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Thermal evolution of the repository – the effect of heat generating waste

Report for the safety evaluation SE-SFL

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Contents

1 Introduction

SKB is planning to build a repository for long-lived low and intermediate level waste, SFL. Two vaults will be situated in crystalline granitic rock. The BHA vault is intended to hold legacy waste as well as waste from medical, industrial and research activities. The BHK vault will hold metallic waste consisting mainly of reactor core components. This waste constitutes a heat source that may cause temperature elevation in the repository.

The objective of the present work is to evaluate the spatial and temporal evolution of the temperature in the SFL near-field affected by heat generating waste. The modelling assumes that the repository is located at 500 m depth in the Laxemar area.

2 Modelling

2.1 Equations and assumptions

The calculations assume that conduction will be the dominating heat transfer process. The space and time dependent heat balance is then given by

$$(\rho C_p)_{eff}\frac{\partial T}{\partial t} + \nabla \cdot \left(-k_{eff}\nabla T\right) = Q$$

where $(\rho C_p)_{eff}$ is the effective volumetric heat capacity (J/(m^3·K)), T is the temperature (K), k_{eff} is the effective thermal conductivity (W/(m·K)), and Q is a heat source (W/m^3). The effective thermal properties of the porous media in the system are given by the arithmetic mean of fluid and solid properties, weighted by volume fraction, θ_i.

$$k_{eff} = \sum \theta_i k_i$$

$$(\rho C_p)_{eff} = \sum \theta_i \rho_i C_{p,i}$$

The thermal properties of the waste, the barrier materials and the rock are assumed to be constant.

It is worth noting that heat dissipation from groundwater flow is not considered. The temperature evolution calculated from the conductive heat balance equation will therefore be a conservative estimate.

2.1.1 Boundary conditions

The temperature at the model outer boundaries is assumed to be constant over time and vary linearly with depth according to Sundberg et al. (2008a), see Figure 2-1.

The groundwater temperature at repository depth (–500 m) is approximately 14.9 °C.

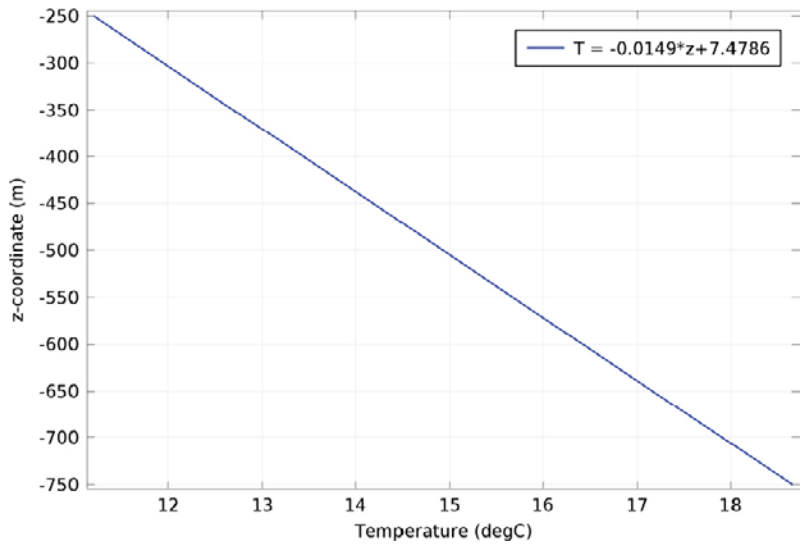

Figure 2-1. *Temperature (°C) in the rock as a function of depth (m).*

2.1.2 Source term

The heat generated by the metallic waste in the BHK vault has been estimated[1] and varies over time. Initial heat generation is dominated by the decay of Co-60. After a few hundred years, the decay of long-lived Ni isotopes determines the heat release. The expected power output as function of time is shown in Figure 2-2.

Significantly less heat is generated by BHA waste as compared to the waste in BHK. The BHA source term is ignored in the modelling.

2.2 Geometry and materials

A 3D model of the repository and surrounding bedrock has been used for the heat transfer calculations. The model geometry has been discussed in previous modelling work by Abarca et al. (2016). Geological data from the Laxemar area has been used to represent the granitic host rock. This area is well characterized with high data density, having been considered as a potential site for the final repository for spent nuclear fuel (SKB 2011). The repository vaults have been positioned at depth of 500 m, corresponding to the location labelled 500_1 in Abarca et al. (2016).

