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MODELLING OF DECAY HEAT REMOVAL FROM POSSIBLE GEOLOGICAL REPOSITORY FOR RBMK-1500 SPENT NUCLEAR FUEL IN CLAY FORMATION IN LITHUANIA

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ABSTRACT

In this paper we are presenting the results on the modelling of the decay heat removal from the repository in clay formation. A 3-dimensional model of the repository was developed in order to evaluate heat removal. Since domain is symmetric only ¼ of this domain was modelled in order to make computer modelling faster. All the mesh contained about 400000 8-noded elements. The mesh was refined in the areas of interest. i.e. in steel, bentonite and excavation disturbed boundaries. For time dependant temperature evolution modelling FLUENT 6.1 code was used. Modelling was performed for different distance between canisters and for different bentonite moisture content. The results of temperature modelling in the SNF emplacement tunnels illustrate the significance of bentonite thermal conductivity either thermal capacity on temperatures at the canister surface. bentonite backfill and host rock.

1. INTRODUCTION

During 2002-2005 the assessment of possibilities for disposal of SNF in Lithuania was performed with the support of Swedish experts. Extended studies on selecting of suitable geological formation had led to the conclusion that crystalline rock and argillaceous rocks are the primary candidates for disposal of spent nuclear fuel (SNF) and long-lived intermediate level waste (ILW) in Lithuania.

EKRA's concept developed for disposal of the SNF in Switzerland with horizontal canister emplacement was chosen as prototype for disposal of RBMK-1500 SNF in clay formations in Lithuania [1]. In this paper the results of temperature evolution modelling in the spent nuclear fuel emplacement tunnels are presented.

2. METHODOLOGY

Temperature evolution in the SNF tunnels was modelled using FLUENT 6.1 code [2]. FLUENT is the world leading CFD code for a wide range of modelling fluid flow and heat transfer in complex 2D or 3D geometries. Since analysis was based on a 3D model, in this case FLUENT solves three-dimensional conduction equation.

Heat transport was assumed to be only by conduction. Influence of convection was expected to be negligible, because of low gas and hydraulic conductance of surrounding materials – bentonite and host rock.

The geometry of the domain is illustrated in figure 1. Spent nuclear fuel canisters are emplaced horizontally in the tunnel. Each steel canister has a length of 4.27 m and a radius of 0.625 m. Canister's wall thickness is 0.15 m. The void around and between canisters is filled with bentonite.

