# Development of the Korean Reference Vertical Disposal System Concept for Spent Fuels

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## ABSTRACT

The development of a deep geologic disposal system for the spent fuel from nuclear power plants has been carried out since this program was launched at 1997 in Korea. In this paper, a pre-conceptual design of the **K**orean **R**eference HLW **V**ertical disposal **S**ystem (KRS-V1) is presented. Though no site for the underground repository has yet been specified in Korea, a generic site with granitic rock is considered for reference HLW repository design.

Depth of the repository is assumed to be 500 meters. The repository consists of the disposal area, technical rooms with four shafts to connect them to the ground level in the controlled area and technical rooms with an access tunnel and three shafts to connect them to the ground level in the uncontrolled area. Disposal area consists of disposal tunnels, panel tunnels and a central tunnel. The repository will be excavated, operated and backfilled in several phases including an Underground Research Laboratory (URL) phase.

The result of this preliminary conceptual design will be used for an evaluation of the feasibility, analyses of the long term safety, information for public communication and a cost estimation etc.

## INTRODUCTION

Since the first commercial nuclear plant in Kori site was initiated in 1978, there are now 20 operating nuclear power plants, 4 CANDU reactors at Wolsong and 16 PWR reactors at the Kori, Younggwang and Uljin sites in Korea. And the spent fuels from these reactors are being accumulated at the sites.

A long-term R&D program for a HLW, such as spent fuels, disposal technology development was launched in 1997. There have been active research activities for the development of the Korean HLW Disposal system.[1] The researches for the development of the engineered barriers were carried out, and the canisters for PWR and CANDU spent fuels and Korean Calcium Bentonite block as a buffer material were designed. Thermal-Mechanical analyses for the disposal tunnels and deposition holes were carried out to develop the technology for the disposal system. No site for the underground repository has yet been specified in Korea, but a generic site with granitic rock is considered for the reference HLW repository development.[2] And also the layout of the repository, excavation-operation methods and closure are implemented based on the results of research and analyses.

This concept for the Korean reference HLW disposal system can be used to evaluate the feasibility of the designed high-level waste disposal system, to formulate data for a long-term safety analysis, to obtain a communication material for information and public relations and to help in the budget and funding calculations.

## DESIGN BASIS AND DESIGN REQUIREMENTS

### Design Basis

The disposal system of spent nuclear fuels is based on a geological disposal, where the fuel is encapsulated into canisters and disposed to a repository excavated deep into bedrock (deep geological repository). The objective is to isolate the spent fuel from organic nature for as long as it could be harmful to the people's health or the environment.[3] The repository consists of disposal tunnels with disposal holes drilled to the floor of the tunnel and other underground facilities (i.e. central tunnel, auxiliary facilities and access routes). The bedrock and the canister, together with a bentonite buffer placed around the canister and backfilled disposal tunnels, are considered as barriers that will isolate the spent nuclear fuel from the biosphere.[4] The safety of the reference repository system should be ensured for short and long time frames, by an adequate implementation of multiple barriers to the system so that in all conceivable circumstances the barriers can, individually and/or in combination, sufficiently confine the radionuclides of the disposed waste within the repository system. The long-term safety of the repository system will be evaluated with a safety/performance assessment based on the best scientific bases.

The general principle of a radiation safety is that the repository shall be designed so that the radiation doses to humans and the environment will be kept as low as reasonably achievable. A law/regulations concerning a radiation safety in connection with the final management of a high-level nuclear waste is under preparation in Korea. The radiation safety is supervised by the Korea Institute of Nuclear Safety (KINS).

### Design Requirements

- Spent fuel

The total amount of high-level spent nuclear fuel in Korea is presented in Table I.[5] The dimensions for the PWR and CANDU canisters are the following: outer diameter 1.22 m, total length 4.83 m and weight approximately 39.1 t (including the weight of the fuels). The minimum distance between two deposition holes for the PWR canisters is 6 m. According to previous calculations, the minimum distance between two deposition holes for the CANDU canisters was determined to be 3 meters. However, the distance was increased up to 4 meters to improve the rock's mechanical stability between the holes. Thermal calculations for determining the distances were done by assuming that the heat generation of the canisters is 1,540 W for the PWR and 760 W for the CANDU canister, the distance between the parallel tunnels is 40 m, and the temperature at the canister surface should not rise above 100 ºC.

