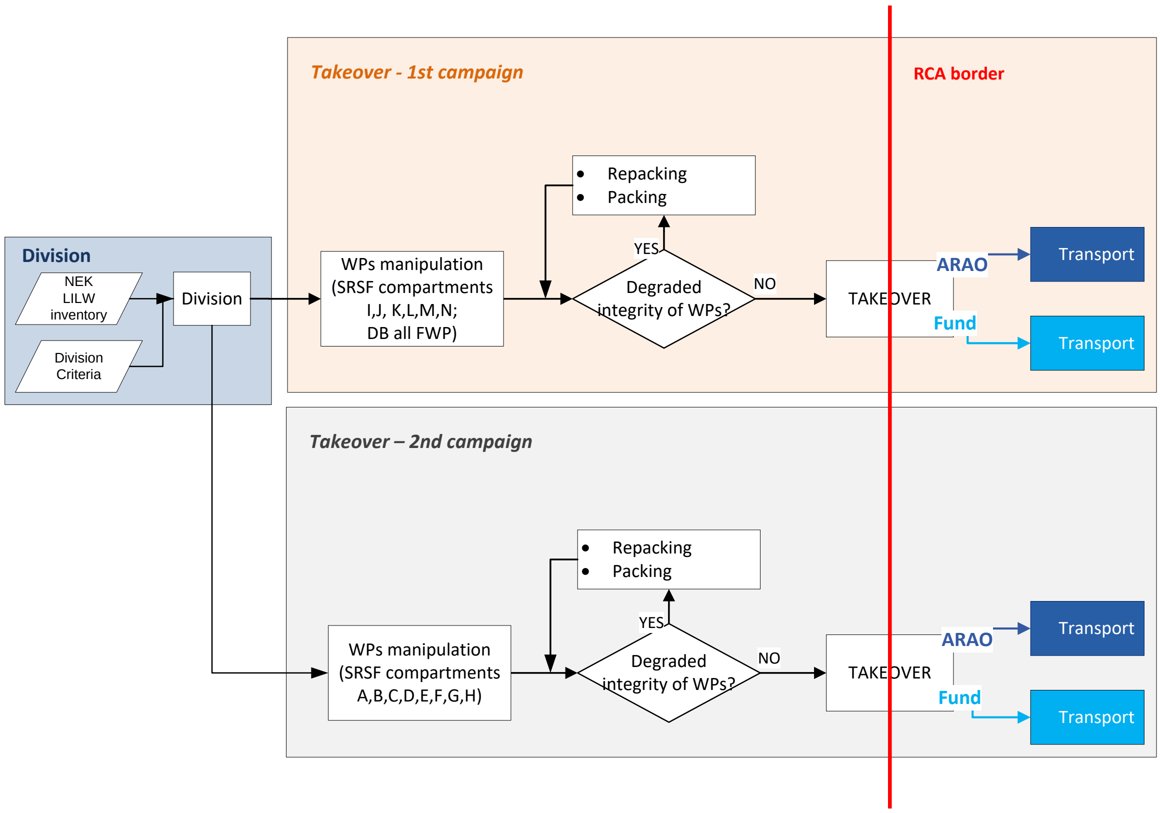


Figure 7-3: Takeover process scheme

Related to this campaign there is a question how to determine the compartment where to start with takeover and the sequence of emptying the remaining compartments. We think that answer on this question should be left to Krško NPP. The reason for it lays in various

practicalities that have to be taken into account, such as: the crane position at the time of conducting takeover process, procedures for transferring the crane from compartment to compartment, occupancy of particular compartment etc.

However, the recommendation here is that in relatively short period of time WPs with SDR above 2 mSv/h should be available for manipulation. These WPs have to be combined with other types of WPs in order to meet the criteria regarding the production of ILW-1 and ILW-2 types of N2b disposal containers on one hand. On the other hand the WPs with higher SDR have to be adequately combined with other WPs to meet the transport requirements. Aforementioned has to be thought-out while defining the emptying sequence.

Regarding the potential WPs with degraded integrity the proposal is to single out these WPs and locate them in designated location and then to deal with them case by case in accordance with Krško NPP procedures for packing and repacking of WPs.

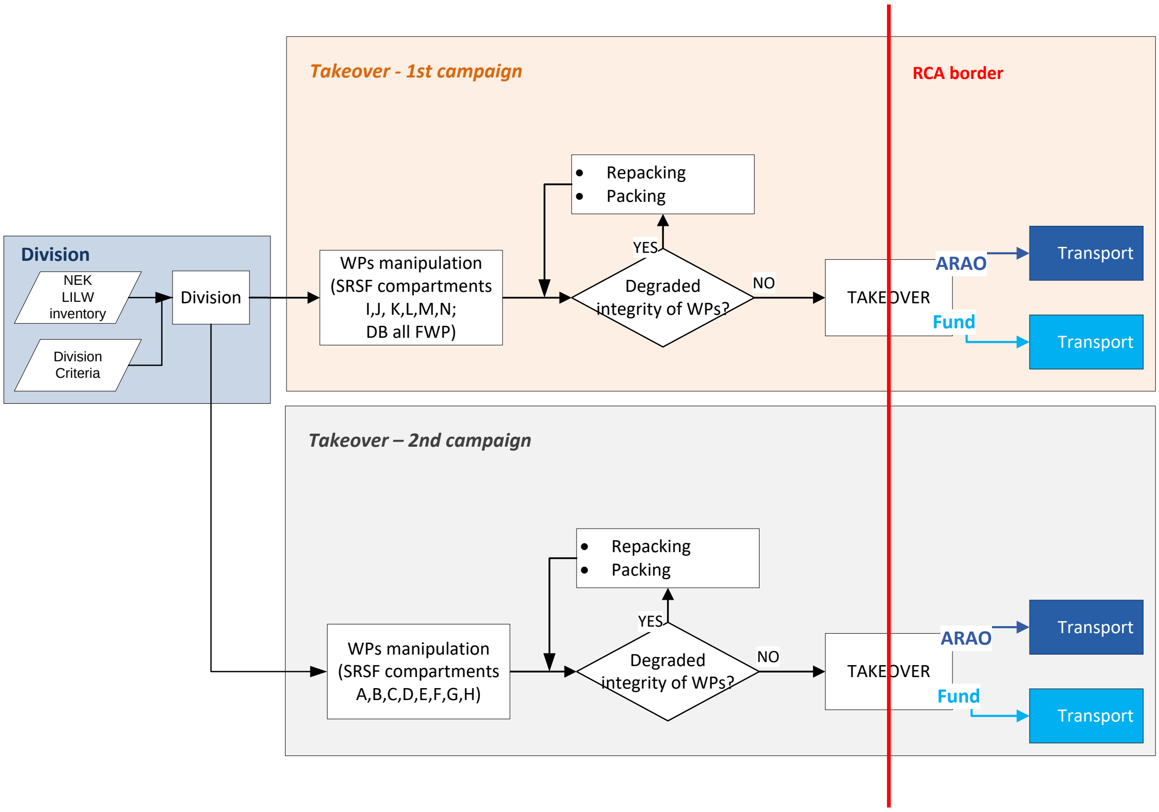


Figure 7-3 presents process scheme for the proposed takeover.

Takeover strategy described above relates to the time period 2023–2025 only. The operational LILW that will be generated over the extended lifetime of Krško NPP will be taken over during the time period 2050–2058. For now it is too early for developing the takeover strategy for aforementioned operational LILW.

7.4.2. Important consideration prior to takeover and division

According to Vrbina WAC [4], Post-Closure Safety Optimization [5] and Krško RW Characterization Project [6] there are at least three waste stream candidates for additional

treatment. These waste streams are not presently stabilized in the manner to fully satisfy disposal requirements. Therefore additional treatment is necessity. These waste streams are:

- EC - IDDS products (Waste form is highly corrosive because content of the boric acid),
- SIR - IDDS products (Waste form is hygroscopic meaning that in the presence of moisture it has unwanted property of swelling), and
- SF – for WPs that are not grouted (void fraction in such WPs should be reduced as much as achievable).

Additionally, all the WPs should be conditioned in long term storage/disposal containers (N2d or RCC).

Treatment and conditioning is performed in specialized facilities. Such a facility is not foreseen neither in Vrbina repository nor in the RWM Centre plans. For now there is no agreement of the Krško NPP owners on the establishing treatment and conditioning capacities within Krško NPP.

In such a circumstances this is important point to be resolved prior to takeover and division of the operational LILW either by establishing facility for treatment and conditioning on Krško NPP location or by contracting treatment and conditioning of Krško NPP LILW as a service in suitable and authorized facility in the third county.

7.4.3. Takeover dynamic

As defined by Intergovernmental Agreement parties have to take over complete operational radioactive waste generated up to year 2023 in period 2023 – 2025.

Takeover dynamic of FWPs in period 2023 – 2025 will be defined:

- by dynamic of conditioning of N2b containers and
- by agreed dynamics of transport of FWPs to treatment facility.

It has to be noted that Fond can take more FWPs at once since the limit will be defined by manipulation and loading time of FWPs into trucks. For NEK the limit is, according to Investment Program, 200 N2b containers per year (approximately 800 TTCs).

According to plans, Vrbina repository is in the idle phase with no reception of LILW in the period 2027–2049, so takeover of Slovenian half of operational LILW generated after 2023 will be after 2050. Also, according to plans long term storage in RWM Centre will be in idle phase from 2029–2049. During this period there will be no takeover of LILW. Croatian half of operational LILW generated after 2023 will be taken over during period 2050 – 2058.

7.5. Inventory of decommissioning LILW

Inventory of decommissioning LILW (Table 7-14) is assessed in PDP Rev.6 where extensive decryption of waste could also be found.

Table 7-14: Decommissioning LILW Inventory

LILW category	Mass to be disposed (t)
LILW from controlled area	2,000.0
LILW from monitored area	744.0
Secondary LILW	508.0
Total	**3,252.0**

Therefore, total decommissioning LILW mass of 3,252.0 t is the subject of division and takeover. Mass of all contaminated material which is presently stored in DB building is included in the total decommissioning LILW mass listed in the table above. Total activity of the mass in the Table 7-14 is assessed to be 5.60×10^{12} Bq.

7.6. Proposal takeover of the decommissioning LILW

Criteria for division of the decommissioning LILW should be consistent with the division criteria for operational LILW taking into account specific properties of decommissioning LILW. Following characteristics of decommissioning LILW will be considered:

- Waste stream (primary and secondary)
- Type of LILW forms packed into distinctive containers (RCC and N2d)
- Mass of LILW packed into distinctive containers
- Total activity of LILW packed into distinctive containers.

The division will be based on specific LILW forms and their corresponding packing concept. According to PDP Rev. 6 following packaging concept will be applied:

- Non-compressible material (cut parts of thick walled components, components which are handled in complete i.e. motors, pumps, valves, steel girders and others) will be packed directly in N2d and RCC (primary LILW).
- Compressible material will be filled in 200-l drums and supercompacted to reduce volume (reduction factor is ranged from 3 to 5). Pellets will be filled in TTCs which will be packaged into N2d containers. In the case of RCC containers pellets will be packed directly (primary LILW).
- Insulation will be filled in 200-l drums. The mean filling grade is estimated to be 50 kg per drum. These drums will be supercompacted (reduction factor of 5) and packaged into a TTCs which will be packaged into N2d containers. In the case of RCC pellets will be packed directly in it (primary LILW).
- Concrete rubble will be directly packaged in the N2d and RCC (primary LILW).
- Activated concrete from biological shield will be cut *in situ* - partially under remote control conditions to suitable dimensions. The material will be packaged directly in N2d and RCC (primary LILW).
- Solids from mechanical decontamination will be collected in 200-l drums which will be packaged in N2d and RCC (secondary LILW).

- Concentrates from decontamination will be treated by evaporation. The concentrates will be collected in 200-l drums which will be packaged in N2d and RCC (secondary LILW).
- Slags and filters which will be sent back from the melting facility will be packaged in 200-l drums which will be put into N2d and RCC (secondary LILW).
- Combusted wastes which will be sent back from the incineration facility will be supercompacted and packaged in 200-l drums. These 200-l drums will be placed into N2d and RCC (secondary LILW).

