Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1998

Approaches for the Reference Concept Development of A Deep Geological Repository System

Jongwon CHOI, Chulhyung KANG, Kwan-sik CHUN and Hyun-Soo PARK
Korea Atomic Energy Research Institute
P.O. Box 10, Yusong, Taejon, Korea

Abstract

This study addresses the basic approaches and relevant specific activities to develop a reference deep geological repository system with technical feasibility, reasonable cost and long-term safety. The safety philosophy in developing a reference concept is based on the multiple barrier principle, i.e. safety does not depend on the performance of a single barrier. The approaching steps for developing the Korean Reference Disposal System are : selection of reference spent fuel; determination of the basic assumptions and the technical/safety criteria for system design requirements; screening the most promising option by qualitative analysis, comparison and ranking of the proposed repository alternatives with regarding the technical feasibility, the long-term safety and the cost aspects; pre-conceptual design to define a reference repository system.

I. Introduction

Korea Atomic Energy Research Institute (KAERI) has started R&D program for HLW disposal technology development since 1997. The main purpose of the program is to establishment a reference HLW repository concept to accommodate any political, social and environmental conditions anticipated in Korea by the year 2006.

The disposal concept being conceived in the study is to encapsulate the spent fuel in corrosion resistant canisters. The spent fuel packages are then deposited in a mined deep underground facility located at some hundred meters depth in crystalline rock. No site has been specified but a generic site with granitic rock is considered for the study. The waste packages are placed in boreholes from the floors in a system of parallel disposal tunnels. Different patterns for emplacement of the canister alternatives are considered as well as different distances between deposition holes and tunnels. Some analysing works to determine the reference canister and emplacement pattern have been carried out.

This study addresses the basic approaches and relevant specific activities to determine the most promising options through the system alternative study and then to develop a reference deep geological repository system with technical feasibility, reasonable cost and long-term safety. The safety philosophy in developing a reference concept is based on the multiple barrier principle, i.e. safety does not depend on the performance of a single barrier. The approaching steps for the concept development of the Korean Reference Disposal System are as followings (see Fig.1) :

¨ ç Selection of reference spent fuel

¨ è Determination of the basic assumptions and the technical/safety criteria for system design requirements

¨ é Most promising options regarding spent fuel packages, near field design, repository layout and performance assessment : qualitative analysis, comparison and ranking of feasible alternatives with respect to the technical feasibility, the long-term safety and the cost aspects

¨ ê Pre-conceptual design of surface facilities and underground repository

¨ ë Sensitivity analyses to define a reference repository concept with respect to spent fuel burnup and age, disposal capacity, deposal depth, retrievable operation (with or without buffer/backfill, backfilling time, etc.) and usage of multi-purpose (storage, transportation, disposal) canister or cask.

As a step-by-step approach, such an approach starts with many alternatives and screen out alternatives progressively, initially based on brief analyses, and later based on more and more detailed studies.

II. Step 1&2 : Determination of the Reference spent fuel and the Basic Assumptions and General Criteria

The first activity in the scheme in Fig.1 is to define the reference spent fuel to be disposed of, what type, in what form, radionuclide inventory, residual heat, etc. In defining a reference fuel it should be also considered that there would be necessarily a broad variation of spent fuel characteristics which must be accommodated by any future repository. Therefore, the reference fuel has to be determined to be representative of the reasonably conservative average fuel to be disposed of because reference fuel influence the bases of repository such as the design of canister, layout of canisters in underground, etc.

The second activities are to establish ground rules/assumptions and functional/technical criteria which are necessary for developing and defining the reference repository concept as the basic assumptions (disposal capacity, disposal depth, operation time, geologic medium as repository host rock). However, these are not necessarily fixed once and for all, but may change in parts in the course of repository study due to for instance new scientific information or adjustments of waste management policies or strategies.

The activities described in step 1&2 have completed during the past years. The two types of reference spent fuel (PWR, CANDU) were determined based on screening the representative characteristics of all spent fuels from the existing and planned nuclear power plant [1]. The reference PWR fuel is giving on the average 45,000MWd/tHM(4.0wt.%) burnup and being cooled for 40 years after irradiation before encapsulation and disposal. A variance level of burnup, as an alternative for PWR, is 55,000MWd/tHM(4.5wt.%). For CANDU fuel, the reference burnup was determined to be 7.5 MWd/tHM(for natural uranium fuel). Based on these reference fuel information and on the National Logn-term Nuclear Energy Plan (23 PWRs and 4 CANDUs by the year 2010), the capacity of a reference repository was estimated to be 36,000 tHM (20,000 tHM of PWR fuel and 16,000tHM of CANDU fuel).

