10.6 Use of Simplified Models in the Performance Assessment of a High-Level Waste Repository System in Japan

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This paper explores simplifications to the H12 performance assessment model to enhance performance in Monte Carlo analyses. It is shown that similar reference case results to those of the H12 model can be derived by describing the buffer material surrounding a waste package as a planar body. Other possible simplifications to the performance assessment model in areas related to the stratification of the host rock transmissivity domain and solubility constraints in the buffer material are explored.

Keywords: high-level waste management, performance assessment, H12 model, buffer material

1. Introduction

A generic performance assessment model to study the feasibility of a deep disposal system of high-level waste in Japan was published in the H12 Report.[1)] This report concluded that such a repository was feasible without compromising public safety. In this paper, an independent performance assessment model is discussed, and results assuming H12 model parameters are compared to the reference case results in the H12 Report. Simplifications to the H12 performance assessment model are investigated (in areas related to buffer material geometry, number of pathways in the one-dimensional multi-pathway model for the host rock, and solubility constraints in buffer material) to enhance model efficiency for future Monte Carlo analyses. Because a performance assessment model is a tool to inform decisions, it should be clear and transparent and should only incorporate complexity commensurate with the amount of available information and model purpose.

2. Model Description

Our performance assessment model was implemented in GoldSim Version 8.02.[2)] Other authors[3),4)] have used GoldSim to construct performance assessment models based on the H12 model description and derived results consistent with those in the H12 Report. Nasif et al.[5)] proposed an alternative solution, based on wavelet expansions, to the H12 Report contaminant transport equations and derived similar results. These authors provided an independent verification of the numerical algorithms without considering an alternative mathematical representation of the repository system. The buffer material around waste packages is an important barrier to radionuclide transport. The current selection for buffer material is bentonite, which swells when saturated with water and, therefore, can become an effective seal around the waste. Should waste containers fail, the buffer material will retard the release of radionuclides into the geosphere. Wakasugi[4)] implemented a two-dimensional transport model in GoldSim to assess radionuclide retardation in the buffer material and the excavated disturbed zone (EDZ) around the buffer material. Similar to the H12 model, Wakasugi's models[3),4)] accounted for the cylindrical geometry of the buffer material. In the GoldSim model in this paper, a planar geometry (described using one-dimensional Cartesian coordinates) for the buffer material, referred to as IHI–CNWRA model, was adopted. It is demonstrated that release rates from the buffer material computed using the simplified planar geometry are consistent with

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reference case results in the H12 Report. The planar model is represented in Figure 1. Both the H12 model and the IHI–CNWRA model considered the same volume of glass per waste package (0.15 m^3) and the same volume of buffer material (7.15 m^3). The H12 model conservatively assumed a constant exposed waste form surface (17 m^2) and an identical assumption was employed in the IHI–CNWRA model. The length of the diffusive radial pathway in the H12 model was 0.7 m; thus, the IHI–CNWRA model considered a slab of buffer material 0.7 m thick.

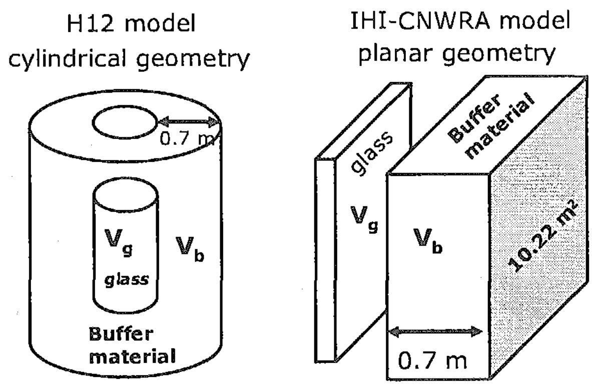

Figure 1. Cylindrical geometry (H12 model) and planar geometry (IHI–CNWRA model) adopted to describe the buffer material.

