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THERMAL PERFORMANCE ANALYSIS OF REPOSITORY CODISPOSAL WASTE PACKAGES CONTAINING ALUMINUM-CLAD SPENT NUCLEAR FUEL

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Abstract

The leading codisposal waste package (WP) design proposes that a central DOE Aluminum-clad Spent Nuclear Fuel (Al-SNF) canister be surrounded by five defense waste process facility (DWPF) glass log canisters, and placed into a WP in the Mined Geologic Disposal System (MGDS).

Two waste form options are being considered for the DOE Al-SNF disposition using the codisposal WP design configuration. They are the direct and the melt-dilute SNF forms. For the direct form option, a number of Al-SNF assemblies are to be packed directly without any change of physical forms or chemical isotopes in a DOE Al-SNF canister. For the melt-dilute form option, a number of the SNF assemblies are melted and diluted to be emplaced in the central DOE Al-SNF stainless steel canister, which result in a SNF storage canister containing uranium-aluminum alloy ingots. For the present analysis, a SNF canister is estimated to be filled to 90% of the canister volume with an uranium-aluminum alloy ingot.

A two-dimensional baseline model with conduction and radiation coupled heat transport was developed to evaluate the thermal performance for both the direct and the melt-dilute Al-SNF forms in a codisposal waste package canister over the range of possible heat loads and boundary conditions. In addition, a conduction model and a detailed model which added convection to the baseline model were developed to identify the dominant cooling mechanism under the present waste package configuration, to investigate physical cooling mechanism in detail, and to estimate the conservatism imbedded in the baseline model.

The results showed that both the direct disposal and the melt-dilute disposition configurations with a helium-filled WP satisfied the present acceptance criteria for the WP design in terms of the fuel peak temperature criterion, $T_{max} \leq 350\ ^{o}C$, under the reference boundary conditions. Average temperature of the WP was found to be very close to geological ambient temperature at about 2000 years of storage time after emplacement of the WP in a repository.

Introduction

SRS has made a thermal performance analysis to calculate peak temperatures and temperature profiles of codisposal Waste Package (WP) configuration in a geological repository. The analysis results will be used to demonstrate compliance with waste acceptance criteria for the DOE Aluminum-clad Spent Nuclear Fuel (Al-SNF) storage systems and as input to assess the chemical and physical behavior of the Al-SNF forms within the WP. The leading codisposal WP design proposes that a central DOE Al-SNF canister be surrounded by five Defense Waste Process Facility (DWPF) glass log canisters, that is, High-level Waste Glass Logs (HWGL's), and placed into a WP in the Mined Geologic Disposal System (MGDS). The waste package is cylindrical with a diameter of about 6 ft. A DOE SNF canister having about 17 inch diameter and about 10 ft length is placed along the central horizontal axis of the WP. The five HWGL's, each with a 2 ft diameter and 10 ft length, will be located around the peripheral region of the DOE Al-SNF canister internal to the WP. The codisposal WP will be laid down horizontally in a drift tunnel repository as shown in Fig. 1.

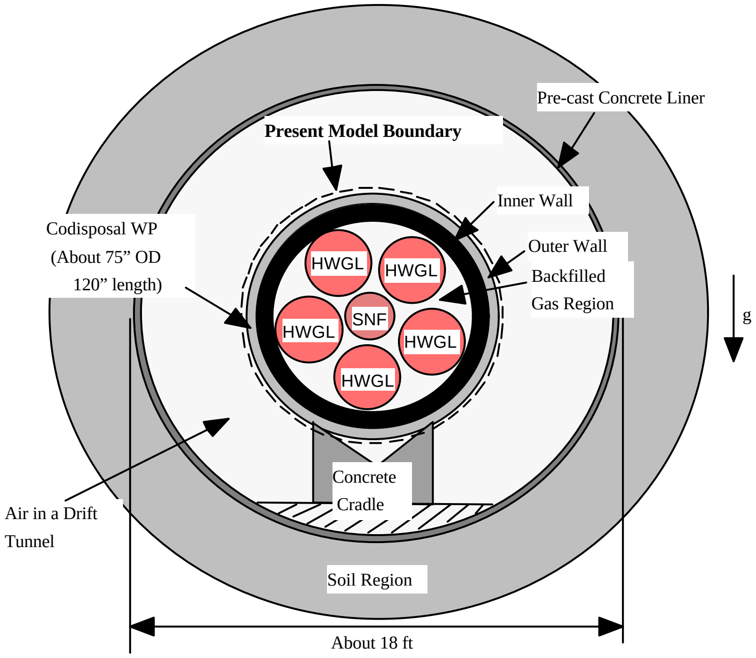

Figure 1. Horizontal emplacement of codisposal Waste Package (WP) in the center of a drift tunnel repository.