III. Step 3 : Determination of the Most Promising Option

Once the bases would be outlined as mentioned in step 1&2, the system alternative study starts in order to find the feasible options with potentials and reasonable rationale to be developed to the desirable concept. This step would be done on a broad scale and logically, in steps starting with the work to define the environmental conditions in the bedrock. Unfortunately, no site has been specified yet. A generic site with granitic rock is merely considered at present conceptual study phase. Then one can proceed to find a reference canister, which is followed by design and layout of the repository, which starts with a number of feasible alternatives. By the pros and cons of different alternatives from the qualitative analysis on the aspects of technical feasibility, cost and safety principle, a specific one (or with another alternative) is selected as the most promising option. From the Swedish experiences [2, 3], from a practical point of view it is concluded to be less complex to analyse different canister designs in the first place and emplacement methods thereafter, than to list and compare all combinations of canister designs and emplacement alternatives in one step.

In step of *Fuel Packaging Options*, various design concepts of the canister alternatives are considered and compared with regard to the aspects of the fabrication technology, long-term integrity and cost. Thus top ranked alternative can be chosen for the near-field design work, i.e. the geometry of the deposition hole or geometry of the deposition tunnel in the case of in-tunnel emplacement. The design of canister and the design of the near-field are practically non-dependent of site specific data, so that relatively detailed analysing works can be made in an early stage based on only general information of the properties of the representative crystalline rock available in elsewhere [2, 4, 5].

The following step labelled *"Repository Layout"* is to calculate how the canisters can be configured in the underground repository. This step involves the thermal calculations to derive the deposition holes and/or tunnels spacing meeting with thermomechanical safety constraints.

The maximum temperature in the bentonite buffer determines the distance between canisters and consequently the length of tunnels to be excavated, and the thickness of the bentonite buffer. Thus, the thermal calculations based on the different thermal properties of the canister, the buffer and the rock result in the cost differences between alternatives.

Once the repository layout would be determined, the technical feasibility of the repository system alternatives with the specific deposition tunnel/hole spacing and the canister emplacement mode has to be evaluated with regard to the constructability, the deposition and sealing technology (including the operation safety) and the possibility of human intrusion. For the analysis of the deposition/sealing technology, emplacing modes of the buffer and the canister (e.g. buffer and canister separately or in one package, with or without surrounding radiation shield, transportation/handling, etc.) and the sealing technology for closure are considered from a practical operation of view.

The first activity in the comparison of the long-term performance and safety of the repository concepts" is to specify design parameters for each concept, such as geometry and spacing of deposition holes/tunnels, and type of emplacement mode. Based on this information, the initial and long-term performance of individual barrier in each concept as well as effects if interactions between barriers are qualitatively evaluated. The sensitivity of the performance of the barriers to future events with a potential detrimental effect is also qualitatively assessed.

In the next step, the individual barriers of the concepts are compared in order to get a qualitative estimate of the relative importance of the different barriers for the safety and to identify differences in barrier performance between the alternative concepts. The relative importance of a barrier for the safety is a key factor to determine the importance of an identified difference between the concepts. Finally a qualitative comparison between the alternative concepts is performed based on a set of the evaluation criteria (i.e. dose limit, possibility of validation, the sensitivity to rare events, etc.). Here the safety evaluation of the individual barriers must be combined with an evaluation of to what degree the overall safety depends on the function of an individual barrier in order to show that the repository safety is depending on the performance of the total system rather than that of a single barrier.

Practically, it may be difficult to distinguish any major quantitative difference in the safety of the repository alternatives because their major design parameters and multiple barriers are similar each other. In that cases, the final evaluation for a reference concept may be controlled by differences in technology and costs.

At present, several canister alternatives based on the separate packaging or co-packaging of PWR and CANDU fuels are considered and some thermal calculations are doing with respect to the proposed emplacement modes and the canister alternatives. This step will be carrier out by the year 1999.

IV. Step 4 : Pre-conceptual Design of the Repository

The pre-conceptual design activities concern some more detailed work regarding the top ranked repository concept selected in the previous step to develop as a “Reference Disposal Concept”. In this step, the surface facilities for spent fuel packaging and the underground repository system are designed at pre-conceptual level and then integrated into an entire repository system with the sketches of the necessary equipment and facilities. The key issues of this step are :

- design and layout of the repository system in accordance with the basic assumptions and the technical/safety criteria established in the step 1&2.
- constructability analysis, which indicates how the repository will look like ”as built”
- quantitative safety assessment of the repository system

If the key issues for accepting the reference concept is the long-term safety, a full safety assessment is necessary to compile quantitatively from the radionuclide migration to the radiological dose assessment in the biosphere based on the assumed reference scenario.

