A Preliminary Assessment of a Deep Borehole Disposal of Spent Fuels

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1. Introduction

Deep borehole disposal (DBD) of such radioactive waste as spent nuclear fuels (SFs) and other waste forms has been investigating mainly at Sandia National Labs for the US DOE[1-3] as an alternative option. DBD can give advantages over less deep geological disposal since the disposal of wastes at a great depth where a low degree of permeability in the potentially steady rock condition will be beneficial for nuclide movement. Groundwater in the deep basement rock can even have salinity and less chance to mix with groundwater above. The DBD concept is quite straightforward and even simple: Waste canisters are simply emplaced in the lower 2 km part of the borehole down to 5 km deep.

Through this study, a conceptual DBD is assessed for a similar case as the US DOE's approach, in which 400 SF canisters are to be emplaced at a deep bottom between 3km and 5km depths, upon which an additional 1km-thick compacted bentonite is overbuffered, and the remaining upper part of the borehole is backfilled again with a mixture of crushed rock and bentonite. Then, the total 5km-deep borehole has three zones: a disposal zone at the bottom 2km, a buffer zone at the next 1km, and backfill zone at the rest top 2km, as illustrated conceptually in Fig. 1.

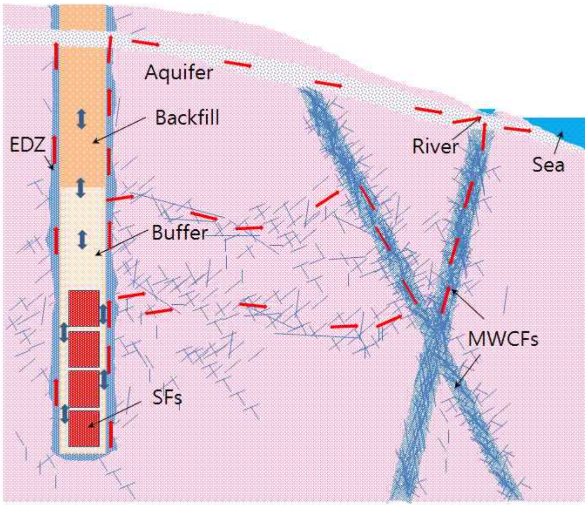


Fig. 1. A conceptual DBD system (red and blue arrows represent advection and diffusion nuclide transport pathways, respectively).

To demonstrate the feasibility in view of long-term radiological safety, a rough model for a safety assessment of this conceptual deep borehole repository system, providing detailed models for nuclide transport in and around the geosphere and biosphere under normal nuclide release scenarios that can occur after a closure of the repository, has been developed using GoldSim[4]. A simple preliminary result in terms of the dose exposure rate from a safety assessment of the DBD is also presented and compared to the case of direct disposal of SFs in a KBS-3V vertical type repository[5], carried out in previous studies[6-7].

2. Model

Since an upward groundwater flow along the borehole has not been shown to be that great, only diffusion transport through the bentonite hollow between the waste canister and the inner surface of the borehole, as well as the upper buffer layer in the buffer zone is assumed to be the dominant transport mechanism. Groundwater flow and advection transport is assumed to occur only through the EDZ, to which all the nuclides released from the disposal zone and buffer zone are collected, and from which nuclide transfer to the fractured rock medium surrounding the borehole takes place for farther transport to the MWCFs, which might provide the shortest and fastest ways for nuclides into the biosphere.

Nuclides from the backfill zone and EDZ at the uppermost part of the borehole meet an aquifer where the groundwater flows toward the surface water bodies in the biosphere, as depicted in Fig. 1.

Far-field and biosphere transport modeling in all other parts except the near-field is quite similar or even the same as the case of disposal of SF and pyroprocessed ceramic waste in the deposition hole at the bottom of the KBS-3V type tunnel[6-7].