The packing should be organized in such manner that approximately equal amount (mass and activity) of each specific waste form will be packed into N2d and RCC. The goal will be to satisfy ≤ 5% difference criterion in mass and activity of packed waste form. To perform the division according to proposed criteria the decommissioning LILW has to be characterized so that the mass and activities of each waste form are known. Also, containers must be packed in such a way that long term storage/repository WAC for both sides are fulfilled and that packages are in compliance with national and international regulations for the safe transport of radioactive material.

Since containers are different by weight and volume (N2d has maximum allowable weight of 40 t and useful volume of 12.28 m^3 whereas RCC has maximum allowable weight of 10 t and useful volume of 2.85 m^3) for equally divided decommissioning LILW total number of RCC will be approximately 2.7 times the number of N2d.

Assuming that mass of the decommissioning LILW is divided equally (and that division is equally applied for waste streams from controlled area, monitored area and for secondary LILW, supposing that waste streams are having uniform activity) proposal for division of decommissioning waste is presented in Table 7-15.

Table 7-15: Number of N2d and RCC needed for decommissioning LILW

LILW category	N2d		RCC	
	Packed mass (t)	Number of Packages	Packed mass (t)	Number of Packages
LILW from controlled area	1,000	121	1,000	342
LILW from monitored area	372	38	372	83
Secondary LILW	254	46	254	112
Total	**1,626**	**205**	**1,626**	**537**

Approximately an average N2d contains 8 t while RCC contains 3 t of the decommissioning LILW. If division is commenced in such a way each side will receive approximate nominal activity of 2.80×10^{12} Bq.

7.6.1. Takeover process

PDP Rev.6 assumes that conditioning of decommissioning LILW (placement of waste into RCC and N2d and cementation of containers) will be performed in Krško NPP i.e. that in time

decommissioning LILW should be taken over and divided adequate facility will be established. Conditioned N2d and RCC will be prepared for transport and loaded onto the trucks. The formal takeover process will take place at the radiation-controlled area (RCA) border. The containers will then be transported to the designated long term storage/repository facilities, i.e. RWM Centre in Croatia and Vrbina repository in Slovenia.

7.6.2. Takeover dynamic

The annual production of packages with decommissioning LILW as assumed in PDP Rev. 6 is presented in Table 7-16.

Table 7-16: Annual number of N2d and RCC

Year	No. of packages	
	N2d	RCC
2045	4.8	10.7
2046	9.3	21.0
2047	17.4	38.8
2048	4.2	9.6
2049	0.9	2.4
Subtotal	**36.6**	**82.5**
2050	1.0	2.4
2051	10.7	24.0
2052	37.9	103.3
2053	5.0	11.6
2054	19.4	97.3
2055	5.2	13.8
2056	37.7	85.6
2057	11.1	25.7
2058	12.6	28.6
Subtotal	**140.6**	**392.3**
Total	**177.2**	**474.8**
2103	27.7	61.4
…	0.0	0.0
2106	0.1	0.3
Total	**205.0**	**536.5**

It is important to notice in the Table 7-16 that the decommissioning of Krško NPP facility during period 2043–2058 will result in a production of 178 N2d and 475 RCC. During SFDS decommissioning in the period 2103–2107 additional 28 N2d and 62 RCC will be produced. Decommissioning of Krško NPP facility will produce 2,860.0 t of LILW for disposal (88% of total quantity) while decommissioning of SFDS facility will produce the rest of 392 t of LILW (12% of total).

According to the Investment Programme for LILW disposal facility Vrbina [7] the repository is in the idle phase in the period 2027–2049. Therefore, decommissioning LILW will be accepted at Vrbina repository after 2050. The LILW from decommissioning of SFDS facility generated in the period 2103–2106 will be transported and disposed in the joint HLW disposal facility since LILW repositories will no longer be in operation.

7.7. Costs estimates for division and takeover of LILW

7.7.1. Costs estimates for division and takeover of operational LILW

Costs of division can be defined as costs of this Study and costs of the final revision of the Study, i.e. final division of operational LILW. The final division has to be performed before takeover starts (year 2023) taking into consideration latest data on LILW inventory and recalculated activities of all WPs.

The bearers of the costs are ARAO and Fond in equal parts. It is estimated that the costs of division will be approximately 60,000 €.

The overall takeover process of the operational LILW include following cost items:

- costs for preparation of documentation (WPS and operating procedures development which include loading FWPs on trucks)
- costs for FWPs handling
- costs for the takeover process oversight
- costs for obtaining permits and
- costs for supervising and control of the takeover process.

Krško NPP should bear the first two cost items. Proposal for WPS structure is developed within Krško NPP Radioactive Waste Characterization Project [6] while operating procedures for takeover still need to be developed. Based on the operating procedures the scope of WPs handling activities, number of workers required for takeover activities, necessary additional equipment and related costs will be determined.

URSJV and URSVS should bear the costs for the takeover process oversight according to their engagement. These two regulatory bodies will cover the oversight costs in accordance with practice applied in similar situations.

ARAO and Fond will bear the costs for obtaining appropriate permits. These costs will be covered as the part of transport costs. It should be noted that costs for obtaining permits are minor part of the overall transport costs.

Costs for supervising and control of the takeover process will bear ARAO and Fond. Assessment of these costs are based on the following assumptions:

- for takeover in period 2023 – 2025 there will be 3,986 FWPs (2,386 TTCs, 617 D6 drums, 903 200 l drums and 80 ingots) with total mass of 5,150 t; for takeover in period from 2050 onwards there will be 629 FWPs with total mass of 883.7 t

- FWPs will be loaded into 20' IP-2 containers (drums and ingots) and custom made IP-2 container for TTCs if they will need to be transported in vertical position (if not, then the standard 20’ IP-2 will be used), one container per truck
- the number of required shipments was calculated taking into consideration maximum authorized vehicle weight defined in Council Directive 96/53/EC, 2002/7/EZ and 2015/719, as well as corresponding Slovenian and Croatian legislation
- number of shipments is assessed to be 260 for period 2023 – 2025, and 46 shipments in period from 2050
- it is assessed that one day will be enough for preparing and loading one shipment
- 2 persons are assumed to perform the takeover supervision and control.

Based on above assumptions the total engagement for ARAO and Fond in period 2023 – 2025 will be 520 man-days i.e. 260 man-days per each organization.

For takeover of operational LILW generated until end of Krško NPP lifetime (2043) which will take place after 2050 the total engagement for ARAO and Fond will be 92 man-days i.e. 46 man-days per organization.

The costs of supervising and control of the takeover process include man-hour costs for 2 persons, travel expenses and per diem. Total expenses were calculated by assuming 35 € per man-hour. Calculation is based on 11 € per diem allowance for Slovenia (travel within the country single-day trip lasting 8–12 h) and 25 € per diem allowance for Croatia (travel in Slovenia single-day trip lasting 8–12 h) taking into account appropriate mileage rates (0.215 €/km in Slovenia and 0.27 €/km in Croatia) using as reference distance from ARAO and Fond headquarters to Krško NPP.

Total expenses calculated for period 2023 – 2025 are 164,000 € for ARAO and 166,000 for Fond, while expenses for period after 2050 are 29,000 € for ARAO and 30,000 for Fond.

7.7.2. Costs estimates for division and takeover of decommissioning LILW

Costs of division can be defined as costs of further revisions of this study. These revisions will follow further development of decommissioning project i.e. further revisions of the PDP document.

Considering that revisions of PDP will be made every 5 years and that revisions of PDP will not have detailed characterisation of decommissioning LILW until the final version the cost of future revisions of division of the decommissioning LILW are estimated to be 20.000 € for next 4 revisions and 40.000 € for final revision, which totals to 120.000 €.

The costs of the takeover process are costs of: WPS preparation, loading of conditioned containers onto trucks, takeover process oversight, takeover process control and transport permits. Assuming that the supervision will be performed for each shipment and that 4 containers will be shipped per day the engagement for ARAO and Fund will be 88 man-days and 238 man-days respectively. Assuming standard travel expenses and per diem allowances

for Slovenia and Croatia total expenses are estimated to be approximately 28,000 € for ARAO and 76,000 € for Fond. These expenses will be generated during 9 years (2050 – 2058).

The costs of permits necessary for transport of conditioned containers will be covered as part of contract for transport. It should be noted that costs for obtaining permits are minor part of the overall transportation costs.

7.7.3. Cost optimization

Table 7-17 presents all the estimated costs for division and takeover of operational and decommissioning LILW.

Table 7-17: Division and takeover costs

Cost item	ARAO	Fond	Total
Operational LILW	**223,000€**	**226,000€**	**449,000€**
Division costs – final study	30,000€	30,000€	60,000€
Takeover process control 2023-2025 y	164,000€	166,000€	330,000€
Takeover process control 2050 y	29,000€	30,000€	59,000€
Decommissioning LILW	**88,000€**	**136,000€**	**224,000€**
Division costs – revisions of study	60,000€	60,000€	120,000€
Takeover process control 2050-2058	28,000€	76,000€	104,000€
Total	**311,000€**	**362,000€**	**673,000€**

If the takeover process control will be performed by ARAO and Fond employees than the costs can be reduced significantly i.e. overall costs of division and takeover are more than 60% lower for both ARAO and Fond (Table 7-18).

Table 7-18: Optimized division and takeover costs

Cost item	ARAO	Fund	Total
Operational LILW	**53,000€**	**55,000€**	**108,000€**
Division costs – final study	30,000€	30,000€	60,000€
Takeover process control 2023-2025 y	19,000€	21,000€	48,000€
Takeover process control 2050 y	4,000€	4,000€	9,000€
Decommissioning LILW	**64,000€**	**70,000€**	**134,000€**
Division costs – revisions of study	60,000€	60,000€	120,000€
Takeover process control	4,000€	10,000€	15,000€
Total	**117,000€**	**125,000€**	**242,000€**

7.8. Comment

This is the first analysis of division and takeover. Analysis shows that takeover and division is technically feasible and economically not excessively demanding but that present circumstances in SRSF as well as present level of knowledge of waste packages should improve.

The storage capacity at Krško NPP is almost full. On one hand, it necessitates as early as possible start of emptying, on the other hand, it may hamper an optimum emptying strategy. Due this fact to couple the emptying strategy with any planned division and takeover may be quite difficult, if no manipulation and buffer storage is planned and build for all needed operations.

The proposal for the division of LILW is equitable and reasonable, but from long-term safety and environmental burden points of view, the most important aspect is the content of long-lived radionuclides in waste. Therefore, basing the division on total activity without full knowledge of long-lived radionuclides and difficult to measure radionuclides, only with present knowledge of waste is in itself not the best approach. Renewed waste characterization, including improved determination of the difficult-to-measure nuclides (DMN) will determine the conformance of the inventory and the division with WACs for long term storage and disposal of both sides, since takeover of waste packages from Krško NPP in conformance with national (storage and/or disposal) WACs is expected.

This analysis opened few additional issues.

The approach to the application of clearance levels may need further consideration. If there were different approaches to clearance in the two countries this would inevitably complicate the division of waste and affect the costs to be borne by both countries. It is expected that large amount of slightly contaminated waste streams have already been generated and will be generated during the Krško NPP and SF storage facilities operation, therefore consideration should be given to effective use of the clearance concept and the VLLW disposal option.

Takeover of the decommissioning LILW will take part from year 2050 up to year 2058. Until this time there might be radical changes in strategies (recycle, reuse, free release, etc.). Instead of setting numbers of containers to be shared, in next iteration of this document it is better to agree on the principles and the regular revision of those developments which might influence the division.

Croatian Regulatory Body should be much more involved in takeover process oversight and that has to be agreed with Krško NPP and SNSA.

Waste division can only be considered a defendable and sustainable practice if a set of conditions are precisely agreed and observed by all parties. In the absence of clear and objective criteria, there is a potential for future disputes.

