Korean Reference Disposal System for High-level Radioactive Wastes

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Abstract

This paper outlined the status of the development of Korean Reference Disposal (KRS-1) system for high-level radioactive wastes. The repository concept was based on the engineering barrier system which KAERI has developed through a long-term research and development program. The design requirements were prepared for the conceptual design of the repository. The amount of PWR and CANDU spent fuels were projected with the current nuclear power plan. The disposal rates of PWR and CANDU spent fuels were analyzed. The reference geologic characteristics including classification of fracture zones were set for the KRS. The disposal concepts and the layout of the repository were described.

1. Introduction

There are around 20 nuclear power reactors in operation, and around 7,300 tU of spent fuels has been accumulated in Korea. Spent fuels from the reactors are kept in the storage pool of the nuclear power plants. Most countries with nuclear power plants tried to find a way to dispose of spent fuels finally. MOST launched a long-term research and development program for the disposal of high-level radioactive waste (HLW) in 1997. The third stage of the long-term research and development program has performed since 2003. The main purpose of the third stage is to show the feasibility of the geologic disposal of HLW through a reference disposal system. Thus, KAERI has developed technologies related to the safe disposal of high-level wastes.

KAERI is developing the reference repository for the high-level radioactive wastes. To this end a generic site with granite is considered for the reference HLW repository. The authors designed the canisters for PWR and CANDU spent fuels [1, 2]. The buffer blocks were designed with Korean Calcium Bentonite characterized in KAERI [3]. The design requirements for the engineered barrier were prepared. The distance between disposal tunnels and the spacing of deposition holes were determined through Thermal-Mechanical analyses [4]. The preliminary conceptual design of the underground facilities for the KRS-1 was carried out through a joint study with Finnish POSIVA. KAERI plans to improve the preliminary conceptual design in order to complete the KRS-1 concept.

The total amount of spent fuels in Korea is expected to be around 20,000 tU of PWR and 16,000 tU of CANDU. The Korean Reference Disposal System is based upon the concept of direct disposal of all the spent fuels from PWR and CANDU reactors in Korea. The KRS-1 is expected to be used for the comparison of other options for the spent fuel management in the future. The final disposal will start with CANDU fuel in the year 2040 and with PWR fuel in the year 2065. The Korean disposal facility consists of disposal tunnels with vertical deposition holes, central tunnels, auxiliary facilities, and access tunnels. The disposal facility will be excavated at the depth of 500 m below the ground level. The depth of the repository will be fixed after site characterization.

The objectives of this paper are to introduce the design requirements for the KRS-1, to outline the outputs of the preliminary conceptual design of KRS-1, to show the feasibility of the deep geological disposal of HLW with the current engineering design and technologies, and to present a preliminary concept of a repository including preliminary drawings for the repository, tunnels, and systems.

2. Design Requirements

2.1. Spent fuel

There are 4 CANDU reactors in Wolsong and totally 16 PWR reactors in Kori, Younggwang, and Uljin sites. The total amount of high-level spent nuclear fuels expected in Korea is presented in Table 1. The minimum distance between two deposition holes for PWR canisters is 6 m. According to previous calculations, the minimum distance between two deposition holes for CANDU canisters was determined to be 3 meters. However, the distance increased up to 4 meters to improve rock mechanical stability between the holes. Thermal calculations for determining the distances were done 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 shall not rise above 100 °C.

Table 1. Total amount of spent 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

2.2. Time schedule and disposal rate

The cooling time for CANDU spent fuel is 30 years and for PWR spent fuel 40 years. It was recommended that the final direct disposal 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 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. The pre-conceptual design was based on the total operation time of 55 years.

