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Basic Assumptions and Safety/Technical Criteria for A Reference Geological Repository System

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Abstract

This paper presents basic assumptions and safety/technical criteria that are being used as guidelines in developing a reference geological repository system. These should be continuously revised based on more specific information collected from the site characterization processes and the repository system design and performance assessments to be carried out in the future. It is also important to investigate closely the other countries' repository concepts and safety and technical criteria that would be developed further.

I. Introduction

Korea has started basic R&D program for high-level waste (HLW, including spent fuel) disposal technology development since 1997. The medium-term target of the program is to develop a reference geological repository system that could accommodate any political, social and environmental conditions anticipated in Korea. To develop such a reference concept, during the past years Korea Atomic Energy Research Institute (KAERI) has prepared some prerequisite information such as the estimation of spent fuel inventories to be disposed of and the determination of the reference spent fuel [1].

The disposal concept being conceived in the KAERI's program 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 500m depth in crystalline rock. The waste packages are placed vertically in deposition holes or horizontally in deposition tunnels. Different patterns for emplacement of the canister alternatives are considered as well as different distances between deposition holes and tunnels.

In order to develop such conceived concepts to a reference repository system with technical feasibility, reasonable cost and long-term safety, pre-conceptual design of the repository system, at least, has to be carried out. For such work, in this paper, ground rules and assumptions and a set of safety and technical criteria are presented. These assumptions and criteria are used as the guidelines to establish a reference repository system and should be continuously revised based on more specific information collected from the site characterization processes and the repository system design and performance assessments to be expected in the future. It is also important to investigate closely the other countries' repository concepts and safety/technical criteria that would be developed further.

II. Ground Rules and Basic Assumptions

As prerequisite requirements that must be followed for the establishment of an reference system, ground rules and basic assumptions are assumed as the followings :

Reference spent fuel

Reference spent PWR and CANDU fuels were defined based on screening the representative characteristics of all spent fuels from the existing and planned nuclear power plant[1]. The proposed range in characteristics provides greater confidence in the reliability of the resulting in repository behavioral predictions. The characteristic bounding data of the reference spent fuels should encompass a variability in characteristics of all existing and future spent fuels of interest, as much as possible. Key parameters considered in the reference fuel screening processes were the nuclear and mechanical design parameters and the burnup histories for spent fuels generated from the existing reactors as of 1996 and for future spent fuels with more extended burnup the initial enrichment and the fuel burnup. The selected reference fuels characterized in terms of initial enrichment, discharge burnup, geometry, dimension, gross weight and age (cooling time after discharge) are summarized as :

- types of the reference spent fuel
  - spent PWR fuel assembly
    - fuel rod array : 17 x 17
    - total weight : 665 kg
    - dimensions : 21.4^2 cm^2 (cross-section) x 453 cm (length)
    - decay heat per assembly : 385 Watt/assembly
  - spent CANDU fuel bundle
    - fuel rod array : 37 rods in bundle
    - total weight : 25 kg
    - dimensions : 10 cm (diameter) x 49.5 cm (length)
    - decay heat per bundle : 2.28 Watt/bundle

- initial enrichment and discharge burnup of the reference fuel
  - spent PWR fuel assembly
    - nominal burnup case : 4.0wt.% for 45,000MWd/tHM
    - high burnup case : 4.5wt.% for 55,000MWD
  - spent CANDU fuel bundle
    - 0.71 wt.% (natural uranium) for 7,500 MWd/tHM
- cooling time before disposal : 40years

Disposal capacity **:** 36,000 ton of heavy metal (tHM)

The total spent fuel inventories to be disposed of are estimated under the assumption that the nuclear reactors to be commissioned by 2010 are 24 PWR reactors and 4 CANDU reactors and their lifetimes are all 40 years but 30 years for Kori-1.

- spent PWR fuel : 20,000 tHM (45,500 Assemblies)
- spent CANDU fuel : 16,000 tHM (842,000 Bundles)

Operation time **:** 50 years

The time for operation of the repository system facilities and equipment is assumed to be 50 years. This time encompasses the time from the encapsulation of spent fuels of 36,000tHM at the surface facility to the final deposition at the underground facility. Here 50years are just assumed based on the general lifetime of the nuclear facility with complicated instrumentation and control system under the high radiation field. Of course, the effect of a shorter or longer operation time than 50 years should be considered after establishing a reference concept in the future.