There are two waste form options for the DOE Al-SNF disposition using the codisposal WP design configuration. They are the direct and the melt-dilute SNF forms. For the direct form option, a total of up to 64 standard-sized Material Test Reactor (MTR) type SNF assemblies are to be packed in a DOE Al-SNF canister. For the melt-dilute form option, a number of the SNF assemblies are melted and diluted to be emplaced in the central DOE Al-SNF stainless steel canister, which result in a SNF storage canister containing uranium-aluminum alloy ingots. For the present analysis, a SNF canister is estimated to be filled to 90% of the canister volume with an uranium-aluminum alloy ingot. The composition of an ingot will have the eutectic composition of the binary alloy (13.2 wt. % uranium, 86.8 wt. % aluminum) with less than and equal to 20% enriched uranium-235.

The transient decay heat loads were recently developed for this analysis. The heat loads included: i) the Al-SNF assemblies in the direct form; ii) the melt-dilute form for the case where all the krypton and 80% of the cesium are assumed to be removed; and iii) the HWGL. The Al-SNF heat loads were computed using the ORIGEN code under SCALE 4.2 system.

The objective of this study is to develop a thermal analysis methodology and to perform parametric analyses of codisposal storage configurations to estimate the SNF, HWGL, and WP temperatures in a geological repository under various boundary conditions. This paper addresses thermal performance internal to the codisposal WP as shown in Fig. 1. The thermal models were developed to assess the storage performance of the codisposal WP design using intact prototypic geometry created under the body-fitted coordinate system in the computational fluid dynamics (CFD) preprocessing environment. A two-dimensional baseline model with conduction and radiation coupled heat transport was developed to evaluate the thermal performance for both the direct and the melt-dilute Al-SNF forms in a codisposal WP canister over the range of possible boundary conditions. In addition, a conduction model and a detailed model which included all possible heat transfer processes, conduction, convection, and radiation, were developed to identify the dominant cooling mechanism under the present WP configuration, to investigate physical cooling mechanism in detail, and to estimate the conservatism imbedded in the baseline model. Calculated temperatures are used to demonstrate compliance with criteria for waste acceptance into MGDS and as input to assess the chemical and physical behavior of the waste form within the WP.

The results will show that the present baseline model can predict reasonably accurate thermal performance for the direct and melt-dilute Al-SNF options within a dry codisposal WP. It is expected that the present approach can be used to accurately predict thermal performance of similar spent nuclear fuels in various WP configurations.

Present Approach of Modeling and Solution Methods

The heat generated by the radioactive decay process of SNF in a dry storage container will be cooled by back-filled gas medium and eventually will be transported to the surrounding environment or geological repository medium through the physical mechanisms of conduction, convection, and radiation heat transport processes. In this situation the temperature gradient at the wall is dependent on the gas flow field driven by the density gradient at the boundary layer since the temperature gradient is dependent on the rate at which the gas fluid convects the heat away. Thus energy transport is coupled to the momentum transport through the wall interface of the solid and fluid regions. The complicated geometrical configurations internal to the codisposal WP containing Al-SNF assemblies with decay heat source require a multi-dimensional heat transfer model with a high computational efficiency. CFX code has been used as a tool to model the prototypic configurations of the codisposal WP.

A steady-state solution is desired for the present work, and this can be achieved either by advancing the governing equation set through a sequence of time steps or by dropping the transient term completely from the equations and using a purely iterative approach. For the present analysis, the first approach, that is, the quasi-steady approach was used by solving the transient equations. This approach was proven to be an efficient method in the V&V test of the code (Lee, 1996). The analysis was mainly made for the temperature distributions and the buoyancy-driven flow field induced by the temperature gradient within an enclosed package. Temperature decreases rapidly due to the convective cooling effect within a boundary layer region. The flow internal to the WP is a buoyancy-induced motion resulting from body forces acting on density gradients which, in turn, arise from temperature gradients in the fluid. The gravitational body force is oriented in the negative y-direction for the present analysis. The transient equations governing the present problems under the Cartesian coordinate system are shown below.