The model geometry details the vaults, their concrete structures, the access tunnels, and the sealing components installed at closure. The BHA vault has six separate concrete compartments while the BHK vault will be built as a single concrete structure. The waste is emplaced inside the concrete structures and is then grouted. Individual waste packages are not resolved in the model. Instead, the waste, the packaging and the surrounding grout is treated as a homogenized domain in each of the concrete structures. The engineered material domains of the model are illustrated in Figure 2-3.

A rock volume measuring $1\,000 \times 1\,000 \times 500$ m^3 surrounds the repository geometry in the model.

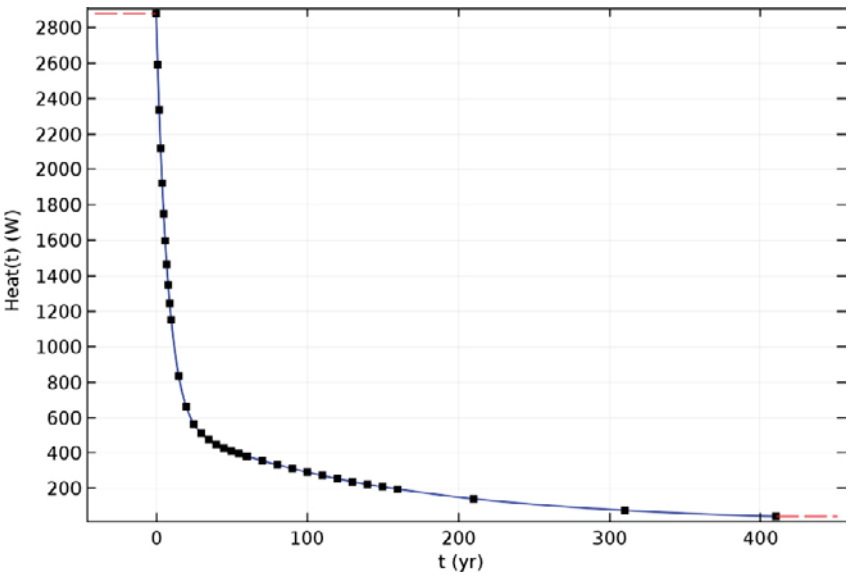

Figure 2-2. *Power output from BHK waste as a function of time (yr). Constant extrapolation is assumed.*

[1] **Herschend B, 2016.** Initial state SFL. SKBdoc 1441724 ver 1.0, Svensk Kärnbränslehantering AB. Internal document.

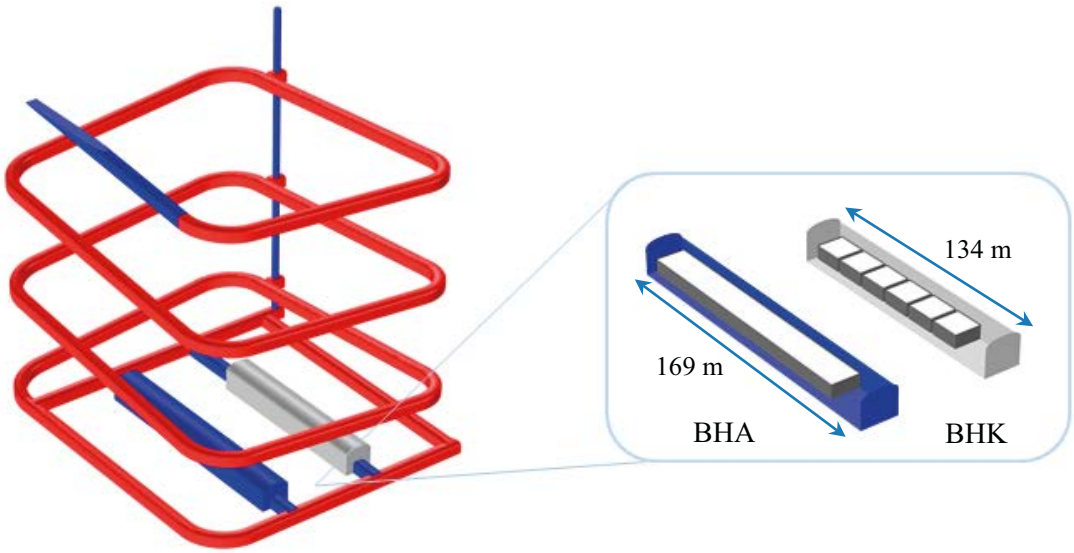

Figure 2-3. *Materials in the SFL repository model; crushed rock (red); bentonite (blue); concrete backfill (grey); concrete structure (dark grey); waste (white).*

