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TECHNICAL DESIGN OF THE DEEP GEOLOGICAL REPOSITORY 2025

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Abbreviations

AZ	Nuclear reactor active zone
ČBÚ	Czech Mining Authority
DGR	Deep geological repository
EDU	Dukovany nuclear power plant
ETE	Temelín nuclear power plant
FA	Fuel assembly
HLW	High-level waste
IRS	Ionising radiation source
LVR-15	Tank-type light water research reactor with a thermal output of 10 MW
NNS	New nuclear sources
NPP	Nuclear power plant
RAW	Radioactive waste
ILW	Intermediate-level waste
SMR	Small modular reactor
SNF	Spent nuclear fuel
SÚRAO	Czech Radioactive Waste Repository Authority
TBM	Tunnel boring machine
VPVR/M	Container for the dry storage and transportation of nuclear fuel from research reactors
VVER-1000	Eastern-type pressurised water reactor with a nominal electrical output of 1000 MW (ETE reactors)
VVER-440	Eastern-type pressurised water reactor with a nominal electrical output of 440 MW (EDU reactors)
WDP	Waste disposal package
WP	Waste package

Explanation of terms:

Buffer

The buffer comprises the engineered sealing and damping barrier that will surround the WDP in the disposal well. Its main functions concern the protection of the WDP from damage and the retardation of the migration of radionuclides in the event of damage to the WDP.

Backfill

The backfill comprises the engineered barrier that will both fill and seal the disposal corridors. It will also serve to keep the buffer in place so that it does not swell into the disposal corridors, which would lead to the loss of its protection and radionuclide retention properties.

Dose, radiological dose

This refers to the total exposure of a reference individual from external exposure as quantified by the effective dose and internal exposure quantified by the time of the effective dose.

Drainage base

Drainage base refers to location at which groundwater joins surface water flow. The primary recipients of groundwater comprise the sediments of valley floodplains and, subsequently, the river network.

Deep geological repository (DGR)

This refers to a radioactive waste repository that is located hundreds of metres below the earth’s surface and is intended for the disposal of high-level waste (Decree 378/2016 Coll., Section 2).

Institutional RAW

Radioactive waste that is generated other than via the operation of nuclear power plant reactors, i.e. via the use of radioactive sources in the industrial, research, health, etc. sectors.

Engineered barrier

A man-made barrier that serves to prevent the transport of radionuclides. Engineered barriers comprise, for example, the waste disposal package and bentonite-based sealing materials (see also *Buffer* and *Backfill*).

ILW waste package

The waste package for intermediate-level waste designed in the form of a cube, which allows for the placement of up to four 216-litre steel drums.

Waste acceptance criteria

The safety, technical and administrative conditions and limits concerning the properties of radioactive waste that can be accepted for disposal (Concept 2019).

Waste disposal package (WDP)

The waste disposal package serves as the primary physical barrier in terms of ensuring the long-term safety of the deep geological repository.

Sealed Radionuclide Source (SRS)

A radionuclide source, the encapsulation or protective covering of which ensures testing-verified sealing and prevents the leakage of radionuclides under predictable use and wear conditions (according to Act No. 263/2016 – the Atomic Act). For the purposes of this report, emitters that failed the sealing test are also included in this category.

Abstrakt

Tento dokument stručně shrnuje technické řešení hlubinného úložiště (HÚ) radioaktivního odpadu v České republice. Jedná se o popis aktualizovaný k roku 2025. V úvodu dokumentu je popsán inventář, jakožto zásadní vstup při návrhu HÚ. Dále je popsán stručně celý komplex hlubinného úložiště a jeho rozdělení na povrchový a podzemní areál.

Hlavní část dokumentu je zaměřena na podzemní část HÚ, konkrétně na ukládací sekce a inženýrské bariéry, které jsou pro dlouhodobou bezpečnost zásadní. Pro každou komponentu jsou shrnuty návrhové parametry.

Klíčová slova

Hlubinné úložiště, inženýrské bariéry, buffer, backfill, UOS 440, UOS 1000, VJP, výplň

Abstract

This document provides a summary of the technical design of the Czech deep geological repository (DGR) for radioactive waste as updated in 2025. The report begins with a description of the waste inventory as one of the essential inputs for the design of the DGR. This is followed by a brief description of the DGR complex and its various components as divided into its surface and underground parts.

The main part of the document focuses on the underground part of the DGR, specifically on the disposal sections and the engineered barriers, which are essential in terms of long-term safety. A summary of the design parameters is provided for each DGR component.

Keywords

Deep geological repository, engineered barriers, buffer, backfill, WDP 440, WDP 1000, SNF

1 Introduction

The technical design of the Czech deep geological repository (DGR) for radioactive waste has been under development since the 1990s (Holub et al. 1999). Over the years, the input information has been refined, whether it concerns the rock mass or the waste inventory, and new scientific knowledge has been gathered in this area. The purpose of this document is to provide a summary of the currently considered technical parameters for the future DGR and its various components. In addition, the report includes references to key SÚRAO documentation that describes the overall concept of the Czech DGR technical design, thus rendering this report an important source of relevant and up-to-date information.

The report provides both a general description of the DGR system and a more detailed description of the underground complex, i.e. technical descriptions of the underground mine workings, the engineered barriers and other components in the context of the currently anticipated inventory, the rock environment, the construction technology to be used and the overall layout of the disposal site.

The report has been prepared in such a way that it can be regularly updated at intervals that follow the attainment of SÚRAO's strategic milestones, e.g. the selection of the final and backup sites for the DGR. Clarification is provided at each of these intervals based primarily on data obtained from the ongoing research and development of the engineered barriers and other components, project design solutions and the study of the four potential sites for the construction of the DGR.

This document comprises the third update of the Technical design of the deep geological repository report and follows on from report 711/2023 (Hausmannová et al. 2023) and reports 580/2022_rev.1 (Dohnálková et al. 2022b) and 580/2022 (Dohnálková et al. 2022a).

The main changes and clarifications provided in this update compared to report 711/2023 are as follows:

1. Justification for the chosen depth of the disposal horizon,
2. Recalculation of the inventory according to the latest version of the Concept, the publication of which is planned for the end of 2025 (new: the consideration of 4 NNS and 6 SMRs compared to the previous 3 NNS)
3. Change in the height of the WDP 440 from 3790 mm to 3810 mm due to structural modifications
4. Notice of the preparation of the updating of the height of the buffer and depth of the disposal wells in connection with the change in the height of the WDP 440 (see point 3)

2 Description of the deep geological repository system

The approach to the management of spent nuclear fuel and other RAW that does not meet the waste acceptance criteria for disposal in existing disposal facilities in the Czech Republic is based on the requirement to ensure the long-term protection of the environment by means of disposal in a deep geological repository (DGR) according to the latest version of the RAW and SNF Management Concept, the publication of which is planned for the end of 2025. Disposal in the DGR will ensure the long-term isolation of the waste via the so-called multi-barrier system, i.e. a set of natural and engineered barriers and structural components that serves to physically prevent the release of radionuclides into the biosphere for as long as the waste remains a potential threat. All the waste that is unacceptable for disposal in existing surface and near-surface repositories will eventually be disposed of in the DGR.

The technical design of the DGR reflects the requirements set out in Section 45 of Act No. 263/2016 Coll., on the requirements for nuclear facilities without nuclear reactors and radioactive waste disposal facilities:

a) the physical prevention of the occurrence of critical and supercritical conditions,

b) ensuring the removal of the heat generated by the waste and

c) ensuring radioactive shielding and the prevention of the release of radioactive materials and ionising radiation into the environment.

A further essential requirement when dealing with ionising radiation sources in planned exposure situations, including the DGR, is that the activity dose that can be received by a representative person does not exceed the so-called dose optimisation limit, which according to Act No. 263/2016 Coll., Section 82, is set at 0.25 mSv per year.

The DGR will comprise a surface and an underground area (Fig. 1).

The surface area will serve for the operation of the DGR complex. This area will house the administrative buildings, technical equipment for the construction of the DGR (including the underground section), and the technical facilities for the operation of the DGR (including the equipment necessary to ensure operational safety). The surface area will also house the trans-shipment facility for the receipt of RAW and SNF and a hot chamber for the transfer of RAW to WDPs and the repackaging and processing of RAW according to DGR operational requirements where necessary. It is envisaged that the trans-shipment facility and the hot chamber will be located below the surface. The research concerning the trans-shipment facility (RAW acceptance area) is ongoing and the project will be finalised according to the conditions that prevail at the finally selected DGR site.

The surface area will be connected to the underground section by two inclined tunnels (this project design component will be subject to updating going forward; it is possible that access to the underground area will be via a combination of a vertical mine shaft and an inclined tunnel). The greater part of the underground area will comprise the disposal spaces. The first section will serve for the disposal of high-level waste (HLW) and spent nuclear fuel (SNF); it will be divided into sub-sections, which will be excavated and put into operation on a gradual basis according to the requirement for disposal capacity, which will depend on the amount of

HLW and SNF produced going forward. The second section will be used for the disposal of intermediate-level waste (ILW).

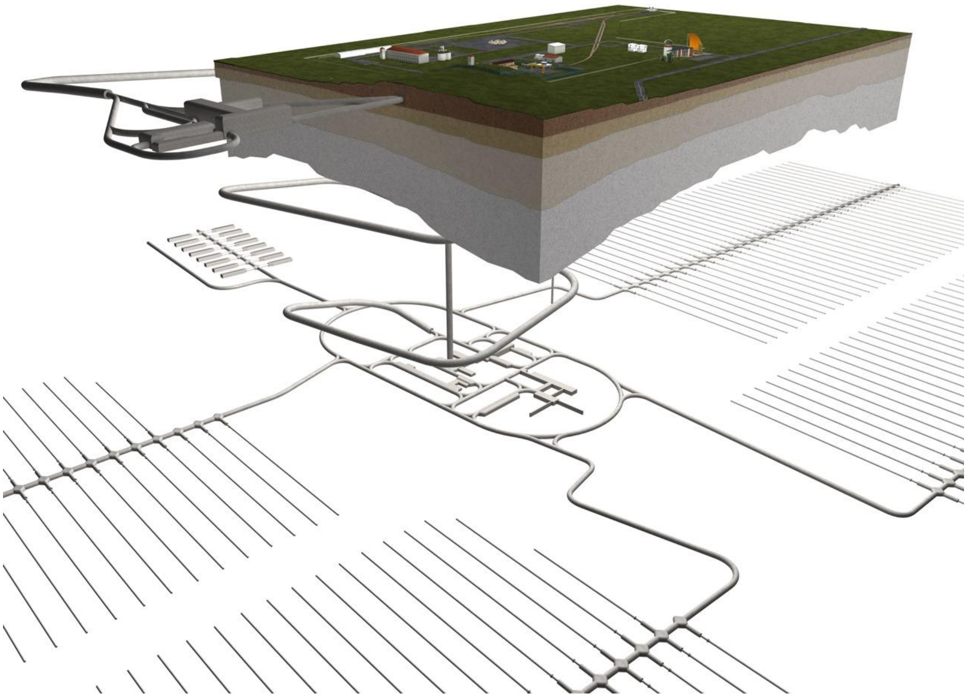

Fig. 1 Diagram of the DGR; underground and surface areas

2.1 Inventory

The DGR will serve for the disposal of spent nuclear fuel (SNF), waste generated during the decommissioning of nuclear facilities, and other waste that is unacceptable for disposal in existing surface and near-surface disposal facilities. Following the termination of the operation of existing disposal facilities, institutional waste will also be disposed of in the DGR (Podlaha and Trtílek 2023, report 676/2023).

2.1.1 Spent nuclear fuel

The DGR concept is based on requirements for the disposal of SNF from the existing Dukovany (EDU) and Temelín (ETE) nuclear power plants (NPP), the construction of 4 new nuclear sources (NNS) and the construction of 6-10 small modular reactors (SMR) according to the Update of the inventory and properties of the radioactive waste intended for the DGR (Podlaha and Fejt 2024b) report. The disposal concept assumes the direct disposal of SNF (i.e. without reprocessing). The time between the removal of the fuel from the reactor active zone and its disposal in the DGR is considered to be 65 years for all the NPP blocks (including NNS). The cooling time that will be necessary for the SNF from SMRs has not yet been determined. The expected inventory of SNF has recently been updated and is presented in a SÚRAO report (Podlaha and Fejt 2024b.). Some of the parameters, e.g. the development of the thermal output of the waste disposal packages (WDP) over time, will be updated as soon as details are available on the operation of NNS and the types of SMRs to be constructed, etc.

are known. The expected number of fuel assemblies planned for disposal and the related number of WDPs and their thermal output at the time of disposal in the DGR are presented in Tab. 1.

Tab. 1 Overview of the basic parameters of the production of SNF from NPPs. The values marked ( ) were determined via expert estimates (Fejt 2024)*

Reactor	**VVER-440**	**VVER-1000**	**NNS**	**SMR**
No. of blocks	4	2	4	6
Burn-up (MWd/tHM)	64,000	55,000	55,000	45,000
Operation (years)	60	60	60[c]	60[c]
Total no. of fuel assemblies	19,537	5,578	13,329	11,684
Total mass of uranium (tonnes)	2,518	2,553	5,744	4,377
Thermal output of the WDP (W)	655	1,125	(1,045)*	(908)*
No. of fuel assemblies in the WDP	7	3	(3)*	(3)*
Total no. of WDPs	2,791	1,860	(3,907)**	(3,895)*
Width of fuel assembly (mm)	144.0[a]	234.0[b]	currently unknown	currently unknown
Length of fuel assembly (mm)	2,601.5[a]	4,520[b]		

[a] according to (TVEL, 2022)

[b] according to (Westinghouse Nuclear 2022)

[c] the total number of fuel assemblies and other related parameters were recalculated for 60 years of NPP operation

* expert estimate

** expert estimate (original values for fuel from a nuclear power plant with a gross unit output of 1200 MWe were recalculated for fuel from a nuclear power plant with a gross output of 1055 MWe)

2.1.2 Other high-level waste

Other high-level waste will also be disposed of in the DGR. This waste, which is described in SÚRAO report 676/2023 (Podlaha and Trtílek 2023), will be emplaced in the same section of the DGR as the SNF. This waste will comprise:

- RAW from the processing of SNF from the LVR-15 research reactor (vitrified) and
- spent unprocessed fuel from the LVR-15 research reactor.

Tab. 2 lists the properties of the vitrified material created via the processing of the SNF from the LVR-15 research reactor. Vitrified material will be returned from the Russian Federation to the Czech Republic in two planned shipments (2026 and 2033). More detailed information on this material is provided in a report by Podlaha and Trtílek (2023).

Tab. 2 RAW balance from the processing of SNF from the LVR-15 research reactor (Podlaha and Trtílek, 2023)

	Number of WP with HLW	**Volume of HLW (m^3)**	**Weight of HLW (kg)**	**Weight of HLW incl. the WP**	**Measured activity of the HLW[a] (Bq/kg)**	**As at date[b]**
First shipment	2	0.1468	367	591	4.49E+12	12/2026
		0.1492	373	597		
Second shipment	1	0.190	475	699	4.39E+12	2033

[a] of all the radionuclides contained in the vitrified material

[b] date to which the measured activity from the previous column relates

The SNF that will be created via the continued operation of the LVR-15 reactor will also be disposed of in the DGR. The operation of the Czech Republic's other research reactors (LR-0, VR-1 and VR-2) does not result in the creation of SNF due to their low thermal output and limited operating times. Only mildly irradiated nuclear fuel is produced, which will most probably be used in other research reactors or recycled following the decommissioning of the reactors.

The SNF from the LVR-15 reactor will be stored in ŠKODA VPVR/M transport WPs in the HLW storage area at ÚJV Řež, a.s. The total production of SNF anticipated following the extended operation of the reactor up to 2038 is estimated at 390 fuel assemblies, which corresponds to 11 ŠKODA VPVR/M WPs.

2.1.3 Intermediate-level waste

Intermediate-level waste that does not meet the waste acceptance criteria for disposal in surface and near-surface disposal facilities will also be disposed of in the deep geological repository. This waste will be disposed of in the same repository complex as SNF, but in a separate section (the ILW section). The locations of the SNF/HLW and ILW sections must be such that the safety functions of the two sections are ensured. The weight of RAW that will be disposed of in the ILW section will amount to approximately 9,460 tonnes (Podlaha 2024a).

The types of waste that will be disposed of will be as follows (Podlaha and Trtílek, 2023):

- RAW from the decommissioning of NPPs,
- RAW from the decommissioning of the LVR-15 research reactor,
- institutional RAW and
- sealed radionuclide sources.