For the mass continuity,

$$\frac{\partial \rho}{\partial t} + \sum_{i=1}^{3}\left\{\frac{\partial\left(\rho\, u_i\right)}{\partial x_i}\right\} = 0 \tag{1}$$

where the variables with the subscript, i = 1, 2, or 3, correspond to those of the x-, y-, or z-direction, respectively.

For the momentum equation in tensor notation,

$$r\left(\frac{\P u_i}{\P t} + u_j \frac{\P u_i}{\P x_j}\right) = \frac{\P s_{ij}}{\P x_j} + X_i \tag{2}$$

where the variables with the subscript, *i* (or *j, k*) = 1, 2, or 3, correspond to those of the x-, y-, or z-direction, respectively. s_{ij} is the stress tensor and X_i the body force term.

$$s_{ij} = -\left(P + \frac{2}{3} m \frac{\partial u_k}{\partial x_k}\right) d_{ij} + m\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

$$d_{ij} = \begin{pmatrix} 1 \;\; for \; i = j \\ 0 \;\; for \; i \neq j \end{pmatrix}$$

$X_1 = X_3 = 0$ for the present model.

For the energy equation,

$$r\frac{Dh}{Dt} - \sum_{i=1}^{3}\left\{\frac{\P}{\P x_i}\left(k\frac{\P T}{\P x_i} - q_{r,i}\right)\right\} - \frac{DP}{Dt} - \Phi - q''' = 0 \tag{3}$$

where Φ is viscous dissipation term, *h* thermodynamic enthalpy, and q''' heat generation source term. $q_{r,\,i}$ in eq. (3) is net radiative heat flux in the *i*-direction. The viscous dissipation term is not included in the present model.

For the present analysis, the Boussinesq approximation was used for the gravitational term in the momentum equation to include the buoyancy-induced natural convection. It is a two-part approximation: It neglects all variable property effects in the governing equations and it approximates the density difference term with a simplified equation of state, that is, the gravity term in the y-direction, $X_2 = -\, rg$, in eq. (2) is replaced by the following relation:

$$rg = r_\infty\{1 - b(T - T_\infty)\}g \tag{4}$$

where *b* is thermal expansion coefficient, and r_∞ is the density at $T = T_\infty$.

Detailed geometrical configurations for the codisposal WP design including Al-SNF are shown in Fig. 1. Natural convective flow regime for the He-cooled design shown may be estimated based on the non-dimensional quantity, Grashof number (Gr_Z), which is the parameter describing the ratio of buoyancy to viscous forces. The Grashof number performs much the same function for natural convection flow as the Reynolds (Re) number does for forced convection. Under normal conditions one may expect that the laminar-to-turbulent transition will take place at about $Gr_D \approx 10^9$.

For a typical reference design condition such as helium-cooled, intact codisposal WP as shown in Table 1,

$$Gr_D = \frac{gbD^3(T_w - T_\infty)}{n^2} \tag{6}$$

$$\approx 4.0 \text{ x } 10^7 < 1.0 \text{ x } 10^9 \text{ (laminar flow)}$$

where D = characteristic length parameter (=1.7545 m),

b = thermal expansion coefficient (= 2.00 x 10^{-3} K^{-1}),

T_W = wall temperature,

$T_{¥}$ = ambient temperature,

n = kinematic viscosity (= 2.91 x 10^{-4} m^2/sec).

This corresponds to the laminar flow according to the literature information (Kays and Crawford, 1980). For the present analysis, natural convection regime internal to the WP is assumed to be laminar.