Table I. The Total Amount of High-Level Nuclear Fuel in Korea

| Fuel | Amount (tU) | Assemblies | Bundles | Canisters |
|---|---|---|---|---|
| PWR | 20,000 | 45,000 | | 11,375 |
| CANDU | 16,000 | | 842,000 | 2,835 |
| Total | 36,000 | | | 14,210 |

- Time schedule & disposal rate

The cooling time for CANDU spent fuel is 30 years and for PWR spent fuel 40 years. The final disposal will start with CANDU fuel canisters in the year 2040 and continue with PWR fuel canisters in the year 2065. See Figure 1 for the disposal time-schedule. The annual disposal rate of CANDU spent fuel will increase gradually during the first decade (2040 - 2049) and continue with a rate of 146 canisters per year until the year 2065. The annual disposal rate for PWR fuel will be 380 canisters per year for the last 30-years period.[6]

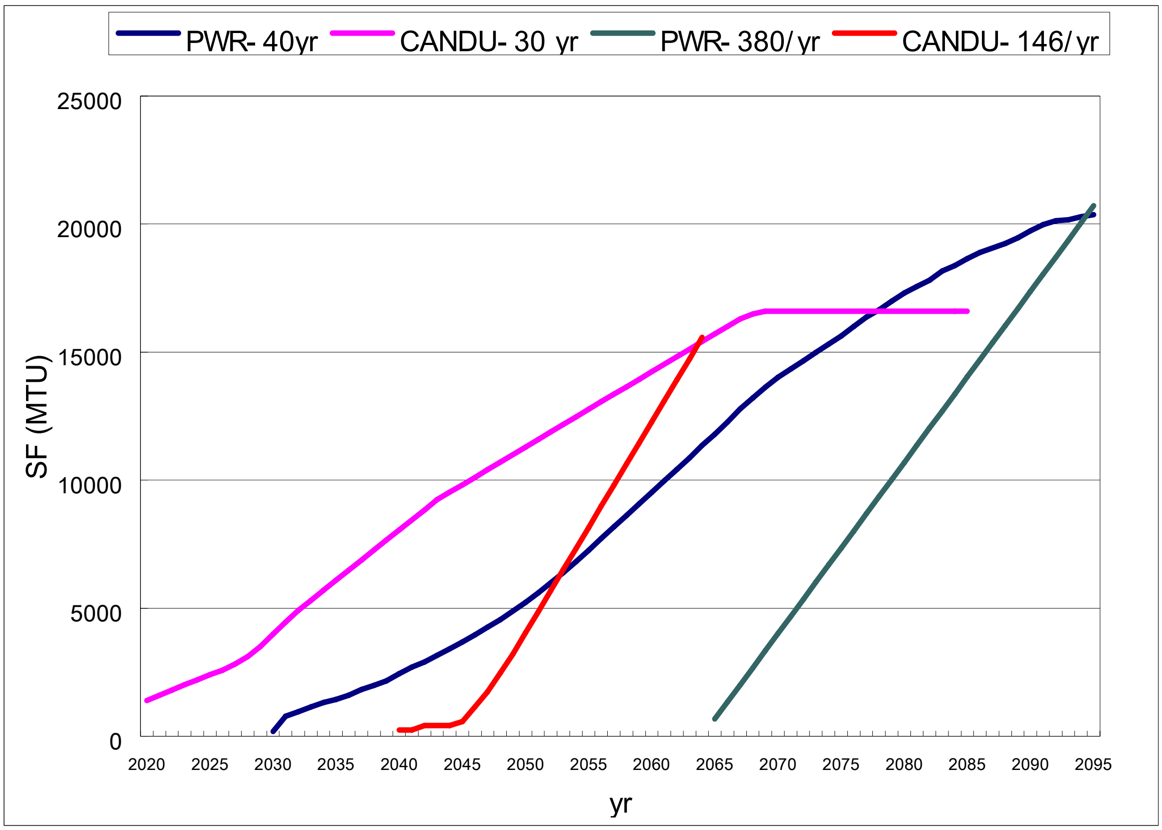


Fig. 1. Time-schedule for the disposal of spent nuclear fuel in Korea.

- Disposal Facility

The Korean disposal facility consists of:

- Disposal tunnels, with vertical deposition holes drilled to the floor
- Central tunnels
- Auxiliary facilities
- Access routes.

The Korean disposal facility will be excavated at the depth of 500 m below the ground level in a stable plutonic rock body. The estimated total area of the repository is approximately 8 $km^2$. For this pre-conceptual design it is assumed that the Korean repository will be built at one repository level (i.e. in one storey). Due to the fracturing of the bedrock, it is assumed that the number of disposal tunnels will be 5 % more than what the nominal amount of canisters would require.

The long-term safety of the repository will be ensured by applying the multi-barrier principle (passive multiple barriers). After an emplacement of the canister the deposition holes will be filled with pre-compacted bentonite blocks with a high density (2,000 $kg/m^3$ in water content of 10 %, corresponding to dry density of approximately 1,820 $kg/m^3$). The disposal tunnels will be backfilled with a mixture of crushed rock and calcium bentonite (bentonite:crushed rock, 30:70) as well as other parts of the repository. The functional requirements of the buffer and the backfill are the following :

- Control and minimise water flux into the repository
- Restrict the release of radionuclides into the host environment
- Dissipate the decay heat from the waste in order to avoid high thermal stress on the canister and the deterioration of the properties of the buffer
- Support the container and waste from the external mechanical stress.