Estimates of the amount of waste that will be generated from the decommissioning of NPPs vary depending on the selected decommissioning approach. The immediate NPP decommissioning option will result in the generation of more waste than via the gradual decommissioning approach; however, the difference will not be particularly significant (Podlaha and Trtílek, 2023).

The ILW inventories for 1 block of EDU and 1 block of ETE that will be disposed of in the DGR, assuming the gradual decommissioning approach, are shown in Tab. 3 and Tab. 4. Tab. 5 provides a summary of the amount of such waste that will be generated by 1 block of NNS assuming the immediate decommissioning approach and Tab. 6 provides a summary of the weight of the materials from 1 SMR block assuming the immediate decommissioning approach. Tab. 7 illustrates the amount of RAW from the decommissioning of the LVR-15 reactor that is expected to be disposed of in the DGR.

Tab. 3 Inventory of the amount of ILW considered for disposal in the DGR for 1 EDU block; gradual decommissioning option

Item	Weight (tonnes)
Reactor shaft	53.0
Core basket	8.8
Inner surface of the pressure vessel	10.1
Heat insulation	14.0
Serpentinite concrete	38.5
Bottom of the core basket	13.2
Outer surface of the pressure vessel	90.9
Serpentinite concrete edge of the active zone	38.5
Block of protective tubes	18.0
Serpentinite concrete internal cladding	4.0
Inlet and outlet pipes up to 1 m from pressure vessel	8.0
Activated structural concrete	200.0
Activated components - sensors, cables	14.3
Total (rounded up to whole tonnes)	**511**

Tab. 4 Inventory of the amount of ILW considered for disposal in the DGR for 1 ETE block; gradual decommissioning option

Item	Weight (tonnes)
Core sheath	35.0
Reactor shaft	58.1
Pressure vessel coating	22.7
Reactor pressure vessel	204.0
Heat insulation	20.5
Serpentinite concrete in front of the ionisation channels	32.1
Serpentinite concrete internal cladding	22.6
Fuel assembly steel supports	10.2
Block of protective tubes	17.1
Ionisation chamber channels	5.3
Support ring	11.4
Structural concrete cladding under serpentinite concrete	1.4
Activated components - sensors, cables	4.3
Total (rounded up to whole tonnes)	**444**

Tab. 5 Inventory of the amount of ILW considered for disposal in the DGR for 1 NNS block; immediate decommissioning option

Item	Weight (tonnes)
Steel	488.1
Other (activated components from operation)	5.1
Serpentinite concrete	38.5
Total (rounded up to whole tonnes)	**532**

Tab. 6 Inventory of the amount of ILW considered for disposal in the DGR for 1 SMR block of 470 MWe; immediate decommissioning option

Item	Weight (tonnes)
Steel	307
Other (activated components from operation)	28
Serpentinite concrete	77
Total (rounded up to whole tonnes)	**412**

Tab. 7 Amount of RAW from the LVR-15 reactor for disposal in the DGR

Item	Weight (kg)
Reactor vessel with stainless steel fittings (it is expected that only the lower part of the vessel will be disposed of in the DGR)	4,220
Aluminium reactor vessel fittings	387
Control rods	10
Beryllium reflectors (standard blocks: 27 items, atypical blocks: 6 items)	14,815
Parts of loops, probes, irradiated channels	
Total	**19,432**

With respect to the waste produced via the decommissioning of the nuclear facilities listed above, as well as for other ILW, work on the waste package concept is currently ongoing. A summary of the total estimated number of WPs from decommissioning is provided in Tab. 8.

Institutional radioactive waste that is currently stored at the Richard radioactive waste disposal facility will also be disposed of in the DGR. This RAW does not meet the waste acceptance criteria for disposal in surface or near-surface disposal facilities. Estimates of the future production of this type of RAW were based on a list of RAW accepted for storage from 2005 to 2014 (Podlaha and Trtílek, 2023). This waste is expected to amount to around 2000 drums, which corresponds to approx. 500 ILW waste packages.

High activity ionising radiation sources (IRS), which comprise mainly sealed radionuclide sources, must also be considered with respect to disposal in the DGR. The final number of WPs with IRS will depend on the amount of sources of radionuclides that will be used in the Czech Republic and on the maximum activity of the radionuclides that can be disposed of in one WP. Since it is not possible to determine the exact number of WPs based on the limited information available today, an expert estimate was made based on general characteristics. A study by (Podlaha and Trtílek, 2023) estimated that approx. 261 WPs will be required for the disposal of IRS.

A summary of the estimated number of waste packages (based on the ILW inventory) is provided in Tab. 8.

Tab. 8 Estimated number of ILW waste packages based on data from Podlaha and Trtílek (2023)

Type of ILW	Estimated number of ILW waste packages
4 EDU blocks, gradual decommissioning	2,045
2 ETE blocks, gradual decommissioning	275
4 NNS blocks, immediate decommissioning	952
6 SMR blocks, immediate decommissioning	1,004
LVR-15 decommissioning	20
Institutional RAW	500*
Ionising radiation sources	261

Total	**5,181**

* SÚRAO estimate of the number of WPs that will not meet the waste acceptance criteria for disposal at the Richard radioactive waste disposal facility

2.2 Surface area

The surface area will house the technical facilities and equipment required for the preparation and disposal of SNF and RAW (the facility for the preparation of the disposal of SNF and RAW will be located in the near-surface section), the facilities and equipment required for the construction of the underground area (excavation), including the technical backup, accommodation for workers at the site, and the security, administration, information services, communication, etc. buildings. To date, the proposed design of the surface area is of a general nature, which takes into account all the anticipated requirements. The specific arrangement of the various buildings and facilities will be determined according to the local conditions of the site finally chosen for the DGR. The structures required for the ventilation of the underground area will be located outside the DGR surface area. The various facilities will be secured via a comprehensive physical protection system.

The surface area will consist of a non-nuclear section and a nuclear section. The detailed breakdown of the various buildings will depend on the specific conditions at the given site, especially with respect to their being located within or outside the surface area of the DGR.

It is expected that the surface area will contain the following structures:

- Nuclear facility (NF) area – the surface area buildings located in the secured area associated with the preparation of RAW and SNF for disposal as classified as forming a part of the NF according to Act No. 263/2016 Coll., i.e. they fulfil an operational function. The surface area will also house other facilities e.g. underground area ventilation structures, the wastewater measurement plant, air conditioning supply structures and the sewerage and decontamination station.
- Workshops and warehouses – the provision of basic maintenance and repair services, the storage of materials for the long-term requirements for the construction, commissioning and SNF and RAW disposal phases of the DGR. The various structures will include oil, explosives and gas storage facilities, workshops and a non-nuclear storage hall. These structures will be located within the surface area of the DGR with the exception of the explosives facilities, which will be located both within the surface area and in the underground complex with the official status of a mine construction facility. The explosives facilities will be required to meet the requirements of ČBÚ (Czech Mining Authority) Decree No. 99/1995 Coll. on the storage of explosives. This issue will be addressed in detail in the later stages of the development of the project documentation.
- Fire protection – structures with a fire protection function: the mine rescue service station, the fire station and the water tank. With concern to legislation, underground fire protection is addressed in ČBÚ Decree No. 22/1989 Coll. on occupational health and safety and operational safety during the conducting of mining activities and the underground extraction of non-reserved minerals (part 6 - Fire Protection) and ČBÚ Decree No. 2/1994 Coll., which sets out the conditions for the construction and operation of mine fire water mains. From the point of view of mining legislation, the

deep geological repository is considered to be an “other” (non-gas, non-coal) mine; see ČBÚ Decree No. 22/1989 Coll. Section 172, paragraph 2.

- Reinforced excavated rock dump – interim landfill site; the excavated rock handling facility will be located outside the surface area.
- Administrative buildings – personnel and administration facilities: the central administrative building, catering facility with a dining hall, etc. and the related infrastructure, i.e. transport services and non-nuclear-related facilities.
- Information centre – the information centre itself, cafe, gatehouse and related transport services and infrastructure.
- Other – to be specified depending on the conditions that prevail at the finally selected site.

It is currently assumed that the following structures will be located outside the DGR surface area:

- Preparation of bentonite – structures related to the preparation of the bentonite material. It is assumed that all the parts of this facility will be located outside the surface area of the DGR.
- Excavated material handling – structures for the processing of excavated material. It is assumed that all the parts of this facility will be located outside the surface area of the DGR, with the exception of the reinforced excavated rock dump, parts of which will be located both within and outside the surface area.

2.2.1 Trans-shipment facility and facility for the preparation of RAW and SNF

These facilities will be housed in the near-surface section of the DGR; the main component will consist of the hot chamber, which will serve for the transfer of the contents of the waste transport containers into the WDPs in a hermetically sealed space.

Further, they will serve for the acceptance, unloading and storage of SNF in the interim storage building that will be located near to the hot chamber. They will also be used for the receipt, preparation and inspection of empty WPs, their storage, filling and preparation for final disposal in the underground area of the DGR. Moreover, they will serve for the acceptance and preparation of RAW for disposal. One part will be used for the preparation of SNF and another for the preparation of other RAW and the components that are common to both.

Subsequent stages of the project documentation will contain an update of the design of these facilities and a revision of the proposed technical design at the required level of detail.

2.3 Underground area

The concept for the design of the underground area is based on the requirement to ensure both the efficient functioning and safety of the DGR during all its life stages (construction, operation, decommissioning, closure and post-closure). The underground area will comprise two parts, one for the disposal of SNF/HLW and the other for the disposal of ILW. In addition to the disposal areas, the underground area will include service corridors, the technical facilities and equipment required (workshops, storage areas and the drainage, mine water pumping and ventilation infrastructures) and connections with the surface area.

2.3.1 Excavation method

Two excavation methods are used for the excavation of underground structures such as the DGR in crystalline rocks - mechanised excavation (TBM) and conventional excavation (Drill and Blast). Both methods were considered in the process applied for the reduction of the number of candidate sites from 9 to 4; feasibility studies were prepared for 7 of the sites by (Špinka et al., 2020); for the Janoch site, see (Zahradník et al. 2020b) and for the Na Skalním site, see (Zahradník et al. 2020a). The choice of the mining procedure influences various aspects of the DGR, e.g. the extent and design of the surface area, the handling procedure, the volume of backfilling material required and the costs (Ikonnen 2023). Differences in terms of the best choice of excavation method for the four candidate sites are not significant from the point of view of the selection of the final and backup sites and will not influence the final choice of these sites. Therefore, in 2023 SÚRAO decided that just one approach would be considered in the subsequent stages of the research, which will allow for the adoption of the most efficient and, above all, most cost-effective approach in the next steps of the project. Moreover, the choice of one method will contribute to the optimisation of the DGR development time schedule, which is essential in terms of fulfilling the requirements of EU Commission Regulation 2022/1214 of 9 March 2022, i.e. the commissioning of the Czech DGR 15 years earlier than originally planned (see the RAW and SNF Management Concept (2019)).

When choosing between the mechanised excavation (TBM) and the Drill and Blast methods, it was essential to study both methods in depth and to decide, based on the latest knowledge, whether they can be considered suitable for the excavation of the DGR. Each method was found to have its advantages and disadvantages in terms of DGR construction (Ikonnen, 2023).

It was decided that the **conventional excavation method will be used; the decisive factors concerned its temporal and spatial flexibility compared to the TBM approach**. In contrast to the construction of classic underground structures, the construction of the DGR will proceed in stages over a relatively long period of time. Firstly, an adit will be driven into the disposal horizon; this will be followed by characterisation research aimed at obtaining detailed information on the rock mass in the horizon. Subsequently, a number of disposal spaces will be excavated in the disposal horizon, which will be followed by a period of disposal only (the excavation process will be suspended). The intermittent nature of the mining process renders the TBM approach significantly less advantageous than the conventional excavation method and, in certain respects, more complicated. Conventional excavation allows for ease of access to the rock face for the needs of the geological characterisation research and easier solutions in cases where non-standard geological conditions are encountered. Further advantages of the conventional method include a smaller tunnel profile, which will reduce the amount of excavated rock produced and the consequent reduction in backfilling materials, and a simpler tunnel construction design solution.

2.3.2 Main mine workings

The term main mine workings refers to those workings that are directly connected to the surface. They comprise mainly access routes to the underground complex (excavation tunnels, loading tunnel and ventilation shafts and boreholes) that are used primarily for the transport of people, materials and waste to, and ensuring the ventilation of, the underground area of the DGR.

Two inclined tunnels will be constructed, one for the ongoing excavation of the underground area and the other for the loading of the SNF and RAW, so that once the DGR comes into operation, the excavation of new disposal sections will be separated from the already completed preparation and disposal sections. Moreover, the two-tunnel approach will allow for the separate access of personnel to the mining and disposal sections during the routine operation of the DGR. Although the loading and extraction tunnels will be separated by physical barriers, the design will allow for the simultaneous ventilation of both areas. In addition, the two inclined tunnel approach is ideal from the point of view of reacting to potential extraordinary events, i.e. it will be possible to shorten the escape routes via the construction of evacuation connections between the two tunnels. Fresh air will be supplied via the loading tunnel and polluted air will be removed via the extraction tunnel. Alternatively, a combination of a vertical mine shaft and an inclined tunnel is being considered.

2.3.2.1 Loading tunnel

The loading tunnel will be inclined at a maximum longitudinal slope of 1:10. The length of the tunnel will depend on the longitudinal slope of the mine working and the height difference between the tunnel portal on the surface and the disposal horizon. This tunnel will be used for the transport of SNF and other RAW to the disposal horizon and the loading of the waste and for the transport of personnel, materials and excavated rock between the surface and the disposal horizon and vice versa. In terms of operational safety, it will also serve as an emergency escape route if required.

The design parameters of the loading tunnel (Butovič et al.) for the selected conventional excavation method will be:

- shape: arched,
- tunnel height: 6,550 mm,
- tunnel width: 6,000 mm and
- reinforcement method: according to the prevailing geological conditions.

A cross-section of the loading tunnel is shown in Fig. 2. The geometry of the inclined tunnels will be updated in subsequent stages of the DGR project.

2.3.2.2 Extraction tunnel

The extraction tunnel will run parallel to the loading tunnel and will be used to transport excavated rock to the surface (by means of wheeled vehicles or conveyor belts). The transport of excavated rock in the disposal horizon towards the extraction tunnel will be via the main and connecting corridors. The extraction tunnel will also be used to transport workers to and from the excavation and construction sections. In terms of operational safety, it will also serve as an emergency escape route if required. The design parameters of the extraction tunnel will be identical to those of the loading tunnel. A cross-section of the extraction tunnel is shown in Fig. 2. The geometry of the inclined tunnels will be updated in subsequent stages of the DGR project.

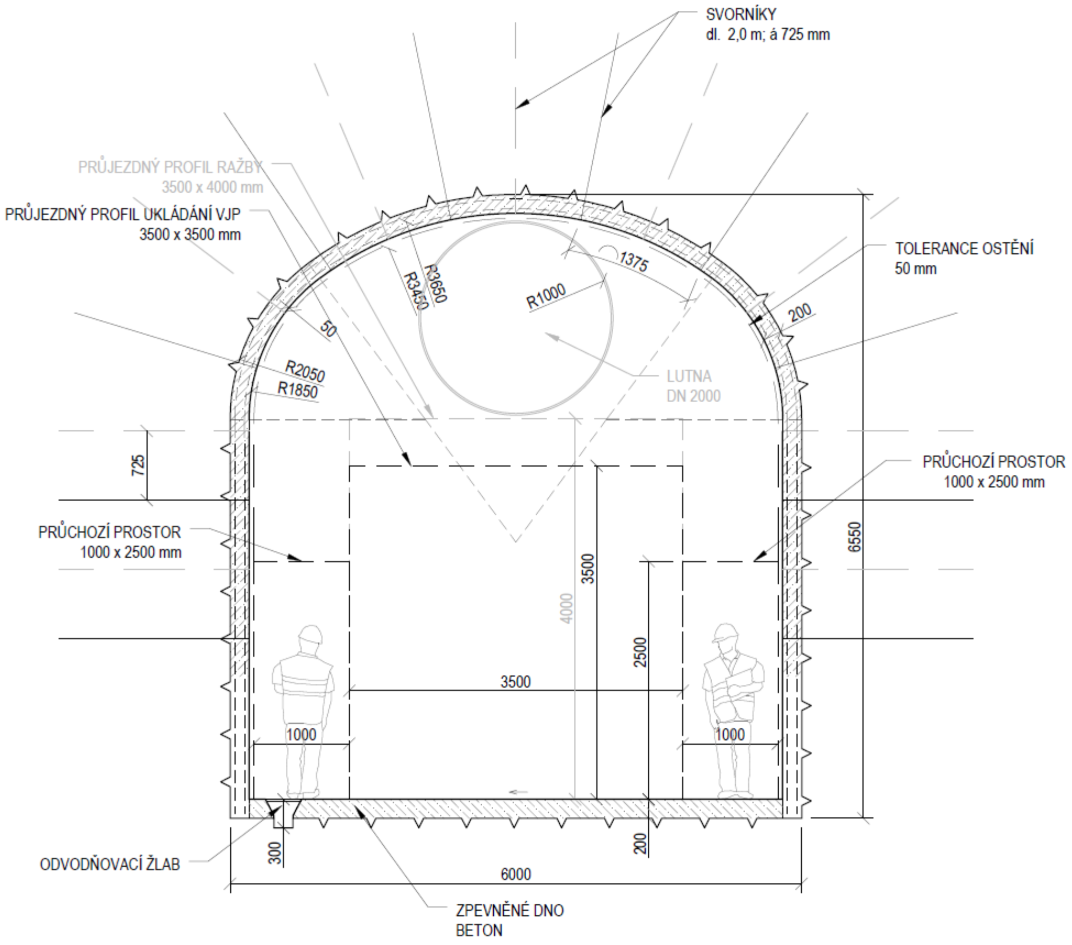

Fig. 2 Cross-section of the loading/extraction tunnels (Butovič et al. 2020)

2.3.2.3 Vertical mine workings

The design solution for the vertical mine workings (mining and extraction shafts) will be selected according to the Grünwald et al. (2017) and Butovič et al. (2020) reports, taking into consideration the parameters of the given site; alternatively, a variant involving a system of ventilation boreholes will be proposed. These technical design variants and the related design parameters will be processed in updates of selected components of the reference design solution going forward.

