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Probabilistic dose calculations and sensitivity analyses using analytic models

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Abstract

Newly developed analytic models mimic numerical models for radionuclide transport and dose calculations for a deep repository for spent nuclear fuel, reducing computation times more than three orders of magnitude. In this paper, the analytic models are used to extend preliminary probabilistic dose calculations reported in a recent performance assessment for a deep repository in Sweden. It is demonstrated that the analytic models are useful for gaining insights into the probabilistic properties of the system concerning, e.g. the importance of input variable correlations and various properties of input distributions. Regarding sensitivity analyses, the analytic model is used for screening out nuclides which do not influence the calculation end-point, for demonstrating monotonicity and for developing tailored regression models with non-linear expressions.

Keywords: Probabilistic; Radionuclide transport; Sensitivity analysis; Deep repository

1. Introduction

In the KBS 3 concept for storage of spent nuclear fuel, the waste is placed in 5 cm thick corrosion resistant copper canisters with a cast iron insert giving mechanical strength. The canisters are surrounded by 35 cm bentonite clay and emplaced in individual deposition holes at a depth of approximately 500 m in crystalline bedrock, Fig. 1.

In the recently completed safety assessment SR 97 [1] of this concept, it is shown that *initially intact* canisters are expected to keep their isolating capacity for millions of years. An important scenario in the assessment treats canisters with *initial defects* due to, e.g. imperfect sealing. Such deficiencies are today deemed unlikely but must be further evaluated by results from the development of fabrication methods for the canisters.

The consequences of the canister defect scenario are evaluated probabilistically by numerical radionuclide transport and dose calculations. Three sites in different parts of Sweden, all with real bedrock data, are evaluated. The calculation end-point is the peak total annual dose to man in the time interval up to one million years after repository closure. The regulatory target is the expectation value of this entity, which must not exceed 1.5×10^{-4} Sv/yr for the situations discussed in this paper. (The Swedish compliance regulations were issued recently; discussions of their interpretation are on-going.)

Input data for the SR 97 transport and dose calculations are evaluated and selected in Ref. [2]. Hydrology parameter distributions are determined numerically in separate modelling exercises for each site, Fig. 2. Also biosphere data distributions are determined in separate modelling. The so determined hydrology related and biosphere data distributions are then used in all the probabilistic realisations of the transport models. The hydrology parameter distributions cover the different possible pathways in the rock and thus propagate the heterogenic rock properties to the transport models. For the remaining uncertain input variables, only a reasonable, best estimate value, and a pessimistic, most unfavourable value, given current knowledge, were determined [2]. In the probabilistic calculations, the probability density functions (PDFs) of these variables were simplistically taken to be discrete distributions with p (reasonable) $= 0.9$ and p (pessimistic) $= 0.1$. This assumption is based on a general evaluation of the data for the calculations and was deemed to be on the pessimistic side. Table 1 lists all input distribution types for the probabilistic analyses. Detailed information on the input distributions contributing most to output uncertainty is given in Table 5.

The numerical models for radionuclide transport in canister, buffer and geosphere have recently been approximated by simple analytic expressions [3]. The analytic

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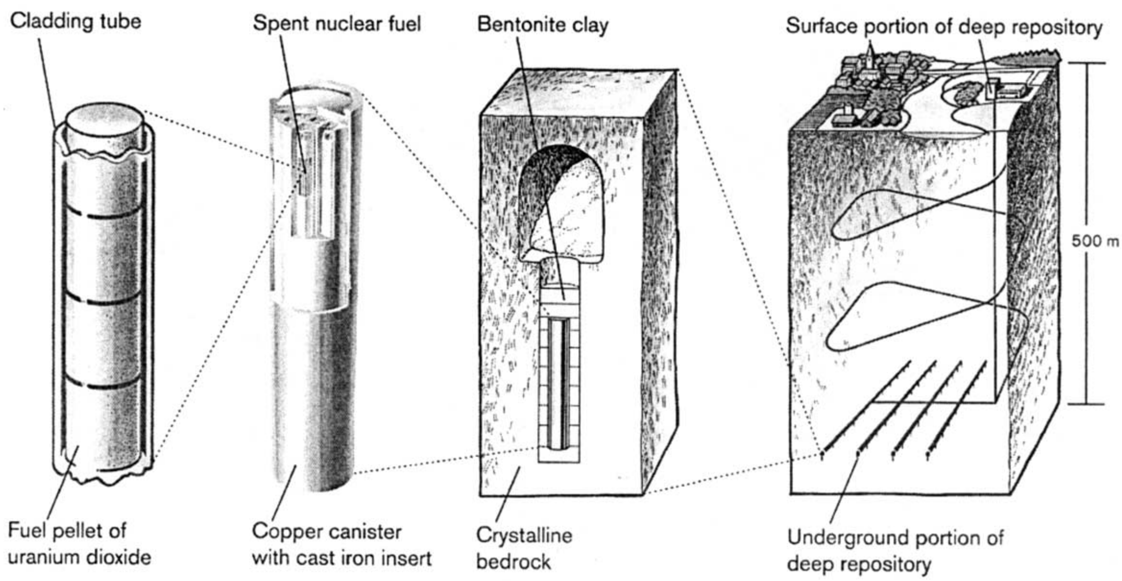