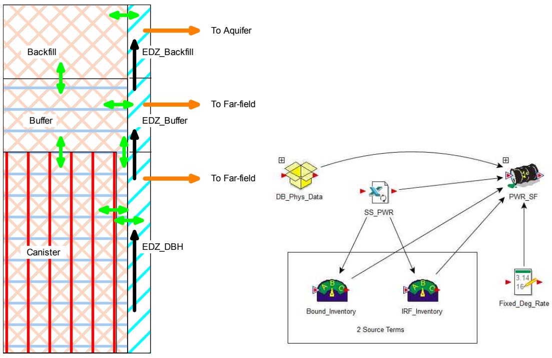


Fig. 2. Nuclide transport in the borehole and a GoldSim source term module.

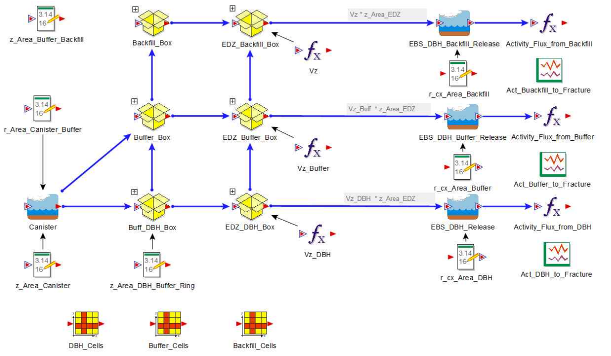


Fig. 3. Nuclide transport in the near-field

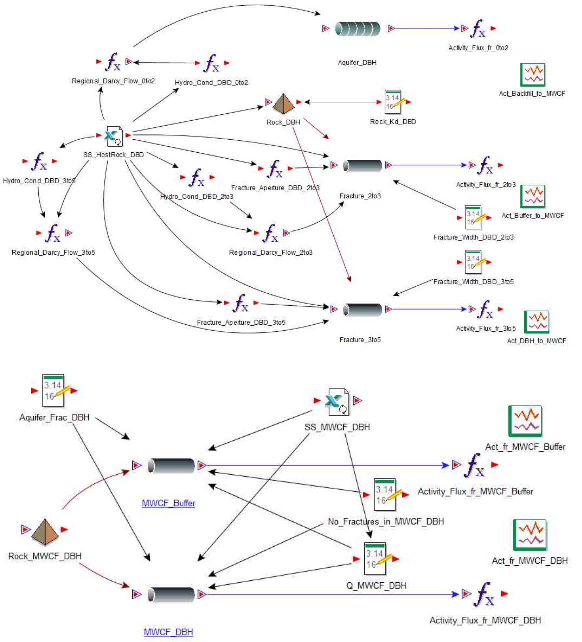


Fig. 4. Nuclide transport in the far-field.

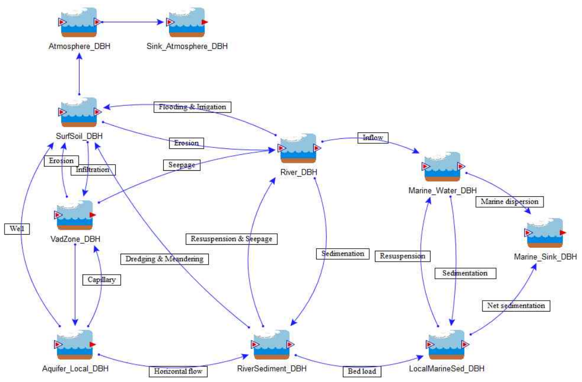


Fig. 5. Nuclide transport in the biosphere.

