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Progress of the long-term safety assessment of a reference disposal system for high level wastes in Korea

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A B S T R A C T

KAERI developed a reference repository system for the disposal of radioactive wastes resulting from the pyroprocessing of PWR spent nuclear fuels (A-KRS; Advanced Korean Reference Disposal System). To check the design feasibility of this system, we developed a total system performance assessment (TSPA) tool using Goldsim program (GoldSim, 2006) and assessed the exposure dose rates for the reference scenario and three alternative scenarios such as earthquake, well intrusion, and initial defect of waste packages by using this tool. And then, we compared the exposure dose rates for each scenario with a draft supplementary safety goal, 10 mSv/yr, which was suggested by the regulatory body in Korea. In the original TSPA tool, we use a single source term model by assigning the same reference radionuclide inventory data for each waste package and the same shortest distance from the waste package to the MWCF (Major Waster Conducting Features) for conservatism. We developed a multi-lattice source term model by assigning various radionuclide inventory data and various distance from the waste package to the MWCF for more realistic safety assessment. Then, we found that the exposure dose rates for the case of multi-lattice source term model was one order of magnitude lower than those for the case of single source term model. According to the draft safety guideline, the primary safety goal is expressed in risk, that is, the total annual risk for the representative person resulting from the radiation exposure should not exceed 1.0×10^{-6}/yr. Therefore, we developed a methodology for complex scenarios to perform the risk-based safety assessment of a HLW repository, and applied it to a reference repository system. And we found that the suggested methodology can be used to perform the risk-based long-term safety assessment of a radioactive waste repository. We can make various risk profiles by making various kinds of complex scenarios with this methodology, and they can be used to support the development of safety cases for acquiring public acceptance.

1. Introduction

For the disposal of spent nuclear fuels (SFs) from both PWR and CANDU reactors, KAERI developed a conceptual repository system (KRS; Korea Reference Disposal System), which is similar to the Swedish KBS-3 repository concept (KBS, 1983). According to this conceptual design of a repository system, SFs encapsulated in waste packages will be disposed of in deposition holes at a depth of about 500 m in a crystalline rock, and then then filled with consolidated bentonite clay buffer (Lee et al., 2002). And we developed a TSPA (Total System Performance Assessment) program using Goldsim program in order to estimate the exposure dose rate for various scenarios such as the reference scenario and three alternative scenarios such as earthquake, well intrusion, and initial defect of waste packages (Lee et al., 2002). It consists of several unit modules such as a source-term evaluation, a detailed near- and far-field transport and biosphere assessment models. Using this program, we can check the design feasibility of the conceptual repository system by quantifying a nuclide release and transport through the near- and far-field of a repository system as well as the exposure dose rate for the representative exposure groups. Therefore, it can be used not only for the estimation of long-term safety assessment and but also for the design feedback of a reference repository system.

Another conceptual repository system (A-KRS; Advanced Korea Reference Disposal System) (Choi et al., 2011) was made for the

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disposal of two kinds of radioactive wastes resulting from the pyroprocessing of PWR spent nuclear fuels, low-level metal wastes and high-level ceramic wastes. A-KRS is a conceptual hybrid type repository system which may be constructed at two different depths in geological media. Low-level metal wastes with lower or no decay heat producing nuclides will be disposed at a 200 m depth, and high-level wastes with a rather higher radioactivity concentration and heat generation rate will be disposed at a 500 m depth.

A program has been developed by utilizing GoldSim (GoldSim, 2006), which is a commercial Windows-based development tool and by which nuclide transports in the near- and far-field of a repository as well as a farther transport through a biosphere under various release scenarios could be modeled and evaluated (Lee and Hwang, 2009). With this program, we checked the design feasibility of A-KRS by estimating the exposure dose rates for the representative person and comparing them with draft safety goal and natural background radiation exposure in Korea.

In the original TSPA tool, we use a single source term model by assigning the same reference radionuclide inventory data for each waste package and the same shortest distance from the waste package to the MWCF (Major Waster Conducting Features) for conservatism. However, we developed a multi-lattice source term model by assigning various radionuclide inventory data and various distance from the waste package to the MWCF for more realistic safety assessment. By applying multi-lattice source term model, we can estimate exposure dose rate more realistically.

In 2012, the regulatory body in Korea made a draft guideline for the safe disposal of high-level wastes, and promulgated it in Janurary 2016. According to the guideline, the primary safety goal is expressed as risk, that is, the total annual risk for the representative person resulting from the radiation exposure should not exceed 1.0×10^{-6}/yr. Therefore, we developed a methodology for complex scenarios to perform a risk-based safety assessment of a HLW repository (Kim et al., 2014). The complex scenarios are combinations of a reference scenario and alternative scenarios such as an earthquake and well intrusion. The methodology was applied to a reference repository system, A-KRS, considering the combination of a reference scenario and an earthquake scenario and well intrusion scenario for illustration.