2.2.1 Groundwater

The following properties of groundwater are assumed:

$\rho = 1\,000$ kg/m^3

$k = 0.58$ W/(m·K)

$C_p = 4.18$ kJ/(kg·K)

2.2.2 Saturated granitic rock

The thermal properties of the granitic rock at Laxemar are taken from Sundberg et al. (2008a). The effective thermal properties of the solid-liquid system are assumed to be the same as the properties of the rock:

$k_{eff} = 2.20$ W/(m·K)

$(\rho C_p)_{eff} = 2.20$ MJ/(m^3·K)

2.2.3 Saturated crushed rock backfill

The porosity of the crushed granitic rock is assumed to be 0.3 (SKB 2001). The effective thermal properties of the solid-liquid system are calculated to:

$k_{eff} = 1.71$ W/(m·K)

$(\rho C_p)_{eff} = 2.79$ MJ/(m^3·K)

2.2.4 Saturated concrete

The porosity of the concrete is assumed to be 0.11, and the density 2 500 kg/m^3 (SKB 2014). The thermal conductivity is assumed to be 2.0 W/(m·K) and the heat capacity is 900 J/(kg·K) (Ljungkrantz et al. 1997). The effective thermal properties of the solid-liquid system are calculated to:

$k_{eff} = 1.84$ W/(m·K)

$(\rho C_p)_{eff} = 2.46$ MJ/(m^3·K)

2.2.5 Saturated bentonite

The effective thermal properties of bentonite (backfill) are taken from Börgesson and Hernelind (1999):

k_{eff} = 1.50 W/(m·K)

$(\rho C_p)_{eff}$ = 2.40 MJ/(m^3·K)

2.2.6 Waste domain

Steel is the main component in the BHK waste domain, taking into account both waste material and packaging. The thermal properties of the solids in the waste domain are assumed to be an arithmetic mean of carbon steel, concrete and water properties. The volume fractions are 21 % steel, 50 % concrete, and 29 % water (see Appendix A). Carbon steel is assumed to have a density of 7 850 kg/m^3, a thermal conductivity of 43 W/(m·K) and a heat capacity of 490 J/(kg·K). The effective thermal properties calculated for the waste domain are then:

k_{eff} = 10.2 W/(m·K)

$(\rho C_p)_{eff}$ = 3.14 MJ/(m^3·K)

The BHA waste domain is assumed to have the same thermal properties as the BHK waste.

2.3 Simulation software

Calculations have been performed using the software Comsol Multiphysics v5.0 (COMSOL 2014a). The model has been set up using the interface Heat transfer in porous media, available in the Subsurface flow Module (COMSOL 2014b).

3 Results

Figure 3-1 shows the volume average of the temperature increase relative to the groundwater temperature as a function of time. The curves agree qualitatively with the transient power output from the BHK waste (Figure 2-2). The initial, short-term rise in temperature corresponds to the relatively high intensity decay of Co-60. Beyond five hundred years, the temperature decreases slowly, affected by the decay of long lived Ni-isotopes.

The maximum volume average temperature increase is 1.3 °C for the BHK waste, 1.2 °C for the concrete structure and 0.7 °C for the concrete backfill. After five hundred years the average temperature increase is less than 0.2 °C for BHK. The temperature increase in the bentonite backfill of BHA is due to heat transfer from BHK. The increase is less than 0.1 °C.

Figure 3-2 shows the spatial distribution of the temperature increase relative to the groundwater after ten years. The maximum temperature in the waste domain is approximately 1.4 °C.

It can be noted that the thermal conductivity of the rock in the Laxemar area is relatively low, compared for instance to the rock in Forsmark (Sundberg et al. 2008b). A different host rock may therefore dissipate heat from the waste more efficiently, further limiting any temperature increase in the repository.

