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A THERMAL ANALYSIS OF A DRY STORAGE SYSTEM - TN-24P CASK

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ABSTRACT: *The capability of on-site storage of used nuclear fuels(UNF) generated in the domestic nuclear power plants is project to reach the limit from the year of 2024. It seems necessary to utilize dry storage casks for the interim storage of used nuclear fuels at near future. Hence the accurate thermal safety evaluation of a dry storage cask looks quite important. The evaluation of the peak temperature of the fuel cladding for the safe storage of UNF is very important. The temperature in a dry storage cask should remain below a specified limit (400 ºC) to prevent unacceptable degradation during storage. The heat transfer properties of the Transnuclear, Inc. TN-24P dry storage cask with 24 PWR used fuel assemblies were measured at the Idaho national engineering laboratory. The temperatures of the claddings of UNF were measured to be acceptable (below 400 ºC) under backfill gases such as nitrogen, and helium and under the vacuum in the cask in a vertical orientation. In this work, the temperature distributions in UNF in the TN-24P vertical cask were obtained by conjugate heat transfer simulations. The COMSOL MULTIPHYSICS 5.2a computer program was used to evaluate the conjugate heat transfer simulations coupling with three types of heat transfer by solids and fluids and the natural convection fluid flow. Three cases of simulation (under helium, nitrogen gases and vacuum) were performed to get the temperature distributions of UNF in the cask. Comparison of the simulation results and measured values from the tests for the three conditions showed good agreement within 10% in the active region.*

KEYWORDS: *TN-24P Dry Storage Cask, Thermal Evaluation, COMSOL MULTIPHYSICS Program, Conjugate Heat Transfer, Backfill Condition.*

I. INTRODUCTION

The capability of on-site storage of used nuclear fuels (UNFs) generated in the domestic nuclear power plants is project to reach the limit from the year of 2024. It seems necessary to utilize dry storage casks for the interim storage of used nuclear fuels at near future. Hence, the accurate thermal safety evaluation of a dry storage cask looks quite important. The evaluation of the peak temperature of the fuel cladding for the safe storage of UNFs is very important. The temperature in a dry storage cask should remain below a specified limit (400 ºC) to prevent unacceptable degradation during storage. The heat transfer properties of the Transnuclear, Inc. TN-24P dry storage cask with 24 PWR used fuel assemblies were measured at the Idaho national engineering laboratory. The temperatures of the claddings of the UNFs were measured to be acceptable (below 400 ºC) under backfill gases such as nitrogen, and helium and under the vacuum in the cask in a vertical orientation. In this work, the temperature distributions in the UNFs in the TN-24P vertical cask were obtained by conjugate heat transfer simulations. The COMSOL MULTIPHYSICS 5.2a computer program was used to evaluate the conjugate heat transfer simulations coupling with three types of heat transfer by solids and fluids and the natural convection fluid flow. Three cases of the simulations under helium, nitrogen gases and vacuum condition were performed to get the temperature distributions of the UNFs in the cask.

II. METHODS AND RESULTS

II.A. Heat Transfer Performance Testing of TN-24P Cask

The heat transfer performance testing of the Transnuclear, Inc. TN-24P dry storage cask with 24 PWR used fuel assemblies was conducted at the Idaho national engineering laboratory. The cask is 5.0 m long and 2.3 m in diameter and weighs approximately 100 tons when loaded with unconsolidated PWR UNFs. The fuel basket within the cask is configured to hold 24 PWR UNF assemblies and is composed of stacked, interlocking plates constructed of aluminum and boron. The Surry UNF assemblies used during testing are of a standard Westinghouse 15X15 rod design. The decay heat output of the assemblies ranged from 845 to 919 watts, with an average output per assembly of 860 watts at the start of testing. The fuel assemblies had cooling times of 50 months at the start of testing. The load pattern placed the hot assemblies in the center of the basket and the cooler assemblies around the outside. The vertical view and radial cross section of the TN-24P dry storage cask are shown in the left and right figure of Fig. 1, respectively (Ref. 1).