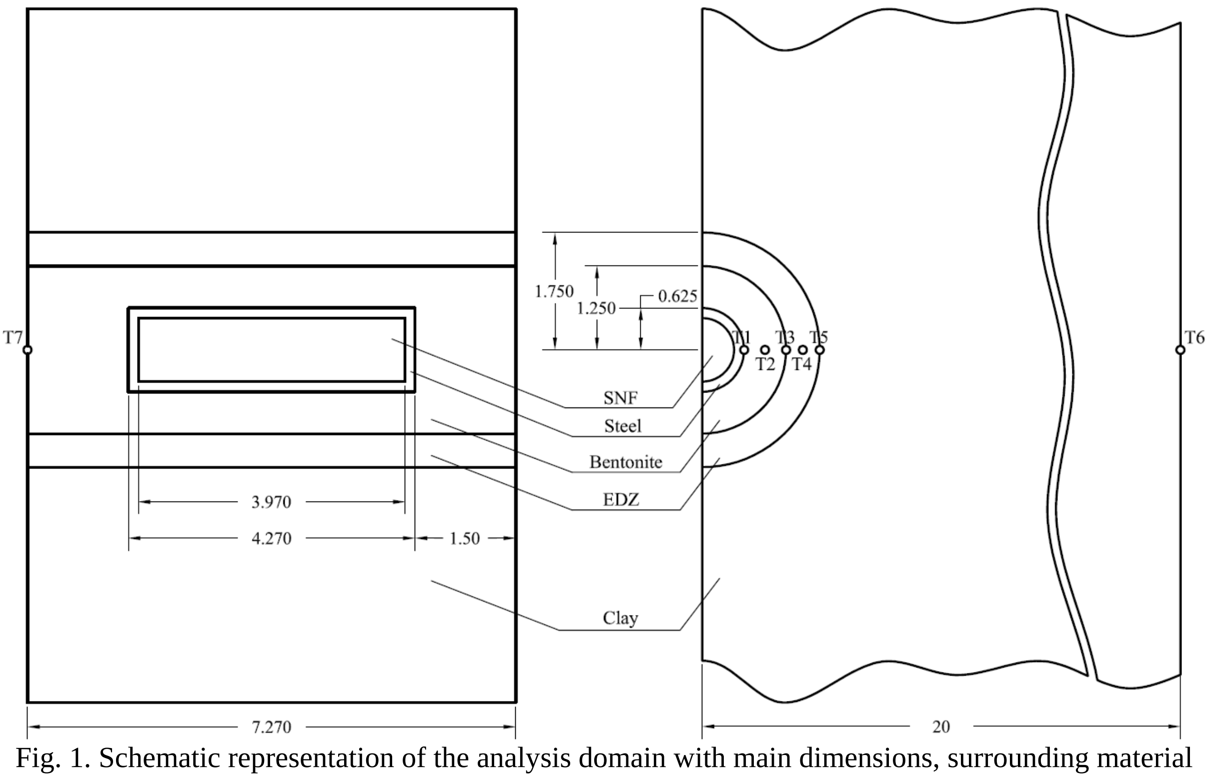

Fig. 1. Schematic representation of the analysis domain with main dimensions, surrounding material names and locations at which the temperatures are modelled

Excavation disturbed zone (EDZ) is around bentonite as shown in the figure 1. Tunnels have a diameter of 2.5 m. For modelling the distance between canisters was assumed to be 2 or 3 meters.

Disposal canister should fit some mechanical, chemical, etc. and thermal requirements. It was assumed that max. canister's surface temperature should not exceed 100 °C to avoid boiling at the canister surface (boiling could lead to enrichment of salts on the surface which could cause corrosion effects, change bentonite properties, etc.).

Points T1÷T7 indicate locations at which the temperatures were modelled. T1 is the temperature at the canister radius. T2 is the temperature at horizontal mid-bentonite. T3 is the temperature at the horizontal radius tunnel. T4 is the temperature at horizontal mid-EDZ. T5 is horizontal radius EDZ temperature. T6 is the temperature at radial midpoint and T7 is the temperature at mid-point between canisters.

In figure 2 three-dimensional view of the model geometry with main dimensions is shown. During modelling thickness of clay formation (≈ 200 m) was divided into two parts (fig. 2) – upper clay layer (which has higher thermal conductivities due to higher quartz content) and lower clay (lower thermal conductivities due to lower quartz content) layer. The repository is located in the upper clay layer – at a 650 m depth (centre of clay).

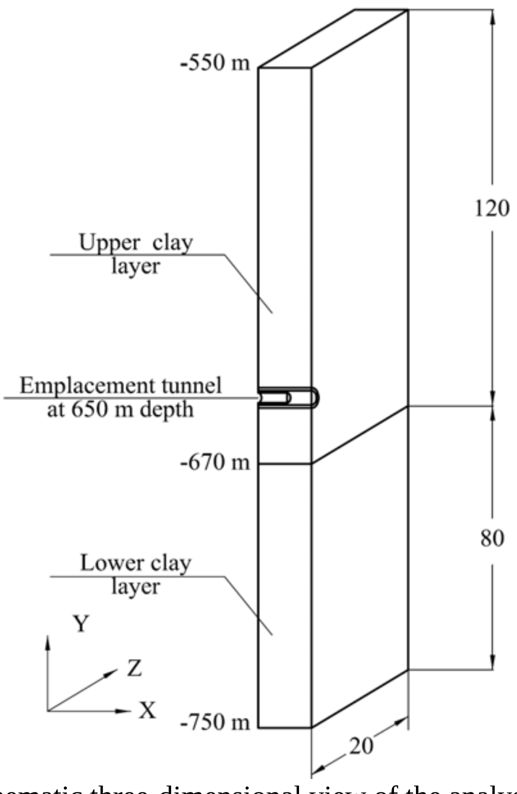

Fig. 2. Schematic three-dimensional view of the analysis domain

Since domain is symmetric only ¼ of the domain was modelled in order to make computer modelling faster. A part of three-dimensional mesh is shown in figure 3. In contains about 400000 8-noded elements. The mesh is refined in the area of interest, i.e. in steel, bentonite and EDZ boundaries. The vertical sides of the domain are assumed to be zero-flux boundaries (symmetry planes).