7.9. Appendix

WAC for Disposal in Croatia and Slovenia

Preliminary WAC for storage and disposal in Croatia [8]

Properties	Acceptance criteria	Qualitative description	Remarks
1. Radiological	1.1 Radionuclide composition and specific activity	Radionuclide composition and specific α i β/γ activity must be familiar.	LILW containing radionuclides with a half life less than 30 years. α emitter activity is limited to 4.000 Bq/g (NN, 12/2018) [9]
	1.2 Dose rate (mSv/h)	Dose rate on surface of the package and at 2m distance must be measured.	Values below 2 and 0,1 mSv/h are suggested respectively [10] and [11].
	1.3 Surface contamination (Bq/dm²)	Specific α i β/γ fixed contamination must be limited. Non-fixed contamination must not be measurable.	Limitations are defined in regulatory framework of Republic of Croatia and Republic of Slovenia [12]. α concentration ≤40 Bq/100 cm². β/γ concentration ≤ 400 Bq/100 cm².
	1.4 Degradation effects of radiation	LILW must have radiation stability.	Cumulative dose $\leq 10^6 - 10^7$ Gy.
2. Chemical	2.1 Leachability	LILW must be conditioned in a way to ensure low leachability of radionuclides and other hazardous substances.	Leachability index (LIX) LIX≥6, za diffusion coefficient 5×10^{-3} cm²/day, a leachability rate 3×10^{-5} g/cm²/day.
	2.2 Free liquids	Free liquid content must be reduced to the lowest level that is practically achievable.	Free liquid content ≤ 1% package volume.
	2.3 Corrosivity	Corrositivity of LILW must be reduced to the lowest level that is practically achievable	pH value must be 4≤pH≤9 for waste form, ≤11 for cement. Corrosive materials content must be ≤1% of package weight.
	2.4 Corrosion resistance	Metal containers and concrete containers for storage and disposal must be made out of materials that are resistant to corrosion.	Corrosion rate for metal containers must be 10^{-2}-10^{-4} cm/god.
	2.5 Chelating and complexing agents	Chelating and complexing agents content must be reduced to the lowest level that is practically achievable.	Chelating and complexing agents must be ≤0,1% package weight.
	2.6 Hazardous constituents	Hazardous constituents content must be reduced to the lowest level that is practically achievable	Depending on the type of hazardous material the limitation should be taken from the relevant regulations.
	2.7 Gas generation	Accumulation of flammable and explosive gases and mixtures must be reduced to the lowest level that is practically achievable.	Depending on type of gas and mixture limitation must be below lower limit of explosivity/ignitability.
	2.8 Explosivity	LILW must not contain explosive materials.	Elimination criteria.

Properties	Acceptance criteria	Qualitative description	Remarks
	2.9 Chemical stability	LILW must be chemically compatible with metal and concrete containers. LILW must be resistant to thermal cycles.	Thermal cycles are referred to temperature differences in the range between -40 to +60°C
3. Physical	3.1 Permeability and porosity (void content)	Permeability of LILW must be sufficiently high to allow gases to be vented. Porosity of LILW must be low enough to minimise the release of radionuclides.	For permeability, an orientation limit of $5x10^{-18}$ m^2 (nitrogen) is proposed. Porosity is suggested not to exceed the value of 0,5% of the RCC volume.
	3.2 Homogeneity	LILW must be evenly distributed in metal and concrete container.	Heterogeneous and non conditioned LILW is not allowed to be disposed.
	3.3 Density and weight	Density and weight of LILW must ensure structural stability.	Depends on choice of storage-disposal container. The orientation limit for weight of filled container is 15 t or ~3,5 t/m^3 density.
4. Mechanical	4.1 Compressive strength	Structural stability of disposal units for 300-year period must be ensured.	Proposed value for the compressive strength of LILW waste form is 5 MPa. For concrete container 60 MPa. Tensile strength of waste form should be 1 MPa and for concrete container 5,5 MPa.
5. Thermal	5.1 Ignitability	Self-ignitable, easy ignitable and ignitable materials are not permitted in LILW.	Elimination criteria.
	5.2 Flammability	Metal containers and waste package should withstand external fire.	According to IAEA recommendations for transport of LILW packages (30 min at a 800 °C temperature)
6. Biological	6.1 Organic material	Organic material content must be reduced to the lowest level that is practically achievable	Organic material content must not exceed 3% of the package weight.
7. Package and labelling	7.1 Labelling	Waste packages must be labeled in accordance with the requirements of the regulatory body.	Requirements are set out in[12] and [13].
	7.2 Package	Metal and concrete containers must be approved by the regulatory body. Treatment and conditioning technologies must be approved by the regulatory body.[1]	Requirements are set out in [12] and [13].

1 Particular attention should be focused on aging of H1, H2 and T2 seals.

WAC for disposal in Slovenia at the stage of obtaining the Building Consent and Construction Permit [14]

Properties	Acceptance Criteria	Remarks
Radiological	R.1 Total concetration of α emitters, with half -life exceeding 30 years, in individual waste package	Limit value ≤ 4000 Bq/g
	R.2 Content of individual α emitters in waste package	For each α emitter its content (Bq) should be stipulated
	R.3 Average concentration of α emitters, with half life exceeding 30 years in disposal package	Limit value ≤ 400 Bq/g in average for overall amount of waste in the disposal unit or repository in whole
	R.4 Content of fissile material in waste package	The content of fissile radionuclides shall be limited so that the package is exempted from ADR requirements (ADR Art. 6.4.11.2)
	R.5 Content of β/γ emitters in waste package	For each β/γ emitter content (Bq) should be stipulated.
	R.6 Content of indicvidual β/γ emitters from the list of critical radionuclides in radioactive waste package	Limit values for activity of each β/γ emitter from the list of critical radionuclides Lim Ai(rwp) (beta/gamma): C-14 5.6E+12 Bq; Cl-36 4.2E+07 Bq Ca-41 6.2E+11 Bq; Co-58 8.0E+11 Bq Co-60 1.1E+11 Bq; Se-79 4.3E+08 Bq Nb-94 6.9E+10 Bq; Tc-99 9.7E+10 Bq Ag-108m 4.1E+09 Bq; I-129 3.2E+08 Bq Cs-137 1.9E+12 Bq A rradioactive waste package containing more than one of the above critical radionuclides shall also meet the following condition: $\Sigma(Ai(rwp) Lim/Ai(rwp)) \leq 1$ where: Ai(rwp)–activity of an individual critical radionuclide Lim Ai(rwp)–limit value for activity of the respective critical radionuclide

<table>
<tr><th>Properties</th><th>Acceptance Criteria</th><th>Remarks</th></tr>
<tr>
<td>Radiological</td>
<td>R.7 Content of individual β/γ emitters in disposal package</td>
<td>
R.7.1 Limit for estimated average specific activity of β/γ emitters - ADR limits for LSA materials:
Limit for radioactive waste (except activated metals) is
$Asp_{aver.} \leq 10^{-4} A_2/g$ (LSA-II); and
Limit for activated metals is $Asp(m)_{aver.} \leq 10^{-4} A_2/g$ (LSA-III).
R.7.2 Limit values for total activity of each beta/gamma emitter from the list of critical radionuclides *Lim* Ai(dp) (beta/gamma):
<table>
<tr><th>Radionuclide</th><th>Packaged & unpackaged[2] waste from all waste streams</th><th>Unpackaged metallic waste from NPP decommissioning</th></tr>
<tr><td>C-14</td><td>5.6E+12 Bq</td><td>5.6E+12 Bq</td></tr>
<tr><td>Cl-36</td><td>2.5E+10 Bq</td><td>2.5E+10 Bq</td></tr>
<tr><td>Ca-41</td><td>6.2E+11 Bq</td><td>6.2E+11 Bq</td></tr>
<tr><td>Co-58</td><td>1.0E+12 Bq</td><td>1.6E+13 Bq</td></tr>
<tr><td>Co-60</td><td>1.9E+11 Bq</td><td>2.6E+12 Bq</td></tr>
<tr><td>Se-79</td><td>4.3E+08 Bq</td><td>4.3E+08 Bq</td></tr>
<tr><td>Nb-94</td><td>3.0E+11 Bq</td><td>3.0E+11 Bq</td></tr>
<tr><td>Tc-99</td><td>9.7E+10 Bq</td><td>9.7E+10 Bq</td></tr>
<tr><td>Ag-108m</td><td>3.7E+12 Bq</td><td>3.7E+12 Bq</td></tr>
<tr><td>I-129</td><td>3.2E+08 Bq</td><td>3.2E+08 Bq</td></tr>
<tr><td>Cs-137</td><td>2.0E+12 Bq</td><td>2.0E+12 Bq</td></tr>
</table>
A disposal package containing more than one of the above critical radionuclides shall also meet the following condition: $\sum_i \frac{A_i(dp)}{Lim\ A_i(dp)} \leq 1$
where:
$A_i(dp)$ – total activity of an individual critical radionuclide
Lim $A_i(dp)$ – limit value for total activity of the respective critical radionuclide
</td>
</tr>
</table>

2 Except unpackaged metallic waste from NPP decommissioning.

<table>
<tr><th>Properties</th><th>Acceptance Criteria</th><th>Remarks</th></tr>
<tr><td rowspan="3">Radiological</td><td>R.8 Content of radionuclides in disposal unit or repository</td><td>The limit values for activity of individual β/γ (Bq) are:

Radionuclide[3] Activity
Ag-108m 3.70E+13
C-14 9.83E+13
Ca-41 6.21E+12
Cl-36 2.54E+11
Cs-135 2.49E+10
Cs-137 7.29E+15
I-129 3.24E+09
Nb-94 3.57E+15
Ni-59 4.62E+14
Ni-63 6.59E+16
Se-79 4.32E+09
Sr-90 1.83E+16
Tc-99 1.20E+12
Content of alpha emitters, with half-life exceeding 30 years, and those present in the estimated inventory and giving raise to activity of alpha emitters, with half-life exceeding 30 years, shall not exceed 400 Bq/g, averaged for the overall amount of waste in any disposal unit and repository in the whole.

Total activity6 of radioactive waste disposed in the repository shall not exceed 3,46x10^{17} Bq.</td></tr>
<tr><td>R.9 The dose rate from a disposal packages</td><td>Limit values for dose rate from a disposal package are:

1) surface dose rate ≤2 mSv/h
2) dose rate at 2 m distance from any external surface of the package ≤0,1 mSv/h</td></tr>
<tr><td>R.10 Surface contamination of disposal package</td><td>The non-fixed contamination on the external surfaces of disposal package shall be kept as low as practicable. Under routine conditions of transportation the limit values for surface contamination, averaged over any area of 300 cm2 of any part of the disposal package, are:
1) 4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters
2) 0,4 Bq/cm^2 for all other alpha emitters.</td></tr>
</table>

3 Only beta/gamma emitters that exceed respective exemption levels 300 years after repository closure are listed.

Properties	Acceptance Criteria	Remarks
Chemical	C.1 Free liquid content	Free liquid content inside a disposal container should generally be excluded but small volumes of free liquid in a waste package (<2 %) could be accepted as long as the average free liquid content by volume is less than 1 %.
	C.2 Corrosive content	Waste packages containing forms with pH value lower than 2.5 or higher than 12.5 are not acceptable for disposal. The unpackaged waste forms with pH value lower than 5 or higher than 9 should be neutralized by conditioning.
	C.3 Corrosion resistance	The disposal container shall be of such design as to ensure 300-year functional effectiveness of physical stability of disposal package given expected corrosion processes.
	C.4 Content of chelating and complexing agents in waste package	Chelating and complexing agents content in radioactive waste package and disposal package shall be as low as practicable. Contents (kg) of each chelating and complexing agent present in disposal package shall be stipulated. Limit values for mass fraction of total content of chelating and complexing agents: • RW package ≤1% • disposal package ≤0.5%%
	C.5 Content of toxic materials	The content of toxic materials in waste package should be reduced as much as practicable. Content of individual toxic materials, their quantity (kg), present in waste package shall be stipulated. The limit values for toxic material content (kg) in disposal unit or repository are: Antimony 205 kg; Arsenic 836 kg; Boron 9006 kg; Cadmium 34 kg; Chromium 210737 kg; Copper 65919 kg; Lead 2524 kg; Mercury 4 kg; Nickel 216987 kg; Selenium 169 kg-
	C.6 Gas generation and content	Disposal of radioactive waste containing pressurized vessels is not allowed. Content of gas generating material in radioactive waste forms, radioactive waste packages and disposal packages shall be reduced as much as practicable. Limit value for total gas generation in disposal package - 194 l/day.
	C.7 Explosive content	Disposal of radioactive waste with explosive content is not allowed.
	C.8 Chemical stability	Radioactive waste form chemistry shall be compatible with materials from which the metal container and concrete disposal container are made, with material of concrete container infill, and with RC structure of silo.
Mechanical	M.1 Compressive strength	The disposal container and silo walls shall be of such design and materials as to ensure 300 y structural stability.
Thermal	T.1 Ignitability	Qualitative formulation proposed for this radioactive waste acceptance criterion is that disposal of radioactive waste containing pyrophoric, low flammable and flammable materials is not allowed.