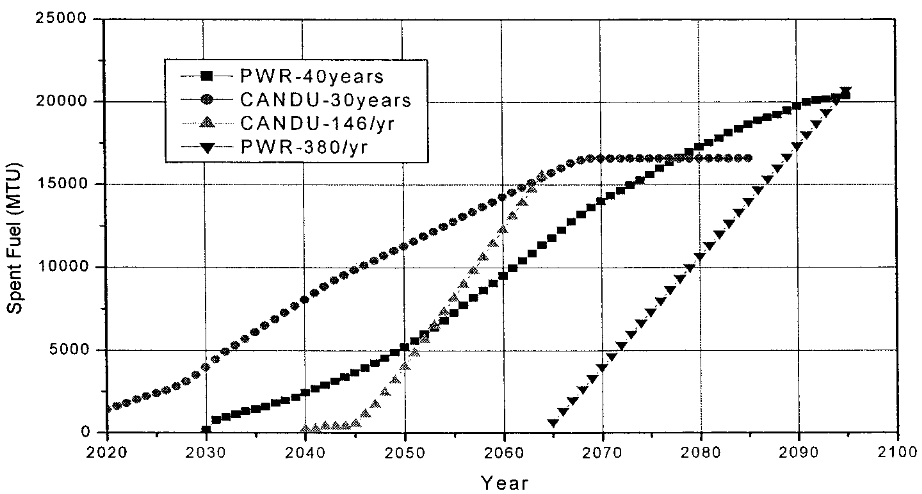

Figure 1. Time-schedule for disposal of spent nuclear fuels.

2.3. General site data

The repository site has not been chosen yet. The Korean peninsula is located relatively near the eastern margin of the Eurasian plate. The majority of the peninsula belongs tectonically to a shield area occurring in the eastern margin of the Korea-China platform. Generally, the peninsula is considered as relatively stable landmass with no active volcanoes and rare severe earthquakes. The thermal gradient of the Korean bedrock depends on the area. Thermal gradient of 30 °C/km was used as a design basis for the preliminary design in this study. In this paper we assume that the repository will be constructed into granite rock mass.

The fracture zones are divided into four main classes (see Table 2). As presented in Figure 2, the repository shall 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 shall be certain safety distances to the nearest disposal holes. In addition, all potential fast pathways shall be isolated from the tunnel with plug structures.

Table 2. Classification of fracture zones.

	Order	Length (m)	Width (m)	Interval (km)	T (m^2/s)	Safety distance (m)
Regional fracture zone	1	>10,000	>100	>4	1×10^{-5}	100 (to unit facility)
Local major fracture zone	2	1,000 - 10,000	5 - 100	1 - 4	1×10^{-6}	50 (to deposition tunnels)
Local minor fracture zone	3A	500 - 1,000	1 - 5	1<	$1\times10^{-7} \sim 1\times10^{-8}$	5 (to dep. holes)
	3B	<500	<1			3 (to dep. holes)
Bedrock fracture system	4	<10	<0.01	-	$<1\times10^{-9}$	-