The canisters are designed for 16 (32 fuel-half assemblies) fuel assemblies of RBMK-1500 spent nuclear fuel, 2.8% initial enrichment, burnup 30 MWd/kgU. Residual heat decay of a SNF canister after 50 years of interim storage was evaluated using ORIGEN-S [3] code.

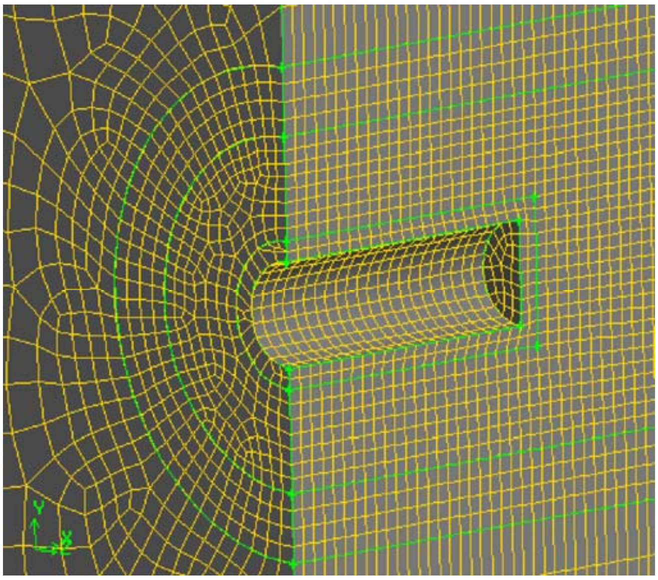

Fig. 3. Three-dimensional mesh for temperature evolution modelling for SNF emplacement tunnels

Since there is a lack of geotechnical properties of the geological formations in Lithuania in this stage modelling was performed using Swiss proposed repository environment parameters for opalinus clay [4].

3. RESULTS ON TEMPERATURE EVOLUTION MODELLING

Modelling was performed for different distance between canisters and for different bentonite moisture content. Four cases were analysed in total and they all are presented in table 1.

Low bentonite thermal conductivity is when it is almost dry (2% moisture) and about three times higher thermal conductivity is when bentonite is saturated [4]. Similar differences are for thermal capacity.

Table 1 Analysed cases

Cases	Distance between canisters, m	Bentonite humidity
Case 1	3	Low moisture content (2%)
Case 2	3	Saturated
Case 3	2	Low moisture content (2%)
Case 4	2	Saturated

Case 1

The time-dependant temperature evolution in the horizontal orientation SNF emplacement tunnels is shown in figure 4. The results show that for expected condition bentonite (low moisture content and low thermal conductivity) the peak temperature of ≈ 97 °C (T1) reaches within few years. Within 100 years the temperature decreases to 71 °C. The temperature of mid-bentonite (position T2) remains lower than 75 °C. Temperature within a clay (T6) reaches a peak of 52 °C after about 150 years. The results also show that temperature in the mid-point between canisters (T7) newer exceeds 60 °C. This temperature is point T7 peak temperature, which reaches such value after about 30 years.