Properties	Acceptance Criteria	Remarks
	T.2 Flammability	The following qualitative formulations are proposed for this radioactive waste acceptance criterion: 1) Radioactive waste packages shall have thermal stability. 2) Disposal container shall be fire resistant. 3) Thermal cycles shall not compromise structural stability of disposal package.
Biological	B.1 Organic substances composition	Organic content in waste package should be reduced to practically achievable minimum. Content of organic materials in disposal package shall be specified by mass and type.
Physical	P.1 Permeability	Average gas permeability of disposal container concrete (m^2) shall be in the range $1x10^{-16}$ - $4x10^{-18}$.
	P.2 Porosity	Average total porosity of disposal container concrete shall be in the range 9%-12%.
	P.3 Homogeneity	Local concentration of materials in waste package that may compromise the ability of the disposal package to meet any of acceptance criteria related to radiological or chemical properties should be avoided.
	P.4 Density	The disposal package shall concurrently meet the following conditions: 1) Total mass of disposal package ≤ 40 t 2) Density of grout in the disposal container ≥1900 kg/m^3 3) Average density of the disposal container content ≤3974 kg/m^3
	P.5 Void Fraction	Volume of voids in radioactive waste package and disposal package shall be reduced to practically achievable minimum by a suitable waste conditioning process. Disposal package containing in drum drying system (IDDS) processed spent ion-exchange resins shall have sufficient void space to accommodate swelling of the waste form in contact with water. Limit value for voids fraction in disposal package ≤ 16%.
Identification and Packaging	I.1 Package marking	The disposal package shall be marked to meet the requirements of paras 1-3 Article 10, Regulation JV7, namely: 1) Disposal package shall be identified with radioactivity symbol and label, 2) The label shall contain unique identification of the package in both eye-readable and digital form, package mass, radioactive waste category and type, and the highest measured package surface dose rate. 3) The radioactivity symbol and the label shall be durable, affixed at visible locations and clearly legible.
	I.2 Disposal container and packaging method[4]	Certified reinforced concrete container N2d meeting the LILW repository design requirements must be used for radioactive waste disposal in LILW repository.

4 Particular attention should be focused on aging of H1, H2 and T2 seals.

Properties	Acceptance Criteria	Remarks
		Radioactive waste forms and radioactive waste packages shall be packaged in N2d concrete disposal container. Packaging method shall be in compliance with the LILW repository design and not compromise the ability of the disposal package to meet any of the defined waste acceptance criteria for disposal.

7.10. References

1 Analysis of Potential Division and Takeover of Operational and Decommissioning RW from Krško NPP, Extended Contents, Enconet and Ekonerg, 2018 and

ToR for the development of the study Analysis of the Possible Division and Takeover of Operational and Decommissioning LILW from Krško NPP, FUND & ARAO, 3-1/18-2-1/1, January 26, 2018

2 Gospodarenje z radioaktivnimi odpadki v NE Krško, NEK ESD-TR-03/97, Rev.9, NEK,2018

3 There are certain concerns that because of the long-term storage (30 years) some WPs could be degraded.

4 Merila sprejemljivosti RAO za odlagališče NSRAO, Rev.1, NSRAO2-POR-014-01, ARAO, 2017

5 EISFI, Safety Analysis and Waste Acceptance Criteria Preparation for Low and Intermediate Level Waste Repository in Slovenia, Post-Closure Safety Optimization Report Rev.1, NSRAO2-PCS-002-01, June 2012.

6 Krško NPP Radioactive Waste Characterization Project, Enconet, 2006

7 IBE, Investment Programme for the LILW disposal facility Vrbina, Krško, Rev. D with appendices, 2017

8 Enconet, Preliminarni kriteriji i specifikacije paketa za prihvat i skladištenje RAO i II u Centru, 2016.

9 Ordinance on the Management of Radioactive Waste and Disused Sources, Official gazette of Republic of Croatia, No. 12/2018

10 European Agreement concerning the International Carriage of Dangerous Goods by Road: ADR applicable as from 1 January 2017, United Nations Economic Commission for Europe (UNECE), 2017

11 IAEA, Regulations for the Safe Transport of Radioactive Material, Specific Safety Requirements, No. SSR-6, Rev. 1, 2018

12 UV2, Decree on limit doses, reference levels and radioactive contamination, Official Gazette of Republic of Slovenia, No. 18/2018

13 Ordinance on Permissions and Allowances for the Application and Transport of the Ionizing Radiation Sources, Official gazette of Republic of Croatia, No. 42/2013, 9/2017

14 ENCO, WAC Synthesis Report – Summary and Optimization Recommendations at the Phases of Obtaining Building Consent and Construction Permit, ARAO, EISFI-TR-(11)-15 Volume 3, Revision 2, January 2019

8. Overview of the costs

This chapter is based on the costs previously presented in chapters 3, 5, 6 and 7.

Abbreviations

€	euro (EUR)
DP Rev.3	3rd Revision of the NPP Krško Decommissioning Program
DGR	Deep Geological Repository
FUND NEK	Fund for the Financing of the Decommissioning and Disposal of Radioactive Waste and Spent Nuclear Fuel from the Krško Nuclear Power Plant, Zagreb, Croatia
LILW	Low and Intermediate Level Waste
IRR	Internal Rate of Return
R&D	Research and Development
RC	Republic of Croatia
RS	Republic of Slovenia
SF	Spent Fuel
VAT	Value Added Tax
ARAO	Agency for Radwaste Management, Ljubljana, Slovenia
SKLAD NEK	Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Radioactive Waste from the Krško NPP, Ljubljana, Slovenia

8.1. Introduction

This chapter presents overview of all the costs for baseline scenarios (joint SF and HLW management and separate management for LILW with division and takeover according to national strategies) of different Krško NPP SF and RW management segments. Presented costs cover: compensation to local community for SF and HLW dry storage (establishment and operation of facility until 2043 are part of Krško NPP operational costs), SF and HLW disposal (including establishment, operation, decommissioning and closure of Deep Geological Repository, establishment, operation and decommissioning of encapsulation plant and transport costs), LILW division and takeover, management of Slovenian half of LILW (establishment, operation, decommissioning and closure of Vrbina LILW repository) and management of Croatian half of LILW (transport, treatment and conditioning, establishment, operation and decommissioning of long term storage and establishment, operation, closure and institutional control of LILW repository).

Scenarios describe different activities including establishment of SF, HLW and LILW management facilities and its operations from 2018 till 2112 when institutional control of Croatian LILW repository ends.

First part presents overview of nominal costs in € 2018 for baseline scenarios with time distribution of costs. Second part presents discounted costs.

8.2. Nominal costs

Since VAT is defined in accordance with the Slovenian and Croatian tax regulations (in 2018 for RS VAT was 22% and in RC VAT was 25%) there is difference in the total price of SF disposal management depending on whether the SF repository is built in Slovenia or in Croatia. Consequently, there are two overall total nominal costs for baseline scenarios.

Overview of costs is done through five costs categories: (1) Investment costs, (2) Operational costs, (3) Contingency, (4) VAT and (5) Compensation to local community (CLC).

Regarding SF dry storage, construction costs are part of Krško NPP operating costs e.g. costs of Krško NPP operator. The same is true for SF storage operational costs during the Krško NPP lifetime. SF and HLW dry storage operational costs after 2043, costs for SF storage canisters and transport in phase III and decommissioning costs are included in the Third revision of the NPP Krško Decommissioning Program under WBS project 16. Only the costs foreseen for compensation for restricted land use (compensation to local community) are considered here.

Investment costs for SF Disposal management presented here unite Investment and construction costs for disposal unit and encapsulation plant, decommissioning and

closure costs in addition to siting, project administration, R&D and site purchase costs in single item to be compared with operation costs which envelop operation and maintenance costs for disposal facility as well as for above ground facilities. There is difference in total costs for baseline scenario as result of VAT difference between RS and RC (Slovenian VAT for disposal unit in Slovenia is 22% as compared to Croatian VAT of 25% for disposal unit in Croatia) resulting in RS VAT 171,53 mil. €, and RC VAT 194,92 mil. €.

Included in overview of the costs here are optimized costs for division and takeover e.g. costs with the assumption that ARAO and FUND staff will actively participate in the takeover and division activities.

Different presentation of the LILW management costs for RS and RC (in the chapters 5 and 6) was also unified by regrouping the costs into 5 categories. For RS it was done using Table 5-9 (costs Total financed from SKLAD NEK) where already invested funds to Vrbina repository are included as investment funds, and for RC it was done using Table 6-10 assuming that treatment, conditioning and transport costs are part of investment costs.

Overview of the nominal costs is presented in Table 8-1. Costs are in rounded mil. € 2018. TOTAL SLO and TOTAL CRO represent overall costs assuming SF and HLW repository in RS and SF and HLW repository in RC, respectively.

Table 8-1 Overall Krško NPP SF and LILW management costs

		Investment	**Operation**	**Contingency**	**VAT**	**CLC**	**Total**
		costs					
		in mil. € 2018					
SF dry storage		-	-	-	-	37,12	37,12
SF disposal	**SLO**	405,07	240,47	193,67	171,53	126,12	1.136,86
	CRO	405,07	240,47	193,67	194,92	126,12	1.160,25
Division and takeover		-	0,24	-	-	-	0,24
LILW management SLO		84,89	58,00	5,56	27,38	164,47	340,30
LILW management CRO		93,59	31,07	13,47	24,31	44,00	206,44
					TOTAL DGR in SLO		1.720,96
					TOTAL DGR in CRO		1.744,35

8.3. Time distribution costs

In order to prevent presentation of overall nominal costs for two possible scenarios of SF disposal in CRO or SLO, which differ in VAT, the Slovenian costs will be used for both countries.

Following is the Table which summarizes Slovenian LILW and SF management nominal costs from 2018 to 2110, and the Figure which presents annual distribution of LILW and SF nominal costs from 2018 to 2110. Already invested funds (including CLC) to Vrbina repository until 30/06/2018 are estimated to 74, 310 mil. € and are included in total LILW management costs for the Vrbina repository as presented in Table 8-1. For SF&HLW storage and disposal there were no funds invested until 30/06/2018 other than very small amount for preparation of supporting studies for HLW&SF management.

Table 8-2 LILW and SF nominal costs (RS) in mil. €.