The initial storage time, "Year 0", is defined as the time the canister leaves the site and is put into the WP canister and emplaced in the repository. For the present analysis, initial times for the SNF and the HWGL are assumed to be 10 years cooling time after fuel discharge from the reactor and after the production of high-level waste glass log. The WP temperatures are then computed for selected times during the first 2000 years after emplacement in the repository. A quasi-steady state temperature distribution is assumed for each selected time since the package transient temperatures will reach equilibrium in a few days. The present modeling boundary is shown in Fig. 1. For the reference design conditions shown in Table 1, the physical cooling mechanism has been investigated to understand how decay heat energy is transported through the WP to the geological environment. Specifically, how the waste package temperature affects the buoyancy-driven natural circulation inside the WP, and what is the most dominant mode of thermal energy transport for the present codisposal WP configuration are investigated. This information may be important to assess corrosion degradation of the WP and to determine the movement of moisture outside the WP boundary. The present model includes conduction, convection, and radiation cooling mechanisms inside the codisposal WP container by using a two-dimensional approach. The analysis was performed using uniformly-distributed heat generation sources within HWGL and SNF canisters to predict the thermal performance of the package within a geological repository.

Table 1. Reference design conditions of codisposal WP for the present thermal analysis.

Design Parameters	**Design Conditions**
• Back-filled gas inside / outside of SNF canister in codisposal WP	• Helium gas inside and outside of SNF canister
• Initial reference time (storage time: "Year 0")	• 10 years cooling time since discharge from reactor and production of HWGL
• Internal structure of the WP container	• Intact codisposal geometry
• Repository ambient temperature	• 100 °C
• WP location in a repository tunnel	• Center of a drift tunnel

For the present analysis, the radiation energy term of eq. (3) was obtained by using discrete transfer method to solve a differential radiative transfer equation. A differential transfer equation is solved along discrete path through the radiation domain to compute radiative heating and cooling on the solid surface. The back-filled gas medium was assumed to be transparent to the radiation. The absorptivity a is independent of wave length assuming the solid surface is gray. For any surface in an enclosure, Kirchoff's law is obeyed, $e = a$. The radiant heat flux $q_{r,i}$ can be obtained at surface temperature T.

$$q_{r,i} = e\, s\, T^4 \qquad (7)$$

In eq. (7) e is the emissivity of the wall surface, and s is Stefan-Boltzman's constant (5.670×10^{-8} W/m^2K^4). Temperature in eq. (7) can be obtained from the conduction-convection fluid calculation, and the updated radiative heat fluxes are then passed back to the fluid solver in the form of volumetric heat sources. The updating process is repeated periodically within the given number of the outer iterations.

A typical natural convective heat transfer coefficient (h) was used as an external wall boundary condition for the present analysis.

$$Nu_L = \frac{hD}{k} = C\,(Gr_L \mathrm{Pr})^m \text{ for } Gr_L \mathrm{Pr} > 10^4 \tag{8}$$

For the present geometrical configuration shown in Fig. 2, C=0.525 and m=0.25 are given by Chapman (1974) using the experimental data. From eq. (7), the heat transfer coefficient (h) is about 1.5 $W/m^2\,{}^oC$ corresponding to $Nu_L \approx 97$ conservatively under the present conditions.

The governing equations are provided in eq.(1) through eq.(4). It is assumed that there are no solid conduction paths among the SNF and HWGL canisters such that the HWGL canisters, the SNF canister, and the inner wall of the codisposal WP do not touch each other since final geometrical configuration for the codisposal WP is neither confirmed nor available yet. The decay heat results for the bounding fuel assemblies calculated with the ORIGEN code are presented in terms of non-dimensional decay heat fraction in Fig. 2. The non-dimensional decay heat quantity q is based on the decay heat at 0 year reference time corresponding to 10 years' cooling time. That is,

$$q = \frac{Q_m(t)}{Q_m(0)}, \text{ where } m = \text{direct Al-SNF form, melt-dilute Al-SNF form, or HWGL.} \tag{9}$$