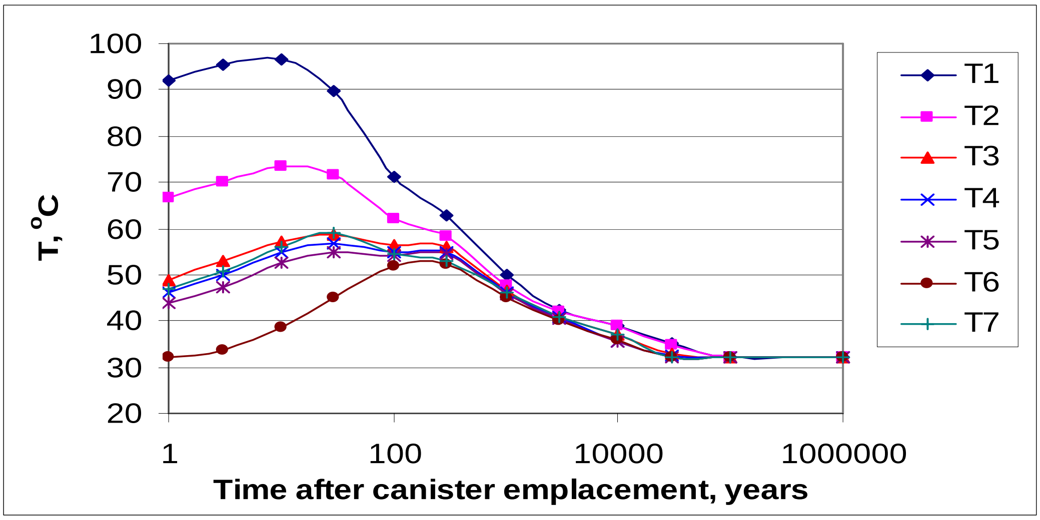

Fig. 4. The time-dependant temperature distribution in the SNF emplacement tunnels for the case of low bentonite moisture content (low bentonite thermal conductivity)

Case 2

The time-dependant temperature evolution in the SNF emplacement tunnels was also modelled for case of saturated (high thermal conductivity) bentonite (fig. 5). The results show that temperatures are much lower than in the case before. The highest temperature of ≈ 68 °C (T1) is reached within 10 years (fig. 5). Within 100 years the temperature decreases to 61 °C. The temperature of mid-bentonite (position T2) remains lower than 65 °C. The highest temperature within a clay (T6) remains in the range 52 to 45 °C for several hundred years. The results also show that temperature in the mid-point between canisters (T7) newer exceeds 56 °C.

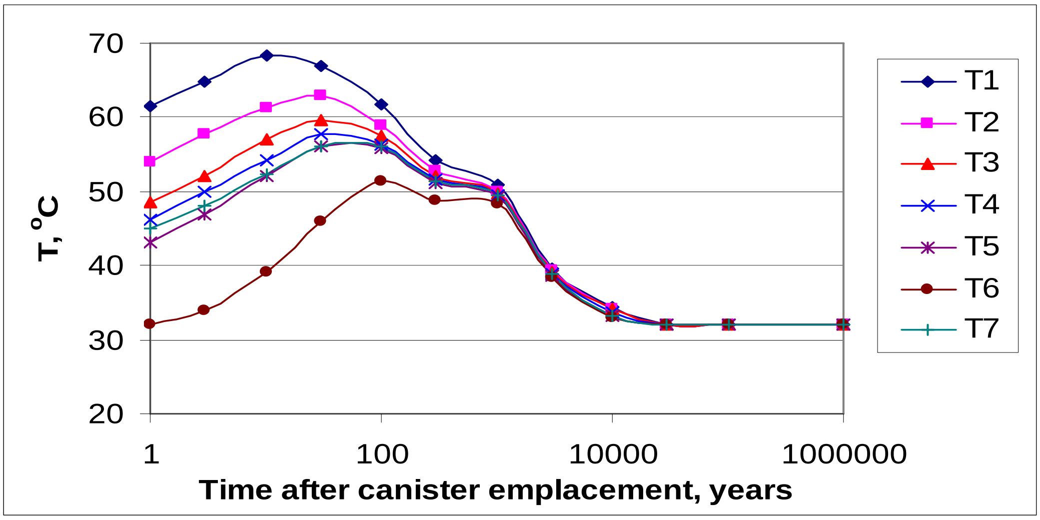

Fig. 5. The time-dependant temperature distribution in the SNF emplacement tunnels for the case of saturated bentonite (high thermal conductivity)

Case 3

Temperature evolution was also modelled in case when distance between canisters is 2 meters. Modelling results are shown in figure 6.