2.3.3 Disposal horizon

The disposal horizon will feature a system with a main and connecting corridors that will serve to connect the disposal sections, all of which will be complemented by the technical equipment for the handling, loading and disposal of WDPs/WPs.

2.3.3.1 Disposal section

The waste disposal sections will be excavated in a suitable rock block(s) (more details on the rock blocks at the four candidate sites can be found in Špinka et al. 2020a; Špinka et al. 2020b; Zahradník et al. 2020 and Butovič et al. 2020). The HLW/SNF part will comprise two sections (see chapter 3) at one height level and the ILW part (see chapter 4) which is planned to be located at a different height level to that of the HLW/SNF part. The dimensions of the transverse profiles for the various types of RAW will be determined in subsequent stages of the project with concern to the main, connecting and loading corridors for HLW/SNF and the loading spaces for ILW (corridors, silos, caverns); the exact final dimensions will depend, inter alia, on the dimensions of the transport equipment and the final decision on the sizes of the WDPs/WPs.

The DGR project currently assumes the emplacement of the WDPs with SNF in individual vertical wells, which will be lined and sealed at the top and bottom with a buffer material (damping and sealing barrier). It is also assumed that each disposal corridor will be filled with either SNF or HLW (but not both types).

Concerning the disposal of ILW, the geometry of the disposal spaces (corridors, caverns or silos), the design of the ILW disposal container and the type of backfilling material for the ILW section (based on cement or bentonite) will be determined as part of subsequent updates to the DGR project.

2.3.3.2 Main and connecting corridors

The main corridors will serve to connect the technical facilities of the excavation and construction section and the preparation and disposal section with the disposal spaces that will be located in a suitable rock block in the SNF/HLW disposal horizon. The disposal corridors in which the vertical disposal wells will be located will be excavated from the main corridors. The dimensions of both the corridors and the wells will be determined in subsequent stages of the DGR project. The figures below show cross-sections of the proposed corridors, see Fig.3 and Fig.4.

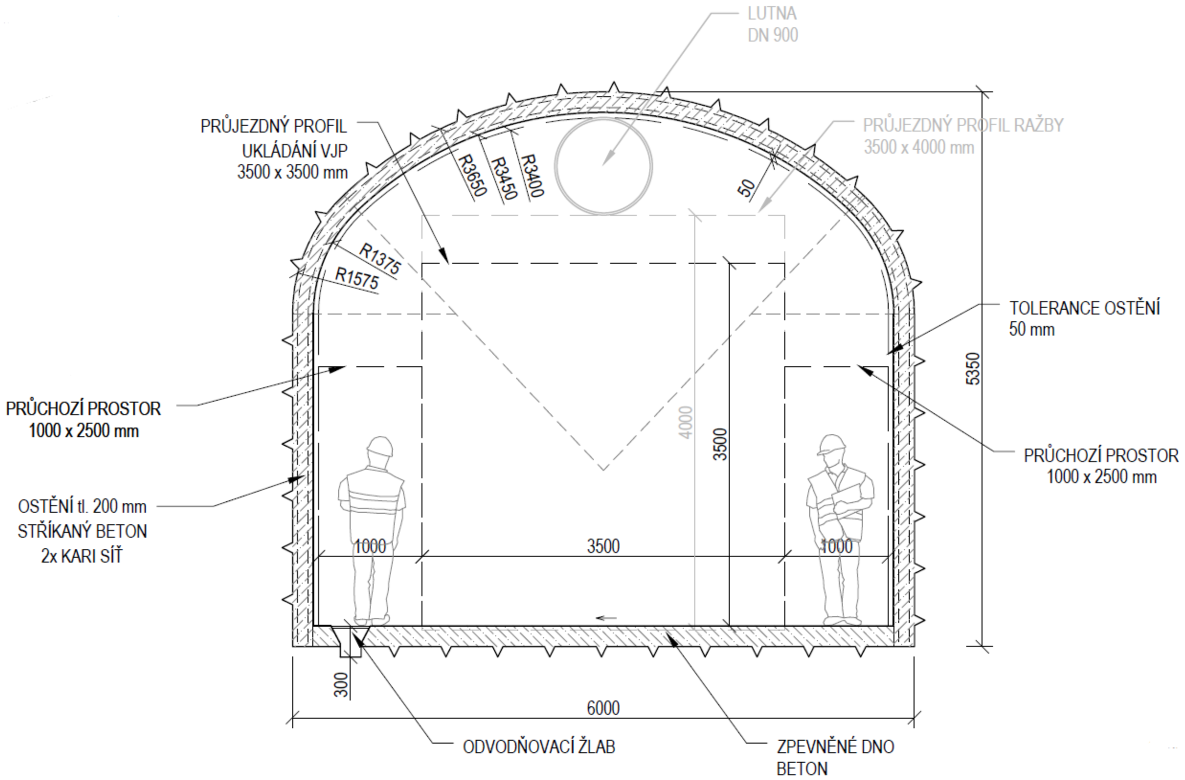

Fig.3 Transverse cross-section of the main/connecting corridors (Butovič et al. 2020)

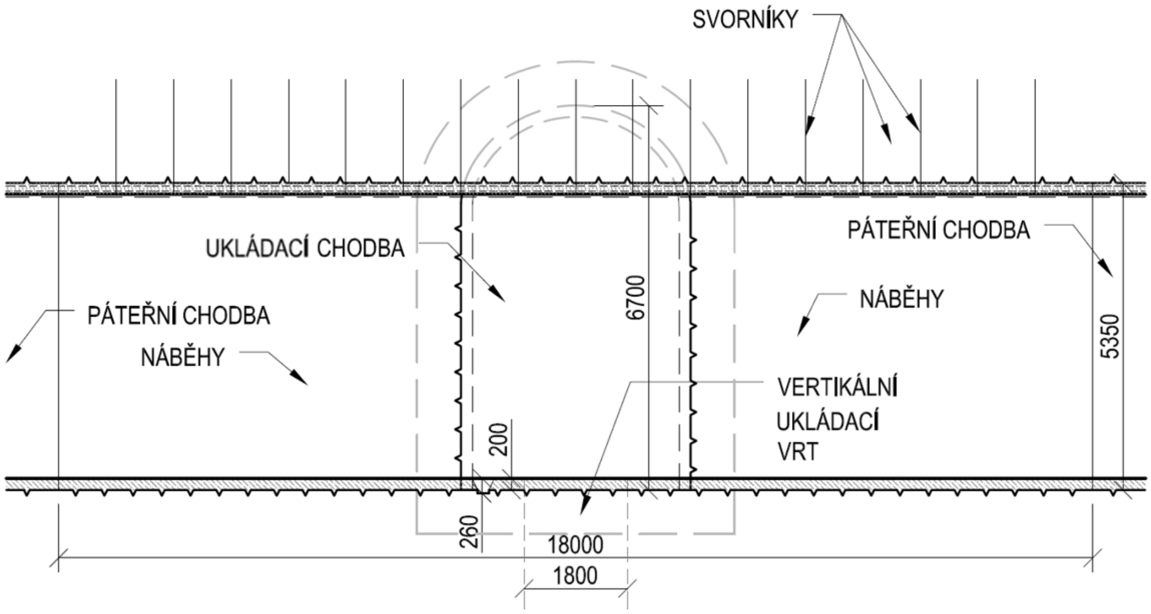

Fig.4 Cross-section of a disposal corridor (Butovič et al. 2020)

According to the project documentation prior to its updating (Špinka et al. 2020a; Špinka et al. 2020b; Zahradník et al. 2020 and Butovič et al. 2020), the main corridors will have an arched cross-section with vertical walls; they will be 6.0 m wide and 5.35 m high. The disposal corridors will also have an arched cross-section with vertical walls; they will be 4.0 m wide and 6.7 m high. The minimum transverse dimensions of the corridor profiles for the approach envisaged for the disposal of the WDPs are: 3.5 m wide and 3.5 m high. These dimensions also apply to the loading tunnel and the main and connecting corridors. The minimum dimensions of the disposal corridors are: 3.5 m wide and 5.5 m high.

The DGR project considers that the disposal facility will also serve as a transport facility, i.e. the transfer of the WDPs from the loading area near to the hot chamber to the storage location and, subsequently, to the final disposal site and the disposal wells. Hence, the dimensions of the loading tunnel profile and the main corridors in the SNF disposal horizon will be identical. However, the situation differs concerning the disposal corridors in which it will be necessary to tilt the WDP handling device into the vertical position prior to emplacement in the disposal wells.

2.3.3.3 Technical layout of the disposal horizon

The technical layout in this part of the underground area of the DGR will comprise a system of corridors and other structures that will serve to ensure continuous support for the construction and subsequent operation of the repository.

- The profiles of the structures and corridors will depend on the transport profiles of the mechanisation required.
- The technical layout will include the structural separation of the ongoing construction and disposal sections.

The design of this part of the repository will take into account the structures and processes associated with the disposal of WDPs in the disposal wells. The processes will comprise the final closure and sealing of the wells and the backfilling of the disposal corridors.

The technical layout of the underground area of the DGR will combine the demands set by the preparation and disposal section (e.g. an electrical power substation, workshops for the repair and maintenance of machinery, fire-related and lubricants storage areas and a cleaning and maintenance facility) and those set by the excavation and construction section (similar components to the preparation and disposal section with the addition of e.g. a sump with a pumping station) and the demands that are common to both sections (e.g. staff meeting areas, a first aid station and a testing chamber).

3 SNF/HLW disposal section

The HLW disposal section will serve for the disposal of both SNF from nuclear power plants (see 2.1.1 and other high-level waste (seeTab 9.). This section will be divided into sub-sections so as to optimise the concurrence of the construction and operation of the DGR dependent upon the rate of the production of SNF and the geometric arrangement of the rock blocks.

Unprocessed SNF will be permanently disposed of in the DGR in WDPs that will be emplaced in the disposal wells and then surrounded by a buffer material. It is currently expected that other HLW will be disposed of following the same principle. The access corridors to these wells, the so-called disposal corridors, will be backfilled and sealed with plugs. It is currently assumed that each disposal corridor will be filled with either SNF or HLW (but not a mixture of both).

The Czech disposal concept is based on the Swedish KBS-3 concept (SKB, 2010) as adapted to the crystalline rock environment of the Bohemian Massif, see Fig. 5. Unlike the Swedish concept, the Czech concept assumes the use of steel WDPs (Matulová et al., 2023) and Czech Ca-Mg bentonite (Hausmannová et al., 2018; Svoboda et al., 2022).

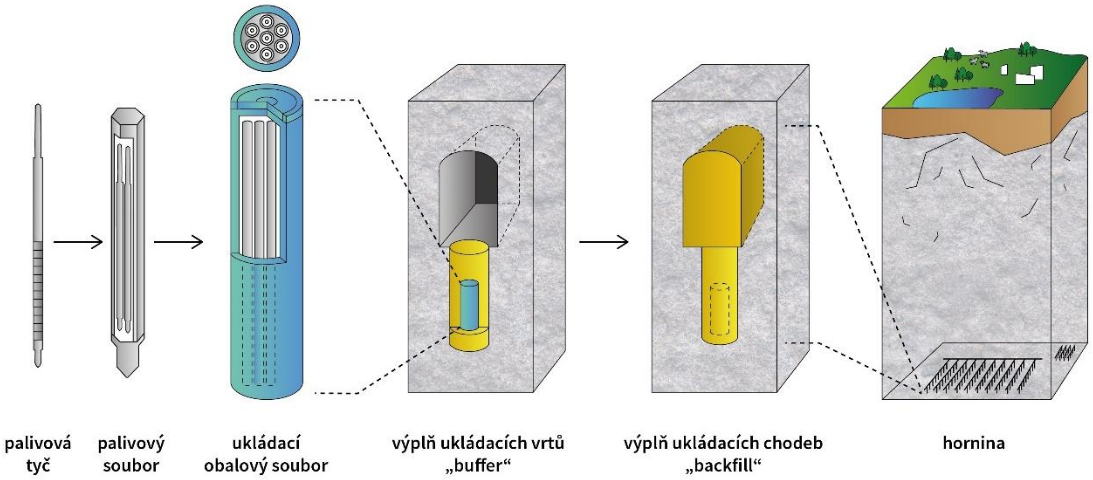

Fig. 5 Illustration of the disposal of SNF in the DGR

The SNF/HLW disposal sections will be made up of disposal corridors in which the disposal wells will be located. The number of disposal sections, the axial distance between the corridors and the number of corridors will be decided in future updates of the DGR design project (Tab. 9). The final choice of the geometric parameters will be determined, in addition to the inventory, by the properties of the rock mass at the selected final site.

Currently, based on calculations and the estimated characteristics of the candidate sites, the preliminary geometry of the disposal corridors as listed in Tab. 9 is being considered (according to Špinka et al. 2020a, Špinka et al. 2020b, Zahradník et al. 2020 and Butovič et al. 2020).

Tab. 9 Geometry of the SNF disposal spaces according to the site

Site	Number of SNF/HLW disposal sections	Axial distance between the disposal corridors	Number of disposal corridors	Total length of all the disposal corridors
Březový potok	2	35.5 m	103	79 km
Horka	2	25.5 m	88	94 km
Hrádek	2	35.5 m	72	72 km
Janoch	2	25.5 m	122	88 km

Basic parameters with respect to the SNF and other RAW disposal sections:

- Long-term safety will be assessed over a time horizon from the closure of the DGR up to 1,000,000 years (Vrba et al., 2023)
- Location at a depth of approx. 500 m below the drainage base (see chapter 3.1)
- The minimum required area for the underground part of the DGR depends on the thermal properties of the candidate sites (Grünwald et al. 2017); 197 ha was defined for the hypothetical site. The required underground areas for the 4 candidate sites according to Špinka et al. (2020a), Špinka et al. (2020b), Zahradník et al. (2020) and Butovič et al. (2020) are as follows: 291 ha (Březový potok), 250 ha (Horka), 269 ha (Hrádek) and 236 ha (Janoch).

3.1 Depth of the disposal horizon

The development of the technical design of the Czech deep geological repository has been underway since the 1990s (Holub et al. 1999) and is being continuously updated and refined, especially with regard to the increasing level of the geological knowledge of the sites. This chapter provides a summary of the information used to estimate the depth of the underground area of the DGR.

According to SÚJB Decree No. 378/2016 Coll. on the assessment of areas for the location of nuclear facilities, specifically requirement a) Section 18, which refers to the deep geological repository, it is necessary to assess the depth range and dimensions of a suitable rock mass for the construction of the DGR and the distance of the rock mass from geological interfaces and tectonic faults that could act as pathways for the transport of radioactive substances.

The SÚRAO MP22 methodological guideline “The requirements, suitability indicators and criteria for site selection” (Vokál et al. 2017) states that potentially usable rock blocks for the construction of the underground part of the DGR must be located at such a depth that prevents human access to the waste, the negative influences of processes that occur on the surface and the rapid migration of radionuclides to water-bearing disturbed zones. A sufficient depth for disposal facilities for the disposal of spent nuclear fuel is considered to be several hundred meters (min. 300 m) below the surface of the earth (IAEA 2011). Based on these assumptions, the minimum depth for the location of the underground part of the DGR has been set at 300 m below the surface, while it is also necessary to take into account a certain reserve, as determined primarily by the geological conditions of the considered site and the requirements concerning DGR safety licensing. With regard to DGRs in other countries with or planning to construct repositories in crystalline rocks, e.g. Onkalo in Finland and Forsmark in Sweden, depths of around 400 metres and 450 metres below the surface were determined, respectively.