In eq. (9) $Q_m(t)$ is decay heat for m component at t years of storage time. As initial decay heat sources for the SNF and HWGL regions, $Q_{SNF}(0)$ is 8.58 W/assembly for the direct form and 5.63 W/assembly for the melt-dilute Al-SNF form, and $Q_{HWGL}(0)$ is 472.30 W/canister for the HWGL region. The Al-SNF heat source was based on the decay heat output from a standard-sized, generic MTR fuel assembly. The decay heat load for the HWGL region was computed using the production time of glass log canister, assuming 5 year old sludge and 15 year old waste precipitate. Thermal and radiative properties of the codisposal WP containing the direct and melt-dilute Al-SNF forms used for the present analysis are shown in Table 2. For the direct disposal option, a total of 64 Al-SNF assemblies packed in the central canister of the codisposal WP in Fig. 1 corresponds to about 50% SNF volume of the total canister volume. The remaining 50% volume of the direct Al-SNF canister is filled with helium for the reference design as back-filled gas. The gas region internal to the direct Al-SNF assembly bundle was assumed to be conduction-dominant since gas gap between the fuel plates is narrow (3.2mm gap). The volume-averaged thermal conductivity over the Al-SNF assembly region inside the canister was used as 34.60 W/mK as shown in Table 2. This helium gas region was treated as conductive medium conservatively since it is distributed inside the SNF canister uniformly and it is hard to define the solid surface boundary internal to the canister. It was also benchmarked against the data obtained by the separate effects test in the previous work (Lee, 1996). The melt-dilute canister has two separate material regions, SNF metal alloy ingot and back-filled gas regions. The metal ingot has high thermal conductivity of 175.20 W/mK for aluminum-uranium metal alloy containing 13.2wt% uranium. Harmonic averaging technique was used to compute the effective thermal conductivity at the interface of the metal alloy and backfilled gas regions since there is significant difference of thermal conductivity between the two neighboring computational cells of the interface.

A half-cylinder model of the codisposal WP shown in Fig. 1 was used as a computational domain for computational efficiency by imposing symmetrical boundary conditions along the centerline of the WP. An optimum grid of about 10000 cells was established from the grid sensitivity analysis.

The overall energy balance should be checked to demonstrate the adequacy of the grid used. This was done by using equation (10).

$$R(W) = -\int_{A_W} q_w^{''} dA + q^{'''} V_F \qquad (10)$$

where $q_w^{''}$ is heat flux along the wall surface boundary, and A_W and V_F are total wall surface area and fuel region volume, respectively.

Volumetric heat source term, $q^{'''}$, in equation (10) is provided by the decay heat input. For all the cases considered here, energy residual (R) is less than about 1.0 watt. For instance, the residual results for the codisposal WP under the reference design conditions are shown as function of grid number in Fig. 3.

The segregated solution technique was selected for the efficient computations of the present geological codisposal WP problems with internal heat sources. Numerical methods for the thermal analysis were described in detail in the previous work (Lee, 1996). A non-staggered grid approach for each control volume was used since the staggered grid approach prohibitively requires large storage of geometric information to describe a fully non-orthogonal grid.

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Figure 2. Non-dimensional decay heat sources for the direct and melt-dilute Al-SNF forms and the HWGL region as a function of storage time.

Table 2. Thermal and radiative properties of the codisposal WP components containing the direct and melt-dilute SNF forms for the present analysis.

Material	Thermal conductivity (W/mK)	Emissivity

SNF canister	Direct disposal form	34.60	---
	Melt-dilute form	175.20	---
	Canister wall	17.30	0.60
High-level Waste Glass Log (HWGL)		1.046	0.60
Back-filled gas	Air	0.036	---
	Helium	0.205	---
Codisposal WP inner wall		10.997	0.80
Codisposal WP outer wall		48.810	---

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Figure 3. Adequacy of the grid fineness for the present analysis (energy residual was computed by Eq. (10)).

Results and Discussions

Thermal performance analyses of the codisposal WP were made based on the well-defined decay heat sources shown in Fig. 2 and the reference conditions of Table 1. The thermal and radiation properties used for the present analysis are provided in Table 2. The direct and melt-dilute codisposal waste package temperatures were then computed for selected times during the first 2000 years after emplacement in the repository. The results for each of the two waste forms are presented and discussed below.

I. Direct Al-SNF Form:

A two-dimensional conduction-convection conjugate model combined with radiation was developed to investigate the detailed cooling mechanism of Al-SNF assemblies and HWGL packages completely enclosed inside the container in relation to the thermal performance of the repository codisposal WP. The results showed that radiation is the most dominant cooling mode among the three energy transport processes, conduction, convection, and radiation, under the present WP design. The analysis was performed based the two main models, which are referred to as the detailed model and the baseline model. The detailed model considers all the possible three heat transfer modes, while the baseline model neglects convective cooling mechanism in the analysis.