In order to fulfil these functional requirements, the buffer & backfill materials should have a low hydraulic conductivity, radionuclide retention capacity, swelling potential/suitable mechanical properties.

- Implementation

In general the repository should be built safe, flexible, technically feasible, effective and acceptable by the public.

The Korean repository should be built in a stepwise manner(one disposal tunnel panel pair at a time) by taking into consideration the geology of the repository area. An URL (underground research laboratory) should be built and underground investigations verifying the suitability of the area for repository operations should be carried through before the construction of the first disposal panels.[7]

The fuel canisters should be handled in the controlled area of the repository. The disposal tunnel excavation, the disposal hole drilling and the tunnel backfilling should always take place in the non-controlled area.

Currently, it is assumed that no canisters will be retrieved after a closure of the repository. Retrieving of canisters is considered only during the operational period in the case where the tunnel has not been backfilled yet. However, the retrievability could be re-evaluated for example in the following cases:

- Recycling/reuse of HLW radioactive waste will become technically and economically feasible
- A better and safer way to dispose of HLW radioactive waste compared to a geological disposal is invented or a way how to make the HLW radioactive waste safe to humans and the environment is discovered.

- The long-term safety of the system differs from what has been presented in the safety analysis.

- Systems

The systems of the repository should be designed so robust that they can maintain their function despite unusual conditions such as earthquakes and extreme meteorological conditions. The design basis for an earthquake ground motion are: horizontal acceleration 0.2 g and vertical acceleration 0.13 g. Thermal gradient of 30 °C/km will be used as a design basis for the repository design.

The controlled area and the uncontrolled area should have separate ventilation systems. The average air exchange rate in the repository is once per two hours. The actual air exchange rate varies inside the repository depending on the situation and demands, e.g. the tunnels that are under construction have a higher than average air exchange rate. The power supply (ring type) should be designed to come from two independent sources. The repository and the ventilation systems should be designed so that the indoor temperature is in the range of +10 ºC to +50 ºC in the controlled area, and +10 ºC to +40 ºC in the uncontrolled area. The relative humidity of the inside air should not exceed 80 %. The quality of the inside air should follow the maximum allowed contents for gases and dust according to the Korean regulations.

The volume of the sedimentation pool should be such that it can treat water in the case of a 48 hours long interruption in pumping.

There will be a system for measuring/monitoring the radiation during the repository operation period.

The repository should have an emergency and escape systems. The repository should have two escape routes (access routes) from the underground facilities to the ground surface. A person should be able to exit the repository within one hour. In addition, a place of refuge (e.g. rescue chamber) should be reached by a person within 30 minutes from leaving the work place.

## General Site Data

The repository site has not been chosen yet. The aim is to find a geologically stable and intact host rock volume with a surface area of approximately 8 $km^2$. In general the host rock area should be free from significant structures, it should have suitable hydrogeological and geochemical characteristics and good mechanical and thermal properties.

Fracture zones are divided into four main classes (Table II) in Korea. The repository should be constructed so that the whole repository fits inside an intact bedrock block bordered by regional fracture zones (order 1). The disposal tunnel panels should be placed so that they will have 50 m safety distance to local major fracture zones (order 2). The disposal tunnels can penetrate local fracture zones (order 3), but there should be certain safety distances to the nearest disposal holes. In addition, all the potential fast pathways should be isolated from the tunnel with plug structures.

Table II. Classification of the Fracture Zones

| | **Order** | **Length (m)** | **Width (m)** | **Interval (km)** | **T ($m^2$/s)** | **Safety distance (m)** |
|---|---|---|---|---|---|---|
| Regional fracture zone | 1 | >10,000 | >100 | >4 | 1E-05 | 100 (to unit facility) |
| Local major fracture zone | 2 | 1,000 - 10,000 | 5 - 100 | 1 - 4 | 1E-06 | 50 (to deposition tunnels) |
| Local minor fracture zone | 3A | 500 - 1,000 | 1 - 5 | 1< | 1E-07 - 1E-08 | 5 (to dep. holes) |
| | 3B | <500 | <1 | | | 3 (to dep. holes) |
| Bedrock fracture system | 4 | <10 | <0,01 | - | <1E-9 | - |

As already stated above, the disposal tunnels can penetrate the order 3 fracture zones (width 0.1 - 5 m). In order to evaluate the required extra need for disposal tunnels due to an order 3 fracturing, it was assumed that the safety distance to the nearest disposal hole should be 3 - 5 m depending on the fracture parameters. According to this assumption, it was calculated that the total length of the disposal tunnel should be at minimum 1 - 3 % more than what the nominal amount of canisters would require (see Table III), by assuming that fractures would always penetrate the tunnel perpendicular to the tunnel and the fracture interval would be every 500 m. However, in reality, fractures will penetrate the tunnel in various angles and therefore the assumption for this report is that the needed extra length of the disposal tunnels is 5 %. This assumption shall be reconsidered when more geological information is available from the potential site.