The comparison of candidate DGR sites in the Czech Republic in 2020 considered (following the conservative approach) a depth of 500 m below the surface. The decision took into account various aspects such as the influence of erosion and the future occurrence of permafrost in the Czech Republic. With concern to the influence of erosion and denudation, such processes occur selectively, and their intensity differs significantly depending on local conditions. The intensity and character of erosion and denudation processes that occurred in the past are reflected in the present-day geomorphological characteristics of the area. The various types of relief we see today are the result of the long-term action of exogenous and endogenous factors at work on the earth's surface. The interpretation of processes that occurred in the past can subsequently be applied to predicting future morphological developments (Hroch 2015). In the Czech Republic, such processes comprise mainly the mechanical and chemical weathering of rocks. The intensity and predominant type of exodynamic processes, including denudation and erosion, depend primarily on the geomorphological characteristics of the area, the climate, vegetation and land use patterns (e.g. Fairbridge 1968, Gaudie 2004). Permafrost, which is likely to reach depths of over 200 m in the next glacial age, will limit the rate of erosion due to its preventing groundwater circulation and its outflow, i.e. it will exert a protective impact. However, the subsequent melting of the permafrost in the following interglacial period will lead to the creation of open subhorizontal orientation fractures, which will result in the acceleration of the groundwater circulation to a depth of up to 200 m, changes in the petrophysical properties of the overburden and the acceleration of erosion caused by the outflow of water from both the permafrost and the melting of glaciers. The rate of erosion and denudation increases after the end of glaciation periods due to the outflow of glacial water (Hroch 2015). With respect to future glaciation, which will occur in present-day northern Europe within the next 100 thousand years, as well as the uplift of the Bohemian Massif, it is necessary to count on a rate of erosion and subsequent denudation of 0.5 to 30 m per 100 thousand years (Czudek 2005). The upper limit corresponds to the acceleration of water erosion in the interglacial period, and the lower limit to ice age and periglacial climate conditions at the candidate sites over the entire period of 100 thousand years (Hroch 2015). In previous glaciation periods in the area of the Czech Republic, none of the wider areas of the candidate sites were glaciated; therefore, the direct influence of glaciers on the sites in the next 100 thousand years can be practically ruled out (Nývlt et. al. 2015).

A further condition in terms of the depth of the DGR concerns the determination of local and regional drainage bases. Drainage bases comprise surface streams, local watercourses and springs, as well as watercourses that traverse areas with significant fault zones. Thus, they form the interface for the penetration of groundwater into surface drainage systems. The area into which runoff from the landscape flows is referred to as the drainage basin (Vondrovic et al. 2019; Krásný et al. 2012). The distance of the drainage basins from the potential DGR sites is considered in the respective site technical reports (Březový potok, Horka, Hrádek, Janoch) (Havlová et al. 2018abcd).

When deciding on the depth level of the underground part of the DGR, it is also necessary to take into account the temperature of the rock environment, with the consideration of a temperature increase of 2.3 - 3.0°C per 100 metres at an average heat flow rate (the geothermal gradient). The lower the overburden, the lower the temperature difference can be expected at depth. However, the temperature at the depth of the repository will also be determined by the thermal conductivity of the rocks in which the DGR will be constructed (Dědeček et. al 2020).

All of these factors are important in terms of determining the optimal depth for the DGR taking into account safety, durability and economic feasibility. A comprehensive analysis of all these so-called boundary conditions is necessary for the design of a repository that will be able to effectively and safely isolate the nuclear waste for the required period of time.

A DGR depth of 500 metres is acceptable after conservatively taking into account 300 metres of erosion and 200 metres of permafrost (the calculation was performed using data obtained from the Digital Relief Model of the Czech Republic, 5th generation, a mapping application for the analysis of elevation https://ags.cuzk.cz/av/). This depth respects all the known relevant parameters. The depth of the repository for the purposes of the technical design of the DGR in the Czech Republic is considered to be -500 metres from the topographically lowest point on the surface of the selected homogeneous blocks, which corresponds to the local drainage base of the given homogeneous block. In the case of the use of two or three homogeneous blocks at one site, the condition of the location of the repository at one level can be attained provided that the lowest topographic points of these blocks are equivalent. This optimisation approach will increase the degree of efficiency in the case of the use of multiple homogeneous blocks at one site when designing the DGR.

3.2 WDP disposal method

One of the most important factors in the technical design of the DGR concerns how the WDPs will be placed, whether vertically in individual disposal wells (see Fig. 1 and Fig. 6) or horizontally in longer wells in which several WDPs are placed end-to-end. In the past, SÚRAO considered the vertical disposal method (Holub et al. 1999), the horizontal disposal method (Pospíšková et al. 2011) and both methods simultaneously (Špinka et al. 2020, Zahradník et al. 2020b, Zahradník et al. 2020a), which resulted in the proposal of 2 technical design solutions. However, with concern to subsequent stages of the DGR project, it has been decided that only one method will be considered, which will allow for the more efficient and, above all, cost-effective continuation of the project. Selecting one approach will also contribute to the optimisation of the time requirements, which is essential in terms of fulfilling EU Commission Regulation 2022/1214 of 9 March 2022, i.e. the commissioning of the Czech DGR in 2050, i.e. 15 years earlier than planned according to the Concept (2019).

SÚRAO has decided that the vertical disposal method only will be considered in the subsequent stages of the DGR project. The fundamental argument concerned the completeness of the information already available on the vertical disposal method (Ikonnen 2023). Proof of the suitability, describability and safety of the vertical WDP disposal method in crystalline rocks is provided in the Finnish Safety Case (POSIVA Safety Case), which was subjected to thorough verification by the regulatory authority.

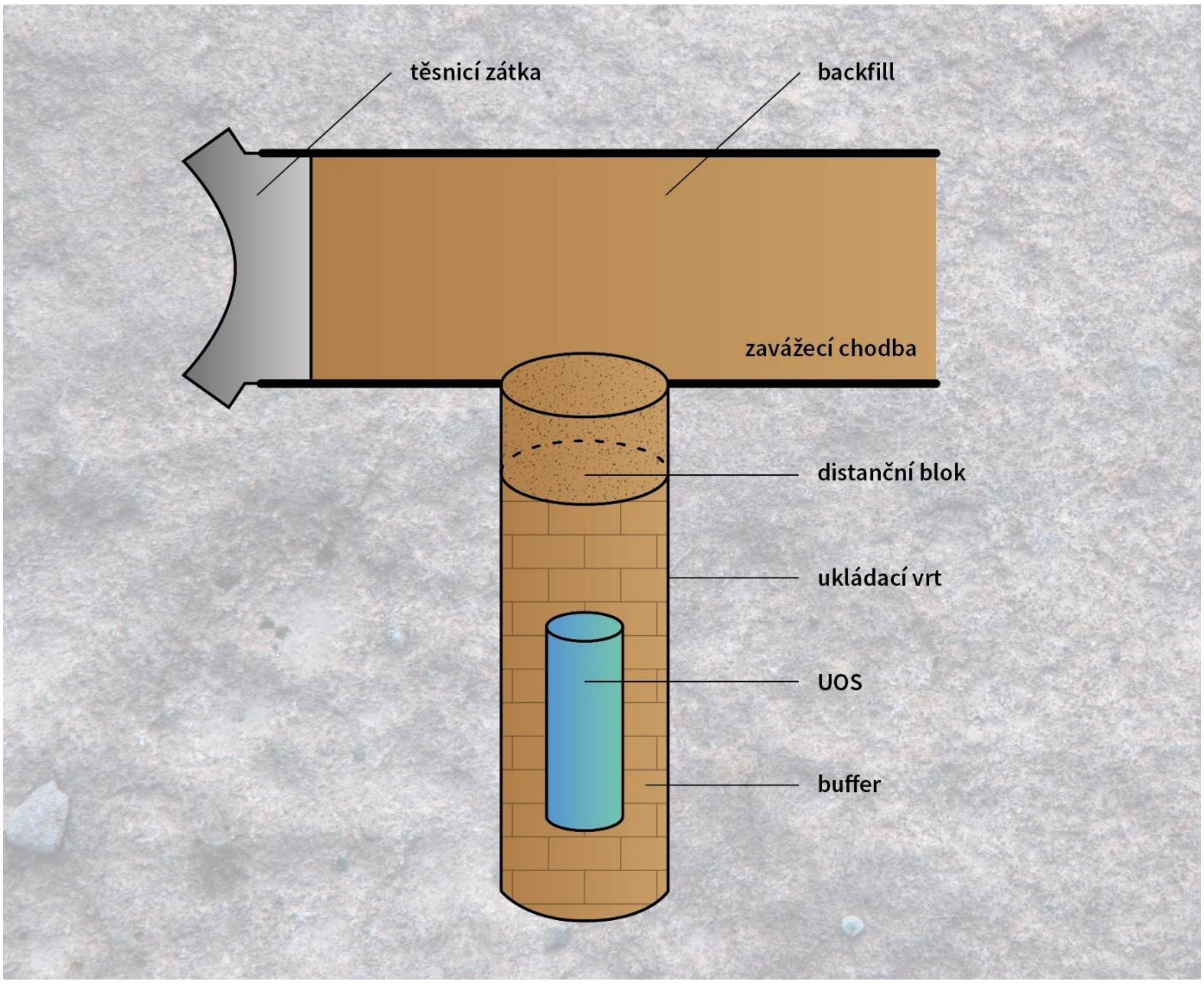

Fig. 6 Diagram of the vertical disposal system

A number of uncertainties surround the horizontal disposal method with respect to crystalline rock masses that could exert major impacts on long-term and/or operational safety, as listed below (Ikonnen, 2023):

- the influence of bentonite erosion and the potential occurrence of the domino effect in horizontal disposal wells,
- the technology applied for the remediation of faults in horizontal disposal wells and the necessity for the development of a so-called mega-packer,
- the necessity for the artificial hydration of horizontal disposal wells,
- the handling of WDPs in horizontal disposal wells in emergency situations, i.e. multiple WDPs may be affected.

However, the horizontal disposal method has one significant advantage over the vertical method, i.e. it is not necessary to excavate and equip disposal corridors, which results in a reduction in the extent of excavated spaces and the associated smaller amount of excavated rock produced and backfilling materials required, both of which reduce the costs of the DGR. Nevertheless, due to the number of issues that remain unresolved with respect to the horizontal disposal method, this option has practically been ruled out; however, SÚRAO will continue to monitor developments in this area going forward.

3.3 Disposal corridors

The term disposal corridor refers to the underground corridors in the disposal horizon in which the vertical disposal wells are located and which are used for the transport of WDPs prior to disposal. Once all the disposal wells in an individual corridor have been filled, the corridor will be backfilled with a suitable material and finally sealed with a sealing pressure plug. The corridors will be required to have no significant geological disturbances or active groundwater inflows (the exact criteria will be specified in the subsequent stages of the DGR development project). Only those materials that will not exert a negative impact on the safety functions of the engineered barriers will remain in the disposal corridors (support structures, soil levelling materials) prior to backfilling and final closure with the sealing plug (Večerník et al., 2022, TZ 616/2022).

It is assumed that the dimensions of the disposal corridors (Grünwald et al. 2017) using the conventional excavation method (Fig.4) will be:

- corridor height: 6,700 mm and
- corridor width: 4,000 mm.

3.4 Disposal wells

The disposal wells will consist of circular large-profile boreholes drilled into the floors of the disposal corridors. Each well will contain one WDP.

3.4.1 Disposal wells for WDPs with SNF

The parameters of the disposal well for the vertical disposal concept were originally defined in SÚRAO technical report 134/2017 (Grünwald et al. 2017). Subsequently, as part of the standardisation of the outer diameter of the WDP for all the types of spent nuclear fuel that will be produced, the dimensions of the disposal wells were adjusted. Subsequently, the proposal for the placement of a concrete plug over the buffer in the disposal well was replaced by the placement of a bentonite spacer plug so that the buffer will not be negatively affected by the elevated pH of the concrete. Aimed at ensuring the homogeneity of the buffer, the spacer block will be 1.5 m longer than the originally planned concrete plug, which led to the requirement to extend the depth of the disposal wells (Svoboda et al. 2022, report 644/2022).

Design parameters of the disposal well:

- Diameter of the disposal well: 1,650 mm (for all types of SNF) (Svoboda et al. 2022),
- Depth of the disposal well for VVER 440 SNF: 6,540 mm[1] and for VVER 1000 and NNS SNF: 7,955 mm (Svoboda et al. 2022),
- The axial distance between the wells will depend on the type of SNF (the thermal output of the WDP, see 2.1.1), the thermal properties of the rock mass and the structural calculations (Grünwald et al. 2017, Butovič et al. 2020, Špinka et al. 2020a, Špinka et

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[1] This value is based on the original height of the WDP 440, i.e. 3,790 mm, which was subsequently changed to 3,810 mm following the introduction of design modifications. The next update of the technical design will take into consideration the new height of 3,810 mm, which is likely to impact the depth of the disposal well.

al. 2020b, Zahradník et al. 2020). The currently assumed axial distances between the disposal wells (according to currently available information) are shown in Tab. 10.

Tab. 10 Axial distances between the disposal wells according to the DGR site and type of SNF

Site/Fuel	**VVER-440**	**VVER-1000**	**NNS**
Hypothetical site	4,600 mm	7,750 mm	18,000 mm
Březový potok	5,000 mm	7,500 mm	13,250 mm
Horka	8,700 mm	8,000 mm *	13,500 mm *
Hrádek	4,750 mm	7,000 mm	11,500 mm
Janoch	5,200 mm	8,250 mm	15,250 mm

* The minimum axial distance for SNF as determined taking into account the extension of the storage period of SNF from VVER-1000 reactors and NNS to 75 years.

- The expected total number of disposal wells is determined by the number of WDP with SNF 12,453 and the estimated reserve for determining the area of the disposal sections of 20% (Grünwald et al. 2017), i.e. a total of 14 944.
- The excavation disturbed zone around the disposal wells is assumed to be 350 mm (Grünwald et al. 2017).

3.4.2 Disposal wells for other HLW

This issue has not yet been fully resolved. In the event that other HLW is disposed of in WDPs with the same dimensions as for SNF (see Pospíšková et al. 2022 – report 657/2022), the dimensions will be identical to those described above. In the case of modifications, however, it will be necessary to adjust the dimensions. The axial distance between the wells will be determined based on the thermo-technical calculations.

3.5 Waste disposal package - WDP

The WDP will serve as the primary physical barrier in terms of ensuring the long-term safety of the DGR.

3.5.1 WDPs for SNF from nuclear power stations

The WDP will consist of an outer casing (cover, lid, plug and bottom) made of S355J2H+N carbon steel and an inner casing (cover, lid, plug and bottom) made of 1.4404 stainless steel. The number of fuel assemblies placed in the WDP will vary according to the type of fuel; 7 for SNF from the Dukovany VVER 440 reactors (see Fig. 7) and 3 for SNF from the Temelín VVER 1000 and planned NNS and SMR reactors (see Fig. 8). The detailed structural design of the WDP and a description of the materials and technologies is described in SÚRAO report 665/2023 (Matulová et al. 2023). Since it is possible that various components of the WDP will be further optimised in the future, its design is currently considered to be preliminary.