	LILW Vrbina	SF & HLW storage	SF disposal	Total
Costs	118,38		322,78	441,16
VAT	23,00		85,77	108,77
Contingencies	5,56		96,84	102,40
CLC	119,17	18,56	63,06	200,79
Total	**266,11**	**18,56**	**568,44**	**853,11**

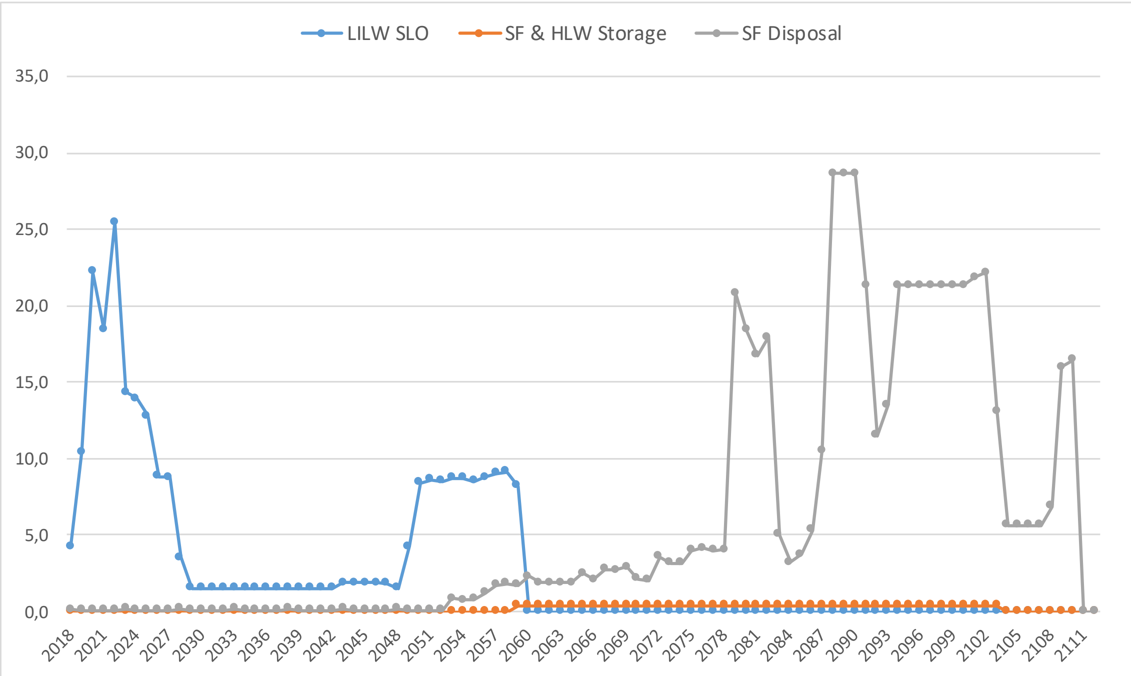


Figure 8-1: Annual distribution of Slovenian nominal SF and LILW costs

Following is the Table which summarizes Croatian LILW and SF management nominal costs from 2018 to 2112, and the Figure which presents annual distribution of LILW and SF nominal costs from 2018 to 2112.

Table 8-3 LILW and SF costs (RC) in mil. €.

	LILW Čerkezovac	SF & HLW storage	SF disposal	Total
Costs	124,66		322,78	447,44
VAT	24,31		85,77	110,07
Contingencies	13,47		96,84	110,31
CLC	44,00	18,56	63,06	125,62
Total	**206,43**	**18,56**	**568,44**	**793,43**

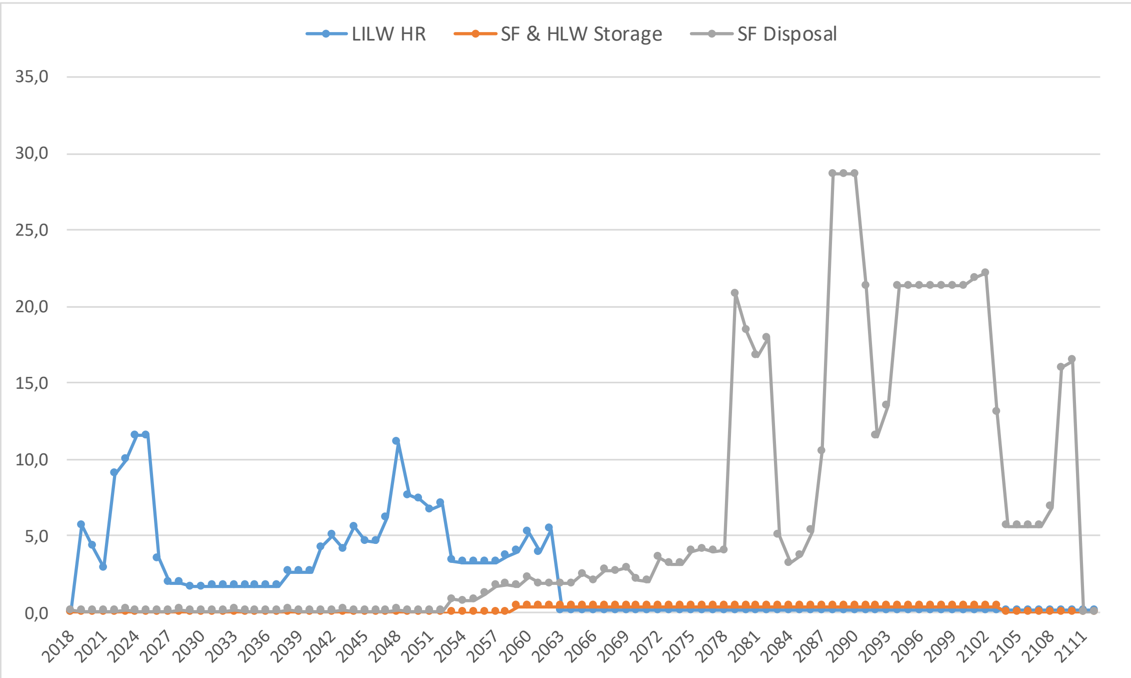


Figure 8-2: Annual distribution of Croatian nominal SF and LILW costs

8.4. Discounted costs

8.4.1. Discounting methodology and selection of discounting parameters

In order to determine the annual amounts (annuities) which both owners have to pay into the national decommissioning fund, an Internal rate of return (IRR) is assumed.

IRR represents the required yield rate that ensures the solvency of the fund, so that it enables settlement of future decommissioning, management and disposal costs of radioactive waste and spent nuclear fuel.

In the mathematical and financial sense, IRR represents a discount rate that equates the present value of the assets of the fund (the fund's net asset value and future payments to the fund) with the present value of the fund's liabilities (future costs)

It is assumed that the fund's assets are accrued and liabilities are discounted at the same IRR on average annual basis.

Here is the mathematical formula for calculating IRR:

$$V_0 + \sum_{t=0,25}^{25} \frac{P_t}{(1+IRR)^t} = \sum_{t=1}^{94} \frac{I_t}{(1+IRR)^t}$$

$$I_t = I_t^{2018.} (1+i)^t$$

IRR - Internal rate of return,
V_0 - Fund's net asset value (NAV) at the end of period (2017.)
Pt - Quarterly payments to Fund,
It - Fund's estimated liabilities
i - Inflation rate

It is assumed that the funds will receive quarterly annuities by 2043 when Krško NPP will shutdown. Annuities are assumed to be paid at the end of each quarter (the first one at the beginning of 2018, the last one at the end of 2043). The calculation is taking into account officially reported amounts accumulated in the funds in RS and RC at the end of 2017 and 2018, while for the remaining period until the end of 2043 assumed annuities are considered.

The nominal costs (which have been determined in €2018) are distributed in time according to the schedule of respective operations (and expressed annually, assumed to be paid by the end of the year), and each of them will be discounted from its respective year to the initial moment i.e. to the year 2018.

The general inflation rate is estimated on the basis of an average weighted inflation rate related to the historical growth rates (2004-2018) of capital goods, construction industry, engineering services and inflation (HICP index) both in Euro zone and Croatia. The general inflation rate is estimated at 1,80% per year.

Internal rate of return was calculated using Microsoft's spreadsheet and data analysis tool – Excel, according to the tool designed by Faculty of Economics & Business, University Zagreb, Croatia [1].

Since the Internal rate of return has to be calculated against all the expected costs it is necessary to include decomissioning costs as well, as estimated in the document "3rd Revision of the NPP Krsko Decommissioning Program FIN, June 2019" [2].

Following are the Tables which include decomissioning costs + SF storage costs together with LILW costs, and SF disposal costs, which will be used for the calculation of Internal rate of return (Total costs).

Table 8-4 Total costs (RS) in mil. €.

	LILW Vrbina	SF & HLW storage	SF disposal	Total
Costs	118,38		322,78	441,16
VAT	23,00		85,77	108,77
Contingencies	5,56		96,84	102,40
CLC	119,17	18,56	63,06	200,79
Subtotal	266,11	18,56	568,44	853,11
Decomm. & SFDS		236,72		

	LILW Vrbina	Decomm. + SF & HLW storage	SF disposal	Total
Total	**266,11**	**255,28**	**568,44**	**1.089,83**

Table 8-5 IRR calculation for the Republic of Slovenia, costs in mil. €.

LILW in the Republic of Slovenia	266,11
Decommissioning & SF storage	255,28
SF disposal	568,44
Total nominal costs	**1.089,83**
GEN annual payments (2004 - 2043)	8,00
SKLAD Net asset value at the end of 2017	198,16
General inflation rate	1,80%
IRR (discounting rate i.e. target yield of the Slovenian fund SKLAD NEK)	**4,72%**

With the assumption of GEN's annual payments in the amount of EUR 8,00 million to be continued until 2043, the total expenditures of the fund in the amount of EUR 1.089,83 million, and estimated cost escalation (inflation) at annual rate of 1.80%, discount rate expressed as an internal rate of return (IRR) for the Slovenian fund SKLAD is 4,72%.

Table 8-6 Total costs (RC) in mil. €.

	LILW Čerkezovac	SF & HLW storage	SF disposal	Total
Costs	124,66		322,78	447,44
VAT	24,31		85,77	110,07
Contingencies	13,47		96,84	110,31
CLC	44,00	18,56	63,06	125,62
Subtotal	206,43	18,56	568,44	793,43
Decomm. & SFDS		236,72		

	LILW Čerkezovac	Decomm. + SF & HLW storage	SF disposal	Total
Total	**206,43**	**255,28**	**568,44**	**1.030,15**

Table 8-7 IRR calculation for the Republic of Croatia, costs in mil. €.

LILW in the Republic of Croatia	206,43
Decommissioning & SF storage	255,28
SF disposal	568,44
Total nominal costs	**1.030,15**
HEP annual payments (2004 - 2043)	14,25
FUND NEK Net asset value at the end of 2017	252,50
General inflation rate	1,80%
IRR (discounting rate i.e. target yield of the Croatian fund FUND NEK)	**3,00%**

With the assumption of HEP's annual payments in the amount of EUR 14,25 million to be continued until 2043, the total expenditures of the fund in the amount of EUR 1.030,15 million, and estimated cost escalation (inflation) at annual rate of 1.80% discount rate expressed as an internal rate of return (IRR) for the Croatian FUND NEK is 3,00%.

Annuities for each country have been calculated in respect to desired Internal Rate of Return ranging from 2% to 6% and are presented in the following Figure.

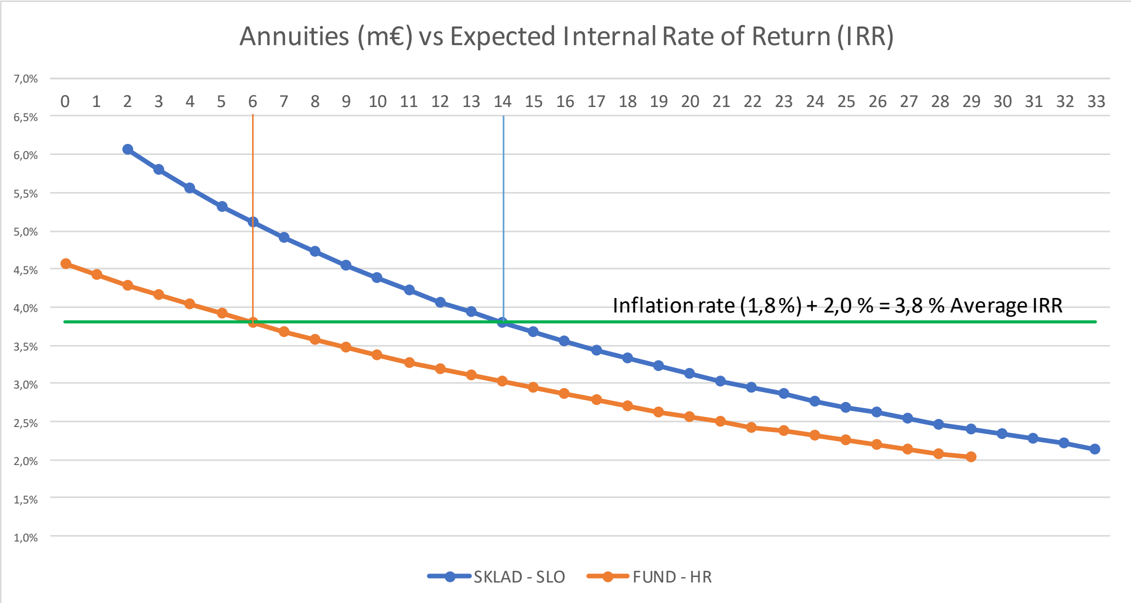


Figure 8-3: Annuities of Slovenian and Croatian Funds in respect to desired Internal Rate of Return ranging from 2% to 6%.