Fig. 1. The KBS 3 concept for disposal of spent nuclear fuel.

model was evaluated in a number of single realisations covering together the data uncertainties identified in SR 97. The agreement with the numerical models is good, both regarding maximum releases and overall time dependencies. For nuclides that dominate the total dose, the agreement is within a factor of two [3].

Fig. 3 shows the results of probabilistic calculations with numerical and analytic models. The numerical results are those presented in SR 97 and these imply that the expectation values of the peak annual dose to man are one, two and three orders of magnitude below the regulatory target at the three sites, respectively. The results obtained with the analytic models agree well with the numerical results, with deviations in expectation values and standard deviations within a factor of two for all three sites, Table 2, base cases. Five thousand realisations per site were run with

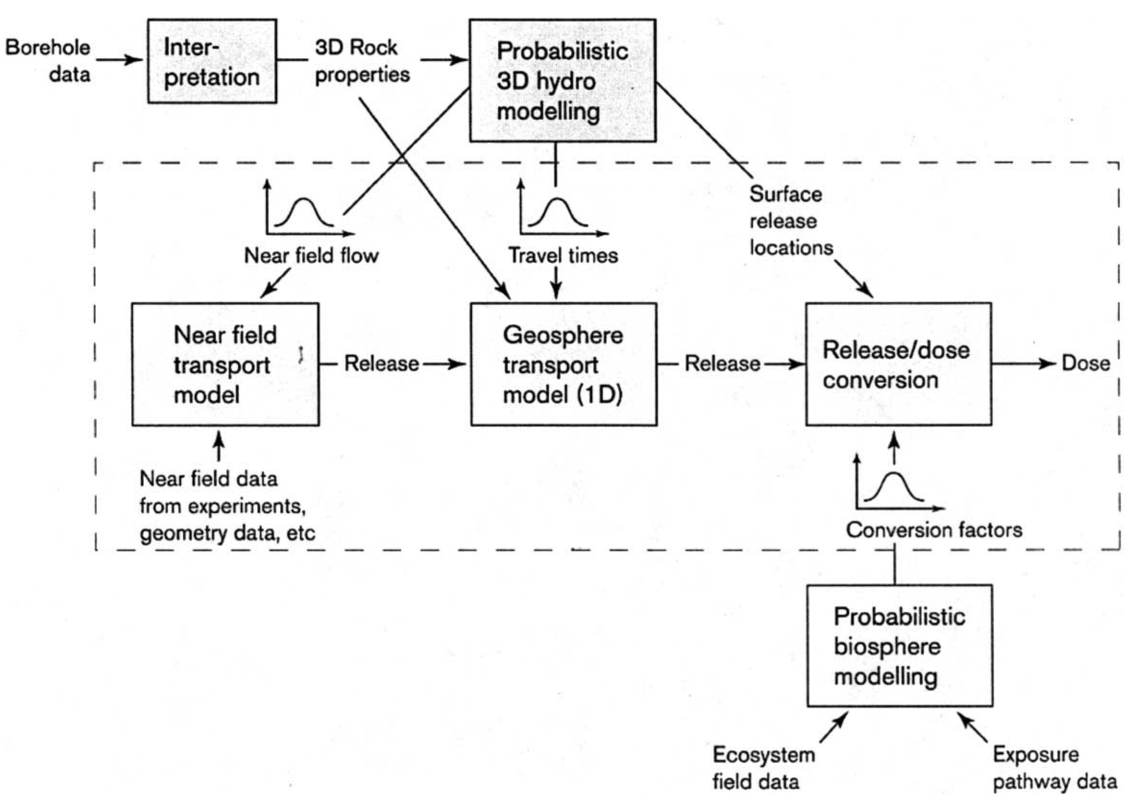

Fig. 2. Overall structure of data and models. The probabilistic transport modelling discussed in this paper is enclosed by the dashed line. The figure illustrates how several crucial input distributions are determined through separate hydrological and biosphere modellings.