WDP design parameters:

- Minimum lifespan: 1,000,000 years
- Maximum temperature on the WDP surface: 95°C (see chapter *3.6 Buffer*)

- Maximum design pressure on the WDP: up to 20 MPa (Hasal et al., 2019)
- WDP specifications according to the SNF, see Tab. 11 :

Tab. 11 Specifications of the WDPs for VVER-440, VVER-1000, NNS and SMR

Fuel	**VVER-440**	**VVER-1000**	**NNS and SMR**
No. of WDPs	2,791	1,860	4,443 and 3,885
Height	3,810* mm	5,205 mm	Value not yet determined
Width	Outer casing 914/65 mm, inner casing 7 assemblies 244.5/36 mm	Outer casing 914/65 mm, inner casing 3 assemblies 355.6/40 mm	

* this value is the currently considered height; the original calculations (e.g. Matulová et al. 2023) considered a height of 3,790 mm, which was changed following the introduction of structural modifications

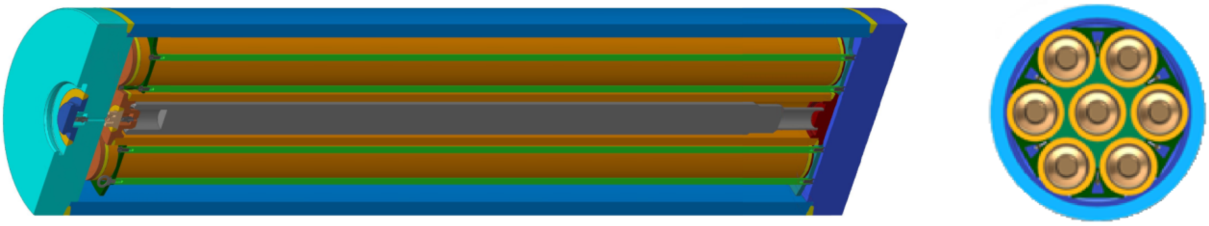

Fig. 7 Model of the ŠKODA 440/7 WDP (Forman et al. 2021)

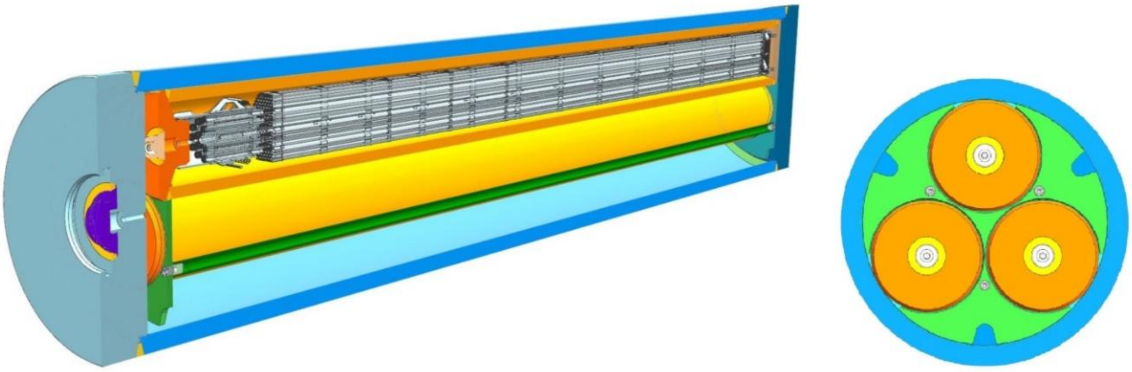

Fig. 8 Model of the ŠKODA 1000/3 WDP (Forman et al. 2021)

3.5.2 WDP for LVR-15 SNF

Whereas no specific WDP design has yet been proposed for SNF from research reactors, one potential solution according to the (Pospíšková et al. 2022, Matulová and Lahodová 2024) report comprises the use of a similar WDP as that for SNF from nuclear power plants. since the WDP requirements will be similar in terms of characteristic properties of the disposed of SNF. However, the design will be required to meet the conditions for ensuring nuclear safety (ensuring subcriticality) and suit the dimensions of the disposed of fuel assemblies.

3.5.3 WDP for processed fuel

No specific WDP has yet been proposed for processed fuel. However, the (Pospíšková et al. 2022) project suggested a potential approach to the design of such a WDP for one or more containers (Fig. 9). The outer dimensions of the WDP will depend on the thickness of the wall, which will be determined based on the results of strength calculations (the fulfilment of mechanical strength requirements) and the required service lifespan (degradation of the WDP and the loss of its safety function). One of the future research priorities concerns the design of the WDP for LVR-15 fuel, which is expected to be similar to that for SNF in terms of the technical specifications of the materials (Matulová and Lahodová 2024).

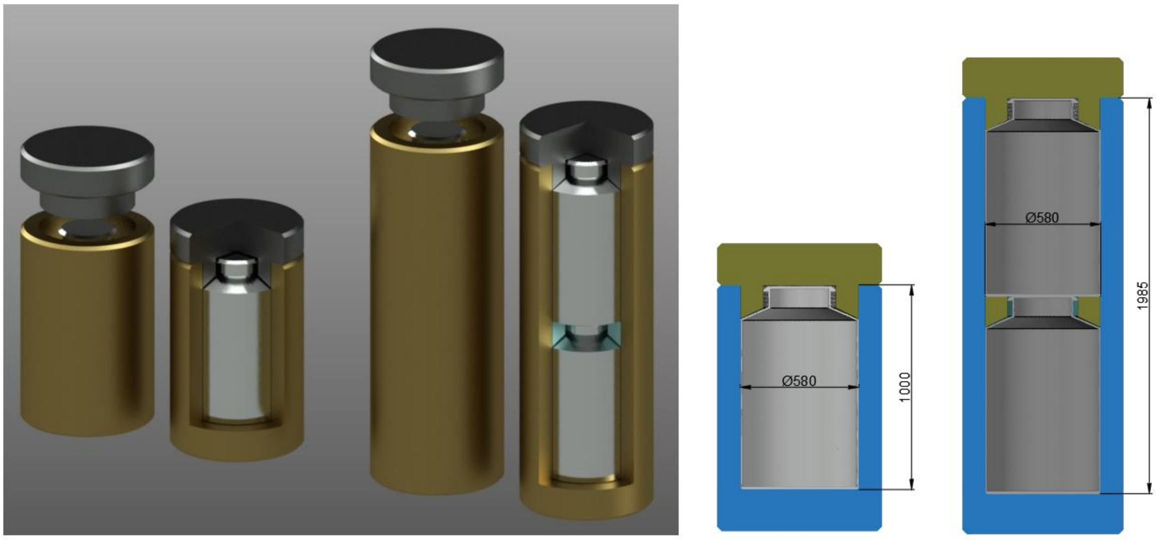

Fig. 9 Conceptual design of the WDP for vitrified waste from the processing of LVR-15 SNF (Pospíšková et al. 2022)

3.6 Buffer

The buffer (damping and sealing barrier) comprises one of the engineered barriers; it will be made of compacted bentonite and will be placed in the disposal wells so as to surround the WDPs. The use of Czech calcium-magnesium bentonite is assumed.

The required safety and technical functions that will be provided by the buffer can be divided into the following categories (Svoboda et al. 2022):

- retardation of the degradation of the WDP via:
  - minimisation of the access of water and aggressive materials (the corrosive substances in the surrounding rock environment, e.g. chlorides and sulphides) to the WDP,
  - prevention/minimisation of the development of microbially-induced corrosion,
  - ensuring the compatibility of the buffer with the WDP construction materials,
- ensuring the removal of heat from the WDP
- mechanical protection and stabilisation of the WDP

- retardation of the migration of radionuclides

The design parameters of the buffer are based primarily on the long-term research of Czech bentonites, as described in SÚRAO report 309/2018 (Hausmannová et al. 2018), the results of which were analysed in report 632/2022 (Šachlová et al. 2022). The buffer was designed on the basis of the results of the analysis and a DGR technical design project (Grünwald et al. 2017), as subsequently optimised following the refinement of the structural dimensions of the disposal well.

The currently preferred option for the buffer comprises a combination of compacted blocks as the main filling material and pelletised material for the gaps between the WDP and the blocks and between the blocks and the rock mass and the levelling of the bottom of the well (Svoboda et al. 2022). The buffer for the 440 WDPs (Fig. 10) and the buffer for the 1000 WDPs (Fig. 11) have the same parameters except for the height, which was determined by the differences in the lengths of the two WDPs. A summary of the properties and composition of Czech bentonite is provided in SÚRAO report 632/2022 (Šachlová et al. 2022) and a proposal for a Czech conceptual design for the filling components is presented in report 644/2022 (Svoboda et al. 2022).

<u>Buffer design parameters:</u>

- form: a combination of blocks (main filling material – 3.6.1) and pellets (bottom levelling layer – and the filling of the technological joints)
- width: 368mm (268mm: main filling material and 50mm: filling of the joints between the WDP/buffer and the buffer/rock mass); this value is based on a minimum buffer thickness requirement of 350mm, which is then extended based on the availability of profiles for drilling and the diameter of the WDP
- thickness under the WDP: 400 mm (350 mm: main filling and 50 mm: levelling layer)
- thickness above the WDP: 350 mm
- height: 4,540[2] mm (WDP 440) and 5,775 mm (WDP 1000),
- dry density (ρ_d): averaged (blocks and pellets) in the area below and above the WDP: ρ_d = 1,664 kg/m^3; and around the WDP: ρ_d = 1,618 kg/m^3 and
- moisture content following the placement of the buffer: at least such as to sufficiently remove the heat from the WDP, the temperature of the surface of which must not be in excess of 95°C. In order to guarantee the minimum thermal conductivity, as well as ability to work with the material, the moisture content should be higher than 4% for the pellets (ρ_d => 1900 kg/m^3) and in the range 10-20% for the blocks (ρ_d = 1700 kg/m^3). The exact moisture values of the bentonite components have not yet been specified; they depend on a wide range of factors that currently form the subject of intensive research.

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[2] This value is based on the original height of the WDP 440, i.e. 3,790 mm, which was subsequently changed to 3,810 mm following the introduction of design modifications. The next update of the technical design will take into consideration the new WDP 440 height of 3,810 mm, which will impact the height of the buffer.

3.6.1 Main filling material

The main filling material of the disposal wells will comprise bentonite blocks with a dry density of 1,700 kg/m^3, which was selected so that even in the space around the WDP, following the filling of the technological joints with pelletised bentonite, the required average buffer ρ_d of 1,600 kg/m^3 will be achieved.

The blocks will be pre-assembled in layers and emplaced layer-by-layer in the wells. The arrangement of the individual blocks in the layers and the thicknesses of the layers will be optimised in the subsequent stages of the DGR project. The arrangement of the blocks, especially those beneath the WDP, will be designed with a view to minimising the mechanical erosion of the bentonite in the vicinity of the WDP; more detailed information is provided in report 794/2024 (Kumpulainen et al. 2024).

3.6.2 Bottom levelling layer

The bottom levelling layer will be constructed from pelletised bentonite (a mixture of granulated bentonite with a determined grain size composition) with a minimum average ρ_d following disposal of 1,400 kg/m^3. The thickness of the levelling layer will depend on the technology selected for the excavation of the disposal wells. The conceptual design assumes a thickness of 50 mm.

3.6.3 Filling of the technological joints

The presence of so-called technological joints is necessary due to a number of factors including borehole tolerances, the ease of the handling of the WDPs and the filling blocks and the ability to efficiently fill the joints between the various components of the disposal well without the formation of cavities. It is assumed that the width of these joints will be 50 mm. The technological joints along the lengths of the WDP and the borehole walls will be filled with pelletised bentonite (a mixture of granulated bentonite with a determined grain size composition) with a minimum average ρ_d following disposal of 1,400 kg/m^3. This will ensure the required average ρ_d of the buffer of 1600 kg/m^3. The consistency of the verification of the sufficiently high bulk density of the filling of the gaps was confirmed in report 750/2024 (Vašíček et al. 2024). The volume of the gaps around the bentonite blocks in the wells will be significant, thus the bulk density of the gap filling material will exert a significant impact on the resulting average bulk density of the filling materials of the wells.

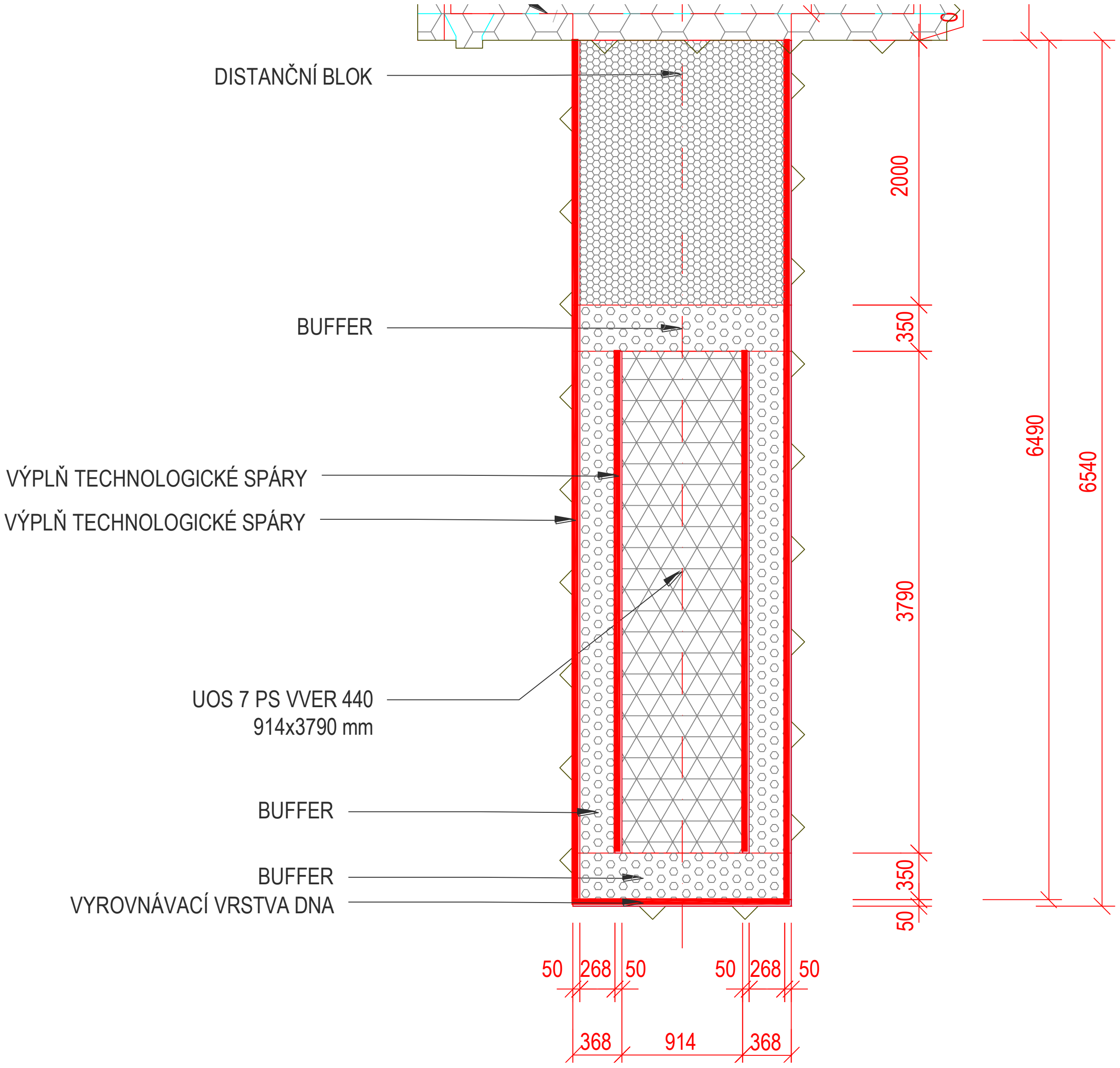

Fig. 10 Diagram of the technical design for the filling of the disposal wells for 440 WDPs (Svoboda et al. 2022)[3]

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[3] The diagram is based on the original height of the WDP 440, i.e. 3,790 mm, which was subsequently changed to 3,810 mm following the introduction of design modifications. The next update of the technical design will take into consideration the new WDP 440 height of 3,810 mm, which will impact the height of the buffer.