Table III. Proportion of the Order 3 Fracture Zones and the Safety Distances from the Unit Length of the Disposal Tunnel

| Width of fracture (m) | Sum of safety distances (m) | Total (m) | Interval/1000 m | Proportion (%) |
|---|---|---|---|---|
| 0.1 | 6 | 6.1 | 2 | 1.22 |
| 1 | 10 | 10.1 | 2 | 2.02 |
| 5 | 10 | 15 | 2 | 3.00 |

## REPOSITORY CONCEPT

### General Data of Repository

The repository is assumed to be constructed along the coast of the Korean peninsula. Depth of the repository is assumed to be 500 meters. From a technical point of view, the repository can be located shallower or deeper.

The repository consists of the following sections (see Table IV):
- Disposal area.
- Technical rooms and connections to the ground level in the controlled area.
- Technical rooms and connections to the ground level in the uncontrolled area.

Disposal area consists of disposal tunnels, panel tunnels and a central tunnel. Panel tunnels connect the disposal tunnels and the central tunnel. Central tunnel leads from the controlled area to the uncontrolled area and connects the panel tunnels to each other.

Technical rooms in the controlled area also include four shafts: canister shaft, personnel shaft and two ventilation shafts. Technical rooms in the uncontrolled area include the correspondingly access tunnel, personnel shaft and two ventilation shafts.

Table IV. The Facilities in the Repository Area

<table>
<tr><th>Area</th><th colspan="2">Facilities</th></tr>
<tr><td rowspan="3">Un-controlled Area</td><td>Tunnel & Shaft</td><td>Access Tunnel<br>Personnel Shaft/Ventilation Shafts(2)<br>Demonstration tunnels</td></tr>
<tr><td>Technical Room</td><td>Power supply centre<br>Telecommunication room etc.</td></tr>
<tr><td>Auxiliary Room</td><td>Rescue chamber, Parking Hall<br>Sedimentation pools, Pumping station</td></tr>
<tr><td rowspan="3">Controlled Area</td><td>Tunnel & Shaft</td><td>Canister Shaft<br>Personnel Shaft/Ventilation Shafts(2)<br>Operation and decommissioning waste halls</td></tr>
<tr><td>Technical Room</td><td>Power supply centre<br>Telecommunication room, Sprinkler centre</td></tr>
<tr><td>Auxiliary Room</td><td>Rescue chamber, Parking Hall<br>Sedimentation pool, Pumping</td></tr>
<tr><td rowspan="4">Disposal Area</td><td rowspan="4">Tunnel & Hole</td><td>Central</td></tr>
<tr><td>Panel Tunnel</td></tr>
<tr><td>Deposition Tunnel</td></tr>
<tr><td>Deposition Hole</td></tr>
</table>

**Repository Layout**

The repository will be excavated under encapsulation plant. Above ground facilities are the encapsulation plant, operating building, shaft building, shaft office building, water plant and heating center, information center, gas station and other structures.

Determining factors affecting the repository layout have been:
- To divide the repository into controlled and uncontrolled areas. Canister handling will always be performed in the controlled area. Excavation and backfilling will be done in the uncontrolled area.
- Boundary between the controlled and the uncontrolled area will move during the lifespan of the repository.

- Disposal and panel tunnels will be excavated and backfilled in phases during an operation phase of the repository.
- Two escape path ways from all the tunnels except for the disposal tunnels which are dead end tunnels.
- Access tunnel is one connection to the ground level.

Above factors have led to the layout that is presented in Table V and Figure 2. Controlled area is on the left side and the uncontrolled area on the right side. Disposal of the canisters starts from the left and shifts to the right.