The H12 model ignored radionuclide retardation in the EDZ, but accounted for contaminant transport in the geosphere. The geosphere pathway model was composed of a host rock pathway and a major water conducting fault (MWCF) pathway. A one-dimensional multi-pathway model was implemented in the H12 description to account for spatial variability in the transmissivity of the host rock. The IHI–CNWRA model for contaminant transport in the geosphere is similar. The only difference is sparser discretization of the transmissivity domain than in the H12 model. A sufficient discretization extent leading to appropriate dose estimates is proposed in this study.

The H12 one-dimensional multi-pathway model for radionuclide transport in the host rock originally considered multiple parallel pathways, each pathway associated with a particular transmissivity value (value used to represent a narrow range within the transmissivity domain). The total radionuclide release rate from the multiple pathways was computed in the H12 model as a weighted average of individual pathway releases with weights equal to the probability of the transmissivity interval represented by each pathway. The H12 model stratified the transmissivity domain into few tens of segments to derive estimates of radionuclide releases from the host-rock into the major water conducting fault. In this study we conclude that coarser stratification of the transmissivity domain is sufficient (15 contiguous ranges suffice) to derive estimates of radionuclide release rates into the major water conducting fault.

The IHI–CNWRA model for contaminant transport in the MWCF is similar to the H12 model. The IHI–CNWRA model lacks a biosphere model. Instead, constant release rate to dose conversion values from the H12 Report, corresponding to the farmer receptor group, were used to estimate doses.

3. Results

Figure 2 compares the release rates and doses of particular radionuclides derived with the IHI–CNWRA model (continuous line) and the H12 model (dotted lines). Figure 2 (A) displays radionuclide release rates from the buffer material into the host rock per waste package. The release rates from the two models are practically identical with differences attributable to numerical error.

The ^{79}Se release rates differ because of the different half-lives used in the analyses.* It is concluded that describing the buffer material as a planar body yields results consistent with those derived with the consideration of a cylindrical geometry. Figure 2 (B) and (C) show release rates leaving the host rock and the MWCF per waste package. Results from the IHI–CNWRA are consistent with those in the H12 Report, with differences in ^{79}Se also due to the different half-lives in the analyses. The similarity in the doses in Figure 2 (D) is a result of the comparable MWCF release rates and the use of dose conversion factors from the H12 Report. It is important to note that the longer ^{79}Se half-life considered in this paper must be associated with a different dose conversion factor. Updated derivations of ^{79}Se dose conversion factors are needed to refine dose estimates. Figure 2 indicates that the main attributes of the H12 model were captured by the IHI–CNWRA model. It is concluded that it is reasonable to approximate the buffer material as a planar body.

