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# Simplified Transport Modelling of a Disposal System and Doses Using Probabilistic Methods

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## ABSTRACT

The disposal system for spent nuclear fuel (SNF) is based on the KBS-3V concept and Posiva is assigned to take care of the disposal for its owners (TVO and Fortum). In the KBS-3V nested barrier system, the spent fuel is emplaced in the bedrock in a copper canister with an iron insert. The canister is further surrounded by bentonite buffer and deposition tunnel backfill. In addition to the SNF repository, Posiva's disposal facility includes a repository for low and intermediate level waste (LILW) generated during the encapsulation process. This study considers radionuclide releases from a canister with an initial defect and from the LILW repository. The scenarios and parameter values are based on the TURVA-2012 safety case [1] that supports the construction license application for the disposal facility and encapsulation plant accepted in 2015.

The migration of radionuclides is depicted by using a simplified solute transport model (later SIPRO) [2] that is an alternative approach compared to numerical methods used widely for radionuclide transport calculations. In SIPRO, the transport in the repository system and biosphere is calculated by using analogy to a branching radioactive decay chain. The release barriers and biosphere objects are described as compartments that are connected with fractional mass transfer rates (and delay times in the release barriers). The radionuclide release rates in different parts of the transport chain can be calculated analytically or numerically. In the biosphere, the dose rates to a member of the most exposed group can be calculated based on the radionuclide concentrations in the biosphere compartments. By using a Monte Carlo simulation and sensitivity analysis methods, the effect of uncertainty related to parameter values is quantified.

The results of the SIPRO model compare well to the release to biosphere and dose rates reported in TURVA-2012 safety case, despite the biosphere model being rather stylized only including a well, a lake and agricultural objects. The distributions for the maxima of the release rates to biosphere have about one order of magnitude difference between the 50% and 95% confidence levels for all nuclides. Similarly, same confidence levels of the total dose rate differ by slightly over one order of magnitude within the dose assessment period of the first 10 000 years. In most of the cases, the distributions of the release and dose rates are roughly log-normal. The parameters causing the most of the variability and uncertainty in the release rates are those related to the transport release barriers with the smallest fractional mass transfer rates (i.e. those with the highest retention capacity). For the SNF repository these are the parameters related to canister performance and for the LILW repository, the groundwater flow through the LILW hall. In the biosphere, the lake area causes most uncertainty to the total dose rate due to C-14 dose calculated with a specific activity model.

## 1 INTRODUCTION

The spent nuclear fuel (SNF) originating from nuclear power plants in Loviisa and Olkiluoto is planned to be disposed of in a SNF repository located in Olkiluoto at the depth of approximately 400 m. In addition to the SNF repository, a low and intermediate level waste (LILW) repository for waste generated during the encapsulation process of the SNF is planned at the depth of 180 m along the access tunnel to the SNF repository [3].

The KBS-3 concept for the SNF disposal is based on a nested barrier system (see Figure 1) and currently, Posiva's plan is to use the KBS-3V version of the concept with vertical deposition holes. The concept consists of copper canisters, bentonite buffer, tunnel backfill and closure forming the engineered barrier system and bedrock forming the natural barrier system. In the disposal concept for the LILW, the intermediate level wastes are emplaced in a concrete basin and the less active wastes in the repository hall. At the closure, the LILW hall will be backfilled with crushed rock and the repository is closed with the closure of the access tunnel of the SNF repository.

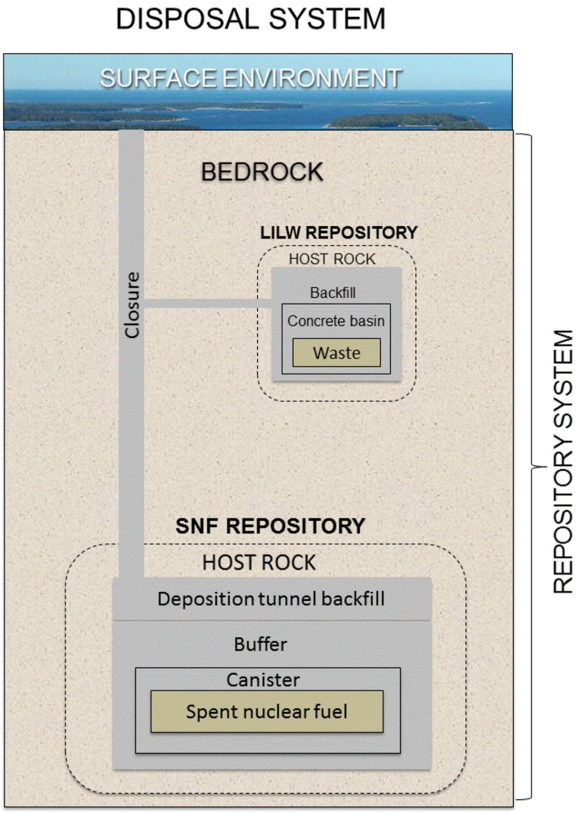


**Figure 1:** The components of the disposal system including the SNF and the LILW repositories and surface environment (i.e. the biosphere). The figure is provided by Posiva.