Table V. The Concept of the Disposal Tunnels

| | |
|---|---|
| Deposition tunnels | - Length 251 meters:<br>. PWR: 37 holes => 36 x 6 m + 30 m + 5 m = 251 meters<br>. CANDU: 55 holes => 54 x 4 m + 30 m + 5 m = 251 meters<br>- 30 meters is for concrete plug and fire wall in the mouth<br>- 5 meters is for equipments and vehicles in the end<br>- Width 5.00 meters, Height 6.15 meters |
| Number of deposition tunnels | - PWR: 1.05 x 11,375 = 11,944 places for holes<br>11,944 / 37 = 323 deposition tunnels<br>- CANDU: 1.05 x 2,835 = 2,977 places for holes<br>2,977 / 55 = 54 deposition tunnels<br>- Totally 377 deposition tunnels |

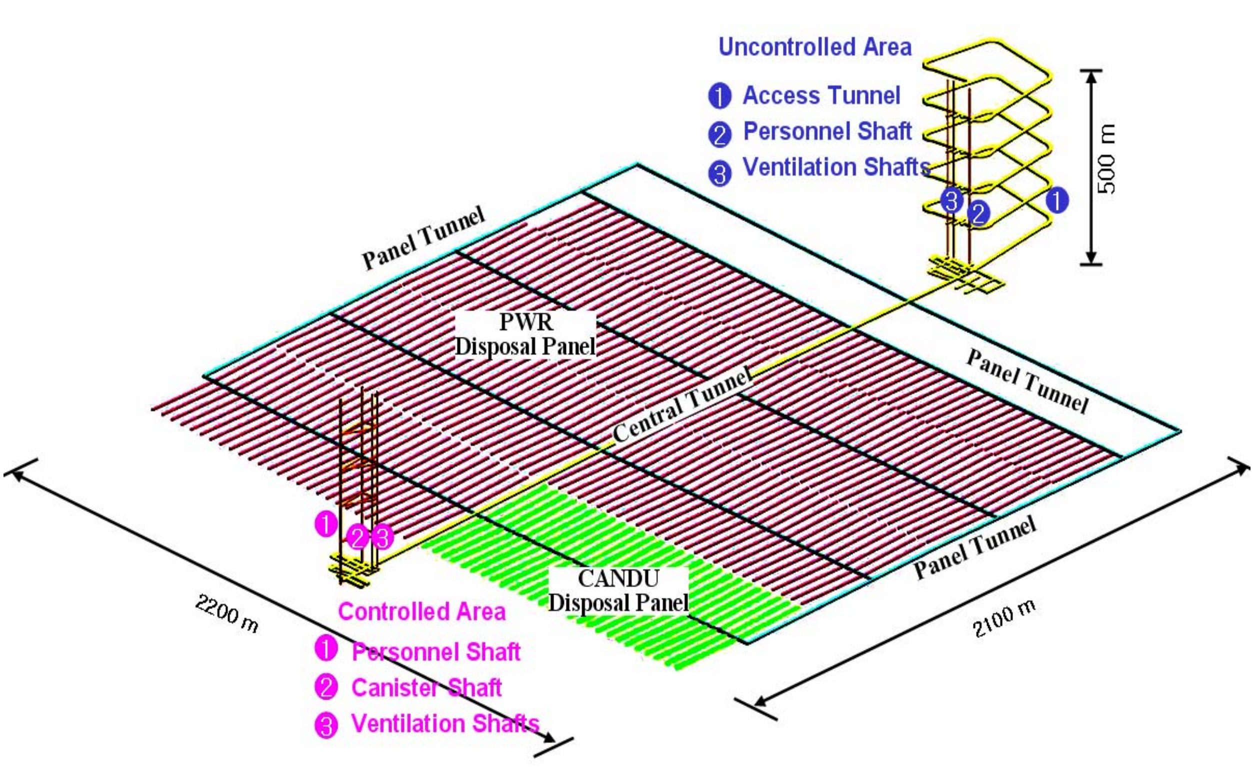


Fig. 2. Layout of the Korean reference HLW Vertical disposal system.
(Green panel is for CANDU canisters.)

**Disposal Principle**

- Canister properties
  Canisters consist of two materials. Insert is carbon steel and the outer shell is made from copper or Nickel alloy.[8]

  Dimensions of the PWR and CANDU fuel canisters are equal:

  - Canister outer diameter is 1.22 m
  - Total length of the canister is 4.83 m
  - Canister weight including the fuel is about 39,100 kg.

- Canister handling
  Canisters are not designed on such a level that a canister handling could be presented in great detail. Key procedures in a canister handling could be:

  - Canister is lowered to the repository in a carriage which is in the canister lift. Canister is in vertical position.
  - Carriage is driven from the lift to a loading station.
  - Canister transfer vehicle picks up the canister and turns it to a horizontal position.
  - Canister transfer vehicle drives the canister to the disposal tunnel.
  - Canister transfer vehicle lowers the canister and simultaneously turns it to a vertical position.