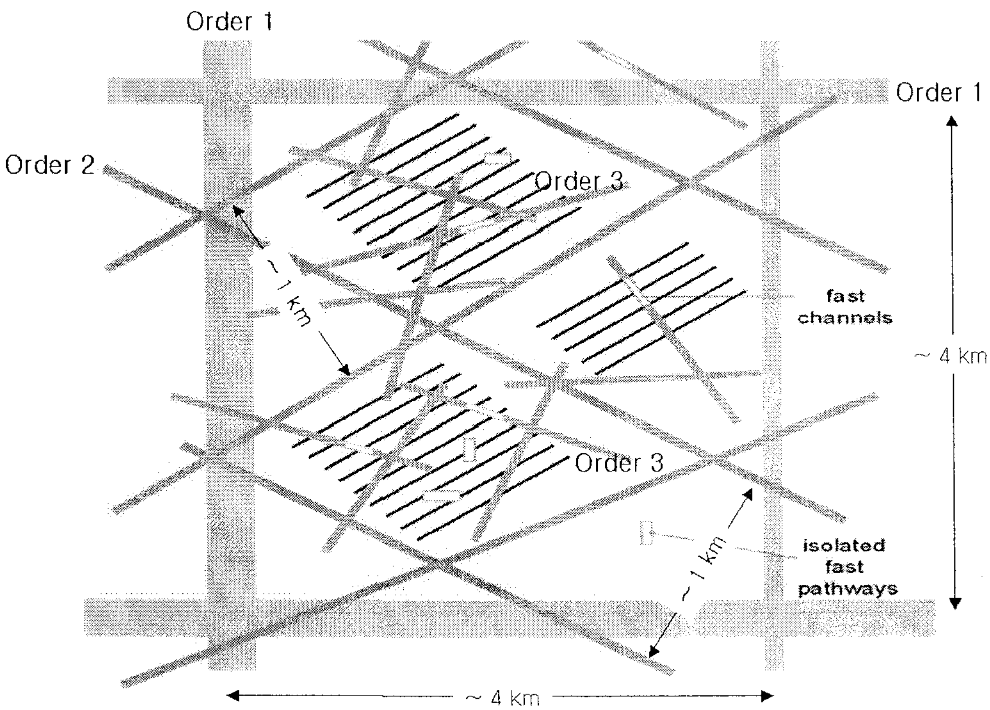

Figure 2. Example of the repository layout with respect to fracture zone classification.

2.4 Regulations

Korea Institute of Nuclear Safety (KINS) supervises and regulates the radioactive waste management in Korea on behalf of Ministry of Science and Technology (MOST). The general principle of 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 radiation safety in connection with the final management of high-level nuclear waste is under preparation in Korea. The radiation safety is supervised by the Korea institute of nuclear safety.

3. Korean Reference Disposal System

3.1 Concept description

The repository is assumed to be constructed along the coast of Korean peninsula. The repository is not designed to be located under the sea. The same type of concept could be used under the sea. The biggest changes would be in the connections between surface and the repository. If the vertical shafts would be used they should be located under the islands. Also it is possible to locate technical rooms and vertical shafts under the peninsula and the disposal area of the repository under the sea. In this case the central tunnel would be longer than in base case. Another alternative is to use more inclined tunnels instead of vertical shafts. Inclined tunnels can easily be used for transporting persons, materials etc. However huge amount of air is needed for ventilation and vertical shafts for air tubes are definitely better than long inclined tunnels. Depth of the repository is assumed to be 500 meters. From technical point of view repository can be located upper or deeper.

The repository consists of the following sections:

- 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 central tunnel. Panel tunnels connect disposal tunnels and the central tunnel. Central tunnel leads from controlled area to uncontrolled area and connects panel tunnels to each other. Technical rooms in the controlled area include also four shafts: canister shaft, personnel shaft and two ventilation shafts. Technical rooms in the uncontrolled area include correspondingly access tunnel, personnel shaft and two ventilation shafts. The repository will be excavated under the encapsulation plant. Layout of the whole disposal plant is presented in Figure 3.