Table 8-8 Values of expected average Internal Rate of Return in relation to annuities as presented in **Figure 8-3**

	Expected average IRR	
Annuities m€	SKLAD - SLO	FUND - HR
0		4,57%
1		4,43%
2	6,06%	4,29%
3	5,80%	4,16%
4	5,55%	4,03%
5	5,32%	3,91%
6	5,11%	3,80%
7	4,91%	3,68%
8	4,72%	3,58%
9	4,54%	3,47%
10	4,38%	3,38%
11	4,22%	3,28%
12	4,07%	3,19%
13	3,93%	3,10%
14	3,80%	3,02%
15	3,67%	2,94%
16	3,55%	2,86%
17	3,44%	2,78%
18	3,33%	2,71%

	Expected average IRR	
Annuities m€	SKLAD - SLO	FUND - HR
18	3,33%	2,71%
19	3,23%	2,63%
20	3,13%	2,56%
21	3,03%	2,50%
22	2,94%	2,43%
23	2,86%	2,37%
24	2,77%	2,31%
25	2,69%	2,25%
26	2,62%	2,19%
27	2,54%	2,13%
28	2,47%	2,08%
29	2,40%	2,03%
30	2,33%	
31	2,27%	
32	2,21%	
33	2,14%	
34	2,09%	
35	2,03%	

Values presented in Table 8-8 show the correlation between average Internal Rates of Return and annuities for each Fund. Since the Croatian Fund has approximately 70 mil. € more than Slovenian Fund at the starting year of calculations, IRR value of 4,57% assumes no additional payments are needed, for which reason it is not possible to present the annuities above this value (annuities tend to negative values).

As the general inflation rate is estimated at 1,80% per year [1] presented data in Figure 8-3 estimate the illustration of needed annuities for both Funds according to Internal Rate of Return to be 2,0% above the inflation rate (1,8%), resulting in IRR of 3,8%. Needed annuities under this circumstance for Slovenian Fund are approximately 14 mil. €, while for the Croatian Fund annuities are approximately 6 mil. €.

8.5. Time distribution of discounted costs

Based on the Internal Rate of Return calculation, discounted costs were calculated for each country and are presented in the following Figures, for the IRR values of 2%, 3%, 4%, 5% and 6%.

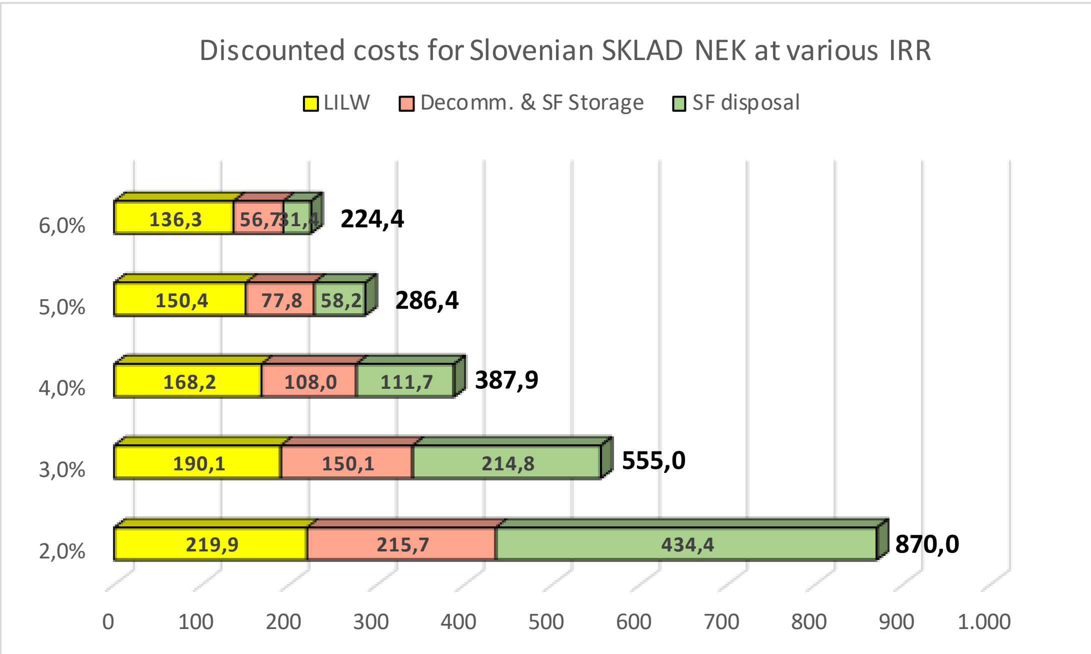


Figure 8-4: Slovenian discounted costs in mil. € for LILW, Decommissioning + SF & HLW storage and SF.

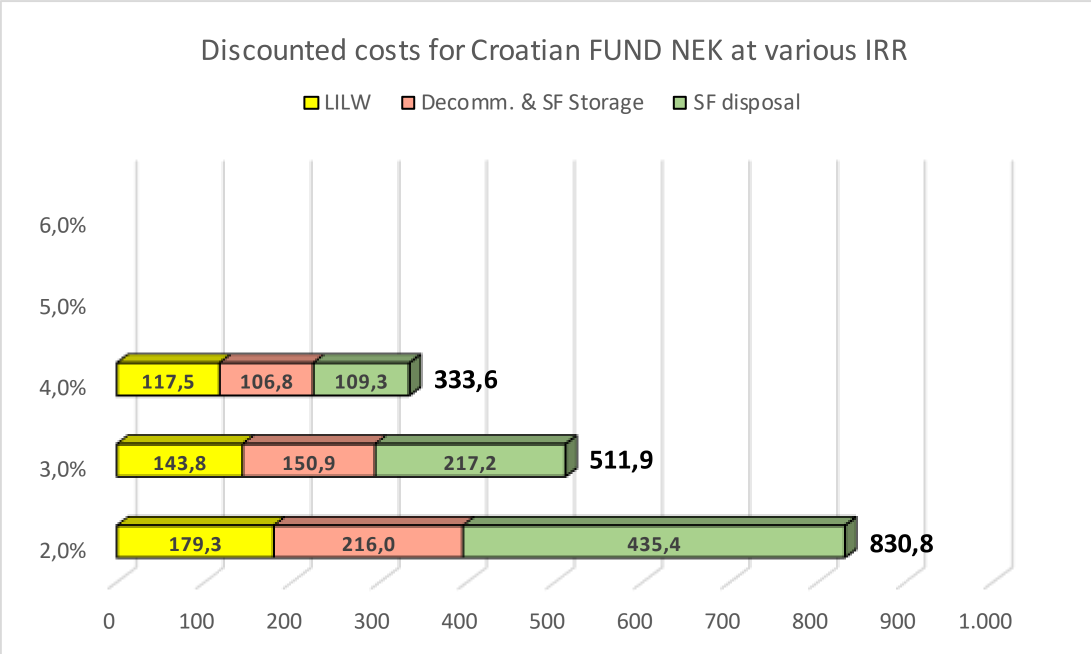


Figure 8-5: Croatian discounted costs in mil. € for LILW, Decommissioning + SF & HLW storage and SF.

Regarding GEN's current annual payments in the amount of EUR 8,0 million by 2043, the total expenditures of the fund in the amount of EUR 1.089,83 million, and estimated cost escalation (inflation) at annual rate of 1.80%, discount rate expressed as an Internal Rate of Return (IRR) for the Slovenian fund SKLAD is 4,72%, as presented above.

Discounted costs for this IRR are presented in the followiong Table, while time distribution of these discounted costs is presenrted in the following Figure.

Table 8-9 Discounted costs for Slovenian Fund in respect to current annuities of 8,0 m€.

	Average yield	LILW	Decomm. + SF & HLW storage	SF disposal	Total
SKLAD NEK (SLO)	**4,72%**	154,99	85,22	69,74	**309,95**

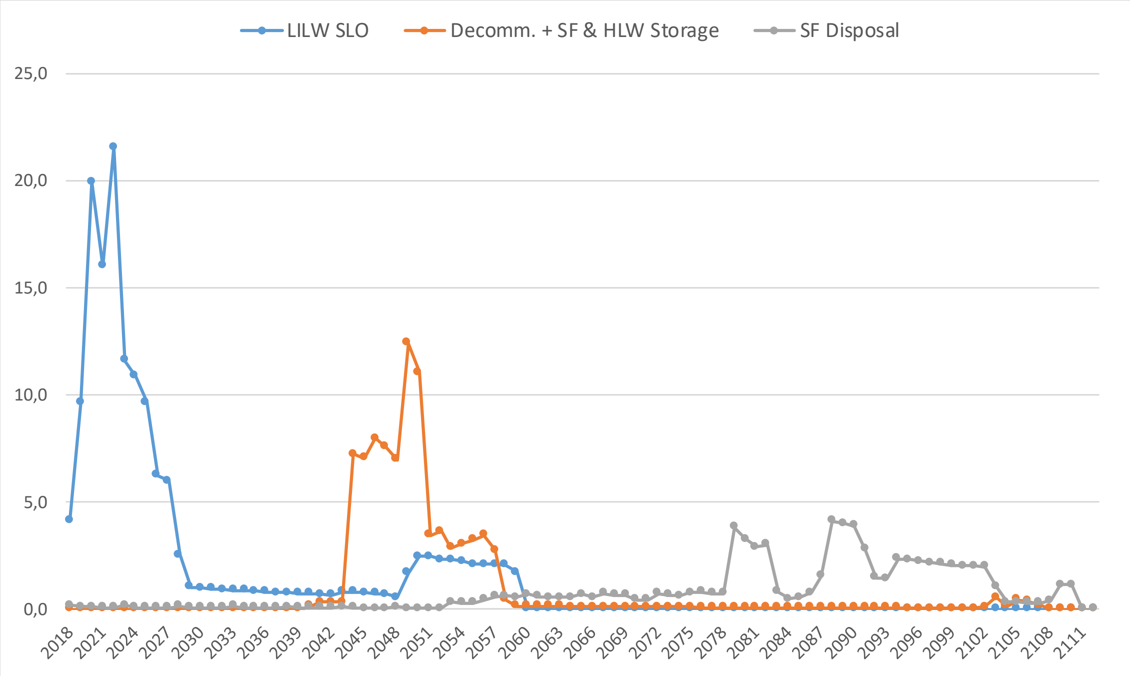


Figure 8-6: Annual distribution of Slovenian discounted LILW, Decommissioning + SF & HLW storage and SF costs at IRR of 4,72% and annuities of 8,0 mil. €..

Discounted costs for IRR of 3,8% (2% above the inflation rate) are presented in the followiong Table, while time distribution of these discounted costs is presented in the following Figure.

Table 8-10 Discounted costs in mil. € for Slovenian Fund in respect to annuities of 14,0 mil. €.