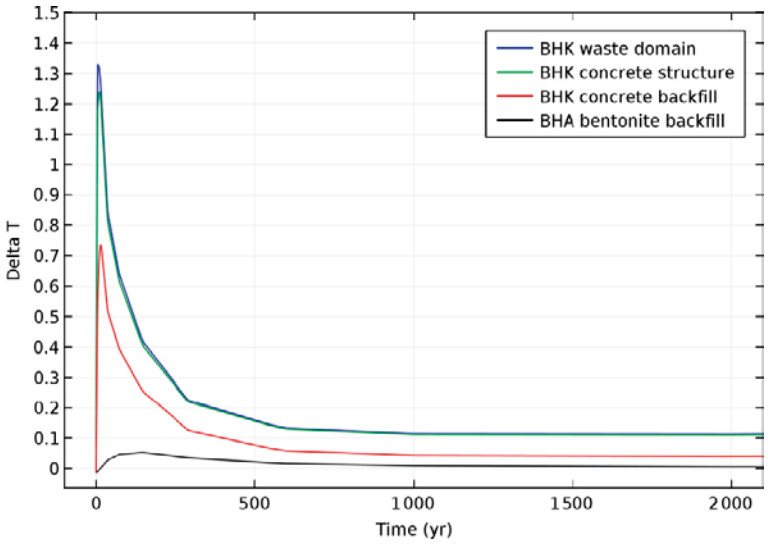

Figure 3-1. *Temperature increase (°C) relative groundwater temperature as a function of time (yr).*

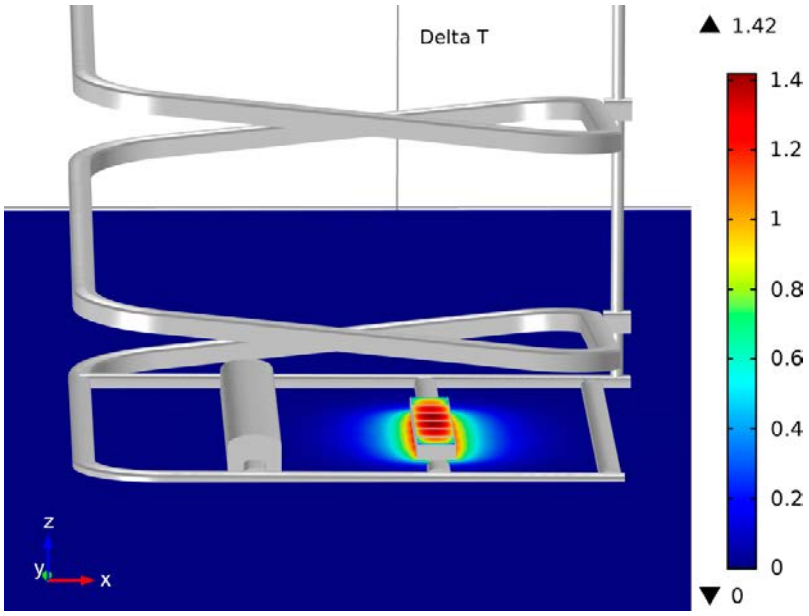

Figure 3-2. *Distribution of the temperature increase relative to the groundwater temperature after 10 years.*

4 Conclusions

The BHK vault will hold metallic waste consisting mainly of reactor core components. The waste constitutes a heat source that may cause a temperature increase in the repository near-field. The temperature evolution in the SFL near-field has been calculated by solving the transient heat conduction equation for porous media. The dissipation of heat due to groundwater flow has been neglected and the results therefore provide a conservative estimate of the temperature increase.

The maximum volume average temperature increase is 1.3 °C for the BHK waste, 1.2 °C for the concrete structure and 0.7 °C for the concrete backfill. After five hundred years the average temperature increase is less than 0.2 °C for the BHK domains. The temperature increase in the bentonite backfill of the BHA vault never exceeds 0.1 °C.

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Appendix A

Calculation of waste domain material volumes

Numbers in the calculations below originate from the pages *Water volume*, *Material* and *Disposal Packaging* and *Volumes* in the SFL initial state spreadsheet[2].

Water

The water accessible volume (m^3) in the waste domain is assumed to be the sum of the waste void, the waste grout pores and the caisson grout pores.

$$V_{water} = 1157 + 812 + 802 = 2771 \text{ m}^3$$

Steel

The steel volume is calculated from the total mass of steel waste and steel packaging and the density of steel 7850 kg/m^3.

$$V_{steel} = \frac{2{,}02 \cdot 10^6 + 9{,}84 \cdot 10^5 + 1{,}97 \cdot 10^4 + 1{,}23 \cdot 10^7}{7850} = 1952 \text{ m}^3$$

Concrete grout

The total volume of the waste domain is 9448 m^3. The grout volume is assumed to be the total volume minus the water and steel volumes.

$$V_{grout} = 9448 - 2771 - 1952 = 4725 \text{ m}^3$$

[2] **Herschend B, 2016.** Initial state SFL. SKBdoc 1441724 ver 1.0, Svensk Kärnbränslehantering AB. Internal document.

Arkitektkopia AB, Bromma, 2018

SKB is responsible for managing spent nuclear fuel and radioactive waste produced by the Swedish nuclear power plants such that man and the environment are protected in the near and distant future.

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