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Determination of Disposal Density of VVER-1200 Spent Fuel Loaded Canisters in Horizontal Geological Disposal

G. Özeşme[1], **B. Bulut Acar**[2]

[1]*Energy Institute, Istanbul Technical University, Istanbul, Turkey*

[2]*Nuclear Engineering Department, Hacettepe University, Ankara, Turkey*

Abstract. Geological disposal is a widely accepted method for permanent disposal of spent nuclear fuel and high-level waste. There are various geological disposal concepts under development in many countries and these concepts have differences mainly in the geometry and material of disposal canisters, geological formations of host rock and orientation (vertical and horizontal) of disposal canisters. The aim of this study is to perform thermal analysis of canisters loaded with VVER-1200 spent nuclear fuel assemblies and disposed horizontally in the granitic rock formation. The ANSYS Mechanical APDL 19.2 finite element code is utilized to perform thermal analysis. In the first part of the study, VVER-1200 spent nuclear fuel characteristics (amount, isotopic composition, heat generation rate, etc.) are evaluated by using the MONTEBURNS 2.0 code. Then, 3-dimensional ANSYS model of geological repository consisting horizontally disposed canisters, buffer material, and host rock regions is developed and transient thermal analysis is performed. As a result of the study, minimum distances between disposal canisters are determined by taking into account the thermal constraints for the components of the geological repository.

Keywords: ANSYS, Geological disposal, Monteburns, Spent nuclear fuel, VVER-1200

1 Introduction

In principle, there are two main approaches for managing spent nuclear fuel (SNF). One approach is to reprocess SNF in order to recover the valuable uranium and plutonium isotopes in it. Another approach is to classify as radioactive waste and send it directly to permanent disposal.

Geological disposal is the most accepted solution for permanent disposal of SNF. This method is based on the isolation of SNF within the geosphere in locations where it is expected to be stable over a very long time. In the geological disposal, SNFs are loaded into canisters and placed into disposal holes drilled in a stable geological formation deep underground. There are various geological disposal concepts under development and these concepts have differences mainly in the geometry and material of disposal canisters, geological formations of host rock and orientation (vertical or horizontal) of SNF bearing disposal canisters.

Thermal loading of disposal holes so as to not exceed specified temperature limits is the key factor in the design of a geological repository. Thermal load strongly depends on the design of canister, the distance between disposal holes and thermal features of the host rock.

The aim of this study is to design a canister for VVER-1200 SNFs and determine the suitable distance between canisters in a horizontal geological repository. In the first part of the study, composition and decay heat generation rates of VVER-1200 SNF is determined. Then, using the decay heat profile and taking into account the thermal constraints, disposal canister model is developed and the minimum distance between canisters is obtained through thermal analysis for a reference geological repository.

2 Determination of VVER-1200 SNF Decay Heat Profile

Isotopic composition and decay heat profile of VVER-1200 SNF is evaluated by using MONTEBURNS code, which couples the MCNP Monte Carlo transport code with the burnup/depletion code ORIGEN2. Unit cell approximation is used in the MONTEBURNS analyses. Material properties and geometric data for VVER-1200 introduced in IAEA status report are used in MONTBURNS modeling of the problem [1]. VVER-1200 unit cell model developed in MCNP is presented in Figure 1. Decay heat profile obtained from MONTEBURNS output is used as a heat source term in the

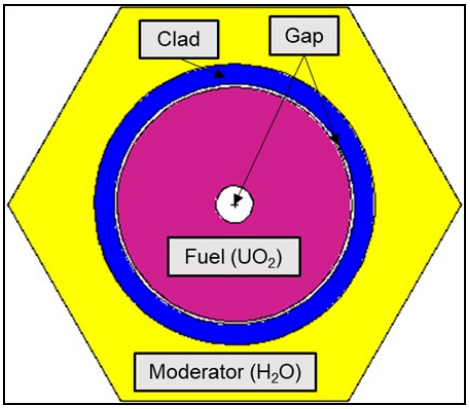

Figure 1. XY cross-section representation of the MCNP input model for the unit cell.