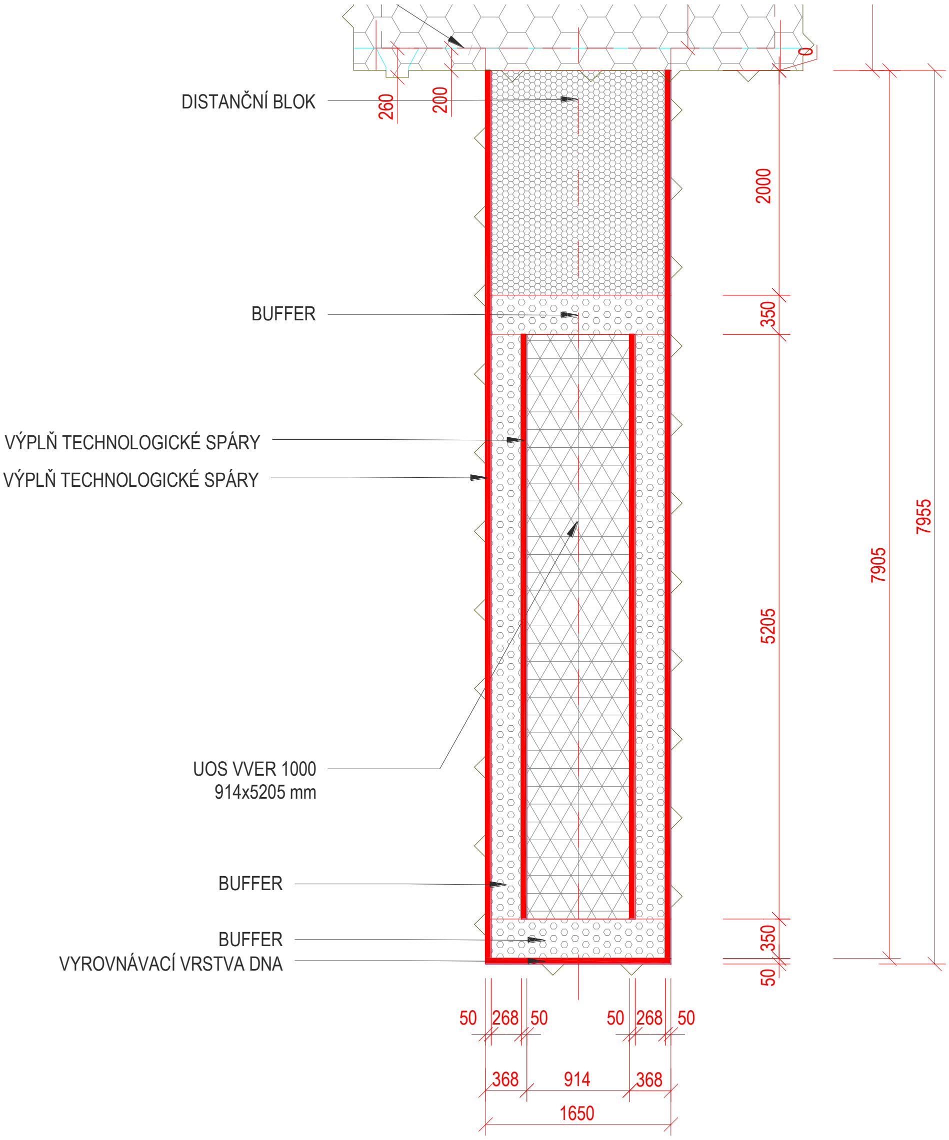

Fig. 11 Diagram of the technical design for the filling of the disposal wells for 1000 WDPs (Svoboda et al. 2022)

3.7 Spacer block

The spacer block, which will be made from bentonite with the same material parameters as the buffer, comprises one of the engineered barriers; it will be positioned in the top part of the disposal wells above the WDP and the buffer. The main function of the spacer block will be to ensure that the buffer remains firmly in place so that it does not swell into the backfill material, thus ensuring its safety function.

The design parameters of the spacer block are based primarily on the long-term research of Czech bentonites, as described in SÚRAO report 309/2018 (Hausmannová et al. 2018), the results of which were analysed in report 632/2022 (Šachlová et al. 2022). The spacer block was designed according to the results of this analysis and the overall requirements of the DGR design project (Grünwald et al. 2017), which proposes a spacer block height of 500 mm; however, this height will probably not be sufficient in terms of preventing the swelling of the buffer. The DGR Concept proposes a minimum spacer block height of 2 m, the suitability of which will have to be verified going forward.

The currently preferred option for the spacer block is a combination of compacted blocks as the main filling material and pelletised material for the filling of the joints (Svoboda et al. 2022), see Fig. 10 and Fig. 11. A summary of a proposal for a Czech conceptual design of the filling components is provided in SÚRAO report 644/2022 (Svoboda et al. 2022).

Spacer block design parameters:

- form: a combination of bentonite blocks (main filling 3.7.1.) and pellets (technological joint filling)
- width: 1,650 mm (main filling: 1,550 mm and technological joint filling: 2 x 50 mm)
- height: 2,000 mm (this value is an expert estimate, which is currently being refined),
- dry density: ρ_d = 1,664 kg/m^3 and
- moisture content following the placement of the spacer block: no specific value has yet been determined.

3.7.1 Main filling

The main filling material will comprise bentonite blocks of ρ_d = 1,700 kg/m^3. The dry density was chosen so that the required average ρ_d = 1,600 kg/m^3 will be ensured in the disposal spaces.

The blocks will be pre-assembled in layers and emplaced layer-by-layer. The arrangement of the individual blocks in the layers and the thicknesses of the layers will be decided in the subsequent stages of the optimisation of the DGR project.

3.7.2 Filling of the technological joints

The presence of so-called technological joints/gaps is necessary due to a number of factors, including borehole tolerances and the ability to efficiently fill the joints between the various components without the formation of cavities. It is assumed that the width of these joints will be 50 mm. The technological joints will be filled with pelletised bentonite (a mixture of granulated bentonite with a determined grain size composition) with a minimum average ρ_d following disposal of 1,400 kg/m^3, which will ensure the attainment of the required average buffer ρ_d of 1600 kg/m^3.

3.8 Backfill

The backfill comprises one of the engineered barriers; it is made from compacted pelletised bentonite and serves to seal the disposal corridors. It must prevent the excessive shifting of the buffer material out of the disposal wells (sufficient resistance to the swelling of the buffer and/or the spacer blocks from the wells into the corridors). Furthermore, the backfill must act to minimise the transport of water and radionuclides. However, it must allow for gases to be drained from the buffer without the impairment of its sealing function. In general, it can be stated that the backfill and the buffer have similar general characteristics.

The design parameters of the backfill (see Fig. 12) are based primarily on the long-term research of Czech bentonites, as described in SÚRAO report 309/2018 (Hausmannová et al. 2018), the results of which were analysed in report 632/2022 (Šachlová et al. 2022). The backfill was designed based both on the results of the analysis and the DGR technical design project (Grünwald et al. 2017). A summary of the Czech concept for the filling component is provided in SURAO report 644/2022 (Svoboda et al. 2022).

<u>Backfill design parameters:</u>

- dry density of the whole of the barrier: 1,400 kg/m^3,
- moisture content following emplacement: this value has not yet been determined
- form: pellets (a mixture of granulated bentonite with a determined grain size composition)
- pellet parameters:
    - ρ_d: over 2,000 kg/m^3
    - moisture content: this value has not yet been determined
    - Granularity: not yet determined

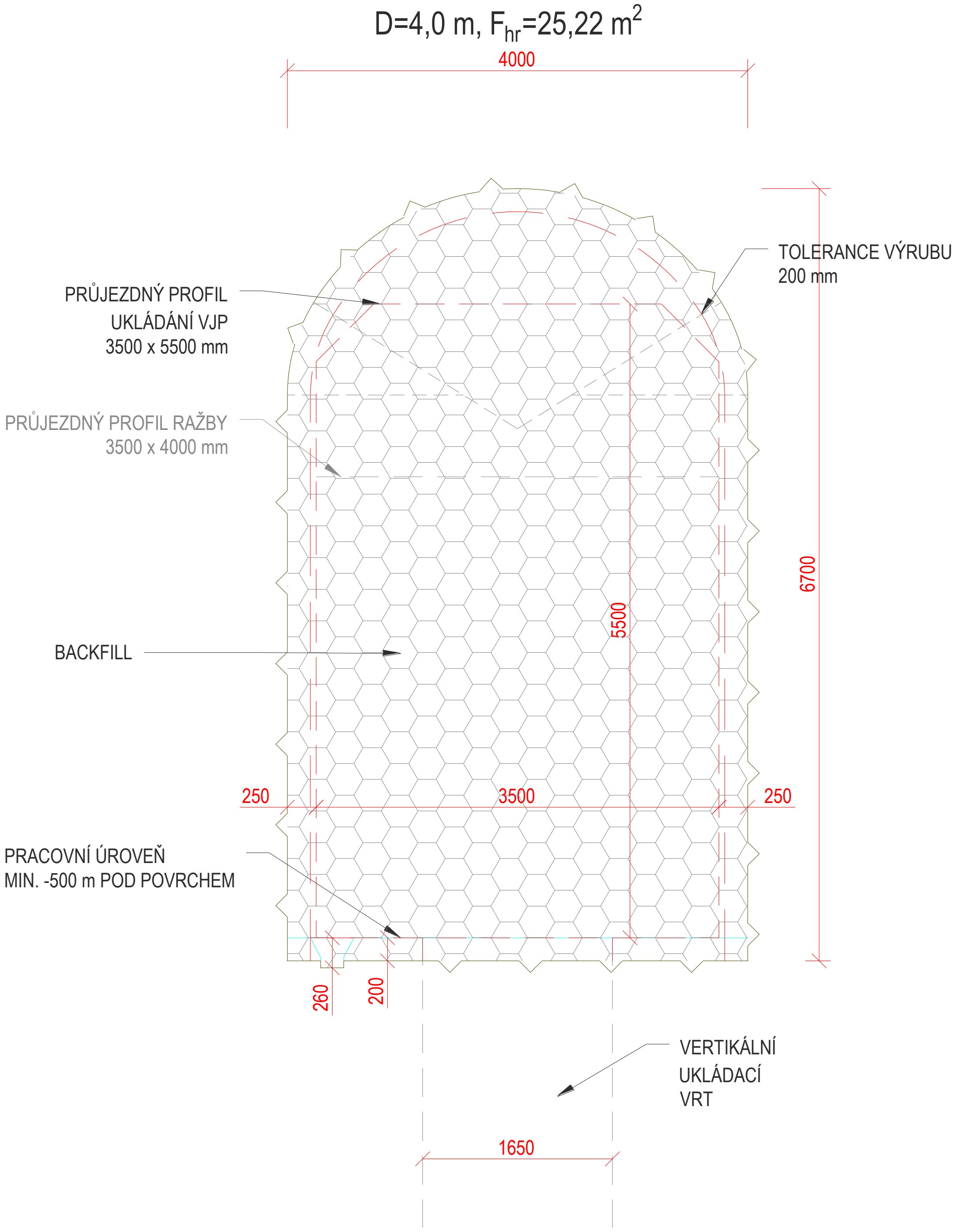

Fig. 12 Technical design of the backfill (Svoboda et al. 2022)

3.9 Disposal corridor plugs

The disposal corridor plug comprises one of the engineered barrier components; it is a multi-layered concrete structure that will be positioned at the mouths of the backfilled disposal corridors. It is conical in shape and is wedged into the rock in the form of a ring around the corridor profile. A diagram of the plug is shown in Fig. 13.

The design parameters of the plug are based primarily on the requirements set out in the DGR project (Grünwald et al. 2017) and the results of the DOPAS international project (Dvořáková et al. 2013).

The preliminarily design of the plug is described in report 644/2022 (Svoboda et al. 2022); however, the current design will have to be verified by means of structural calculations and with regard to the key dimensioning conditions, i.e. the stress conditions in the disposal horizon, the expected swelling pressures that will act on the plug, the operational conditions when backfilling the disposal corridors, etc.

Plug design parameters:

- form: concrete blocks (lost formwork) and the body of the plug made from sprayed or monolithic concrete (a description of the properties of the concrete is provided in SÚRAO report 644/2022, Svoboda et al, 2022)
- preliminary plug thickness: 2,750 mm (the body of the plug: 2,500 mm and the lost formwork: 250 mm)
- resistance to the swelling pressure exerted by the backfill material and hydrostatic pressure: 7 MPa
- compressive strength of the plug construction material (concrete): this value has not yet been determined
- the minimum volume of aggregates in the construction material (concrete) of the plug: this value has not yet been determined.

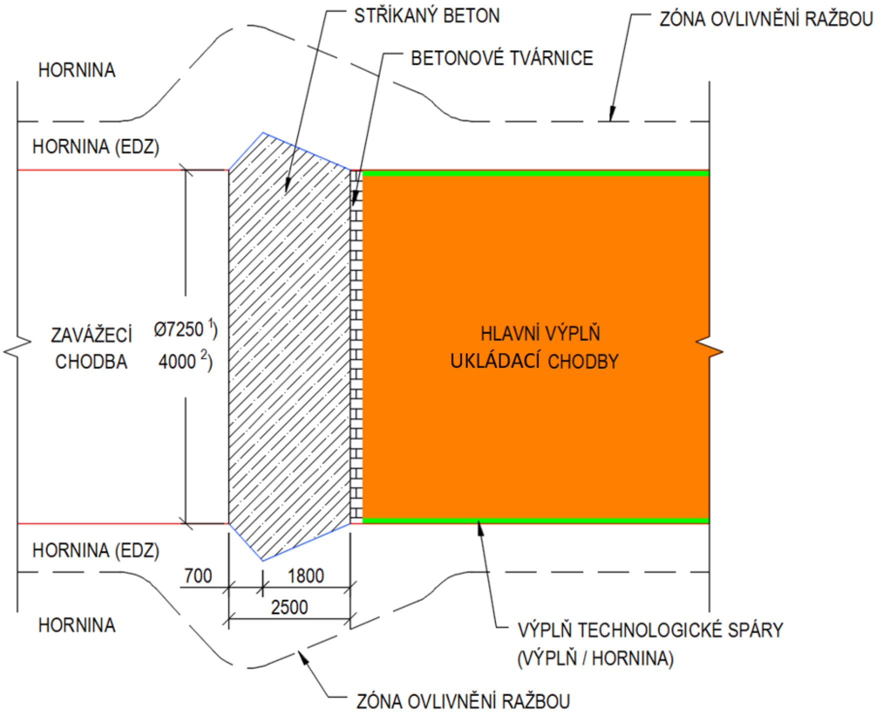

Fig. 13 Diagram of the disposal corridor plug; monolithic concrete may be used instead of shotcrete (Svoboda et al. 2022)

Notes: 1) Diameter of the disposal corridor excavated using the TBM approach, 2) Width of the disposal corridor excavated using the conventional excavation method

4 ILW disposal area

Intermediate-level waste that does not meet the waste acceptance criteria for disposal in existing disposal facilities will be disposed of in a separate part of the underground section of the DGR at a depth of several hundred metres below the surface/terrain. The waste will be emplaced in disposal chambers in special waste packages and then surrounded with the other engineered barriers and components. A diagram of the disposal method is shown in Fig. 14.

A report by Pospíšková et al. (2011) suggested that the disposal horizon chambers for other RAW should be located at the same level as the SNF disposal section. Since it is assumed that the backfill will include cement-based materials, the location of this horizon was re-evaluated since due to the assumed volume of the backfill material and the relatively small distance from the SNF disposal section it could not be ruled out that over the long term the cement would negatively impact the bentonite used as a buffer around the WDPs with SNF.

Hence, the concept of a separate ILW disposal horizon was adopted in subsequent studies on the location of the DGR at the candidate sites (e.g. Špinka et al. 2018, Bureš et al. 2018). The boundary conditions were set as follows:

- disposal of RAW in a horizon with an overburden of min. 300 m;
- disposal of RAW in a horizon at least 50 m above the SNF disposal horizon;
- the RAW must be disposed of at a location at which the potentially usable block(s) and the loading tunnel are first reached (subject to the fulfilment of the above conditions).

At present, it has not been clearly determined where the chambers will eventually be constructed. The final decision on the optimisation of the ILW chambers must take into account:

- the geological conditions at the selected site;
- the disposal inventory (majority radionuclides and their properties, including radiotoxicity);
- the form of the ILW (RAW material and whether in the form of a matrix or not);
- the properties of the backfilling material in the ILW chambers (the material used and its compatibility with the other elements of the DGR, including the WP).

Basic technical parameters of the ILW disposal area in the DGR:

- the time frame for the long-term safety assessment will depend on the site chosen for the DGR. A longer time horizon for the ILW section than for the SNF/HLW section (i.e. 1,000,000 years from the closure of the DGR) is not being considered.
- location depth: the ILW disposal section must be at a sufficient depth below the surface so as to ensure the required degree of isolation from both the surface and the biosphere, as well as from the SNF/HLW disposal section and
- the minimum area required for the ILW disposal section is 5.3 ha (Grünwald et al. 2017).