Daily throughput

Daily throughput is the amount of spent fuel to be daily handled at the repository system, which is estimated based on the system availability of 70% (equivalent 255 full operating calendar days per year). The 70% availability for the repository system covers allowances for normal process systems startup and shutdown times, scheduled and unscheduled repository system equipment maintenance and repair activities, material accountability related tasks that affect system operation, and any scheduled period for major systems refurbishing activities.

- PWR fuel : 4 assemblies (~ 1.6 tHM)
  : 36,000 x 20/(20+16)/(365 days x 0.7 x 50 years) = 1.565 tons/day
- CANDU fuel : 68 bundles (~1.3 tHM)
  : 36,000 x 16/(20+16)/(365 days x 0.7 x 50 years) = 1.252 tons/day

As listed in the reference spent fuel, the two types of fuel be processed are quite different in size and in properties. Whether they will be processed in parallel or in campaigns will probably have a considerable impact on the design of the encapsulation process. Such effects will have to be evaluated in detail in the future optimisation process of the total repository system.

Disposal Depth **:** 500 m

More specific disposal depth will be determined by local site specific geological, hydrogeological and logistic factors in the future. The depth will be of importance in the mechanical design of the engineered barrier system like disposal canister and buffer and of the deposition holes/tunnels in the near-field rock, and in the selection of hoist or ramp access to the underground repository.

Retrievable Operation **:** 50 years

In general, the specific period of retrievable operation means no retrievability in the long-term after final sealing of the repository.

However, some degree of retrievability has to be considered during the operational as well as post-closure phase. In cases of mistakes, equipment failure or other incidents at the canister emplacement or later the encapsulated waste should be recovered for corrections. Also there may be the potentials that the spent fuel disposed of has to be retrieved as useful nuclear resources in the future. In particular this may be important in design and system analysing step. The repository shall be also designed to protect unnecessary any attempts in the future to change the repository or to retrieve the waste.

The effect of a shorter or longer retrievable operation period than 50 years should be considered after establishing a reference concept in the future.

III. Principles for Radiation Protection and Long-term Disposal Safety

In a view of the long period of time, the radiation protection principle and guidelines that must be taken into account when planning a HLW repository are proposed. These are based on the international organizations' recommendations and the design bases of several countries' disposal concepts [2-5] and on the MOST's Notice that was recently published [6].

The repository shall not be dependent for its long-term safety on monitoring and maintenance by future generations. This does not mean, however, that the repository cannot be monitored for a period after disposal of the waste or closure of the repository.

The long-term safety of the repository shall be based on passive multiple barriers so that the degradation of one barrier does not substantially impair the overall performance of the disposal system.
During the operational phase, the radiation dose to individuals caused by the planned activities in the encapsulation and emplacement processes shall be less that 20 mSv/year (2 rem/yr) for the whole body. During a reasonably predictable period of time after the closure of the repository, the doses to individuals caused by expected releases shall be lower than 0.1 mSv/y (10 mrem/yr), of which risk shall be less than 10^{-5}/year.
Particularly great attention should be given to describing protection for the period up to closure of the repository and the first thousand years thereafter, with a special focus on nearby residents.
The individual dose up to about 10,000 years (that could consider the next ice age) should be quantitatively reported as a best estimate with an estimated margin of error. Environmental protection should be described for the same period of time. After the period, qualitative assessments should be made of what might happen with the repository, including deliberations regarding the risk of increased releases.

IV. System Functional Requirements

A deep geological repository for HLW should be designed with a view towards safety, constructability and effectiveness with respect to costs and resources. Of those the long-term safety is the most important key issue in the development step of the reasonable repository concept. The safety of the repository can be influenced by the choice of deposition method, site choice and the adaptation of the repository design and layout to the site characteristics, by choice of technology and inspection methods for construction, and by choice of materials, design, sizing of the engineered barriers. Other important factors that also influence safety are the properties of the waste itself.