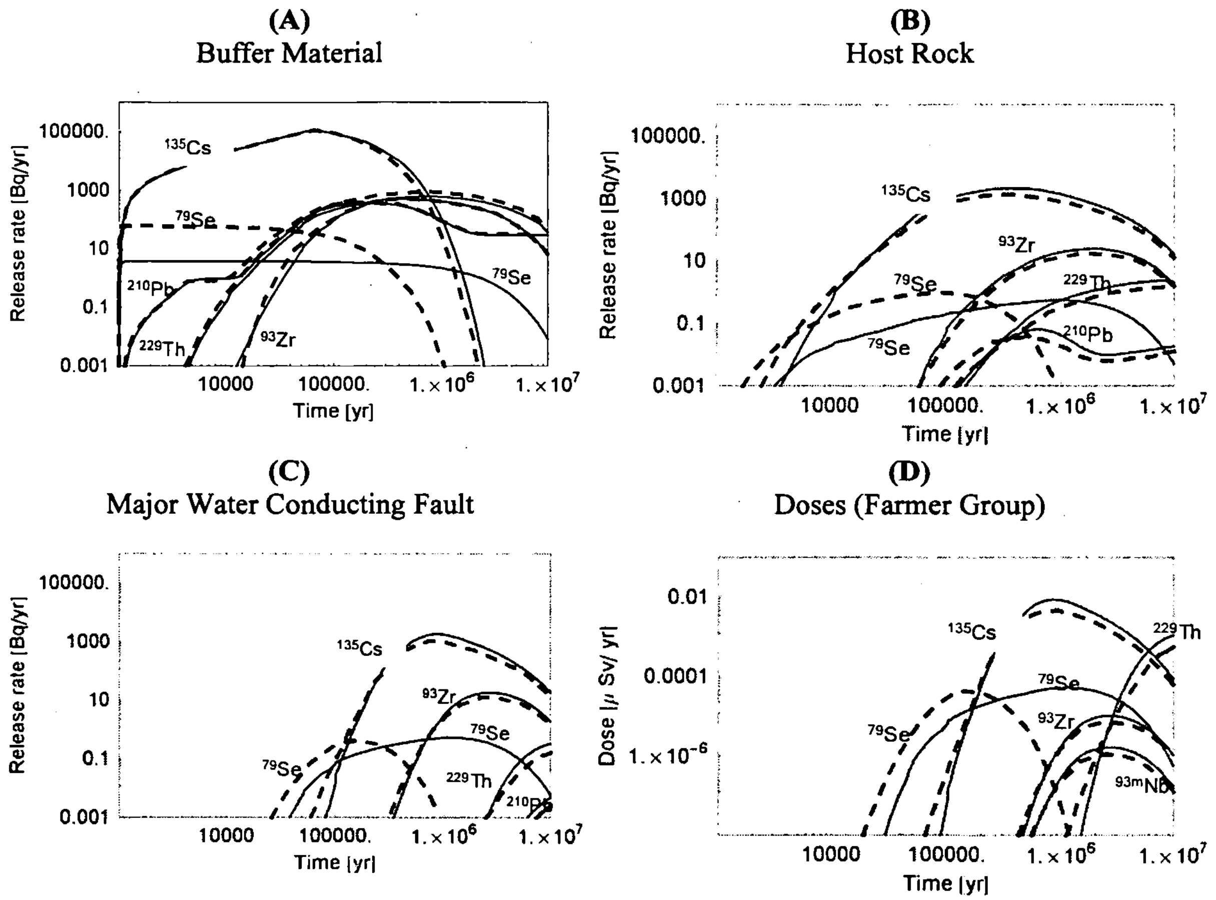

Figure 2. Radionuclide release rates per waste package at various points in the system: (A) away from the buffer material, (B) away from the host rock, (C) away from the MWCF into the biosphere. (D) Doses to the farmer receptor group from 40,000 failed waste packages.

In this paper a sufficient discretization extent of the transmissivity domain to account for spatial variability in the host rock was also investigated. Figure 3 (A) shows the effect of transmissivity stratification on host rock release rate estimates. A 10-range stratification of the transmissivity domain is too sparse and causes the associated release rate curve to "jiggle." A slightly finer stratification (13 partitions and above) is sufficient to produce smooth release rate curves. Figure 3

* The H12 Report employed an older estimate of the ^{79}Se half-life equal to 6.5×10^4 yr. Recent estimates indicate a value of 1.1×10^6 yr.[6] The H12 Report refers to studies by Ishihara et al[7] to support the conclusion that a longer ^{79}Se half-life does not have a significant effect on the maximum ^{79}Se dose in the H12 reference case.

(A) shows that 15- and 20-pathway systems yield similar host rock releases. Since the 15-range stratification is slightly conservative, it is considered that splitting the transmissivity domain into 15 ranges is sufficient for a performance assessment model. Host rock release rates reported in Figure 2 (B) are based on a 20-pathway host rock system.