	Average yield	LILW	Decomm. + SF & HLW storage	SF disposal	Total
SKLAD NEK (SLO)	**3,80%**	172,33	115,51	127,80	**415,64**

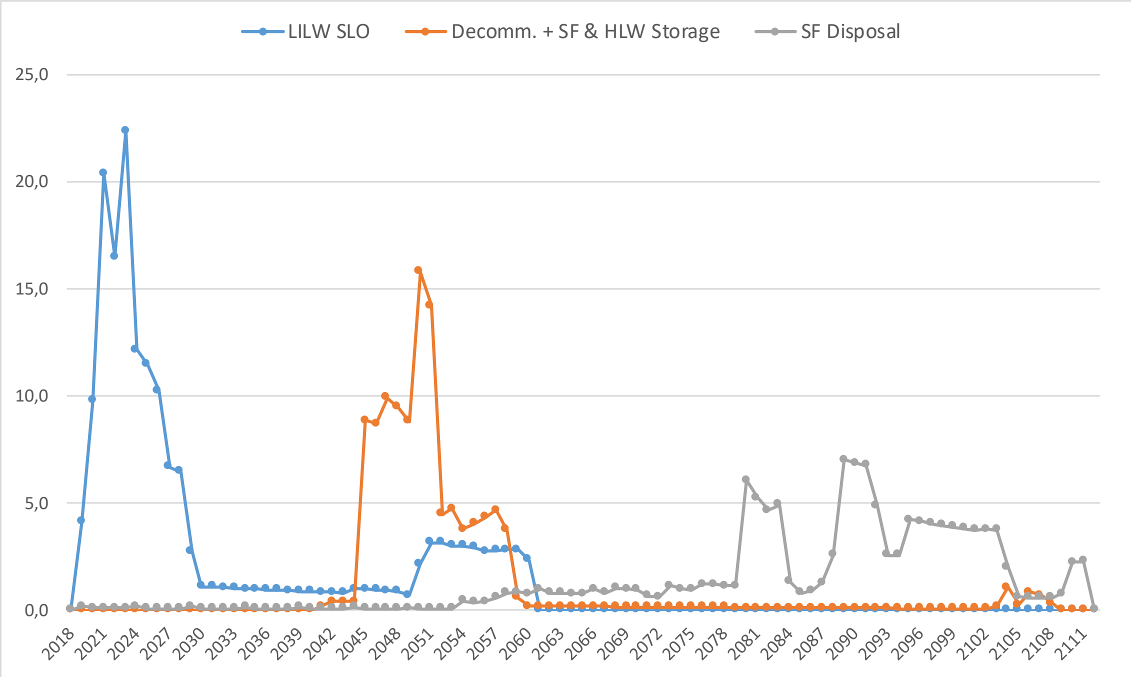


Figure 8-7: Annual distribution of Slovenian discounted LILW, Decommissioning + SF & HLW storage and SF costs at IRR of 3,80% and annuities of 14,0 m€.

Regarding HEP's current annual payments in the amount of EUR 14,25 million by 2043, the total expenditures of the fund in the amount of EUR 1.030,15 million, and estimated cost escalation (inflation) at annual rate of 1,80% discount rate expressed as an Internal Rate of Return (IRR) for the Croatian FUND NEK is 3,00%, as presented above.

Discounted costs for this IRR are presented in the followiong Table, while time distribution of these discounted costs are presented in the following Figure.

Table 8-11 Discounted costs for Croatian Fund in respect to current annuities of 14,25 mil. €.

	Average yield	LILW	Decomm. + SF & HLW storage	SF disposal	Total
FUND NEK (CRO)	**3,00%**	144,41	152,04	220,32	**516,77**

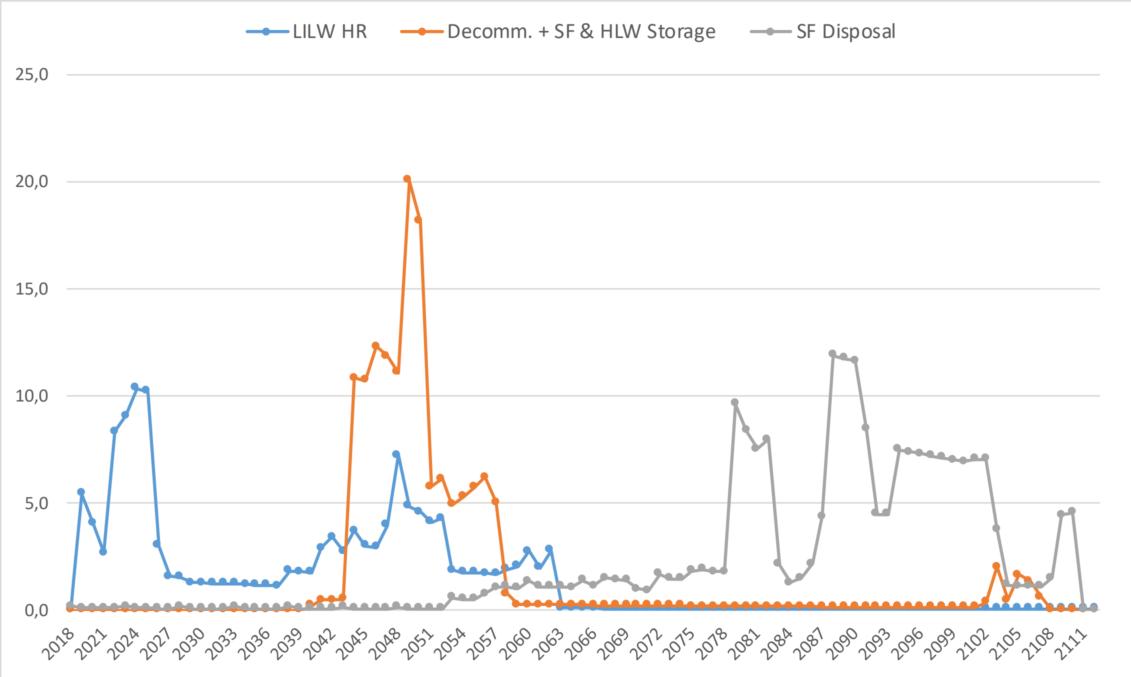


Figure 8-8: Annual distribution of Croatian discounted LILW, Decommissioning + SF & HLW storage and SF costs at IRR of 3,00% and annuities of 14,25 m€..

Discounted costs for IRR of 3,8% (2% above the inflation rate) are presented in the followiong Table, while time distribution of these discounted costs is presented in the following Figure.

Table 8-12 Discounted costs for Croatian Fund in respect to annuities of 6,0 mil. €.

	Average yield	LILW	Decomm. + SF & HLW storage	SF disposal	Total
FUND NEK (CRO)	**3,80%**	122,92	115,59	127,97	**366,48**

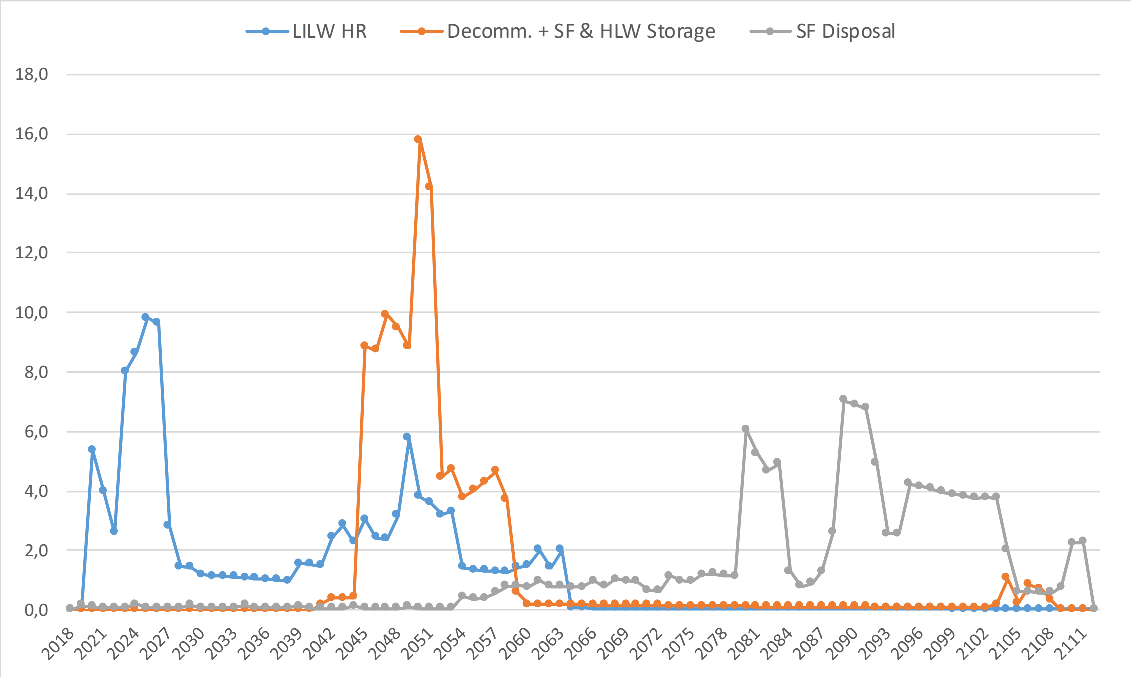


Figure 8-9: Annual distribution of Croatian discounted LILW, Decommissioning + SF & HLW storage and SF costs at IRR of 3,80% and annuities of 6,00 m€.

8.6. References

[1] "Određivanje diskontne stope za utvrđivanje novčanog toka i prinosa na dugoročno ulaganje Fonda NEK", Ekonomski fakultet, Sveučilište Zagreb, 2018."

[2] Siempelkamp NIS Ingenieurgesellschaft mbH, 3rd Revision of the NPP Krsko Decommissioning Program, Document No.: 4520 / CA / F 010640 5 / 01, FIN. June 2019

9. Conclusions and recommendations

Abbreviations

ARAO	Agency for Radwaste Management, Ljubljana, Slovenia
CLC	Compensation to local community
DP Rev.1	*1st revision of the Program of NPP Krško Decommissioning and SF & LILW Disposal*
DP Rev.3	3rd Revision of the NPP Krško Decommissioning Program
EU	European Union
Fund	Fund for the Financing of the Decommissioning and Disposal of Radioactive Waste and Spent Nuclear Fuel from the Krško Nuclear Power Plant, Zagreb, Croatia
HLW	High level waste
IC	Intergovernmental Commission
ICC	Implementation Coordination Committee
ILW	Intermediate level waste
Intergovernmental Agreement	Agreement between the Government of the Republic of Slovenia and the Government of the Republic of Croatia on the Regulation of the Status and Other Legal Relations Regarding the Investment, Exploitation and Decommissioning of the Krško NPP
LILW	Low and Intermediate Level Waste
RC	Republic of Croatia
RS	Republic of Slovenia
RW	Radioactive Waste
SF	Spent Nuclear Fuel
SFDS	Spent fuel dry storage
Sklad NEK	Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of Radioactive Waste from the Krško NPP, Krško, Slovenia
SRSF	Solid Radwaste Storage Facility
ToR	Terms of Reference
VAT	Value added tax

9.1. Introduction

1st revision of the Program of NPP Krško Decommissioning and SF & LILW Disposal (DP Rev.1) was document that combined in single text two programmes required by Intergovernmental Agreement: *Krško NPP Decommissioning Program* and *Krško NPP Radioactive Waste and Spent Fuel Disposal Program*. DP Rev.1 played important role in establishment of a symmetrical bilateral commitment to continuous and transparent sharing of responsibilities for the future implementation of Intergovernmental Agreement. Although neither side interpreted DP Rev.1 as an actual agreement on particular technical solutions, both *sides* accepted their respective shares of financing responsibility for the realization of Krško NPP decommissioning and Krško NPP SF and RW disposal programmes.

ToR for this document assumed separation of decommissioning and SF and RW management programmes in two documents. As a result, this is Third revision of *Krško NPP RW and SF Disposal Program* constraining on RW and SF management only. Third Revision of the Krško NPP Decommissioning Program preparation was entrusted to Krško NPP Ltd. It was drafted as a separate document and used as supporting material for the preparation of this document [1].

Krško NPP is in joint Slovenian-Croatian ownership and although there is joint responsibility for RW and SF management as defined by Intergovernmental Agreement, preparation and revisions of RW and SF management programme has unavoidable political aspects: RS and RC are having each national RW and SF strategies and corresponding National RW and SF management programmes as required by EU Directive reflecting different national interests.