- Buffer properties and handling
  Following preliminary functional criteria for the buffer material has been suggested:
  - Hydraulic conductivity : The hydraulic conductivity of the buffer material for the repository should be below $1x10^{-12}$ m/s.
  - Retention capacity: The apparent diffusion coefficients of the cationic nuclides (excluding strontium) and actinides in the buffer material should be less than $10^{-11}$ $m^2/s$. Those of the strontium and anionic nuclides should be less than $10^{-10}$ $m^2/s$ and $10^{-9}$ $m^2/s$ respectively.
  - Swelling pressure: The swelling pressure should be less than 20 MPa to avoid an excessive external load on the container.
  - Thermal conductivity: The thermal conductivity of the buffer material should be higher than 1.0 W/m °K to effectively dissipate the heat from the decay of the radionuclides in the wastes.
  - Long-term integrity: The peak temperature of the buffer material should be less than 100 °C to assure its long-term integrity.
  - Organic matter content: The organic matter content should be less than 0.5 weight % to minimize any bad influence on the physical and chemical properties of the clay minerals and the formation of any soluble complexes of the radionuclides.
  - Mechanical properties: The buffer material should have good mechanical properties such as the compressive strength and consolidation properties in order to mechanically support the waste container without any significant deformation.

Buffer blocks are compacted with a high pressure to the shape of pineapple rings and disks. Pineapple ring shaped blocks are easier to handle because they can be griped inside the ring. These blocks can be griped with a vacuum gripper on the top of the block or mechanically inside the ring. In this case it has to be assured that the gripper doesn't break the block. Disk shaped blocks should be griped with a vacuum gripper on the top of the block. Pineapple ring shaped blocks are used for the side of the canisters and disk shaped blocks on the bottom and top of the canisters.

- Disposal method

Disposal method is based on the concept that a disposal continues almost uninterrupted through a long operation period. All the technical rooms and connections to the ground level will be excavated before the operation phase. More disposal tunnels will be excavated in the phases. Backfilling of the tunnels always starts shortly after the canisters are disposed to the tunnel. Boring of the disposal holes is done simultaneously with a disposing of the canisters. For the designed disposal method it is also assumed that no canisters will be retrieved after a closure of the repository. Retrieving of the canisters is considered only during the operational period when the disposal tunnel is still open.

**Construction and Operation**

- Construction

Construction of the repository will begin in 2020's when the URL is constructed. Construction includes excavation, construction works and installation of the systems.

Next step of the construction is taken in 2030's when the first part of the repository is constructed. After this phase in 2040 all the disposal tunnels for the CANDU canisters will be excavated. Also one row of the PWR tunnels will be excavated to avoid excavations near the disposed canisters later on. After the start of the operation the rest of the disposal tunnels will be excavated in five phases.

All the tunnels will be excavated with traditional drill and blast methods. First the holes will be drilled, charged and then blasted. After loading of the muck, drilling of the next drilling pattern will be start.

- Operation

Operation will start from the CANDU tunnels which are closest to the controlled area rooms. The disposal holes will be drilled in the first four pairs of disposal tunnels (Figure 3).

The boundaries of the controlled area will be set between the fourth and the fifth tunnel pairs in the panel tunnel(2A) and between the first and the second panel tunnel in the central tunnel(1) looking from direction of the canister shaft.

The fuel canisters disposal will be started from the fourth disposal tunnel pair(⑦,⑧) and the disposal work will progress(Table VI) in pairs in the direction of the central tunnel. Disposal starts from the end of the tunnels. After the fuel canisters are disposed in the fourth tunnel pair the controlled area boundary will be moved 40 meters(2B) towards the central tunnel. The fourth disposal tunnel pair will then be back-filled via the uncontrolled area panel tunnel.

The disposal work will be interrupted during the backfilling of the first disposal tunnel pair(①,②).

The disposal holes will be drilled in the tunnel pairs at the uncontrolled area simultaneously with the disposal work at the controlled area. After the four disposal tunnel pairs are back-filled then the controlled area boundary will be moved between the eighth and the ninth tunnel pair in the panel tunnel. The disposal work will continue again from the eighth tunnel pair towards the central tunnel.

After a disposal of all CANDU canisters the disposal will continue with the PWR canisters in the disposal tunnels on the opposite side of the central tunnel.

In this study, it is assumed that an operation is divided into sections with four disposal tunnel pairs. Four is just an example. If we assume more tunnel pairs to be taken into account in this operation section, then more disposal holes have to be bored beforehand. If we assume less tunnel pairs during the operation section, then we have more often the situation that the disposal work is interrupted during the backfilling of the disposal tunnel pair which is closest to the controlled area.