Maximum temperature for the baseline model is about 304 ^{o}C at the initial storage time (0 years of storage time). The conduction model predicts maximum temperature by 121 ^{o}C higher than the baseline model does. The detailed model predicts about 303 ^{o}C for the maximum temperature of the codisposal WP at 0 years of storage time under the reference conditions. Although there is slight difference of the maximum package temperatures between the baseline model and the detailed model, the cooling mechanism of the detailed model is quite different from that of the baseline model because of the natural circulation effect driven by back-filled gas internal to the enclosed WP.

The radial temperature profiles performed by the two models are compared in Fig. 4. The results of the detailed model provided quantitative estimation of the conservatism imbedded in the baseline model. The detailed model gave highly non-uniform package wall surface temperature such that top surface temperature of the WP is about 10 ^{o}C higher than that of the bottom surface. The detailed model results also showed that temperature gradients across the HWGL regions are much smaller compared to the baseline model results for a given elevation height from the bottom of the WP under a horizontal storage position. Radial temperature profiles for the two models are compared along the A-A' plane in Fig. 5. The results show that back-filled gas temperature of the detailed model around the HWGL region is more uniform than that of the baseline model. This is one of the evidences of the buoyancy-driven circulation internal to the codisposal WP. This phenomenon may be important in relation to the movement of water moisture around the WP surface inside a drift tunnel since the moisture directly affects corrosion of the WP materials. However, peak temperatures obtained by the detailed model are about 1 ^{o}C lower than those of the baseline model under the reference conditions. The baseline model has been used to assess the thermal performance of the codisposal WP under various possible design conditions mainly for computational efficiency since peak temperature of the WP is used as the current waste acceptance criterion ($T_{max} < 350$ ^{o}C).

From the computational results, it was found that there were small vortices near the five corners of the five glass log (HWGL) regions. These vortices helped to reduce the gas temperature of the central region inside the WP as a result of gas mixing. The results indicated that the natural covective flow regime around the Al-SNF canister was close to laminar flow ($Gr_D \approx 4.0\text{x}10^7 < 10^9$) as described in the previous section. The overall gas flow pattern internal to the WP is illustrated in Fig. 6.

It is noted that helium gas temperature changes smoothly from the hot side to the cold, and fluid velocity profiles corresponding to the temperature distributions are shown to be laminar as expected. The effect of fluid motion on the net heat transfer rate q" entering the system through the heated portion of the driving wall of the Al-SNF canister was evaluated and cast in dimensionless form as a Nusselt number (*Nu*) along the vertical wall.

$$Nu = \frac{q_{wall}''}{k\left(\Delta T\right)} = -\int_0^{1.0} \left(\frac{\partial q}{\partial h}\right)_{wall} dh \qquad (11)$$

Dimensionless parameters used in eq. (11) were defined as follows:

$q = (T - T_b)/(T_t - T_b)$, $h = \ell / L$,

T_b = bulk gas temperature,

T_t = temperature at the top surface of the Al-SNF canister, and L = heated length.

Finally, the numerical integration of eq. (11) was performed after the quasi-steady temperature field at 0 years of storage time under the direct codisposal WP option was obtained. The result was found to be about Nu ≈ 23, which is comparable to Nu ≈ 20 of the literature data (Canaan and Klein, 1996).

Figure 7 shows radial temperature distributions of the codisposal WP under the reference conditions as a function of storage time using the baseline model during the first 590 years of storage time. Maximum temperature for the baseline model is about 304 ^{o}C at the initial storage time. The present work was also conducted over a wide range of possible repository temperature conditions. Average temperature of the WP was found to be very close to geological ambient temperature at about 2000 years of storage time after emplacement of the WP in a repository.