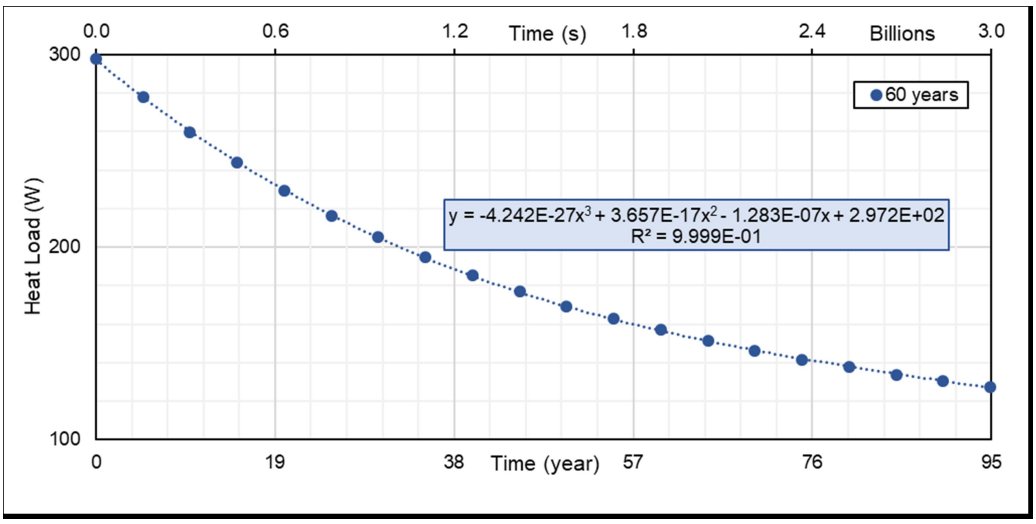

Figure 2. Time-dependent heat load data for a single VVER-1200 SNFA.

thermal model for VVER-1200 loaded canister. In the heat source term calculations, the cooling period before disposal is taken as 60 years for VVER-1200 SNF. Figure 2 shows the decay heat profile of a single SNF assembly (SNFA). Decay heat data is fitted to 3rd order polynomial and used in thermal analysis.

3 Reference Geological Repository

Reference disposal facility is based on Swedish KBS-3 concept, which is a mature and widely adapted method by other countries. In the KBS-3 disposal concept, SNF is placed into a copper canister with a cast iron insert. The SNF loaded disposal canister is surrounded by bentonite buffer material and placed vertically (KBS-3V) or horizontally (KBS-3H) into the holes excavated along parallel tunnels at a depth of 400 meters in granite rock. The depth of the disposal hole is 7.55 meters, and the diameter of the hole is 1.75 meters [2]. The distance between parallel disposal tunnels is 40 meters. In the present study, a VVER-1200 loaded canister is designed for KBS-3H repository concept. Schematic representation of KBS-3H is shown in Figure 3.

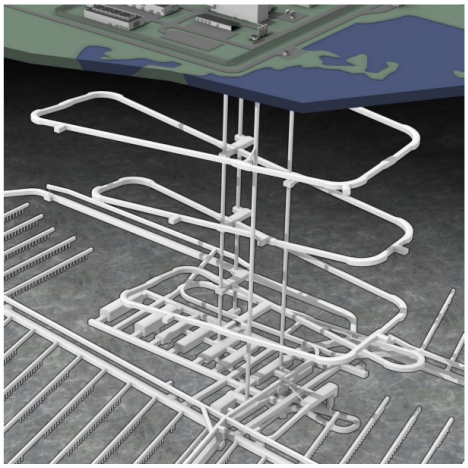

Figure 3. KBS-3H repository concept schematic.