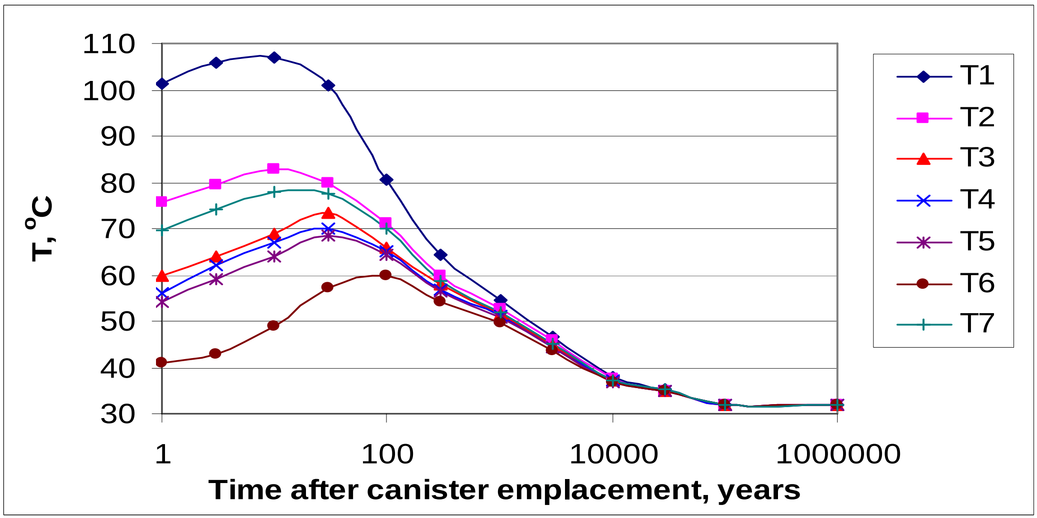

Fig. 6. The time-dependant temperature distribution in the SNF emplacement tunnels for the case of low bentonite moisture content (low bentonite thermal conductivity) and distance of 2 m between canisters

The results show that temperatures in this case (when distance between canisters is 2 m) are much higher than in the case when distance was 3 m. The highest temperature on the outer surface of the canister reaches a maximum of ≈ 107 °C (T1) within few years. Within 40 years the temperature decreases to a value lower than 100 °C. The temperature of mid-bentonite (position T2) remains 10 °C higher for several hundred years in comparison with 3 meters distance between canisters. The highest temperature within a clay (T6) remains in the range 61 to 50 °C for several hundred years also. The results also show that peak temperature in the mid-point between canisters (T7) is ≈ 78 °C. This temperature is about 18 °C higher than it was for the case of 3 m distance between canisters.

Case 4

The time dependant temperature distribution in the SNF emplacement tunnels for distance between canisters of 2 m and high bentonite thermal conductivity is shown in figure 7. For the hypothetical case of bentonite saturated from the beginning temperatures are well below 75 °C on the canister surface and throughout the bentonite. Temperature at the mid-point between canisters (T7) reaches a maximum value of ≈ 63 °C (78 °C in case of low bentonite thermal conductivity) within 30 years.