The dose in Figure 2 (D) is dominated by ^{135}Cs, which is assumed to have infinite solubility. A natural question is whether disregarding solubility constraints on other radionuclides in the buffer material would change the conclusion of ^{135}Cs dominancy to the dose. If the conclusion remains, inclusion of solubility constraints in the buffer material in a performance assessment model may not be necessary. The H12 Report established that solubility constraints and shared solubility with isotopes are relevant to control radionuclide release rates from the buffer material into the host rock. Figure 3 (B) summarizes the effect of disregarding solubility constraints into dose estimates. The *no-solubility* line shows much higher early doses due to enhanced ^{79}Se releases from the buffer material. The later "bump" at the end of the simulation period on the *no-solubility* curve is due to enhanced ^{229}Th release rates away from the buffer material. Therefore, disregarding solubility causes higher dose estimates dominated by other radionuclides than ^{135}Cs, and it is not recommended to further simplify a performance assessment model. In general, performance assessment models should account for and propagate solubility uncertainty into dose estimates; for example, as done by Wakasugi et al.[3)]

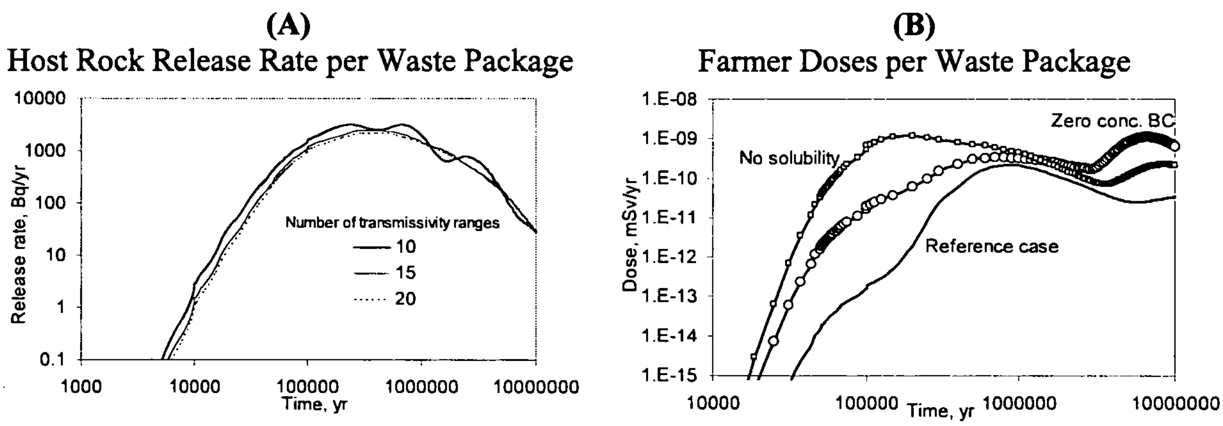

Figure 3. (A) Host rock release rates per waste package as a function of the transmissivity domain stratification. (B) Doses to farmer receptor group under three cases: reference case, no solubility constraints in the buffer material, and zero concentration boundary condition at the end of the buffer material.

Figure 3 (B) includes a comparison to doses estimated by assuming a zero radionuclide concentration at the end of the buffer material (interface in contact with the host rock). Under such assumption, concentration gradients in the buffer material and radionuclide release rates are maximized. The zero concentration boundary condition case provides upper bounds to possible radionuclide release rates from the buffer material and to doses associated with alternative boundary condition selections. Figure 3 (B) indicates that the boundary condition assigned at the end of the buffer material could be important to dose estimates. As previously stated, updated derivations of ^{79}Se dose conversion factors are needed to refine dose estimates accounting for a longer ^{79}Se half-life.

4. Conclusions

An independent performance assessment model that produces consistent results with the reference case of the H12 Report was developed, if similar assumptions and same model parameters are adopted. Simplifications to the performance assessment model were investigated to enhance model performance. It was concluded that H12 Report results obtained by describing the buffer material as a cylindrical body can also be derived by assuming a planar geometry. Also, reasonable results can be derived with a sparse stratification of the host rock transmissivity domain (to account for spatial variability according to the H12 model) in a performance assessment model. Slightly conservative host rock releases can be computed by stratifying the transmissivity domain into less than 20 ranges. It is not recommended to ignore buffer material solubility constraints in a performance assessment model, as doing so causes radionuclides other than ^{135}Cs to dominate dose estimates (e.g., ^{79}Se and ^{229}Th).

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