Third revision of *Krško NPP Radioactive Waste and Spent Fuel Disposal Program* presents in joint document views of both sides on Krško NPP RW and SF management. For SF and HLW it is assumed that management will be joined: SF will be in dry storage on the location of Krško NPP and then it will be disposed in SF repository on the location which is still undetermined, somewhere on the territory of RS or RC, or disposed in a regional or multinational repository, if possible. In current plan, operational and decommissioning LILW will be divided in halves as stipulated by Intergovernmental Agreement and then taken over from the site of Krško NPP. Each country will then manage its LILW in accordance with national RW management programmes disposing finally LILW in the national repositories on own territory. The Intergovernmental Commission after acceptance of ToR (conclusion from its 12 session, January 22, 2019) ordered ICC to analyze the technical, legal and financial conditions for possible joint solution for management of LILW in future iterations.

This document was drafted (with supporting studies) in rather short time (approximately year and the half).

In this revision of document, as compared to the first and approved revision, there is only one main scenario (baseline scenario) for Krško NPP SF and RW management with only two financially important variations due only to different VATs in two countries (SF repository in Slovenia and SF repository in Croatia). For SF/HLW management, a sensitivity scenario was also developed depending on the expected operating time of the SF dry storage facility and the start of SF repository operation.

Scenario presented here is elaborated on several supporting SF and LILW management studies that both countries prepared for the occasion. Those studies are offering technical and technological solutions for LILW takeover and division, HLW and SF management and detailed national LILW management programs with investment and operational costs in €2018 prices. All the calculations were based on the inputs from already prepared *Third revision of Krško NPP Decommissioning Programme* [1], particularly on its SF, HLW and LILW volume and mass assessments.

It should be understood that in the third revision, as compared to first revision, compensation to local communities (CLC) and also value added tax (VAT) were presented separately and included in overall costs.

In the following sections some of the findings and proposals for the future improvements are presented.

9.2. Conclusions

9.2.1. SF&HLW predisposal management and storage

a) In line with recent national policies in RS and RC, construction of dry storage facility for spent fuel (SFDS) at Krško NPP site for a minimal operational life of 60 years with the possibility of extending its operation is approved. SFDS capacity is sufficient to allow storage of all planned SF and HLW inventory from its start of operation in 2021 until final unloading of the core in 2043. Additionally, SFDS project will provide safe and cost-effective storage solution for RW generated from Krško NPP decommissioning including highly activated metal components. SFDS storage can also be used to store solid and conditioned ILW and HLW coming from potential reprocessing of SF. Baseline and sensitivity scenario are considered regarding the operation period and decommissioning of SFDS.

9.2.2. SF management and disposal

a) The reference scenario for repository in suitable hard rock has been prepared. Baseline and sensitivity scenario are considered regarding the start of SF/HLW repository operation and decommissioning. Options of SF disposal in a regional repository and/or use of regional encapsulation plant were considered. SF repository will accommodate also HLW originating from Krško NPP decommissioning and long-

lived LILW from operation and decommissioning of nuclear facilities and other nuclear applications.

b) Location of repository is still generic assuming it is somewhere on the territories of RS and RC.
c) Transport of the spent nuclear fuel to the repository is planned by road.

9.2.3. Predisposal RW management

a) The issue of takeover and division as required by Intergovernmental Agreement and by ToR for Third revision of the Krško NPP Disposal Program is in this revision addressed explicitly, based on the supporting study.
b) The storage capacity at SRFS in Krško NPP necessitates as early as possible start of emptying, on the other hand, it may hamper an optimum emptying strategy. Due this fact to couple the emptying strategy with any planned division and takeover may be quite difficult, if no manipulation and buffer storage is planned and build for all needed operations in the future.
c) Present proposal for the division of LILW is equitable and reasonable, but from long-term safety and environmental burden points of view, the most important aspect is the content of long-lived radionuclides in waste. Therefore, better characterization of stored waste aiming at full knowledge of long-lived radionuclides, particularly at difficult to measure radionuclides (DMR), is needed prior to division and takeover.
d) According to supporting study there are at least three waste streams needing additional treatment. These waste streams (highly corrosive waste because of content of the boric acid, hygroscopic waste with unwanted property of swelling and not grouted waste with unsatisfactory void fractions) are not presently stabilized in the manner to fully satisfy disposal requirements. Therefore additional treatment is necessary.
e) Two sides are intending LILW conditioning in different containers (overpacks): RS in N2d containers and RC in RCCs.
a) Additional characterization of presently stored LILW prior to division and takeover as well as treatment and conditioning for operational LILW is needed to prepare waste to fit in containers and match requirements set in WACs for long term storage or disposal. Conditioning of Croatian half of operational LILW due to the inability of RCC to accommodate TTCs (prevailing quantities of LILW are presently in TTCs) requires repacking (if not treatment) of almost all the waste in the Croatian half.
f) Treatment and conditioning facility is not foreseen neither in Vrbina repository nor in the RWM Centre plans. For now, there is no agreement of the Krško NPP owners on the investment establishing needed treatment and conditioning capacities within Krško NPP prior to the end of Krško NPP operation (2043).
g) *Third revision of Krško NPP decommissioning programme [1]* assumes that conditioning (but not treatment) capacity for decommissioning waste on the Krško NPP site will be available after 2043.

h) For now, RC believes that the only possibility for treatment and conditioning of the operational LILW foreseen to be taken over in 2023 as stipulated in Intergovernmental Agreement is in an appropriate facility in the third country. RS is planning the treatment and conditioning before disposal on NPP Krško site.

9.2.4. RW management and disposal

b) RS and RC are having different RW management schedules as well as storage and disposal technologies. Due to differences in locations for repositories and chosen disposal technologies there are differences between Croatian preliminary WACs for disposal and Slovenian WACs for disposal.
c) There is dramatic reduction in the estimates of operational and decommissioning LILW volume to be disposed in this revision (volume of 6,254.3 m^3 was estimated in the *Third revision of Krško NPP Decommissioning Program*) as compared to the first revision (17,599 m^3, estimated in *NPP Krško Decommissioning Plan* in 1996 and *Proposed Strategy of LILW Management,* ARAO 2000).
d) Croatia has preferential site for RWM Center and has started with preliminary works.
e) Main site investigations for Slovenian Vrbina repository were concluded in 2015, design project documentation and safety case has been prepared and in April 2019 preliminary approval for the radiation and nuclear safety of nuclear facility was issued by the Slovenian Nuclear Safety Administration in the procedure of issuing an environmental protection consent.
f) Dates set in Intergovernmental agreement for the start of two national Krško NPP management programmes with takeover of stored operational LILW from Krško NPP SRFS in the period 2023 – 2025, considering the current status of storage and disposal facility development in both countries, are challenging and will be very difficult to reach.

9.3. Recommendations

9.3.1. General

1) In the next revision *Krško NPP Decommissioning Program* and *Krško NPP Radioactive Waste and Spent Fuel Disposal Program* should be prepared separately and afterwards joined together in the single document as it was done previously in the DP Rev.1 and DP Rev.2 in order to facilitate decommissioning and SF and RW management overall financial analysis, primarily regarding annuities to be paid in national funds by Krško NPP owners.
2) Based on the past experience, revisions should be done regularly in accordance with Intergovernmental Agreement. At least calculations of annuities for both countries based on updated financial parameters should be done on the annual or biannual basis.

3) Joint ARAO and Fund study for the disposal of HLW and SF aiming at the optimization of technical solutions presented as baseline scenario in this document should be started immediately.
4) Future revisions of DP will require experts with specialized knowledge (e.g. for SF storage and disposal) if reliable documents are expected. Those experts should be properly educated for that purpose during the periods between revisions.
5) It is recommended that the derivation of compensation costs is revisited and moreover, that the methodology in both countries is harmonised. It is recognised that compensation costs represent a very high fraction of the overall cost of the programme and a more realistic compensation value should be determined.

9.3.2. Regarding SF management and disposal

1) Joint program aimed at geological investigations and data acquisition on potential hard rock host formations suitable for deep geological repository on the territories of RS and RC should start as soon as possible.
2) Continued participation of RS and RC within multinational working groups (e.g. ERDO-WG) is highly recommended, in order to find the optional deep geological repository outside of RC or RS.
3) For future revisions of the DP it is recommended to prepare further improvements with more details on technical solutions and more reliable cost estimates. In order to be able to further refine the reference disposal scenario it is recommended to:
   - start parallel development of geological disposal concept in other geological environments including the data acquisition for such formations;
   - follow the international progress of different disposal concept and update the reference disposal concept according to the new technical solutions and details;
   - follow further development of regional or multinational geological disposal, sharing of knowledge and sharing of facilities (encapsulation, treatment and conditioning, reprocessing) in other countries with cooperation and integration in this area by participation in joint programmes to achieve significant positive economic effects of extremely small-scale and shared nuclear programme in Slovenia and Croatia;
   - cooperate with Krško NPP on preparing reprocessing analysis with impact on disposal;
   - follow the international practice in Sweden, Finland and France regarding institutional control and long-term monitoring of DGR after closure
4) The Krško NPP is to examine the possibility of SF reprocessing until next revision of this document.

9.3.3. Regarding LILW management and disposal

1) Considering present situation with *on site* characterization of waste and treatment and conditioning facility in Krško NPP it is recommended that issue of establishing such capacities (even by use of mobile or modular facility) should have immediate attention by Intergovernmental Commission particularly since treatment and conditioning in the third countries poses rather complicated radiation safety, administrative, organizational and financial problems as demonstrated in this document.
2) It is recommended that the IC provide for a more realistic framework by revisiting the 2023 and 2025 dates. It is recognised that these dates will be practically impossible to achieve, considering the current status of storage and disposal facility development in both countries. In doing this, it is recommended that:
   a) any future policy does not impose artificial time schedule constraints on the implementors, ARAO, Fond and NEK.
   b) the storage capacity of Krško NPP for both LILW and SF storage is capable of being expanded as necessary and, indeed, will likely require expansion under any currently feasible scenario for the immediate future.
3) Present LILW storage in Krško NPP should have proper manipulation space. Supporting study suggests that presently stored operational LILW could not be manipulated in order to separate waste packages needing treatment from the waste packages that can be directly conditioned. However, licensing issues related to enlargement of Krško NPP LILW storage capacity could cause challenges which are not elaborated here, but on the other hand WMB2 project could pose an elegant opportunity.
6) ARAO and Fund should analyze joint on site treatment and conditioning technologies initiating as soon as possible work on feasibility study for treatment and conditioning facility in Krško NPP. If establishment of treatment and conditioning capabilities presents a problem for operator, a variant solutions should be investigated e.g. *on site* campaigns by mobile facility or separation of LILW since approximately 20% of operational LILW needing treatment could be kept in Krško NPP LILW storage until treatment capacities are established while operational LILW not in a need of treatment will be taken over, divided, conditioned and transported to Vrbina repository in Slovenia or long term storage in RWM Center in Croatia, etc.
7) In RS, in order to obtain a building permit for the construction of the Vrbina LILW repository, the design project documentation should be completed and finalized as soon as possible and environmental protection consent should be obtained.

8) Croatian Regulatory Body should be much more involved in takeover process oversight what has to be agreed with Krško NPP and SNSA[1].
9) In RC research and extensive site exploration on the location of RWM Center in a support of establishing long term storage should start as soon as possible regarding obligations stipulated in Intergovernmental Agreement. Also, Safety case should be developed along Environmental Impact Assessment with the inclusion of all stakeholders.
10) Present experience points out that supporting studies regarding most important issues to be addressed in the next revision should be ordered as soon as possible and certainly before the time of new revision. Consequently, RC should start as soon as possible work on the conceptual design for surface cassette type LILW repository on generic location placed on Trgovska Gora massif.

[1] Croatian regulatory takeover process oversight could improve and strengthen the safety of the process and follow-up activities for transport, treatment and conditioning of the LILW and does not in any way prejudice the competence and responsibilities of the Slovenian regulatory body responsible for nuclear safety.

9.4. References

[1] 6th Revision of the Preliminary Decommissioning Plan (PDP) for NPP Krško, NIS Siempelkamp, document No.: 4520/CA/F 010420 7 / 01, June 2019.”