The long-term safety of any disposal facility is assessed in a safety case that demonstrates the compliance with the regulatory requirements and generally supports the decision-making. In the safety case, radionuclide transport modelling is used to analyse the radiological impacts of the possible radionuclide releases (for example release rates to biosphere or dose rates) according to different future evolutions (scenarios) of the disposal system.

The structure of this paper includes a summary of the applied methodology in Section 2, summary of the interesting results in Section 3 and concluding remarks in Section 4.

## 2 SIMPLIFIED TRANSPORT MODELLING OF A GEOLOGICAL DISPOSAL SYSTEM AND DOSE CALCULATION

In the following sub-sections, the methodology of the simplified model (later SIPRO) is stylistically presented with the focus on how the model works and how the results are produced. The sensitivity analysis and the selection of distributions for the parameters is largely omitted in this paper. A detailed elaboration of the methodology is found in [2].

The radionuclide transport modelling in SIPRO model is based on processes that transport contaminated solutes through the release barriers and in the biosphere. The approach from [4] for the SNF repository is applied for the LILW repository and for the biosphere model in order to examine the full transport chain from the radioactive wastes to the most exposed individual. The performance of each release barrier is described using only two time constants: fractional mass transfer rate and delay time. These time constants indicate the relative importance of an individual release barrier in retarding the radionuclide releases.

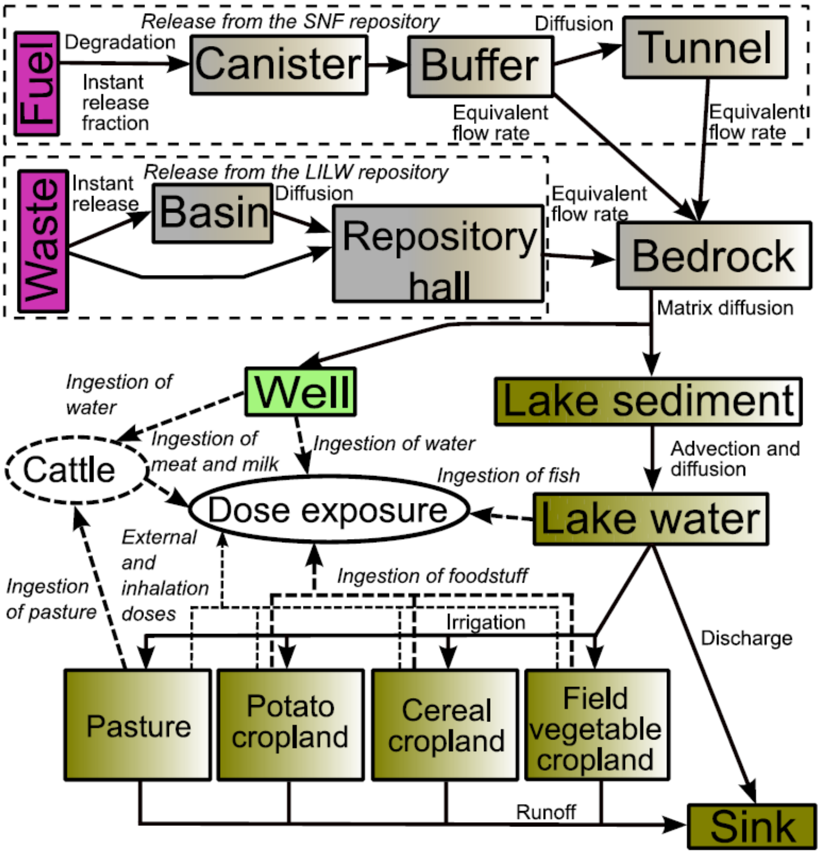


**Figure 2:** The compartments and radionuclide transport paths of the SIPRO model. The mass transfer between the compartments is illustrated by solid arrows and dashed arrows describe the dose pathways considered in the dose calculation. [2]

A flow chart displaying the considered transport paths is in Figure 2. In the base scenario for the SNF repository in the TURVA-2012 safety case, a canister with an initial, penetrating defect is assumed to exist in the SNF repository in any of the canister positions. The groundwater can enter the dry canister through the assumed initial defect and become contaminated by the dissolution of radionuclides. The defect, the saturated bentonite buffer and the backfill together with the fractured bedrock can form a migration path to the biosphere as illustrated in Figure 2.

In the base scenario for the LILW repository, the repository hall and the concrete basin are filled with inflowing groundwater within years or decades after the closure, forming a migration path for solutes that consists of slow diffusion through the concrete basin, advective transport to a host rock fracture and further transport in the fractured bedrock ending up to the biosphere.

The biosphere part of the SIPRO model is rather stylized with a configuration of a well, a lake and irrigated terrestrial compartments including croplands and pasture that are expected to form during the future evolution of the disposal site. In other words, the biosphere evolution is not explicitly modelled, but the variability due to different release locations and time development is to some extent taken into account in the probabilistic analysis by using site-specific results from the terrain and ecosystems modelling [5] at the two relevant release locations. The aim is to include the most relevant biosphere objects considering the time development of the landscape downstream from the two release locations and the most exposed individuals.