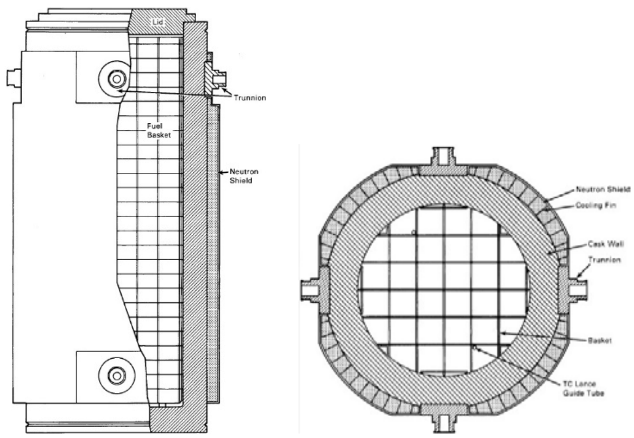


Fig. 1. Vertical and radial view of TN-24P cask.

The vertical cask test matrix included assessments of performance with a full load of 24 PWR UNF assemblies and vacuum, nitrogen, and helium backfill environments. Axial guide tube temperature profiles for three environments are shown in Fig. 2 (Ref. 1).

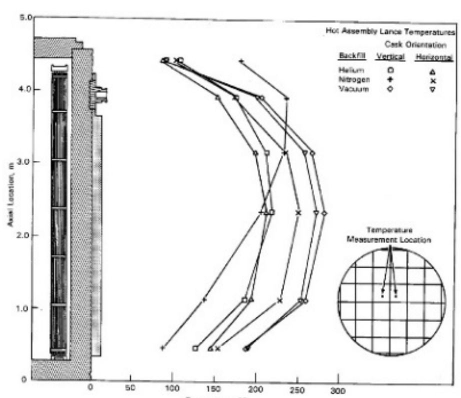


Fig. 2. Axial temperature profiles for three backfills.

II.B. Geometry of Heat Transfer Simulations

The COMSOL MULTIPHYSICS 5.2a computer program was utilized to evaluate the conjugate heat transfer simulations and validate temperature distributions in the TN-24P dry storage cask. The conjugate heat transfer simulations in the computer program is used to simulate the coupling between heat transfer and fluid flow. The heat transfer in solids or fluid provides features for modeling heat transfer by conduction, convection, and radiation. The turbulent fluid flow solves the Navier-Stokes equations for conservation of momentum and the continuity equation for conservation of mass. Flow close to walls is modeled using wall functions.

In this work, the geometry modeling for the TN-24P cask was set up with heterogeneous UNF assemblies to accurately assess temperature distributions in the cask. However, the symmetrical one-eighth geometry model was applied to perform the conjugate heat transfer simulations at a low computational cost as shown in Fig. 3.

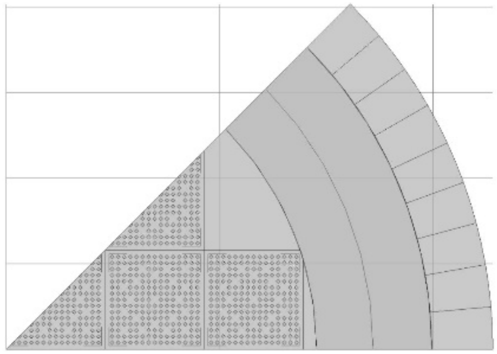
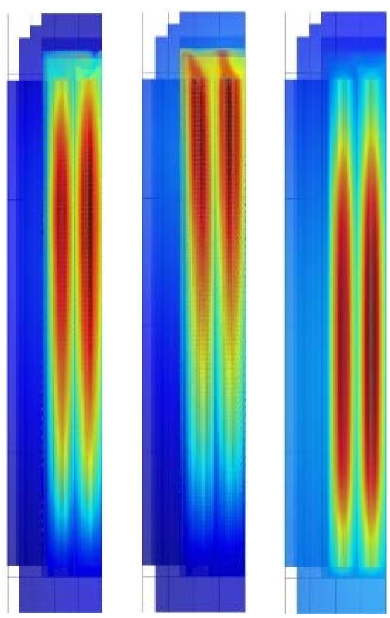


Fig. 3. One-eighth transverse section geometry.