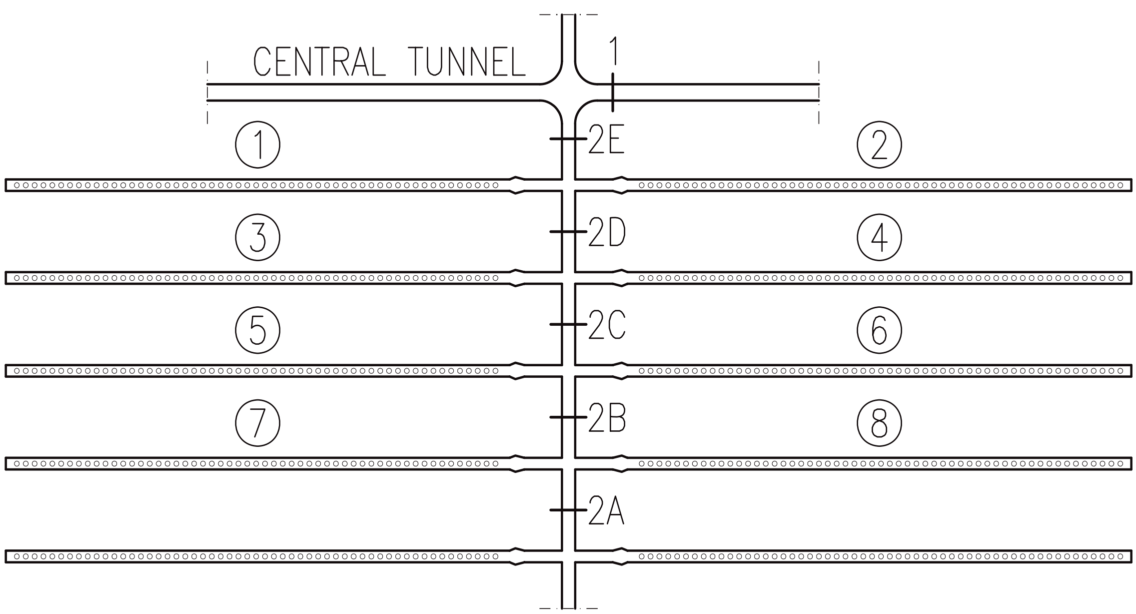


Fig. 3. First operation in the CANDU tunnels of the repository.

Table VI. Emplacement Process

| Task | From | To | Remark |
|---|---|---|---|
| Canister transfer from the buffer storage to the lift | Buffer storage | Lift | Encapsulation station |

| | | | |
|---|---|---|---|
| Canister lift lowering to the repository | Surface | Repository | Canister shaft |
| Canister transfer from the lift to the loading station | Lift | Loading station | Level -508.06 |
| Canister transfer vehicle picks up the canister | Level -508.06 | Level -499.66 | Transfer and install. vehicle |
| Driving of the canister to the disposal tunnel | Canister shaft hall | Disposal tunnel | Transfer and install. vehicle |
| Adjustment of the vehicle above the disposal hole | | | Transfer and install. vehicle |
| Deposition of the canister to the deposition hole | Disposal tunnel | Deposition hole | Transfer and install. vehicle |
| Installation of the bentonite blocks above the canister | Disposal tunnel | Top of the canister | Compacted bentonite |

**Monitoring and Closure**

Design basis of the repository has been that there is no need for a monitoring after a repository closure. During the operation period there may be a desire to monitor several parameters. Need for a monitoring can be information for the long-term safety analyses but also monitoring information can be used for developing backfilling techniques and materials, excavation methods etc. Items for a monitoring can be air quality, water quality, amount of water, swelling pressure of the backfilling material and buffer, stress field, disturbed zone of the tunnels etc.

- Backfilling

Mixture of crushed rock and calcium bentonite is used for a backfilling of all the tunnels and shafts. Disposal tunnels are backfilled shortly after the canisters are installed in the tunnel.

Backfilling is normally performed in two tunnels simultaneously, tunnels are on the opposite side of the panel tunnel. After all CANDU disposal tunnels are filled the corresponding panel tunnel is backfilled. Same systems are used to fill the panel tunnels for the operation phases for the PWR canisters. After all disposal and panel tunnels are filled, the central tunnels and other technical rooms are backfilled. Backfilling is started from the technical rooms in the controlled area. After these rooms, the central tunnel and technical rooms of the uncontrolled area and finally the access tunnel are backfilled. Shafts in the controlled area are backfilled after the technical rooms in the controlled area are filled. Because the shafts of the uncontrolled area have connections to the access tunnel, they should be filled part by part simultaneously with the backfilling of the access tunnel.

Backfilling mixture consists of 70 % crushed rock and 30 % calcium bentonite. Rock is crushed from the muck that has been excavated from the repository. Grain size of the crushed rock could be 0 - 20 mm.

Backfilling technology has to be developed jointly with a backfilling material development. At present the following principles are assumed:

- Excavated muck is crushed in a crushing plant above ground.
- Crushed rock and calcium bentonite are mixed in a mixing station above ground.
- Mixture of crushed rock and bentonite is driven down to the repository via the access tunnel in concrete transportation vehicles.
- Batch of backfill is spread and compacted in layers that are inclined. View from a disposal tunnel during a backfilling is shown in Figure 4.