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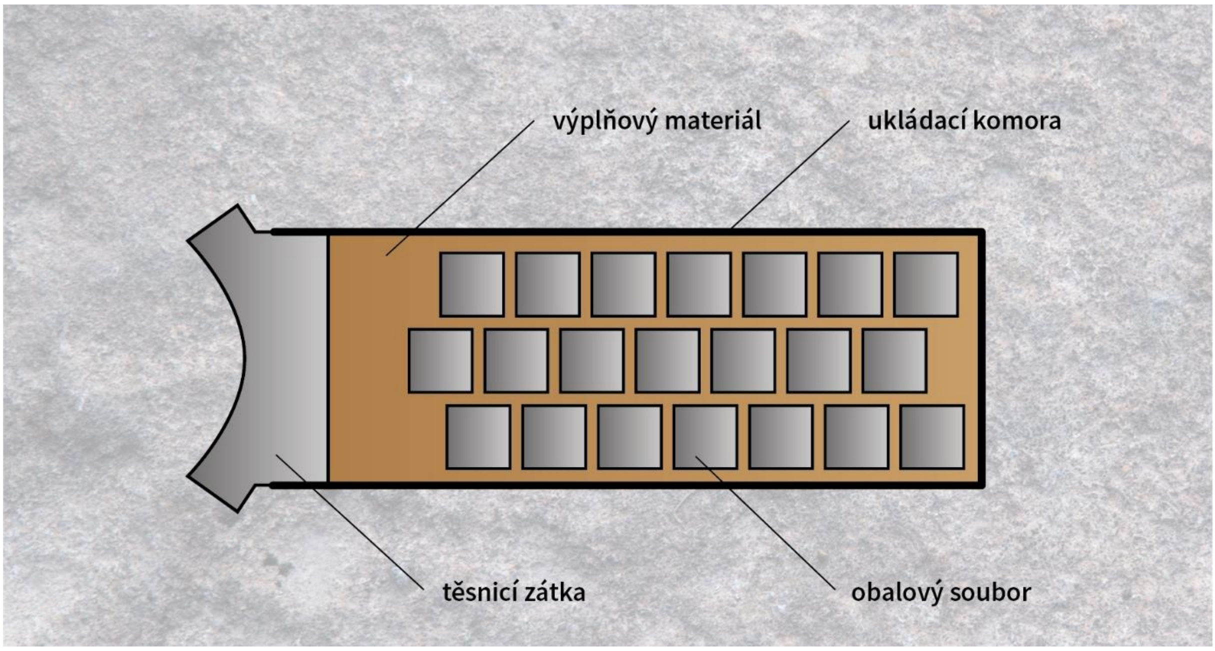

Fig. 14 Diagram of the disposal of ILW in disposal chambers

4.1 ILW disposal chambers

The ILW disposal chambers (see Fig. 15 and Fig. 16) will comprise conventionally excavated caverns situated in the underground part of the DGR that will be used for the disposal of ILW waste packages.

The ILW disposal chambers will be linked via connecting corridors to the loading tunnel. The chambers and connecting corridors will be lined with sprayed concrete reinforced with a metal mesh where necessary. The floors of the chambers will be levelled with a layer of concrete.

The design parameters of the disposal chambers were based on the technical design of the DGR project (Grünwald et al. 2017):

- length: 55,000 mm
- width: 10,500 mm
- height: 4,800 mm
- expected number of WPs: 3,815 (chapter 2.1.3)
- the estimated reserve for determining the areal extent of the disposal sections is 20% and
- number of WP in each chamber: 204

It is assumed that the design of the ILW disposal chambers will be optimised in the subsequent stages of the DGR project.

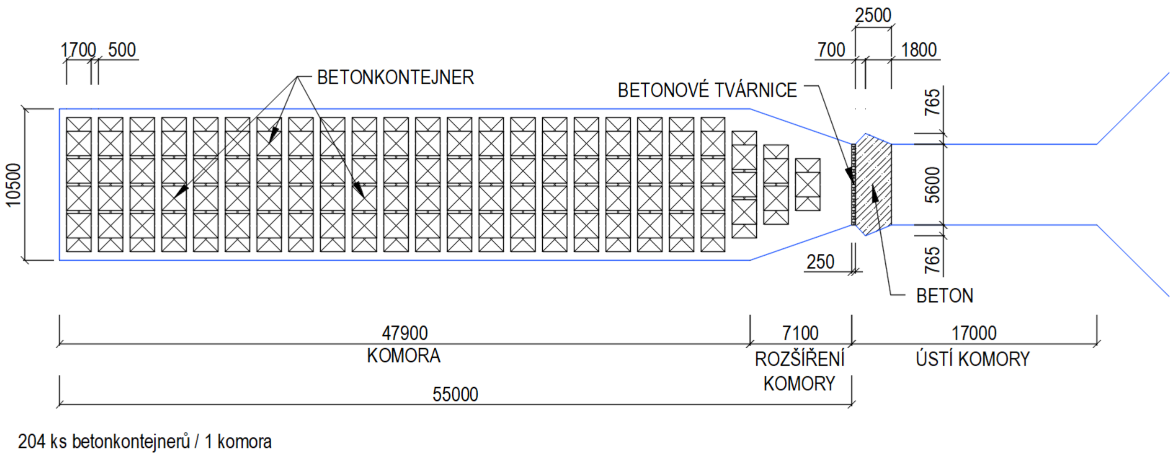

Fig. 15 ILW disposal chamber – floor plan (Svoboda et al. 2022)

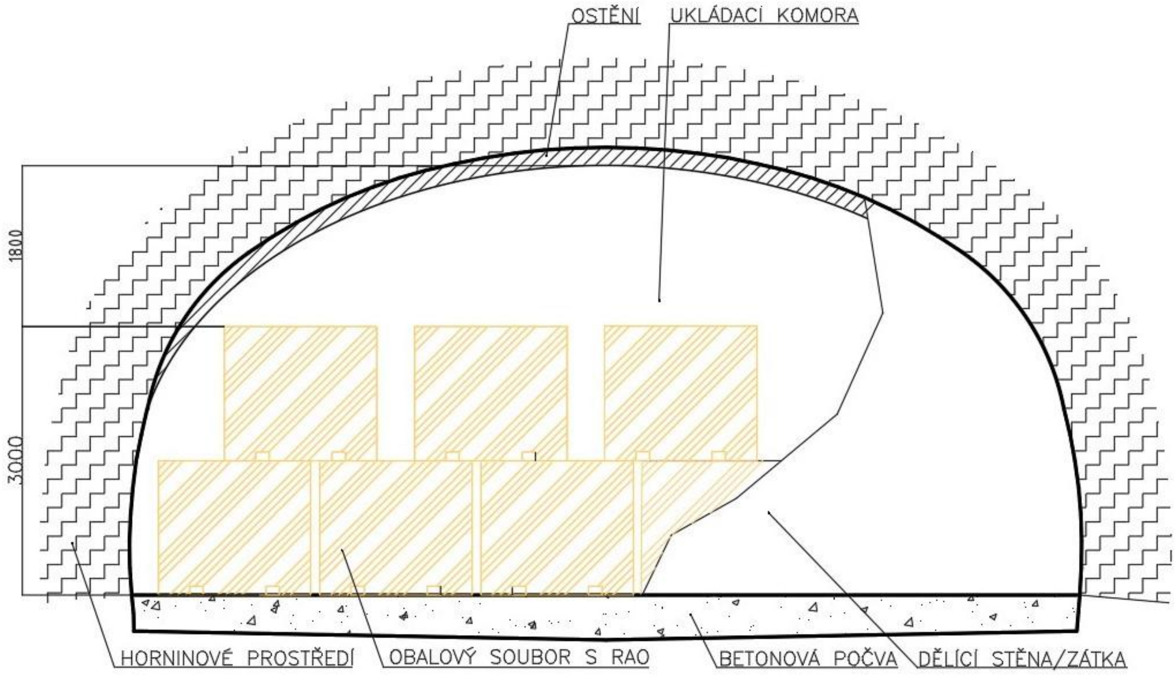

Fig. 16 ILW disposal chamber – cross-section (Svoboda et al. 2022)

4.2 ILW waste package

The technical design of the WP is based on the Reference Project 1999 (Holub et al. 1999). The concrete container (see Fig. 17) features outer and inner casings made of 10 mm-thick sheets of steel sheets welded inner and outer bottoms with a thickness of 15 mm. In the upper part of the WP, the casings are welded to an upper flange ring. The space between the inner and outer casings is filled with concrete. The WP will be sealed with a screw-on lid cast from the same steel as the flange ring. Rectangular grooves in the bottom of the outer casing will serve for the transfer of the WPs in the corridors of the DGR. The surface of the concrete container is coated with ZnAl. This type of WP was considered when calculating the ILW inventory, i.e. a total of 3,815 WPs will be disposed of in the DGR (see chapter 2.1.3).

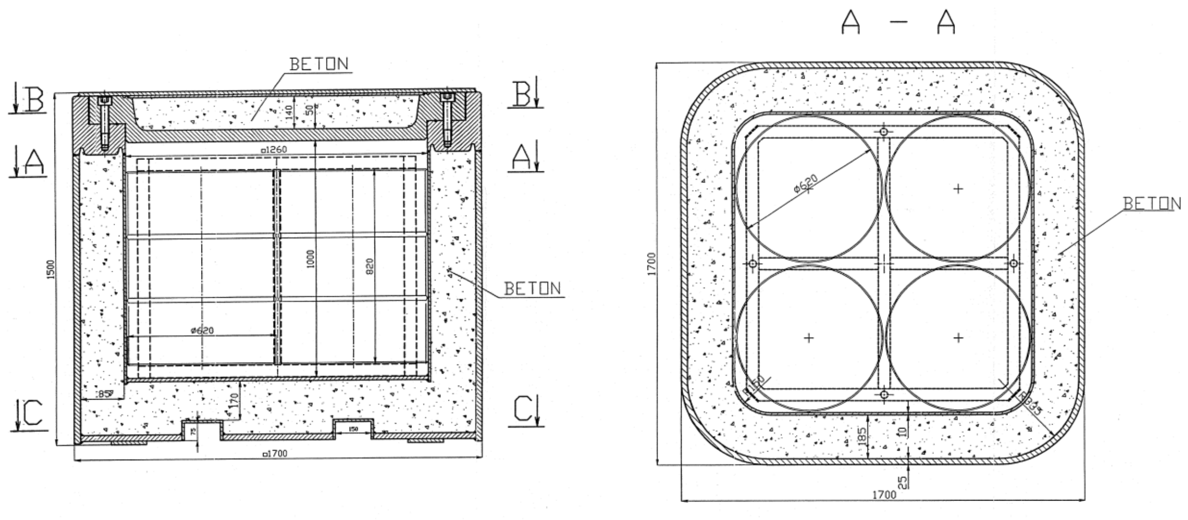

Fig. 17 Drawing of the concrete container and the placement of the 4 drums with RAW

The updated proposal is based on SÚRAO report 657/2022 (Pospíšková et al. 2022). Due to the degree of variability of the forms of ILW, different dimensions and shapes of WPs were proposed for differing types of ILW. WPs were proposed for institutional RAW that does not meet the waste acceptance criteria set for existing disposal facilities in 4- and 2-drum variants (Pospíšková et al. 2022). The standard WP is cube -shaped and allows for the placement of 4 steel drums with a volume of 216 l (see Fig. 18). The steel drums have a diameter of 595 mm and a height of 880 mm. The outer dimensions of the WP will be determined by the thickness of the wall, which will be based on strength calculations (the fulfilment of the respective mechanical strength requirements) and the required service life (degradation of the WP and the loss of its safety function).

- WP for 4 drums of 216 l; basic internal dimensions of 1.3 x 1.3 x 1.0 m (w x d x h)
- potential variant for 2 drums
- internal volume of 1.69 m^3
- filling of the internal space of the WP with a cement mixture
- screws (4) positioned on the lid of the WP to allow for the handling of the lid
- grooves in the bottom of the WP for forklift truck handling

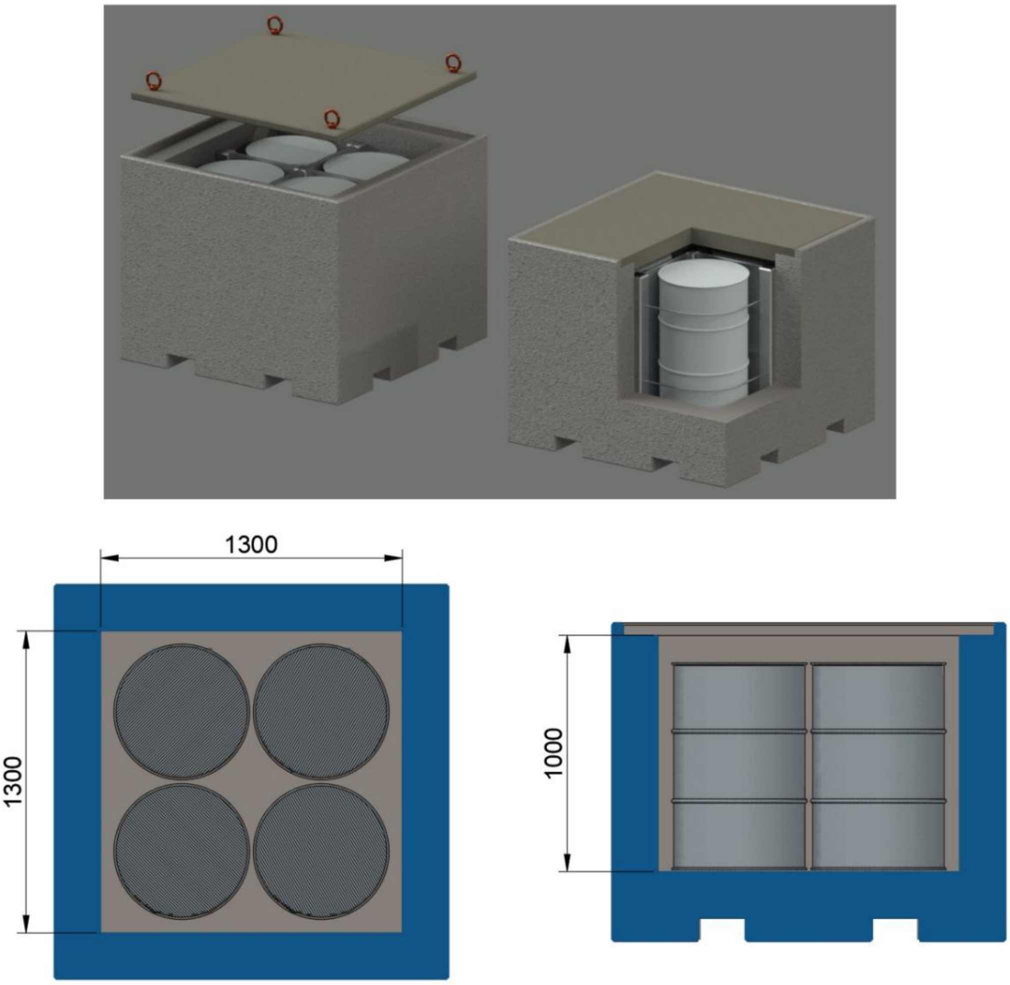

Fig. 18 Illustration of the WP for 4 drums with RAW (Pospíšková et al. 2022)

With concern to solid (lump) RAW of various sizes, a WP (see Fig. 19) with maximum external dimensions of 2.4 x 2.2 x 2.0 m (w x l x h) and a filled weight of approximately 10 tonnes was recommended based on the analysis conducted in Pospíšková et al. (2022). The wall thickness will be based on strength calculations (the fulfilment of the respective mechanical strength requirements) and the required service life (degradation of the WP and the loss of its safety function).

The provisional WP design parameters are:

- total volume of 10.56 m^3,
- filling of the internal space of the WP according to the disposed of RAW,
- length: 1,700 mm,
- width: 1,700 mm,
- height: 1,500 mm and
- weight: value not yet determined.

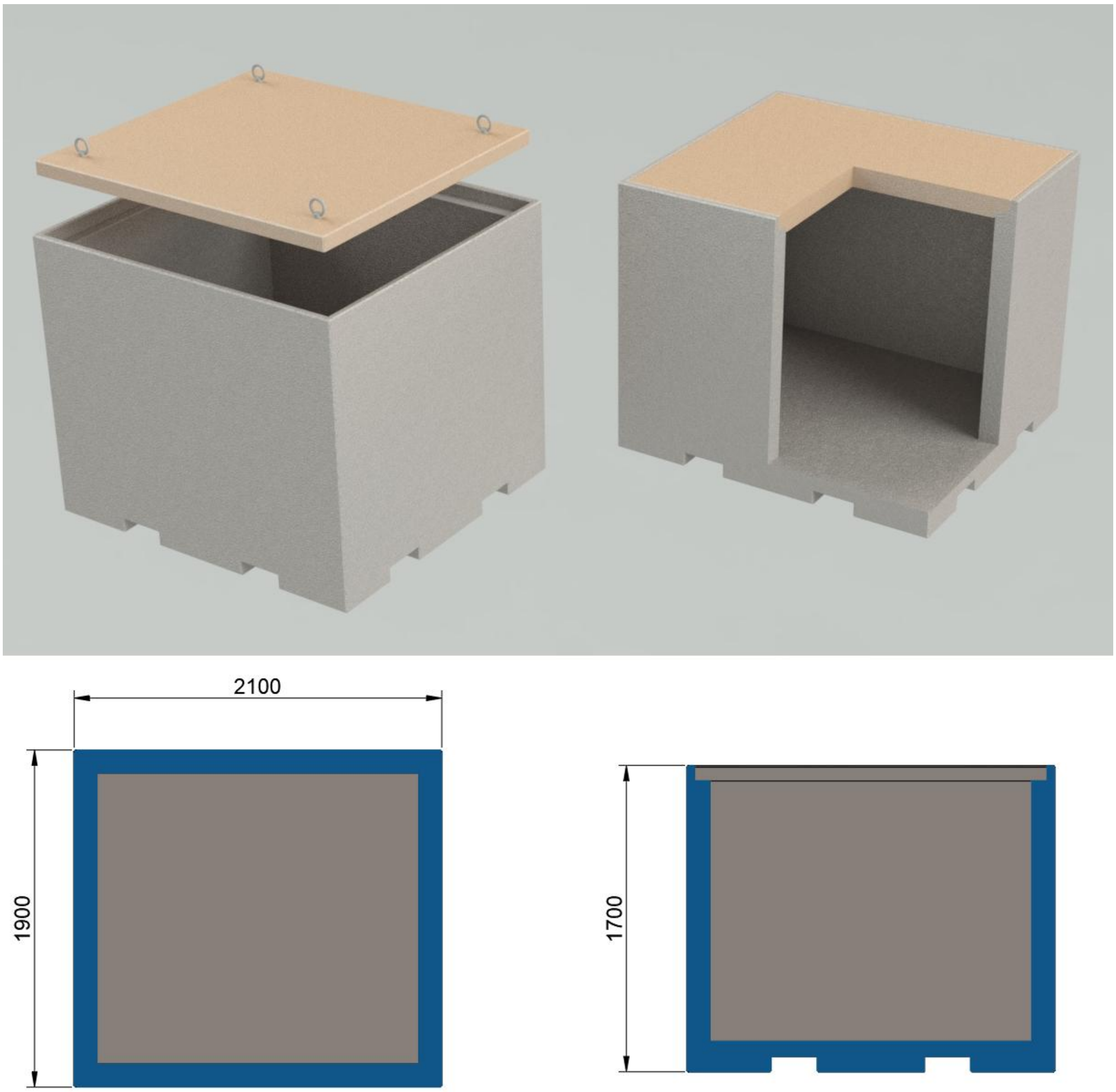

Fig. 19 Conceptual design of the WP for solid (lump) RAW; largest variant

4.3 Chamber backfill material

This filling material will serve for the backfilling of the chambers prior to closure. The form of the material must be such that it ensures the long-term stabilisation of the emplaced WPs.