1. Design and layout

Once the most promising package and repository system alternative are determined in the previous step, further more detailed engineering analysis is necessary in order to refine the system. The geometry of deposition hole and tunnel is based on the criteria to keep the structural stability during the excavation and operation phase.

The layout, i.e. the configuration pattern of the deposition holes and tunnels in the rock, is based on one specific criterion to keep the maximum temperature below 100ºC in the buffer.

The distance between deposition holes and the distance between deposition tunnels due to the temperature limit is also guiding the layout. One choice to be made is whether the rock volume should be used most efficiently or the cost for excavation and buffering/backfilling should be kept as low as possible. The recent SKB’s results [3] indicate that the rock is most efficiently used if the distance between canisters in the deposition tunnel is medium and the distance between deposition tunnels is short. The costs, however, are lower if the distance between the deposition holes is kept as short as possible and the distance between deposition tunnels is correspondingly larger.

For operation and technology for HLW encapsulation and canister emplacement, some necessary equipment and techniques have being used in the mine and heavy industry, so that most of them could be directly applied in the repository system operation. Others may have more or less to be developed to such a detailed level that it is clear how the equipment can be constructed as well as how the operation can take place. In addition to the analysis of the performance of the equipment it is of importance to get a rough idea of how large space the equipment will need when it is in operation.

Deposition of canister including the handling of canister is inevitably accompanied with a potential risk for exposing the personnel to radiation doses. Therefore, handling procedures of canisters have to de designed with the safety criteria for dose limit to the personnel in order to show that any critical operations are feasible. In principle, there is no difference between the radiation protection principle in a repository and a nuclear power station.

2. Constructability analysis

For the chosen designs, layouts and operation processes it is important to analyse how the repository can be constructed. This comprises an analysis of the methods to be used for excavation and building of underground facilities, and aims at a proposal for the construction phase that presents alternative ways to solve difficult construction problems, like how to pass the assumed major discontinuity, etc. Also the deposition and sealing operation is analysed with respect to technical feasibility and consequences for the long-term performance of the repository.

3. Safety assessment

The long-term performance and safety of the repository is the most important issue for the acceptance of a reference repository system. An acceptable degree of isolation of the spent fuel and retardation against radionuclide migration has to be provided in accordance with the safety criteria.

The aim is to find out whether the reference repository concept proposed fulfils the safety requirements established, so that in this step, a set of analyses and discussions are given of the expected repository performance after deposition of the waste packages. For such a full safety assessment, in the first step, the amount and radioactive properties of the reference spent fuel to be disposed of and the canister design and the repository system are defined. Here also the assumed properties of near-field barriers, near-field rock disturbed by the existence and the excavation of the repository, and the far-field rock are presented. And then the description of the function of multiple barriers and the safety requirements are followed. The general principle and methodology of the safety assessment of the reference repository system are presented. The potential migration pathways of radionuclides from the canister to the biosphere are defined with the specific assumptions regarding the short- and the long-term performance of the individual barriers as a reference scenario discussed. Finally the safety analysis phase and the results are discussed in relation to the safety requirements.

The estimation of doses for a reference scenario will always include uncertainties. The uncertainty mainly originate from the limited information of the repository system and the limited identification and understanding of the processes determining the radionuclide release. Uncertainty is also introduced in modelling by the transformation of the systems and processes into mathematical models.

V. Conclusion

The approaches to develop a reference deep geological repository system with technical feasibility, reasonable cost and long-term safety were discussed. The safety philosophy in developing a reference concept is based on the multiple barrier principle, i.e. safety does not depend on the performance of a single barrier. As a step-by-step process, the specific activities for developing a reference repository system are : 1) selection of reference spent fuel; 2) determination of the basic assumptions and the technical/safety criteria for system design requirements; 3) screening the most promising option by qualitative analysis, comparison and ranking of the proposed repository alternatives with respect to the technical feasibility, the long-term safety and the cost aspects; 4) pre-conceptual design to define a reference repository system.

Acknowledgements
This work was carried out under the Nuclear R&D Program by MOST.