II.C. Results of Heat Transfer Simulations

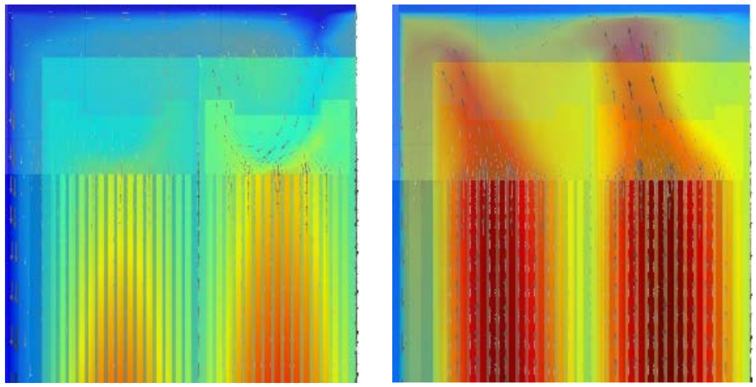
Three cases of the simulations under helium, nitrogen gases and vacuum condition were performed on steady state conditions to get the temperature distributions of the UNFs in the cask. The left, center, and right figure in Fig. 4 show the temperature distributions for the vertical orientation with helium natural convection, nitrogen natural convection, and vacuum radiation backfill conditions, respectively. The red color represents the high temperature, whereas the blue color represents the low temperature.



(a) (b) (c)

Fig. 4. Temperature distributions for (a) helium, (b) nitrogen, and (c) vacuum backfills.

The left and right figure in Fig. 5 show the flow distributions of the natural convections for helium and nitrogen backfill gas, respectively. The directions of arrows represent the directions of gas flows and their lengths represent the magnitudes of flow velocities. The turbulent gas flows at the upper backfill region occurred significantly.



(a) (b)

Fig. 5. Natural convection flows for (a) helium and (b) nitrogen backfill gas.

Figs. 6, 7, and 8 show the axial temperature profiles for the vertical cask with helium natural convection, nitrogen natural convection, and vacuum radiation backfill conditions, respectively. The black squares represent six measured temperatures at the location in Fig. 2 by the heat transfer performance testing of the TN-24P cask. The solid lines represent the calculated temperatures by the computer simulations. Comparison of the simulation results and measured values from the tests for the three conditions showed good agreement within 10% in the active region.

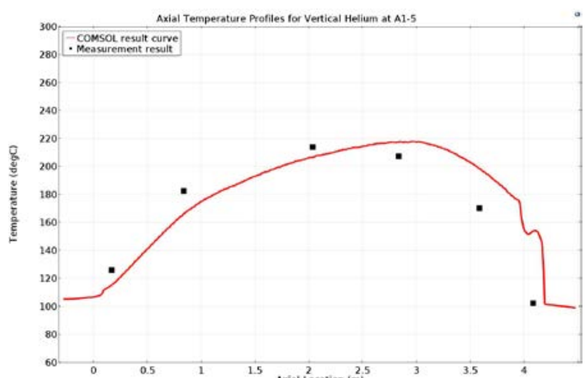


Fig. 6. Axial temperature profile for helium backfill gas.

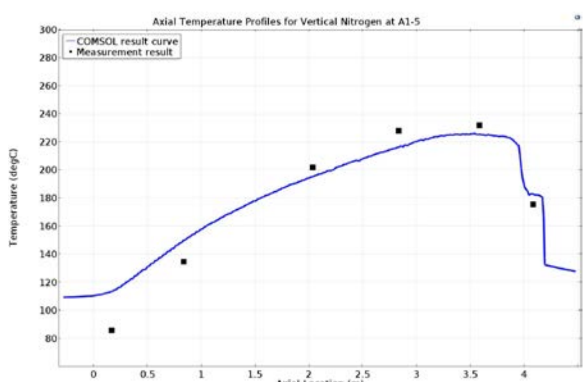


Fig. 7. Axial temperature profile for nitrogen backfill gas.

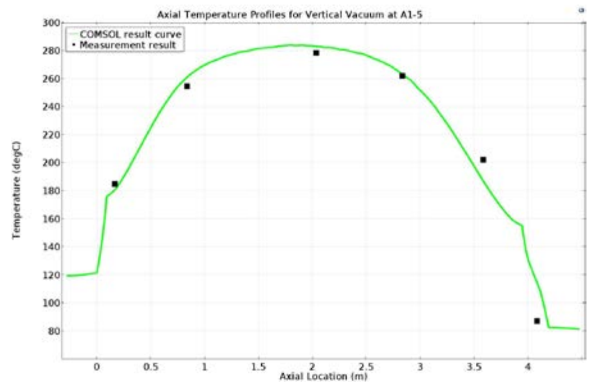


Fig. 8. Axial temperature profile for vacuum backfill.