In this paper, we introduce a reference repository system for the disposal of radioactive wastes resulting from the pyroprocessing of PWR spent nuclear fuels. Also, we introduce the progress of long-term safety assessment of a reference repository system such as development of a TSPA program, estimation and comparison of exposure dose rates, development of multi-lattice source term model for the more realistic estimation of long-term safety assessment, and development of complex scenarios for the risk-based safety assessment.

2. A reference waste repository system

A-KRS (Fig. 1) is a conceptual hybrid-type repository system, in which two kinds of pyroprocessed radioactive wastes, low-level metal waste and high-level ceramic waste that arise from the pyroprocessing of PWR spent nuclear fuel will be disposed (Choi et al., 2011). A-KRS is considered to be constructed at two different depths in geological media: metal waste with low or no decay heat-producing nuclides will be disposed at a 200 m depth, and ceramic waste with a rather high radioactivity concentration and heat generation rate will be disposed at a 500 m depth, which is believed to be within the reducing condition.

Ceramic waste is vitrified molten salt from the electrowinning process, which is the final step of the pyroprocess. Molten salt is vitrified into a cylindrical shape using a monazite-based ceramic

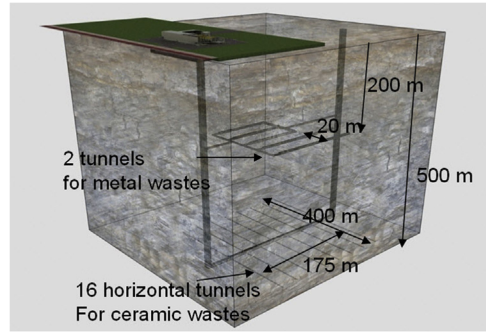

Fig. 1. A-KRS, a conceptual hybrid-type repository system.

binder. The cylindrical block is D 26 cm × H 25 cm in dimension and weighs about 48 kg. The size of the ceramic waste block is determined for effective heat dissipation because high temperature raised from decay heat can cause a phase transition of the ceramic binder. For the convenience of handling in a maintenance facility, the weight of a storage canister with waste is recommended not to exceed 200 kg. Only 2 waste blocks are emplaced in a storage canister to make 120 kg of total weight. A commercially available stainless steel 304 L tube (KS250A Sch. 5S) with a 3.4 mm thickness is selected for the cylindrical body. Stainless steel 304 L plates with 5 mm thickness are used for the bottom and lid plates. There is a collar on the lid for lifting. The sealing between the container body and lid is done by arc-welding. There is a 10% void space in the storage canister for the attenuation of pressure build-up due to decay gases released from the ceramic blocks (Fig. 2 (left)). One disposal canister accommodates 14 storage canisters by 2 layers (Fig. 2 (right)). The disposal canister consists of an inner container for the structural strength and radiation shielding, and an outer shell for corrosion resistance. The dimensions of the disposal canister are D 103 cm × H 173 cm.

The disposal processes for ceramic waste consist of the encapsulation of the ceramic waste canisters at the encapsulation facility at the surface and the emplacement process at the disposal tunnel in the subsurface, which was shown in Fig. 3.

Metal waste consists of hull materials and support frames, which generate negligible heat and radiation. However, they are polluted with a very small amount of TRU. The metal scraps from the pyroprocess are compressed into compact blocks having a 15% void fraction. The block dimension is D 30 cm × H 10 cm, and the

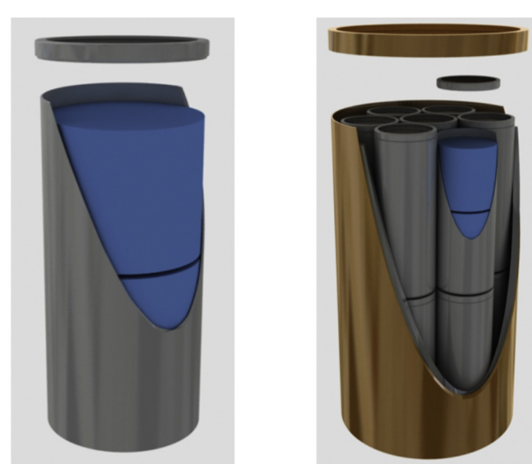

Fig. 2. Wall-cut view of a storage canister containing 2 ceramic waste blocks (left) and a disposal canister containing 14 storage canisters (right).