All the structures are removed from the tunnels and shafts before a backfilling of the room to be filled. Structures are transported up via the access tunnel.

- Closure

Disposal holes are closed immediately after a canister deposition. Holes are closed with bentonite blocks (Figure 4). Blocks are compacted with a high pressure to the shape of pineapple rings and disks. Pineapple ring shaped blocks are used for the side of the canisters and disk shaped blocks on the bottom and top of the canisters. Height of each block can be around 0.5 meters. Disk shaped bottom and top blocks can be griped with a vacuum gripper.

After a backfilling of every disposal tunnel, the tunnel is closed with a concrete plug at the front of the tunnel. Concrete plug prevents the backfilling material from swelling in the panel tunnel. The plug also prevents the fine aggregate of the backfilling from being washed with groundwater. The plug should withstand the water pressure of the disposal tunnel.

Finally, when all the tunnels and shafts are backfilled, 10 meter thick concrete plugs are cast at the top of the shafts and in front of the access tunnel. Structures will obstruct an occasional pass to the repository.

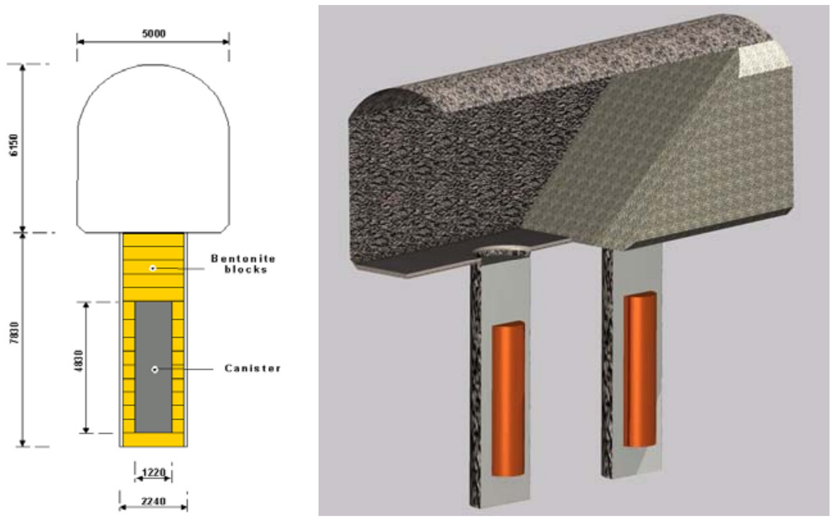


Fig. 4. View of the closed disposal holes and the backfilled disposal tunnel.

## CONCLUSION

In this study, the concept of the **K**orean **R**eference HLW **V**ertical disposal **S**ystem (KRS-V1) is presented. Though no site for the underground repository has yet been specified in Korea, a generic site with granitic rock is considered for the reference HLW repository design.

Depth of the repository is assumed to be 500 meters. The repository consists of the following sections:

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Disposal area consists of disposal tunnels, panel tunnels and a central tunnel. Panel tunnels connect the disposal tunnels and the central tunnel. Central tunnel leads from the controlled area to the uncontrolled area and connects the panel tunnels to each other. Technical rooms in the controlled area also include four shafts: canister shaft, personnel shaft and two ventilation shafts. Technical rooms in the uncontrolled area include the correspondingly access tunnel, personnel shaft and two ventilation shafts.

The repository will be excavated in seven phases. Construction of the repository will begin when the Underground Research Laboratory (URL) is constructed. Next step of the construction will be taken when the first part of the repository is constructed. After this phase, disposal of the CANDU canisters will begin. Disposal of PWR canisters will begin when all CANDU canisters are disposed. Disposal tunnels and panel tunnels will be backfilled during the operation of the repository, and also concurrent with the disposal of the canisters.

Some items for future work in developing the KRS-V1 are:

- To ensure the minimum distance of the deposition holes with a 3D-analysis. The distance has a strong effect on the volumes of the repository and therefore also on the schedules, backfillings, costs, etc. Thermal gradient and thermal conductivity are important data for the analysis.
- Backfilling methods and materials for the tunnels and shafts should be developed further.
- Detailed study of the excavation and construction methods should be carried out for selecting the suitable methods applicable to Korea.
- Material logistics. Since a huge amount of excavated rock and backfilling material is transported in the central and access tunnel, detailed analysis of the material flows should be performed.

This concept for the Korean reference HLW disposal system can be used to evaluate the feasibility of the designed high-level waste disposal system, to formulate data for a long-term safety analysis, to obtain communication material for information and public relations and to help in the budget and funding calculations.

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