II. Melt-Dilute Al-SNF Form:

Aluminum-clad DOE SNF disposition by the melt-dilute technique is one of the alternate SNF treatment technology options. For this option, the aluminum based highly enriched uranium will be melted and diluted with U-238 to reduce the U-235 enrichment to 10 to 20%. In the melt-dilute disposition option, decay heat loads of the SNF canister of the codisposal WP will be dependent on how many assemblies will be melted and diluted to be packed in a DOE SNF canister. The majority of these assemblies will be Material Test Reactor (MTR) type such as aluminum-clad fuel (Al-SNF). The decay heat source per each assembly processed in the melt-dilute option is slightly lower than for each assembly of the direct disposal option since it is assumed that melting will release all of the Kr-85 and some fraction of cesium isotopes, Cs-134 and Cs-137 including Ba_m-137 daughter product. Decay heat source for HWGL will be the same as that of the direct disposal option. The heat source terms for other possible cases of the melt-dilute forms are being developed and will be analyzed in the near future.

The results from using the detailed model showed that flow and temperature profiles of the melt-dilute WP are basically similar to those of the direct disposal WP. The thermal performance analysis of the melt-dilute codisposal WP was performed mainly by using the baseline model under the reference design conditions provided in Table 1. The analysis for the air-cooled WP was also performed at the initial storage time. The paper presented the results for the helium-cooled codisposal WP with decay heat loads shown in Fig. 2 and 100 ^{o}C ambient temperature of a repository using the reference conditions. The case considered here is the SNF canister filled with 90 vol.% of melt-dilute ingot corresponding to 121 fuel assemblies. The ingot is 20% enriched alloy metal containing the composition of aluminum-13.2 wt.% uranium. Table 2 shows thermal and radiation properties of the codisposal package components containing melt-dilute disposition ingot used for the present analysis. Figure 8 shows the radial temperature distributions for the 90 vol.% case along the A-A' line shown in the same figure for selected times during the first 2000 years of storage time. Peak temperature at initial storage time ("0" year) is about 264 ^{o}C, and surface temperature of the WP is about 212 ^{o}C. Temperature gradient across the helium region is much steeper than that of any other region internal to the WP during the first 50 years of storage times. After 600 years of storage time, temperature of the WP becomes uniform over the entire region of the package.

Finally, Fig. 9 compared peak temperatures of the He-filled codisposal WP’s containing the two options, which are the direct and 90 vol.% melt-dilute AL-SNF canisters. The results show that peak temperature of the direct codisposal WP is about 40 ^{o}C larger than that of the 90 vol.% melt-dilute WP at 0 years of storage period although decay heat load for the direct option is about 8% lower than that of the melt-dilute option. It is noted that the melt-dilute WP has 90% metal volume of the SNF canister compared to about 50% of the SNF volume for the direct Al-SNF WP.

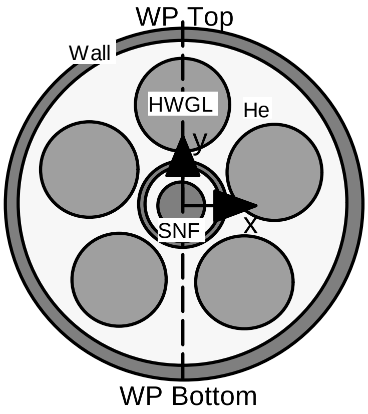

Figure 4. Comparison of centerline temperature distributions based on the baseline model and the detailed model for the direct codisposal WP.

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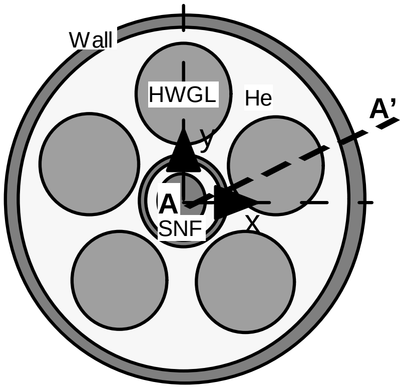

Figure 5. Comparison of radial temperature distributions based on the baseline model and the detailed model for the direct codisposal WP.

