DEPLETED-URANIUM DIOXIDE AS SNF WASTE PACKAGE PARTICULATE FILL: ENGINEERING PROPERTIES

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ABSTRACT

It is proposed that the void spaces in loaded spent nuclear fuel (SNF) waste packages (WPs) be filled with depleted uranium (DU) dioxide (DUO_2) sand-like particulates. The use of DUO_2 fill may reduce the long-term radionuclide release rate from the repository, reduce the potential for long-term nuclear criticality, and dispose of excess DU. The engineering feasibility of using fills depends upon (1) efficient methods to load fills into WPs containing SNF and (2) sufficient fill thermal conductivity to remove decay heat from the SNF. DUO_2-helium fill properties were determined from experiments reported in the literature. Based on this experimental data and analysis, the evidence indicates that it is practical to load WPs with a fill and that this fill will not significantly impact SNF temperatures.

I. INTRODUCTION

DUO_2 particulate fills are being investigated for use in repository WPs containing SNF. The WP with DUO_2 fill would be similar to the WPs currently proposed for the Yucca Mountain (YM) repository. The WP would be first filled with SNF and then filled with DUO_2 particles ranging in size from 0.5 to 1 mm. These particles would fill void spaces in the WP and the coolant channels within each SNF assembly (Fig. 1).

The use of DUO_2 has several benefits[1-3]. It reduces the repository criticality concerns by reducing the average ^{235}U enrichment in the WP. It may reduce radionuclide release rates from the SNF and WP by (1) creating chemically reducing conditions near the SNF that slow fuel degradation, (2) reducing the permeability of the WP to groundwater flow, and (3) acting as a colloid filter and radionuclide absorber to remove radionuclides from groundwater. This application of DU could potentially use much or all of the excess DU in the United States.

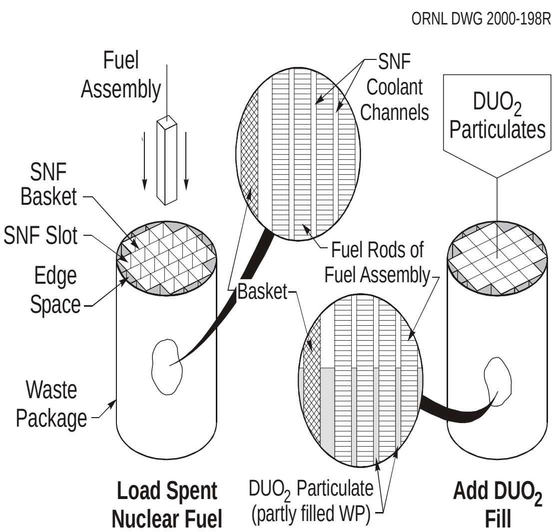

Fig. 1. WP loading sequence.

While there are long-term benefits to the use of DUO_2 fill, there are shorter-term engineering issues that must also be addressed: (1) methods to add particulate fill to the WP and (2) the temperature increase or decrease from added fill. A review and evaluation of experimental data from the literature on the properties and behavior of UO_2 particulate beds in helium were undertaken[4] to provide the data to address these engineering issues. The fill properties and the engineering implications are discussed herein.

II. FILL METHODS

Significant experimental data[4] has been obtained on UO_2 particulate fills to support development of (1) fuel fabrication processes and (2) particulate fuels, where a UO_2 particulate is packed into a fuel pin. Several observations follow from the data.

- *Fill densities*. If a small range of particulate sizes is used, fill efficiencies of -65 vol % can be obtained when filling packages with complex internals—such as SNF WPs. If an appropriate binary-size mixture is used with appropriate fill procedures, fill efficiencies >80 vol % can be obtained.

- *Fill operations*. Single particulate size loadings can be done using gravity filling with little or no vibration. Limited vibration can accelerate loading times and help achieve higher packing efficiencies.

Large-scale experiments have been conducted on the use of fill materials in SNF WPs. In all of these experiments, the fill particulate had a small range of sizes. These experiments have used a variety of materials, but not UO_2.

- *Canada*. The Canadian repository program has proposed disposal of SNF in thin-walled titanium WPs with an inert particulate fill to support the outside wall against external pressures and thus prevent wall collapse. A large-scale development program was initiated, and the fill concept has been successfully demonstrated[5] on full-scale WPs in hydrostatic test chambers to 10 MPa. The WPs with dummy fuel assemblies and fill did not crush and thus demonstrated that there were no significant void spaces in the WPs. The fill was added with limited vibration of the WP. While this program did not examine DUO_2 fill, many other fill materials were shown to be viable for this application. The CANDU SNF clearances between fuel pins are less than the clearances in a light-water reactor (LWR) fuel assembly; thus, filling LWR SNF assemblies is expected to be a simpler operation than filling CANDU SNF assemblies.