4 Design of Canister for VVER-1200 SNF

Disposal canister for VVER 1200 is adopted from the reference repository concept [3]. Reference concept has canister designs for EPR, VVER-440 and BWR SNFs. During the design development, the diameter of the canister is kept constant and height is adjusted according to VVER-1200 SNFA height. Designed disposal canister contains 5 VVER-1200 SNFAs with the loading configuration as presented in Figure 4.

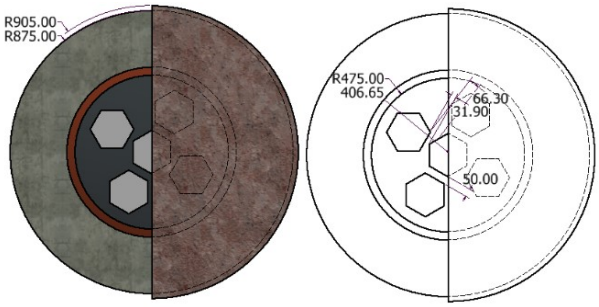

Figure 4. Orientation of VVER-1200 SNFA's in disposal.

5 Thermal Analysis

Thermal analysis is performed for reference geological repository containing disposal canisters designed for VVER-1200 SNF. 3-dimensional thermal model of the reference repository is developed in ANSYS finite element analysis code in order to obtain time-dependent temperature distribution in the repository and determine the proper emplacement distance for adjacent canisters.

ANSYS model of the repository includes a single disposal canister and surrounding layers (buffer material, backfill material, and host rock). Lateral boundaries of the geometric model are the half distance between the adjacent disposal canisters and a half distance between the parallel tunnels. The top and bottom boundaries of the geometric model are 20 meters above and below the disposal tunnel. The geometry of the disposal canister and surrounding layers used in thermal modeling can be seen in Figure 5.

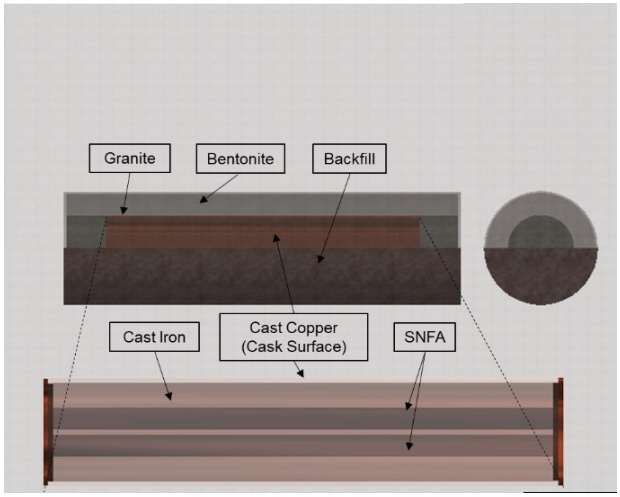

Figure 5. Geometric representation of disposal cask model that used in thermal modeling.

After the development of the geometric model, thermophysical properties of the materials of components are defined and transient heat conduction problem is solved. Thermophysical properties of repository components included in the geometric model are given in in Table 1.

Table 1. Thermophysical properties of materials used for repository thermal modeling [4]

Material	**Density** (ρ) (kg/m^3)	**Conductivity** (k) ($W/m\,^\circ C$)	**Specific heat** (c_p) ($kJ/Kg\,^\circ K$)
SNFA	2000	0.135	2.640
Cast Iron	7200	52.00	0.447
Cast Copper	8940	394.0	0.385
Bentonite	1970	1.000	1.380
Backfill	2270	2.000	1.190
Granite	2900	2.65	0.807

Thermal boundary conditions of the transient heat conduction problem are defined as given below:

- Disposal model will be performed at the depth of $\sim$ 400 m [3] from the surface. Hence, the average temperature of granite host rock at the disposal depth can be calculated by adding a geothermal gradient of 30 km^{-1} [5] from the average temperature of earth surface 20°C.
- Heat load data obtained from MONTEBURNS output file is applied to SNFA's located inside of the disposal canister in terms of W/m^3.
- The symmetric boundary condition is applied in the direction of disposal canister to ensure sequential stacking throughout disposal tunnel is simulated properly during the solution.