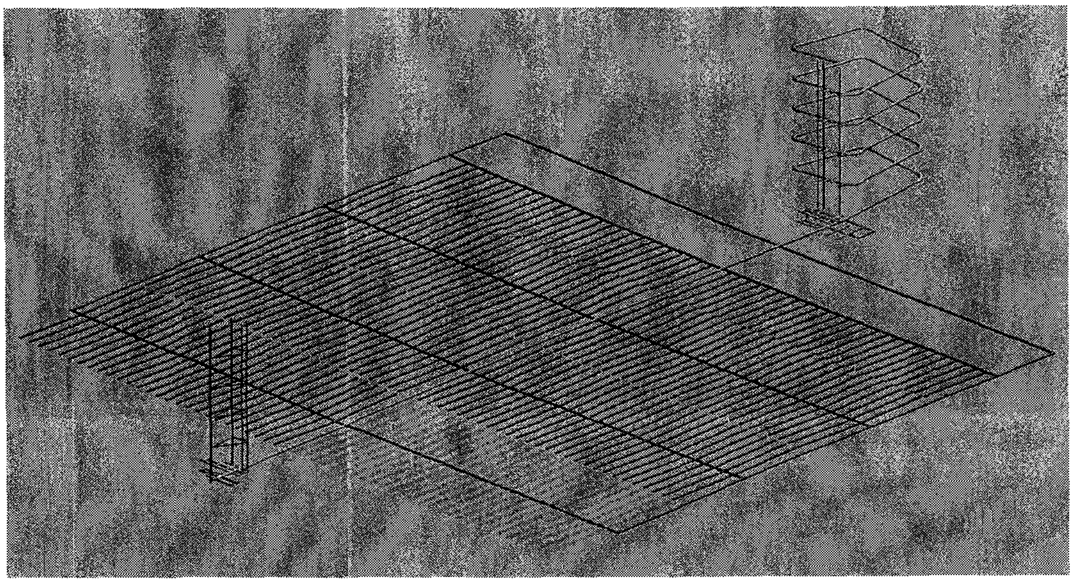

Figure 3. Layout of the Korean reference HLW disposal system. Green panel is for CANDU canisters.

Determining factors affecting repository layout are:

- To divide repository to controlled and uncontrolled areas. Canister handling will always be performed in the controlled area. Excavation and backfilling will be done in the uncontrolled area.
- Border between controlled and uncontrolled area will move during the lifespan of the repository.
- Disposal and panel tunnels will be excavated and backfilled in phases during operation phase of the repository.
- Two escape ways from all the tunnels except disposal tunnels which are dead end tunnels.
- Access tunnel is one connection to the ground level.

Above factors made the layout in Figure 3. Controlled area is on the left side and uncontrolled area on the right side. Disposal of the canisters starts from the left and shifts to the right.

3.2 Disposal principle

Canisters consist of two materials. Insert is made of cast iron and outer shell is made of copper. Dimensions of PWR and CANDU fuel canisters are equal. Key procedures in canister handling could be:

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

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

3.3 Construction and operation

Construction of the repository will begin when URL is constructed. Construction includes excavation, construction works and installation of the systems. Next step of the construction is taken when first part of the repository is constructed. After this phase all the disposal tunnels for CANDU canisters are excavated. Also one row of the PWR tunnels is excavated to avoid excavations near disposed canisters later. After start of the operation rest of the disposal tunnels are excavated in five phases. All the tunnels are excavated with the traditional drill and blast method.

Operation will start from the CANDU tunnels which are closest to controlled area rooms. The disposal holes are drilled in the first four pairs of disposal tunnels. The boundaries of the controlled area are set between the fourth and the fifth tunnel pairs in the panel tunnel and between the first and the second panel tunnel in the central tunnel looking from direction of the canister shaft. The fuel canisters disposal is started from the fourth disposal tunnel pair and the disposal work progresses in pairs in direction to 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 is moved 40 meters towards the central tunnel. The fourth disposal tunnel pair is then back-filled via the uncontrolled area panel tunnel.

Detailed emplacement process from the buffer storage of the encapsulation station to the deposition hole is described in Table 3. Bottom and side blocks of compacted bentonite are installed to the deposition hole before emplacement process.

Table 3. Emplacement process.