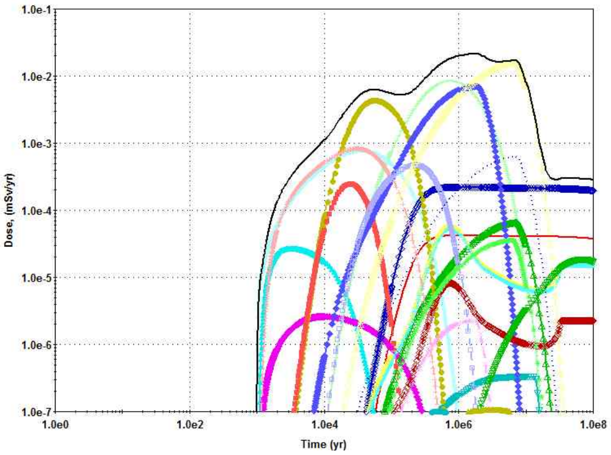
To implement a GoldSim model, a deep borehole and EDZ are discretized into several compartments ready for diffusion and advection transport in and among them, as implemented into a GoldSim module, as shown in Fig. 2. Three principal release pathways, as sketched in Fig. 3, from the boreholes are set in place: first, the base pathway and mid-pathway, associated with the disposal zone and buffer zone, respectively, each of which connects the internal fractures in the fractured medium and then the MWCFs in turn. MWCFs, transplanted as a simple GoldSim module in Fig. 4, are assumed to exist inevitably between the borehole and the biosphere, providing nuclides with the fastest pathway into the biosphere in the far-field area of the repository as described in Fig. 1. Another pathway is ready for the upper backfilled zone that connects an aquifer, which leads the groundwater flow to the biosphere directly. A GoldSim module, the same as the case of KBS-3 type disposal, for the biosphere transport is also shown in Fig. 5.

All nuclides released from the SF canisters into the surrounding buffer are transported by diffusion through the buffer in both the vertical and horizontal directions and transferred to the EDZs, which are porous rock media, where vertical groundwater flows are modeled for 1-dimensional advection and dispersion transport, where they are transported farther along with the groundwater flow through fractures into the natural far-field area.

3. Illustration

For different types and shapes of repositories at each different depth, direct comparison between a DBD and a KBS-3 type disposal of SFs is not that easy, a preliminary level of study reveals a great difference in dose exposure rates, as shown in Fig. 6. ^{129}I is almost the only nuclide contributing the total dose rates above 10^{-7}mSv/yr for the DBD.

The base rock around the disposal zone is assigned a very low permeability value of 5×10^{-14}m/s, whereas rocks around the buffer zone and backfill zone were assigned values of 5×10^{-13}m/s and 5×10^{-12}m/s (which equals the value around the KBS-3 type repository.), respectively.



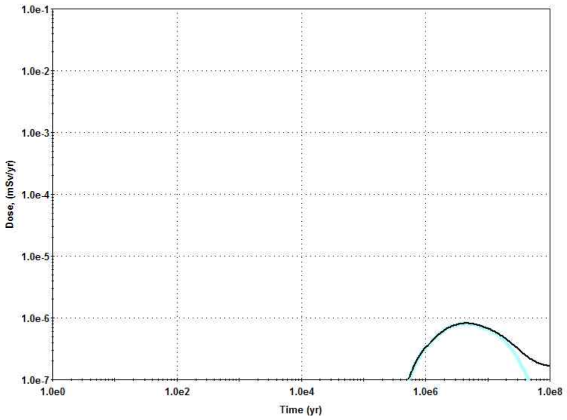


Fig. 6. Exposure dose rate to human being: KBS-3 type disposal (*top*) and deep borehole disposal (*bottom*): Most upper curves represent the total dose rates.

4. Conclusive Remarks

Nuclide release and transport from a deep borehole, a hypothetical repository for SFs after the closure of a repository were roughly modeled, evaluated, and compared to the KBS-3 type repository. As observed in Fig. 6, an assessment result from the DBD is shown to be remarkable and seems to give a sufficient safety margin, compared to the KBS-3 type disposal, even though this study was roughly done in a very straightforward manner. It is believed that this kind of study might be very helpful to address the long-term safety associated with the DBD.

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