Schematic representation of the ANSYS model of the repository with thermal boundaries is presented in Figure 6.

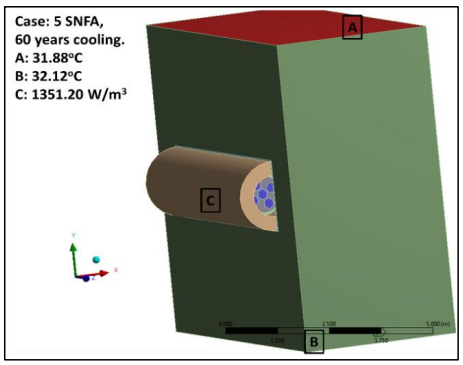

Figure 6. Schematic representation of thermal elements defined in ANSYS Mechanical APDL.

Thermal analyses are performed for various spacing values and suitable distance for disposal of canisters is determined by referring to specified temperature limits for repository components. In the reference repository concept, the thermal constraint is determined as the temperature at the canister surface must not exceed 100°C. In this study, the temperature limit is reduced to 80°C, in order to include a safety margin [6].

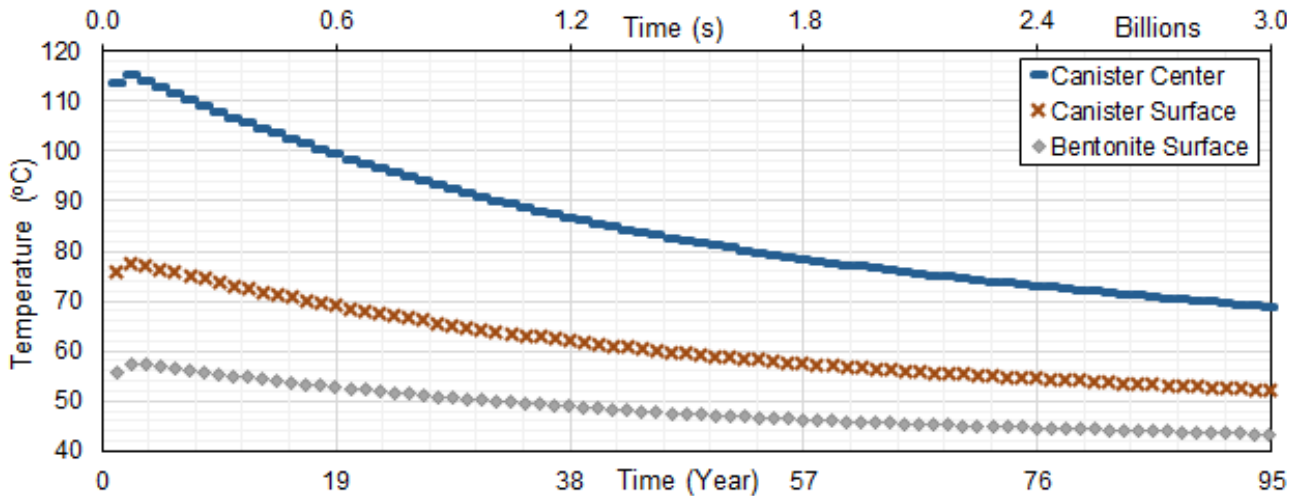

Figure 7. All-time – high temperature distribution of disposal cask and surrounding host rock.