Task	From	To	Duration (minutes)	Remark
Canister transfer from the buffer storage to the lift	Buffer storage	Lift	20	Encapsulation station
Canister lift lowering to the repository	Surface	Repository	10	Canister shaft
Canister transfer from the lift to the loading station	Lift	Loading station	10	Level -508.06

Canister transfer vehicle picks up the canister	Level -508.06	Level -499.66	20	Transfer and install. vehicle
Driving of the canister to the disposal tunnel	Canister shaft hall, C21	Disposal tunnel	20	Transfer and install. vehicle
Adjustment of the vehicle above the disposal hole			20	Transfer and install. vehicle
Deposition of the canister to the deposition hole	Disposal tunnel	Deposition hole	30	Transfer and install. vehicle
Installation of the bentonite blocks above the canister	Disposal tunnel	Top of the canister	10	Compacted bentonite

3.4 Monitoring and closure

Design basis of the repository has been that there is no need for the monitoring after the repository closure. During the operation period there may be desire to monitor several parameters. Need for monitoring can be information for long-term safety analyses but also monitoring information can be used for developing backfilling techniques and materials, excavation methods etc. Items for 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.

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

Mixture of crushed rock and calcium bentonite is used for backfilling of all tunnels and shafts. Disposal tunnels are backfilled shortly after the canisters are installed in the 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 backfilling material development. By now following principles are assumed:

- Excavated muck is crushed on a crushing plant above ground.
- Crushed rock and calcium bentonite are mixed on a mixing station above ground.

- Mixture of crushed rock and bentonite is driven down to the repository via access tunnel in concrete transportation vehicles.
- Batch of backfill is spread and compacted in layers that are inclined.

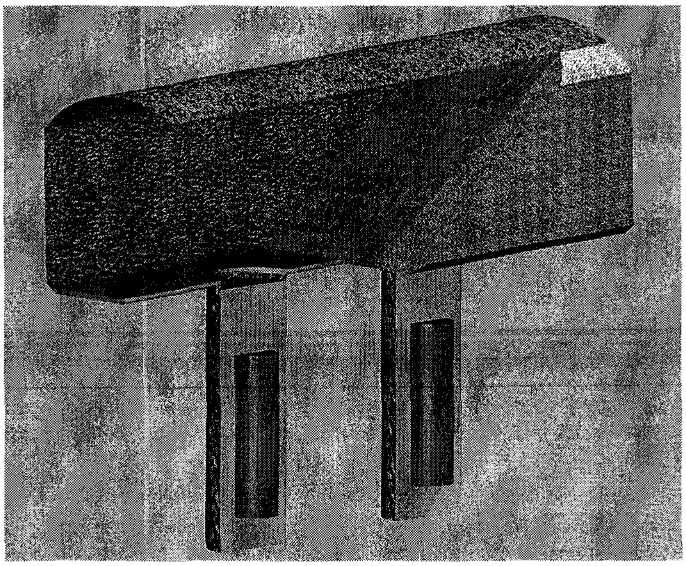

Figure 4. View from the disposal tunnel during backfilling period.

After backfilling of every disposal tunnel, the tunnel is closed with concrete plug in the front of the tunnel. Concrete plug prevents backfilling material to swell to the panel tunnel. The plug also prevents fine aggregate of backfilling to be washed with groundwater. The plug will stand the water pressure of the disposal tunnel. Finally, when all tunnels and shafts are backfilled, 10 meters thick concrete plugs are cast at the top of the shafts and in the front of the access tunnel.

4. Conclusions

The Korean Reference Disposal system for high-level radioactive wastes is being developed and is briefly described in this paper. Though no site for the underground repository has been specified in Korea, a generic site with granite is considered for reference HLW repository design. Depth of the repository is assumed to be 500 meters. The repository consists of the following sections: disposal area, technical rooms and connections to the ground level in the controlled area, and technical rooms and connections to the ground level in the uncontrolled area.

Disposal area consists of disposal tunnels, panel tunnels and central tunnel. Panel tunnels connect disposal tunnels and the central tunnel. Central tunnel leads from controlled area to uncontrolled area and connects panel tunnels to each other. Technical rooms in the controlled area include also four shafts: canister shaft, personnel shaft and two ventilation shafts. Technical rooms in the uncontrolled area include correspondingly access tunnel, personnel shaft and two ventilation shafts. The safety analysis of the KRS-1 will be conducted to show the feasibility of the concept.

Acknowledgement

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