Reference

1. “Reference spent fuel and its characteristics for the concept development of a deep geological disposal system, KAERI/TR-914/97 (1997).
2. R. Pusch, “Waste Disposal in Rock”, Elsevier, London, NewYork (1994).
3. Private communication with Per-Eric Ahlstrom, Senior Consultant of SKB, May 4-15, 1998.
4. “Review and Comments : KAERI’s Conceptual Study for Spent Fuel Disposal, SKB (1998).
5. SKB, Final Disposal of Spent Nuclear Fuel : Importance of the bed Rock for Safety”, SKB TR 92-20 (1992).

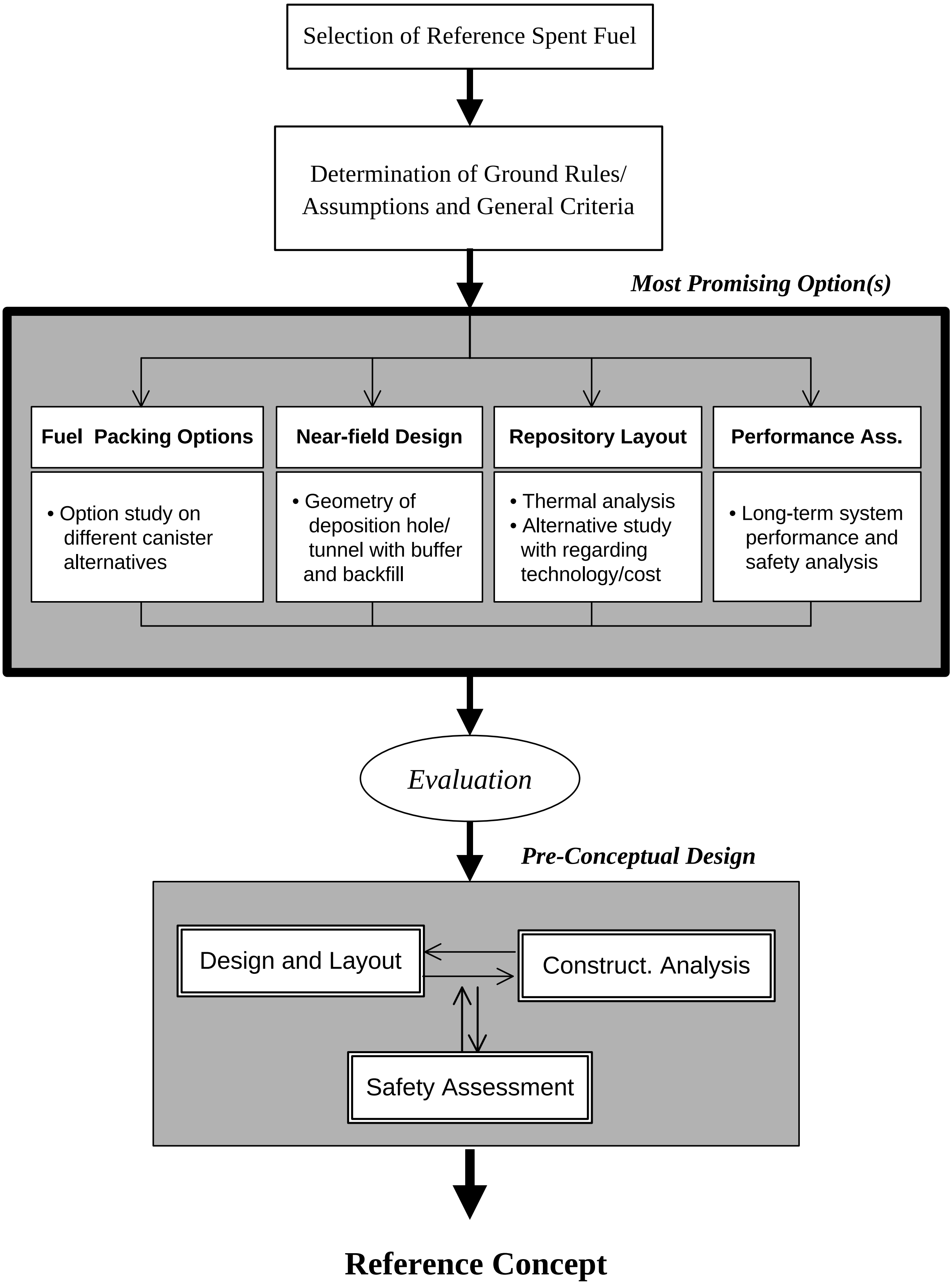

Fig. 1 Approaches for Developing of a Reference Disposal System