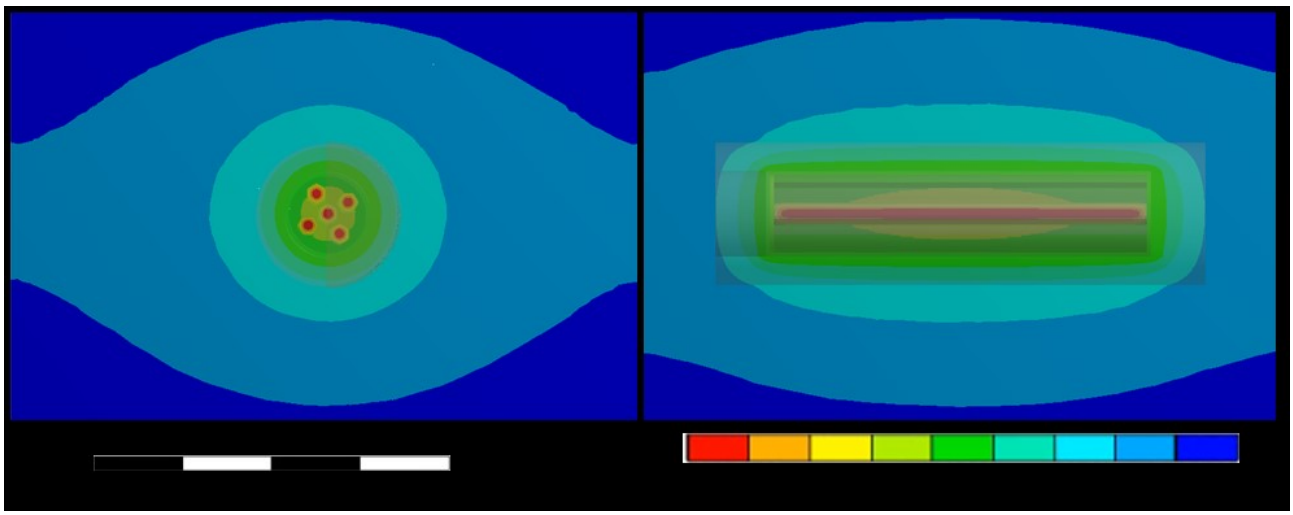

Figure 8. The maximum value of temperature history at the center and surface of the disposal cask and surface of the surrounding bentonite layer.

6 Results

For disposal canisters containing 5 VVER-1200 SNFAs with the loading configuration proposed in this study, minimum spacing is determined as 2.2 meters. For the canister disposal distance of 2.2 meters, time-dependent temperatures on the canister and bentonite outer surfaces and at the center of the canister for 95 years time interval after disposal are given in Figure 7.

As it can be seen from Figure 7, at this canister spacing, specified thermal limit for reference repository is not exceeded. All-time history (95 years starting from disposal) of maximum temperature data in Figure 7 showed that temperature levels gives a peak within a 2 year period and starts to falling continuously. Additionally, as it can be observed from the thermal counter plot given in Figure 8, temperature has risen up to 116.73°C and 78.63°C at the all-time-high temperature point at the center and the outer surface of the disposal canister.

7 Conclusions

The purpose of this study has been to develop a canister for the disposal of VVER-1200 SNFs and to determine the appropriate spacing of designed canisters in a reference geological repository concept.

The study involved the determination of characteristics of VVER-1200 SNF by using MONTEBURNS code, development of canister model, and thermal analysis to determine canister spacing in a reference repository.

The results of thermal analyses show that a minimum emplacement distance of 2.2 meters is needed to safe disposal of designed canisters at the reference repository. Note that, the determined minimum distance strongly depends on the thermal load of the canister. The VVER-1200 SNF loaded canister developed in this study is based on the canister design in the reference repository. Therefore, important parameters such as canister diameter and copper thickness are kept constant. Additionally, it is assumed that 5 VVER SNFAs with a pre-cooling period of 60 years will be loaded to the canister. By changing the number of SNFAs, pre-cooling time and canister dimensions the most appropriate combination of the pre-cooling period, canister dimension and SNF loading pattern can be determined for the horizontal disposal of VVER-1200 SNFAs.

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