Based on resulting radionuclide concentrations in biosphere compartments (green rectangles in Figure 2), the radiological impacts on humans are estimated. Analysis of the exposures of plants and animals or larger groups of people is not included in the SIPRO model.

To estimate effects of uncertainties (natural variability or the lack of knowledge) in the input parameters, a Monte Carlo simulation is used as an uncertainty analysis method. All the input parameters containing considerable uncertainty sampled from probability distributions and identified correlations between parameters are taken into account. Based on a high number of realizations (10 000), confidence levels for the calculation endpoints (release rates, dose rates) are estimated.

## 3 RESULTS

The approach from [4] was implemented to compare the calculation results to corresponding TURVA-2012 safety case results. The release rates from the SNF repository to the biosphere are presented in Figure 3. For the most important radionuclides, the results are in good agreement and the biosphere transport seems a feasible extension of the analysis.

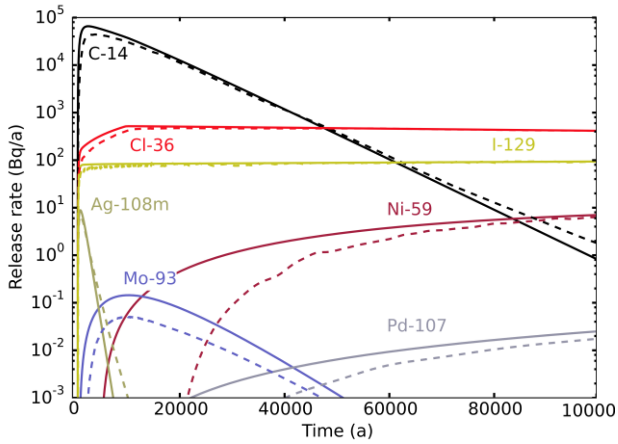


**Figure 3:** The release rates from the spent nuclear fuel repository to the biosphere calculated using the SIPRO model (solid lines) and from the TURVA-2012 safety case (dashed lines).

The release rates can be used to obtain the average annual dose rate from the radionuclides included in the inventory. For the Monte Carlo simulations, both the repositories are combined for the release rates of radionuclides. The dose rates to humans (total including all radionuclides in the inventory) are presented in Figure 4.

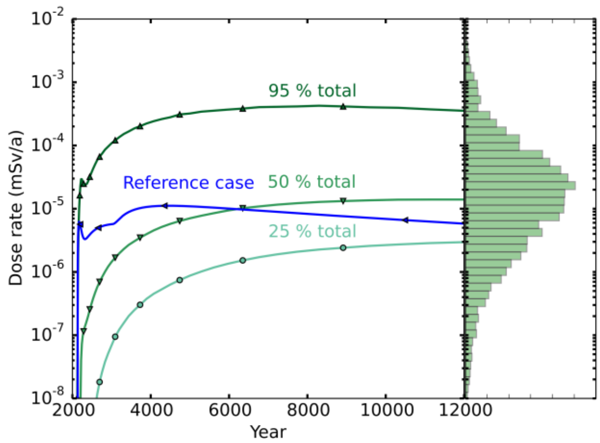


**Figure 4:** The confidence levels for the total dose rate resulting from the releases from both the repositories with 10 000 realizations (solid green lines) and in the reference case (solid blue line). On the right, the total dose rate distribution at the last simulated time point is shown.

The distributions for the resulting release rates or dose rates are roughly log-normal. A sensitivity analysis indicates that the canister related parameter value uncertainties contribute most to the resulting distributions. Also, the flow rates through the LILW repository hall have a considerable effect but of course, the radionuclide inventory is smaller. In the biosphere, the lake properties are important factors for the total dose.

## 4 CONCLUSIONS

The developed SIPRO model build confidence on the radionuclide transport modelling in the repository system to be constructed by Posiva. The model is developed to analyse releases in the base scenarios of the SNF and the LILW repositories [1,3]. The model includes a biosphere analysis with a simplified configuration and dose calculation considering the radionuclide transport for the full transport chain.

Based on the comparison of the results from SIPRO and the TURVA-2012 safety case, the model captures the essential phenomena that govern the release and transport of the radionuclides in the repository system. In the biosphere, the comparisons are not that straightforward because different dose assessment is performed in TURVA-2012 but the conclusions are still supported. However, the base scenarios of the repositories and the static configuration of the well, the lake and the agricultural land system limit the generalization of the conclusions.

The present SIPRO model highlights that, based on the information available, the performance of the canister is critical to the safety of the disposal to prevent the release in the first place, but also, to limit the release in the case of a small defect (an initial hole in this case). At the same time, the groundwater flow in the LILW repository hall has a large impact on the releases from the LILW repository.

The simplified nature of the model increases the transparency of the radionuclide transport modelling providing a straightforward alternative to the mainline elaborate modelling of analysis of releases. It allows computationally efficient probabilistic simulations for sensitivity and uncertainty analyses and helps to identify the release barriers that limit the radioactive releases most efficiently.

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