The temperature profile for the vacuum backfill condition without any natural convection was symmetrical relative to the active fuel length. The calculated peak temperature of about 284 ºC occurred at the nearly center of active fuel rod. However, the temperature profile for the helium backfill gas with natural convection was skewed toward the upper one half of the active fuel length. The calculated peak temperature was about 218 ºC. The temperature profile for the nitrogen backfill gas with natural convection was skewed toward the nearly top of the active fuel length. The calculated peak temperature was about 226 ºC. The peak temperature and its location for the nitrogen natural convection was higher than that for the helium natural convection. Because the Nusselt number for the nitrogen backfill gas was about four times higher than that for the helium backfill gas as shown in Figs. 9 and 10. The Nusselt number is the ratio of convective to conductive heat transfer across the boundary. A larger Nusselt number corresponds to more active convection, with turbulent flow typically in the 100–1000 range. Thus, the nitrogen backfill gas occurred more natural convectively than helium gas or the helium backfill gas occurred more natural conductively than nitrogen gas.

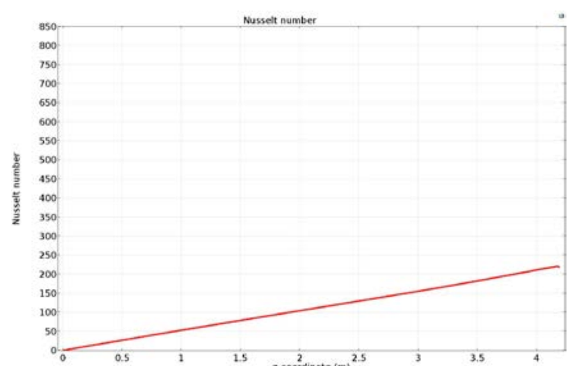


Fig. 9. Nusselt number for helium backfill gas.

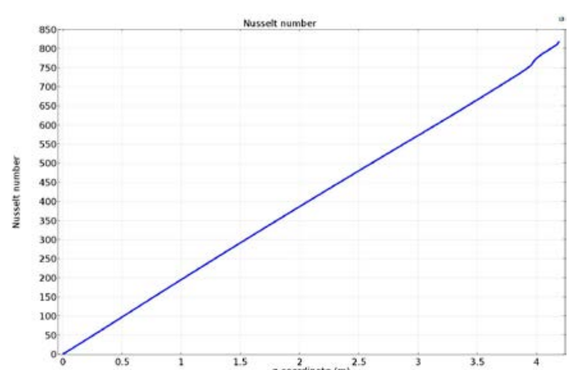


Fig. 10. Nusselt number for nitrogen backfill gas.

III. CONCLUSIONS

In this work, the temperature distributions in the UNFs in the TN-24P vertical cask were obtained by conjugate heat transfer simulations. The COMSOL MULTIPHYSICS 5.2a computer program was used to evaluate the conjugate heat transfer simulations coupling with three types of heat transfer by solids and fluids and the natural convection fluid flow. Three cases of the simulations under helium, nitrogen gases and vacuum condition were performed to get the temperature distributions of the UNFs in the cask. From the results, the following conclusions are drawn.

- Comparison of the simulation results and measured values from the tests for the three conditions showed good agreement within 10% in the active region.
- The temperature profile for the vacuum backfill condition without any natural convection was significantly higher than the other backfill condition.
- The temperature profile for the two backfill gases with natural convection were skewed toward the upper one half of the active fuel length. The peak temperature and its location for the nitrogen natural convection was higher than that for the helium natural convection.
- Because the Nusselt number for the nitrogen backfill gas was about four times higher than that for the helium backfill gas. In other words, the nitrogen backfill gas occurred more natural convectively than helium gas or the helium backfill gas occurred more natural conductively than nitrogen gas.

ACKNOWLEDGMENTS

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