- *United States*. The United States has successfully conducted limited fill experiments with dummy pressurized water-reactor (PWR) fuel assemblies using steel shot and gravity loading techniques. The density of the steel (7.86 g/cm^3) is less than the theoretical density of DUO_2 (10.96 g/cm^3).

The experimental data reported in the literature (1) show that SNF WPs can be successfully filled with many particulate fills and (2) strongly suggests that there should be no major barriers to filling such WPs with DUO_2 particulates.

III. THERMAL BEHAVIOR OF UO_2 FILL

There is a maximum temperature limit of 350EC on SNF in a YM WP to avoid fuel-clad degradation. The added fill must not significantly raise the SNF temperature. Literature data on experimental measurements of the thermal conductivity of UO_2 particulate beds with helium atmospheres were identified[4] and used to evaluate the thermal impact of fills on SNF temperatures.

A. Thermal Conductivity Measurements

Significant experimental data exists on the thermal conductivity of UO_2-helium particulate fills. The thermal conductivity is a function of the gas composition (large effect), particle size, fill density and temperature. Selected experimental thermal conductivity data[4,6] are shown in Fig. 2. Because the fill is used in the hottest locations within the WP, measured thermal conductivity between 300 and 350EC are the applicable data. For the projected DUO_2 fill, the thermal conductivity of a DUO_2-helium particulate bed, as shown in Fig. 2, is expected to be -0.01 W/EC-cm.

B. SNF Temperatures

The impact of the fill material on SNF temperatures was examined for the proposed YM 21-PWR fuel-assembly WP (Fig. 1 and Fig. 3). The SNF basket structure extends from the bottom to the top of the WP, and the WP in the repository will be on its side. The basket walls are a multilayer construction of steel, neutron absorber, aluminum, and steel. The aluminum acts as a thermal shunt to transfer heat from the center of the WP to the outer WP wall. The heat-transfer path is from the fuel assembly to the basket wall, to the cask body, and into the repository drift. The primary impact of a fill is on the heat transfer from the center of a fuel assembly to the nearest basket wall.

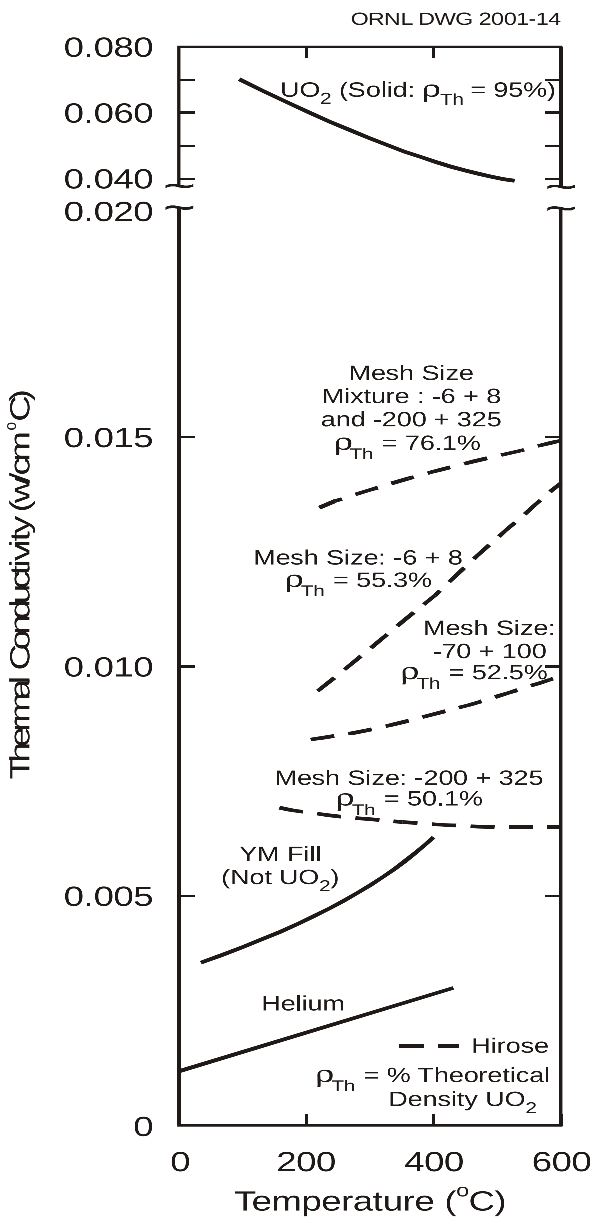

Fig. 2. Measured thermal conductivity for uranium dioxide particulate beds in helium (1 atm).