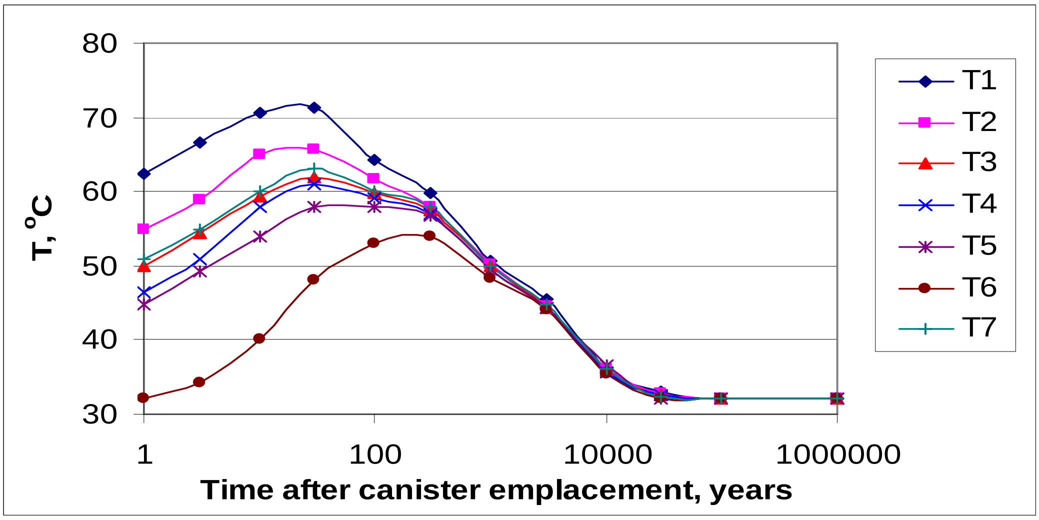

Fig. 7. The time-dependant temperature distribution in the SNF emplacement tunnels for the case of saturated bentonite (high bentonite thermal conductivity) and distance of 2 m between canisters

4. ANALYSIS OF RESULTS

The highest canister's surface (T1), horizontal mid-bentonite (T2) and horizontal radius tunnel (T3) temperatures are presented in table 2 for the different bentonite humidity (different thermal conductivity and heat capacity) and different distance between canisters.

Table 2 The highest canister's surface (T1). horizontal mid-bentonite (T2) and horizontal radius tunnel (T3) temperatures for the different analysed cases

Cases	**T1, °C**	**T2, °C**	**T3, °C**
Case 1 (low bentonite moisture content; distance between canisters-3 m.)	96.7	73.5	58.6
Case 2 (saturated bentonite; distance between canisters-3 m.)	68.4	63	59.6
Case 3 (low bentonite moisture content; distance between canisters-2 m.)	106.8	83	73.5
Case 4 (saturated bentonite; distance between canisters-2 m.)	71.3	65.6	62

Results show that canister surface temperature in case 1, as well as in case 2 and case 4 never exceeds 100 °C. In case 3 the temperature exceeds 100 °C (106.8 °C). All analyzed cases showed that temperature in bentonite layer in any case does not exceed 85 °C.

The table shows the lowest temperatures are achieved in saturated bentonite and when the distance between canisters is 3 m, and the highest temperature is when bentonite has low moisture content and there is a 2 m distance between canisters.

As it was already indicated during modelling the environmental properties of SNF repository proposed by Swiss were accepted in opalinus clay, i.e. specific thermal conductivity of clay and the repository depth, which is equal to 650 m from the earth surface. However in Lithuania the repository depth is planned to be only 350 m (cambrian clay). This means the natural clay temperature will be smaller in this case, then if the depth would be 650 m. The probable thickness of clay layer in Lithuania can be similar or even smaller [1]. The aforementioned statements allow us to draw a conclusion, that because of the lower clay temperature the canister surface temperature will be lower than that, modelled in the case 1, and if the thickness of clay layer will be smaller this would allow the heat to spread more easily, because of that, canister surface temperature will also not be higher than modelled in case 1.

5. CONCLUSIONS

1. The results of temperature modelling in the SNF emplacement tunnels illustrate the significance of distance between canisters and bentonite thermal conductivity either thermal capacity on temperatures at the canister surface, bentonite backfill and host rock.
2. When the distance between canisters is 3 m the maximum canister surface temperature for dry bentonite is very close, but does not exceed 100 °C. So at the moment the recommendation would be to keep a 3 meter distance between canisters for the reference disposal concept.

REFERNCES

[1] P. Poškas. A. Šmaižys. et al. Generic repository concept for the deep geological disposal of the spent nuclear fuel in Lithuania (second stage report S/14-374.3.3-18-G-V:02). Lithuanian energy institute. 2003.

[2] Fluent 6.1 documentation // Fluent inc. 2002.

[3] O. W. Hermann. R. M. Westfall. ORIGEN-S: SCALE System Module to Calculate Fuel Depletion. Actinide Transmutation. Fission Product Buildup and Decay. and Associated Radiation Source Terms. Rev.5. Oak Ridge National Laboratory. March 1997.

[4] Project Opalinus Clay: Safety report. Demonstration of disposal feasibility for spent fuel vitrified high-level waste and long-lived intermediate-level waste (Entsorgungsnachweis). Nagra Technical Report NTB 01-04. Wettingen. 2002.