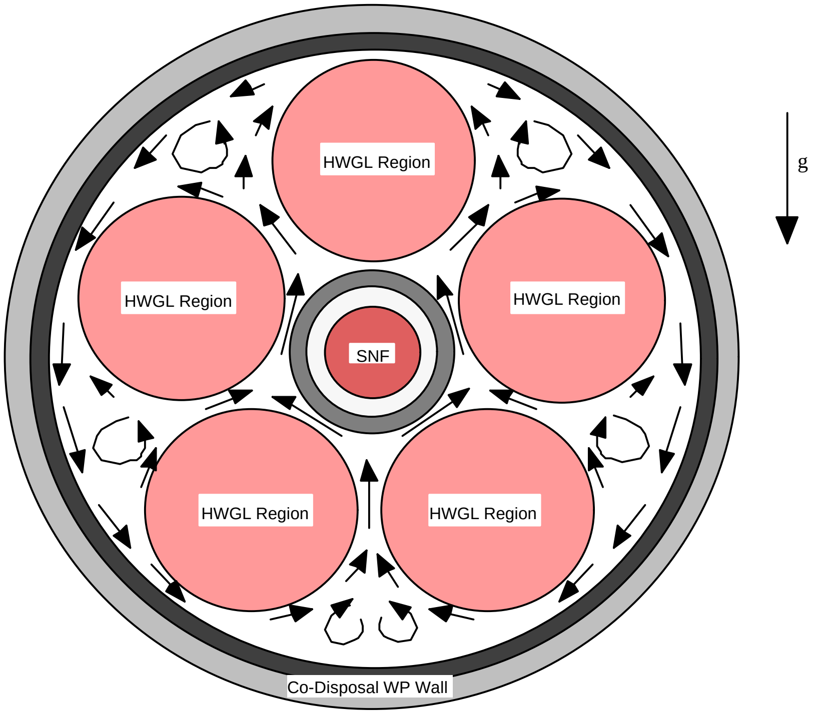

Figure 6. Overall flow pattern due to natural convective effect in an enclosed codisposal WP.

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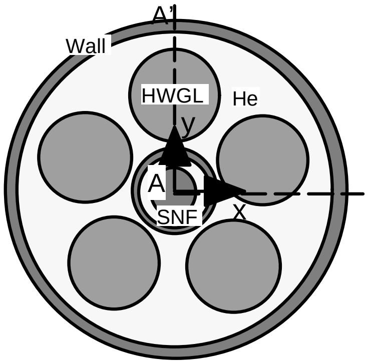

Figure 7. He-cooled direct codisposal WP temperature distributions for various storage times based on the baseline model.

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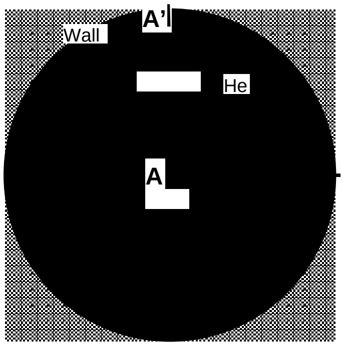

Figure 8. Radial temperature distributions of He-cooled 90% volume melt-dilute codisposal WP for various storage times based on the baseline model.

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Figure 9. Comparison of maximum temperatures for the He-cooled codisposal WP's containing the direct and 90 vol.% melt-dilute SNF forms.

Conclusions

Two main models, the detailed model and the baseline model, were developed to investigate the detailed cooling mechanism of the codisposal WP using computational heat transfer approach and to assess the thermal performance of the geological codisposal WP designs using well-defined decay heat source terms for the standard-sized DOE Al-SNF assemblies. Two-dimensional model predictions of temperature distributions were made for the He-fillled codisposal WP containing one of the two Al-SNF forms. They are the direct Al-SNF form and the melt-dilute form.

For the present analysis, decay heat loads for the two Al-SNF disposal forms and the HWGL regions internal to the codisposal WP were computed using the ORIGEN code under SCALE system. Reference model boundary conditions were provided by the WP performance requirements of a drift tunnel repository. In this project, the direct Al-SNF and the melt-dilute options were considered using the codisposal WP configuration for the alternative SNF treatment program. The results showed that both disposal options with a helium-filled WP satisfied the present waste acceptance criteria for the WP design in terms of the peak temperature criterion, C, under the reference conditions.

It is noted that radiation is the most dominant cooling mode among the three heat transfer modes under the present WP design conditions. The results show that the use of the melt-dilute form as a SNF disposal option has an advantage in terms of the package coolability and SNF disposition efficiency although chemical and preparation processes for the melt-dilute option are more complicated than those of the direct Al-SNF option.

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