THE SKI REPOSITORY PERFORMANCE ASSESSMENT PROJECT SITE-94.

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ABSTRACT

SITE-94 is a research project conducted as a performance assessment of a hypothetical repository for spent nuclear fuel, but with real pre-excavation data from a real site. The geosphere, the engineered barriers and the processes for radionuclide release and transport comprise an integrated interdependent system, which is described by an influence diagram (PID) that reflects how different Features, Events or Processes (FEPs) inside the system interact. Site evaluation is used to determine information of transport paths in the geosphere and to deliver information on geosphere interaction with the engineered barriers. A three-dimensional geological structure model of the site as well as alternative conceptual models consistent with the existing hydrological field data, have been analyzed. Groundwater chemistry is evaluated and a model, fairly consistent with the flow model, for the origin of the different waters has been developed. The geological structure model is also used for analyzing the mechanical stability of the site. Several phenomena of relevance for copper corrosion in a repository environment have been investigated. For Reference Case conditions and regardless of flow variability, output is dominated by I-129, which, for a single canister, may give rise to drinking water well doses in the order of 10^{-6} Sv/yr. Finally, it appears that the procedures involved in the development of influence diagrams may be a promising tool for quality assurance of performance assessments.

I. INTRODUCTION

The Swedish Nuclear Power Inspectorate, SKI, has two tasks related to waste management; to review the R&D plans of the implementor and to act as a licensing authority. SKI's main strategy for developing up and maintaining the necessary knowledge and competence required in order to fulfil these tasks is to conduct a series of independent total systems performance assessment research projects[1]. The latest project in this series[2], SITE-94, is a performance assessment of a repository for spent nuclear fuel hypothetically placed at the Äspö Hard Rock Laboratory in Sweden, which is operated by the implementor, the Swedish Nuclear Fuel and Waste Managemnet Co. (SKB). Basically, all data[3-5] from the pre-excavation phase of the Äspö Laboratory have been available to the project. The data have been independently re-interpretated as part of the project.

II. SYSTEM ANALYSIS

The assessment is structured around a coherent strategy for treating uncertainties and developing scenarios. The geosphere, the engineered barriers and the processes for radionuclide release and transport is viewed as an integrated interdependent system. The advantage with such wide system boundaries is that only few events or processes outside this system will significantly affect the stability of the repository. Basically only large scale climatic changes or future human actions are left as scenario initiating events. The drawback with such wide system boundaries is the complexity, and thus added conceptual uncertainty, of the analyzed system.

The complexity of the system is treated by development, through expert judgment, of an influence diagram (PID) that reflects how different Features, Events or Processes (FEPs) inside the system interact. The influences have in turn been mapped onto the Assessment Model Flow chart (AMF), which describes the data flow between existing

computer models and other information processing procedures used in the assessment. Cross references between the PID and AMF makes it possible to determine the ambition level of the treatment of each FEP and influence. The procedures have also allowed for the generation of a series of variants, reflecting conceptual and parameter uncertainty, both for a Reference Case and a Central Scenario covering the expected climate evolution the next 100 000 years. The central scenario includes permafrost, sea-level changes as well as spells of glacial cover of the repository region.

III SITE EVALUATION

Site evaluation is based on Site Specific Data from Äspö and constitutes the largest segment of the project. It is used to determine information of transport paths in the geosphere and to deliver information on geosphere interaction with the engineered barriers. Such information will always be subject to uncertainty and the site evalution shall identify uncertainties and, when possible, quantify it. Site evalution should also develop an understanding of the site and its history.

Different indications of fractures and fracture zones have been used to develop a potential three-dimensional geological structure model of the site. Alternative conceptual models, including stochastic continuum models and discrete fracture network models have been calibrated to be consistent with the existing hydrological field data. Each model result is a realization of the spatial variability of the flow at the site. The spatial variability in flow is usually considerable, indicating that some regions of the rock mass may be less suitable for a repository. The suite of realizations from the different models reflect the parameter and conceptual uncertainty of these estimates and demonstrates that exact predictions of flow at a given position are highly uncertain. However, the different concep0tual models all predict fairly similar flow variability, even if some differences between model results remain. Thus, spatial variability in flow and potential for higly connected channels apear to be a property of the site and not an uncertainty.