SÚRAO report 657/2022 (Pospíšková et al. 2022) contains the results of a survey on the approaches of other countries to the disposal of ILW. One of the results was that with respect to RAW containing long-term radionuclides, the filling materials considered are based primarily on cement, bentonite and crushed rock or mixtures of these materials. Following on from this research, two options were proposed depending on the materials used, i.e. bentonite and cement backfilling. Details regarding these two options and their potential application and locations are provided in SÚRAO report 644/2022 (Svoboda et al. 2022).

The exact parameters of the chamber backfill material have not yet been determined.

4.4 Disposal chamber plug

The disposal chamber plug comprises one of the engineered barrier components – a concrete structure that is placed at the mouths of the filled disposal chambers; it is conical in shape and is wedged into the rock in the form of a ring around the whole of the corridor. The concept is based on the disposal corridor plug (see chapter 3.9.) taking into account that the geometry will differ according to the dimensions of the corridor, i.e.:

- corridor height: 5,400 mm.
- corridor width: 5,600 mm.

The design proposal for the geometry of the disposal chamber plug will have to be verified by means of structural calculations and with regard to the key dimensioning conditions, i.e. the stress conditions in the disposal horizon, the expected swelling pressures that act on the plug, the operational conditions when backfilling the disposal corridors, etc.

Sealing plug design parameters:

- form: concrete blocks (lost formwork) and the body of the plug made from sprayed or monolithic concrete (a description of the properties of the concrete is provided in SÚRAO report 644/2022, Svoboda et al. 2022)
- resistance to the potential swelling pressure exerted by the backfill material and hydrostatic pressure: 7 MPa
- compressive strength of the plug construction material (concrete): this value has not yet been determined
- minimum volume of aggregates in the construction material (concrete) of the plug: this value has not yet been determined.

The design of the ILW chamber closure plugs will be optimised at the same time as that of the design of the disposal chambers and the decision on the type of material that will be used for the stabilisation of the WPs.

5 Closure of the DGR

The closure of the DGR will be the final stage in the RAW disposal process. Closure will involve the filling of all the free spaces in the DGR aimed at ensuring the long-term isolation of the waste in the repository from the biosphere. Plugs will make up one of the key components in the closure process.

5.1 Backfilling in the closure stage

The design parameters of the sealing material to be used in the final closure of the DGR were based primarily on the DGR design proposal and were defined according to the location and depth (disposal horizon/medium horizon/near-surface) in the DGR (see Tab. 12).

Tab. 12 Division of the closure process into sections according to depth and with the relevant parameters

Depth	**Disposal horizon - 500 m**	**Medium horizon -200 to -500 m**	**Surface to near-surface to -200 m**
Dry density	Identical to the backfill	Value has not yet been determined	Value has not yet been determined
Permeability coefficient	Value has not yet been determined	Value has not yet been determined	Value has not yet been determined
Form	Bentonite	Bentonite/ aggregate	Aggregate

5.1.1 Backfilling of the disposal horizon

This component will be made of bentonite and will serve for the backfilling of the main corridors and technical areas in the disposal horizon of the DGR (corridors, caverns). It is the same material as that of the backfill as described in chapter 3.8 (Svoboda et al. 2022).

Backfill design parameters:

- Dry density of the whole of the barrier: 1,400 kg/m^3
- Moisture content following placement: this value has not yet been determined
- Form: pellets (a mixture of granulated bentonite with a determined grain size composition)
- Pellet parameters:
    - ρ_d: over 2,000 kg/m^3
    - Moisture content: this value has not yet been determined
    - Granularity: not yet determined.

5.1.2 Backfilling above the disposal horizon (medium horizon)

The backfilling materials for the loading and extraction tunnels in the depth range - 500 to - 200 m will be similar to the backfill material described in chapter 3.8 with the difference that the bentonite material will be supplemented with aggregate, which will reduce the costs and allow for the adjustment of the hydraulic and other characteristics so as to better match the prevailing conditions in the surrounding environment (Svoboda et al. 2022).

The design parameters have not yet been determined.

5.1.3 Backfilling above the disposal horizon (near-surface)

It is expected that the filling material for the loading and extraction tunnels in the depth range -200 m to the surface will consist of aggregate (Svoboda et al. 2022).

The design parameters have not yet been determined.

5.2 Closure/sealing plugs

The closure of the DGR will include the installation of plugs, which will fulfil different functions depending on their location:

- plugs in the disposal horizon (chapter 5.2.1),
- pressure and sealing plugs (chapter 5.2.2) and
- closure plugs (chapter 5.2.3).

5.2.1 Plugs in the disposal horizon

The technical design of the plug has not yet been finalised. SÚRAO report 134/2017 (Grünwald et al. 2018) states that the plug will be wedged into the rock mass in the form of a ring around the whole of the corridor. A diagram of the assumed geometry of the plug for the mechanised or conventionally excavated main corridors with respect to its greatest width, regardless of the disposal method, is shown in Fig. 20.

Future research will be aimed at verifying the proposed geometry of the plug via structural calculations taking into account the key dimensioning conditions, i.e. the stress conditions in the disposal horizon, the swelling pressures that can be expected to act upon the plug, the operational conditions during the backfilling of the corridors and caverns that will house the technical equipment used in the underground part of the DGR, etc.

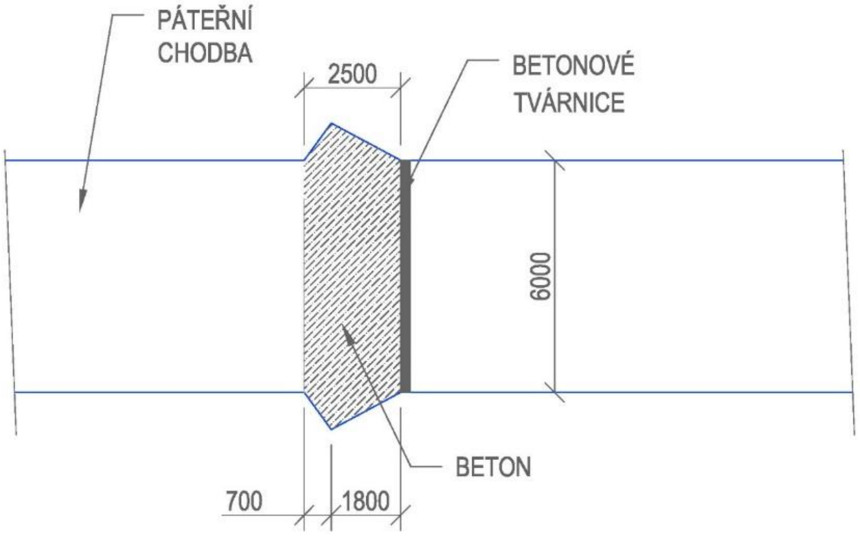

Fig. 20 Diagram of the operational plug for the main corridors in the disposal horizon (Grünwald et al. 2018)

The design parameters of the plug are the same as those of the disposal corridor plugs (see chapter 3.9.):

- form: concrete blocks (lost formwork) and the body of the plug made from sprayed or monolithic concrete (a description of the properties of the concrete is provided in SÚRAO report 644/2022, Svoboda et al. 2022)
- plug thickness: 2,750 mm (the body of the plug: 2,500 mm and the lost formwork: 250 mm)
- resistance to the swelling pressure exerted by the backfill material and hydrostatic pressure: 7 MPa
- compressive strength of the plug construction material (concrete): this value has not yet been determined
- minimum volume of aggregates in the construction material (concrete) of the plug: this value has not yet been determined.

5.2.2 Pressure and sealing plugs

Pressure and sealing plugs will be used in the DGR at locations in the rock mass that need to be hydraulically separated, for example along tectonic disturbances.

The structural design of this component and the respective construction technology were not considered in detail in the DGR design solution proposed by (Grünwald et al. 2018). However, according to the results of the DOPAS international project (Dvořáková et al. 2014), it is assumed that it will comprise a multi-layered structure with conically-shaped external concrete elements, which will be wedged into the rock mass in the form of a ring around the tunnels/main corridors, and an internal sealing element made of bentonite that will be located in saturated sections (tectonic disturbances).

The design of the geometry of the pressure and sealing plugs (report 644/2022, Svoboda et al. 2022) will need to be verified via the appropriate calculations and the plugs will be designed taking into account the key dimensioning conditions, i.e. the stress conditions, the swelling pressures that can be expected to act upon the plug, the operational conditions during the backfilling of the tunnels/main corridors, etc.

A diagram of the pressure and sealing plug for the main corridor excavated using the TBM method is shown in Fig. 21 for illustration purposes

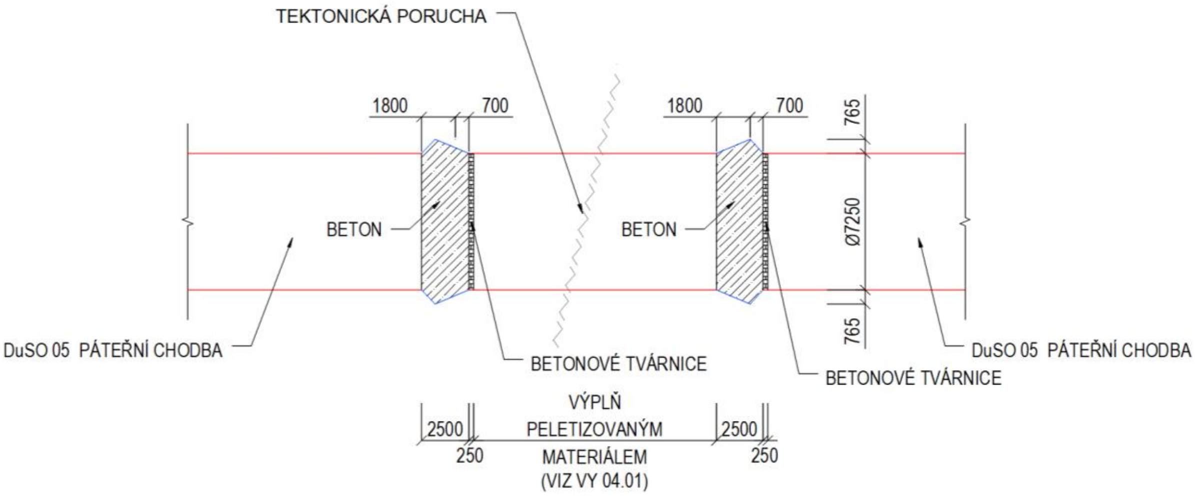

Fig. 21 Diagram of the pressure and sealing plug for the main corridors following excavation using the TBM approach (Svoboda et al. 2022)

5.2.3 Closure plugs

The structural design of this component and the respective construction technology were not considered in detail in the DGR design solution proposed by (Grünwald et al. 2018). It is important to note that the closure of main mine workings is currently governed by ČBÚ Decree No. 52/1997 Coll.

According to Section 2 a) of ČBÚ Decree No. 52/1997 Coll. the closure of such structures requires the placement of a reinforced concrete slab over the mouth of the structure with dimensions that respect the expected load.

A general description of the closure plug for the loading and extraction tunnels is provided in SÚRAO report 644/2022 (Svoboda et al. 2022). A diagram of the closure of a shaft according to ČBÚ Decree No. 52/1997 Coll. is shown in Fig. 22 for illustration purposes.

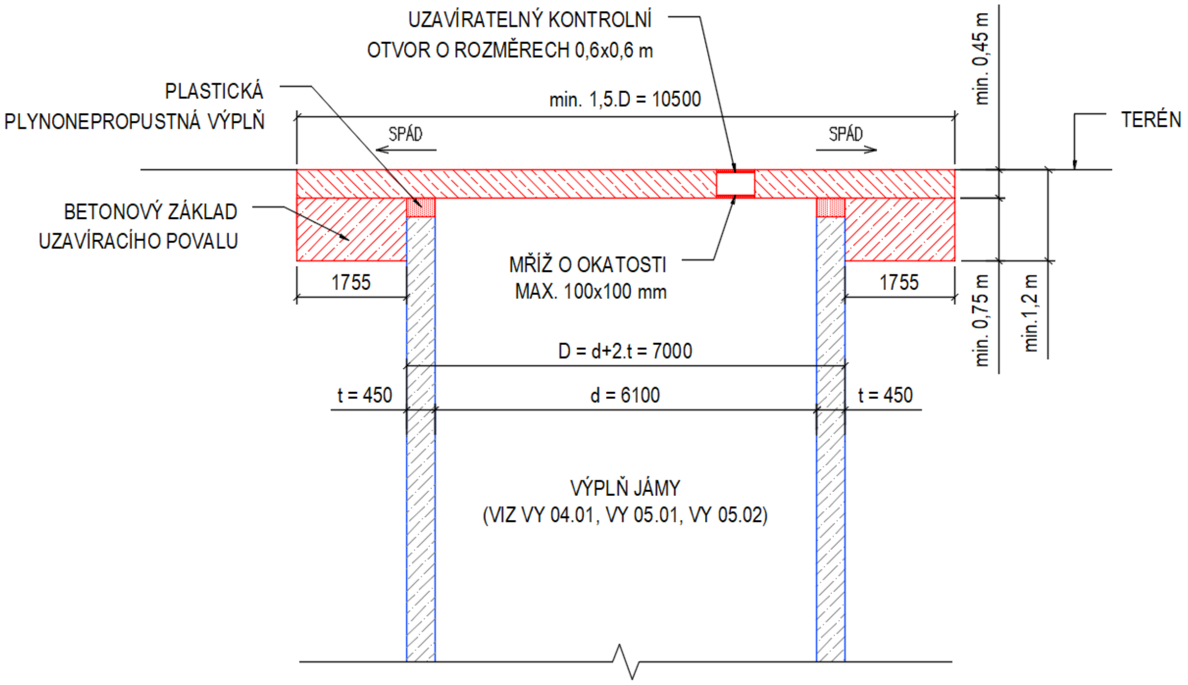

Fig. 22 Diagram of the closure of a shaft (Svoboda et al. 2022)

The above-mentioned decree sets out requirements concerning ensuring health and safety in the workplace and operational safety during the closure of main mine workings, during operation and during the underground extraction of unreserved minerals. However, the closure methods and principles set out in the decree may not suit the requirements for the long-term safety of the DGR following closure. Currently, it is not possible to define in detail the requirements concerning the safety function of this DGR component.

6 Conclusion

The DGR project is constantly evolving and gradually being refined based on currently available information. This document provides a brief description of the technical design of the Czech DGR according to the status in 2025. The most important considerations concern the determination of the basic design parameters of the DGR from the perspectives of the use of the conventional excavation method and the vertical emplacement of WDPs.

The document will be updated regularly in the subsequent stages of the DGR development project so as to include newly-obtained and verified data, which will be used in the further research and development of the future Czech deep geological repository.

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