General requirements

The strategy to accomplish a long-term safe disposal of the spent fuel is based on the multiple barrier principle with independent barriers, which consist of materials with high integrity for a long lifetime in the expected repository environment. That is, the repository safety does not depend on the performance of a single barrier. Considering that the multiple barriers consist of canister loaded with HLW, buffer/backfill, near- and far-field rock, their primary functions are to prevent the ground water intrusion toward the waste package and to retard the migration of radioactive substances escaped from the repository to the biosphere. The canister prevents all dispersal of radioactivity to the surrounding rock, as long as it is intact. The other barriers contribute to the isolation and can retard and attenuate radionuclide dispersal to acceptable levels if the canister starts to leak.

Based on such multiple barriers principle, the basic requirements of the repository system are generally separated into three levels (of course, more specific functions of the subsystems are dependent on selection of site, layout, design and geometry of the technical barriers):

- **Isolation of the spent fuel :** As long as the spent fuel is isolated no radionuclide can come into contact with man and mans environment.
- **Retardation :** If the isolation is broken the amount of radionuclides which can reach the biosphere are limited by
  - very slow dissolution of the spent fuel
  - sorption and slow migration of radionuclides in the near- and far-field rock
- **Dilution :** Different dissipation routes can lead to different degrees of dilution of migrating radionuclides in the biosphere (dilution, water use, land use and other exploitation of natural resources) before they reach man and environment. By proper site selection and suitable adaptation of the repository to the actual site, transport pathways and dilution conditions in the biosphere can be influenced so that any radionuclides that escape will only reach man in very small quantities and concentrations.

Specific requirements of multiple barrier systems

1. Waste package / Canister

The waste package or canister must be design and fabricated so that it

- for isolation,
  - is leaktight at deposition
  - can resist the chemical reaction :
    - oxygen and other oxidants that are introduced during the construction and operation phase
    - substances that can normally occur in reducing groundwater system,
  - limits the effects resulting from
    - external and internal corrosion caused by radiolysis
    - internal corrosion caused by residual oxygen and water
  - can resist mechanical stresses caused by
    - hydraostatic head at repository depth

- the swelling pressure from the buffer
- extra loads during rock movements caused by stress restributions as a consequence of the repository construction

- for retardation,
  - does not unnecessarily and in a detrimental manner affect the normal properties of the rock mass, the stability of buffer surrounding the canister, the rate of dissolution of fuel if the isolation is broken,
  - as far as possible limits and retards the outward transport of radionuclides from the fuel to buffer even if the isolation is broken.

2. Buffer

The buffer should provide the canister a favourable environment for maintaining the isolation, comprise a protective layer between the canister and the host rock with respect to mechanical and chemical forces. Also It should limit and retard the radionuclide migration escaped from the waste package to the far-field of the repository if the canister is failured. Therefore the buffer should :

- for isolation,
  - completely envelop the canister for a long time
  - bear the canister centred in the deposition place
  - prevent groundwater flow and thereby retard the inward transport of corrodants
  - dissipate decay heat from the canister
  - resist chemical transformation for a long time
  - not impair the desired functions of the other neighbouring barriers
  - protect the canister by comprising a plastic protection against rock movements
- for retardation,
  - prevent flow of groundwater and thereby retard the transport of radionuclides
  - resist chemical alteration for a long time
  - completely envelop the canister for a long time
  - permit the generated gas to escape and filter colloids

3. Repository site and rock

The site should be selected so that it has good conditions with respect to: mechanical stability of the rock; chemical environment in groundwater/rock with respect to the canister and the buffer; presence and transport of substances corrosive to the canister; prevention of future intrusions and alternative uses; groundwater.

for retardation,

limitation of radionuclide solubility and transport to the biosphere

chemical environment in groundwater/rock with respect to fuel dissolution and buffer
groundwater
for recipient conditions
groundwater dilution and food chains

V. Conclusions

This paper presents ground rules and assumptions and a set of safety and technical criteria, which are essential in developing a reference repository system with technical feasibility, reasonable cost and long-term safety. These assumptions and criteria are used only as the guidelines in the developing step of a reference repository system and should be continuously revised based on more specific information collected from the site characterization processes and the repository system design and performance assessments to be expected in the future. At the same time, it is also important to investigate closely the other countries' repository concepts and the safety and technical criteria that would be developed further.

Acknowledgements

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