Groundwater chemistry is evaluated and a model, fairly consistent with the flow model, for the origin of the different waters has been developed. The geological structure model is also used for analyzing the mechanical stability of the site.

IV ENGINEERED BARRIERS

In the analysis of the function of the Engineered Barriers, the main emphasis has been on evalulations of the potential for container failures. Several phenomena of relevance for copper corrosion in a repository environment have been investigated: copper chemistry and physical properties of copper compounds, thermodynamic stability of copper-containing species and phases, behaviour of copper in natural systems including kinetic aspects, prerequisites for general corrosion under oxidising as well as reducing conditions. Moreover, corrosion of the inner steel vessel has been studied for the case of a postulated pin-hole through the copper vessel. In addition, some analyses have been made of the significance of design, manufacture, sealing process, testing and quality assurance for the long-term behaviour in the repository.

V RADIONUCLIDE TRANSPORT

Predictions of radio-nuclide release and transport are made through a set of calculation cases specified through the scenario development technique. The analyses of nuclide release and nearfield transport acknowledge different modes of radionuclide release, oxidant and radionuclide migration through a bentonite buffer and fractured host rock, with redox front formation and precipitation of radio nuclides at the redox front. Far-field transport is analyzed in one-dimensional streamtubes associated to each canister position. Processes considered include the effects of advection, dispersion, linear equilibrium sorption onto fracture surfaces, diffusion into the rock matrix combined with sorption within the rock matrix, channeling in the fracture as well as radioactive decay and ingrowth. A suite of calculation cases, variants, have been formulated both for the Reference Case and the Central Scenario.

Each conceptual model of the site geometry is represented by a set of variants expressing the spatial variability (mainly in flow) at the site. Spatial variability in flow is usually several orders of magnitude and is usually much larger than the difference between different conceptual models. Regardless of flow and for reference conditions the output is dominated by I-129, which, for a single canister, may give rise to drinking water well doses in the order of 10^{-6} Sv/yr for a single canister failure. Sorbing nuclides, with shorter half-lives are more strongly affected by the flow variability. The release from canisters situated in positions with high flow is almost entirely controlled by solubility and the transport resistance in the buffer, whereas the release of sorbing nuclides from

canisters in low flow positions may be reduced several by orders of magnitude due to geosphere retardation.

Single cansister failure at 10^3 years, 10^4 years and 10^5 years are evaluated. These single canister cases will later be combined into full repository cases for different assumptions on canister failure rate. For a single canister failure the release is relatively insensitive to the failure time if failures occur between 10^3 to some 10^4 years. Failures after 10^5 years, obviously, show a considerable reduction in release of nuclides which have half lives less than a few 10^4 years, such as C-14, Pu-239, Pu-240, Am-241, Am-243 etc.

VI QUALITY ASSURANCE

SITE-94 also includes a sub-project on development of a Quality Assurance Plan for Performance Assessments. The multitude of information receival, treatment and delivery that is part of a large assessment stress the need for quality control. However, the quality procedures must not conflict with scientific and engineering creativity. It appears that the documentation procedures involved in the development of influence diagrams and calculation cases, coupled with clear identification of which individuals that are responsible for different data and analyses, may be promising tools for quality assurance of performance assessments, as for well as any other systems analysis.

VII CONCLUSIONS

SITE-94 constitutes a major development of the techniques for system analysis, scenario development and treatment of uncertainties in repository performance assessments. Furthermore, for SKI SITE-94 have demonstrated techniques for comprehensive analysis of actual field data from a specific site. Processes affecting the stability of the engineered barriers have also been identified. Consequently, the project represent an important step in the SKI development of the review capacity necessary for oversight of the SKB R&D programme and for the potential licensing of facilities for treatment, handling and final disposal of spent nuclear fuel and other nuclear wastes.

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