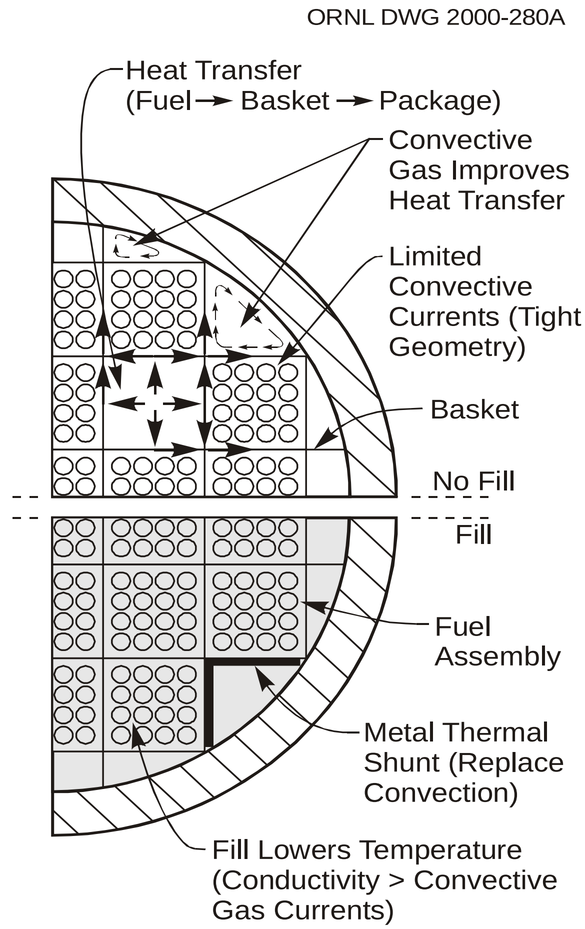

Fig. 3. Fill may improve or reduce heat transfer in a WP.

The WP has a maximum allowable heat load of 11.8 kW. The expected fill thermal conductivity is -0.01 W/cmEC. For this case, the temperature rise from the basket to the center of a 17×17 PWR fuel assembly with a DUO_2-helium fill is 7.1EC. A YM project thermal analysis[7] of an earlier design of a 21-assembly WP with another fill material with the same thermal conductivity yielded a temperature rise of 9EC with fill and 14EC without fill. All of these temperature rises are small compared to maximum allowed fuel-clad temperature (350EC).

The YM project has completed a 1000-year repository thermal analysis[8] for WPs with and without fill. In this analysis, the fill thermal conductivity was based on another fill material with the fill thermal conductivity varying from 0.00379 W/cm-EC at 50EC to 0.00658 W/cm-EC at 351EC (Fig. 2). These thermal conductivities are significantly less than the measured thermal conductivity of the DUO_2-helium fill (0.01 W/cm-EC); thus, the use of the DUO_2-helium fill would be expected to result in lower temperatures than were obtained in this analysis. At different times, the WP with and without fill had the highest internal temperatures. At peak temperatures, the WP with fill had a temperature of 347.5EC vs 345EC for the WP with no fill.

The analysis provided insights to the heat transfer mechanisms (Fig. 3). DUO_2 fill reduces heat transfer by the thermal convective flow of helium gas. However, the thermal conductivity of UO_2 is about 50 times that of helium. Conductive heat transfer is increased. When a horizontal fuel assembly with its small geometric dimensions is inside a basket, the improved thermal conductivity of the fill, as a mechanism for heat transfer, is more important than the loss of thermal convective currents; thus, temperatures decrease. Thermal convective currents are small in tight spaces. In larger WP spaces, such as between the square basket grid and the round WP wall, heat transfer by convective helium flow may be significant and may be a more important heat transfer mechanism than thermal conductivity. In these locations, a fill may reduce heat transfer and increase temperature. If improved heat transfer is required in these spaces, additional aluminum or steel can be added as a thermal shunt.

IV. CONCLUSIONS

Based on experimental data, there is reasonable confidence that DUO_2 particulate fill can be effectively emplaced in a WP with SNF. The thermal performance impact of DUO_2 fill is small. If the fill concept were implemented, large scale experiments should be undertaken to optimize fill-loading conditions.

ACKNOWLEDGMENT

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