CERMET WASTE PACKAGES USING DEPLETED URANIUM DIOXIDE AND STEEL

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ABSTRACT

It is proposed that the structural components and internal basket structures of the spent nuclear fuel (SNF) waste packages (WPs), which will be sequestered with the SNF at the repository, be constructed of a depleted uranium (DU) dioxide (DUO_2)–steel cermet. The use of such a cermet may (1) reduce the long-term potential for nuclear criticality in the repository, (2) improve repository performance, (3) provide radiation shielding, and (4) dispose of excess DU.

I. INTRODUCTION

It is proposed that the steel components of repository WPs be replaced with a DUO_2-steel cermet. The cermet consists of DUO_2 particulates embedded in a continuous-steel phase. Typical cermets use sandwich construction with clean uncontaminated steel layers on both sides of the cermet (Fig. 1).

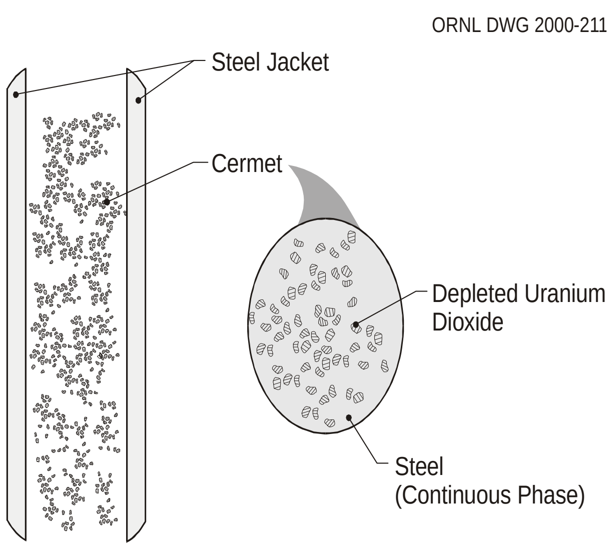

Fig. 1. A Cermet is a *CER*amic *MET*allic Composite

Cermets may meet near-term WP requirements (structural support, radiation shielding, criticality control) while (1) improving the long-term WP performance and (2) beneficially using excess DU. The use of a cermet is not WP- or repository-design specific; thus, it would be applicable to repository designs throughout the world. If a cermet were used for the WP body, an outer layer of corrosion-resistant metal would be chosen to maximize corrosion resistance in the particular geological environment. Cermets could be used as a first generation or second generation WP.

II. CERMET PROPERTIES

Non-uranium-oxide cermets are produced in large quantities (>100,000 tons/year) for a variety of applications. Uranium-dioxide stainless-steel (SS) cermets[1] have been produced with loadings up to 90 vol % UO_2. Cermets have been used as nuclear fuels and are currently being investigated in Europe[2] for very-high-burnup power-reactor fuels. A DUO_2-steel cermet has several desirable properties.

- *Contamination control*. Cermets allow the beneficial addition of DUO_2 to the WP (see below) without the potential for DUO_2 contamination during WP handling operations. The cermet is integral with the clean exterior steel surfaces.

- *Properties.* Cermets have properties between those of metals and ceramics. The use of cermets is a way to use a ceramic without the traditional weaknesses of ceramics—brittle failure and low tensile strength. Important characteristics of cermets include:

  – Material compatibility. Cermets can meet the functional requirements of a WP material with the use of the same materials of construction as are found in existing WPs (same grades of steel and DU in the same chemical form as that of SNF UO_2). No new materials are added that would further complicate the analysis of repository behavior.

– Properties. Unlike uranium metal that rapidly corrodes under moist anoxic conditions, cermets are stable in many environments and acceptable[3] for many uses and as a waste form.

– Variable properties. The ratio of DUO_2 to steel can be changed to produce particular desired properties. Most work on UO_2 cermets has been performed to produce better nuclear fuels; thus, high UO_2 loadings were desired. For WP applications, somewhat lower UO_2 loadings and different types of steel may be desired to minimize production costs and better match WP needs.

Multiple cermet manufacturing methods are possible. One option (Fig. 2) is to mix DUO_2 and iron powder and press the mixture into a flat compact. Large "picture frames" are fabricated from thick steel sections with the compact placed within the picture frame. A sheet of clean uncontaminated steel is placed above and below the picture frame. The edges are welded together, and the compact is vacuum degassed. The section is heated to a high temperature and rolled into a thinner plate to produce the final cermet. These operations are typical of many large, industrial, steel-fabrication activities, and, in principle, are low-cost operations. The cermet costs[4] are expected to be less than the costs for uranium metal because the cost to convert DU in its current form (UF_6) to UO_2 is significantly less than the costs to convert to uranium metal.

III. APPLICATIONS IN WP DESIGN

Cermets could be used for several WP applications as shown in Fig. 3 and described below:

- *Structural support*. Cermets could replace the steel structural components of the WP.

- *Shielding*. Cermets can be added to create a self-shielded WP[5]. A cermet with 65 vol % UO_2 will have a somewhat higher density (9.88 g/cm^3) than steel (7.86 g/cm^3).

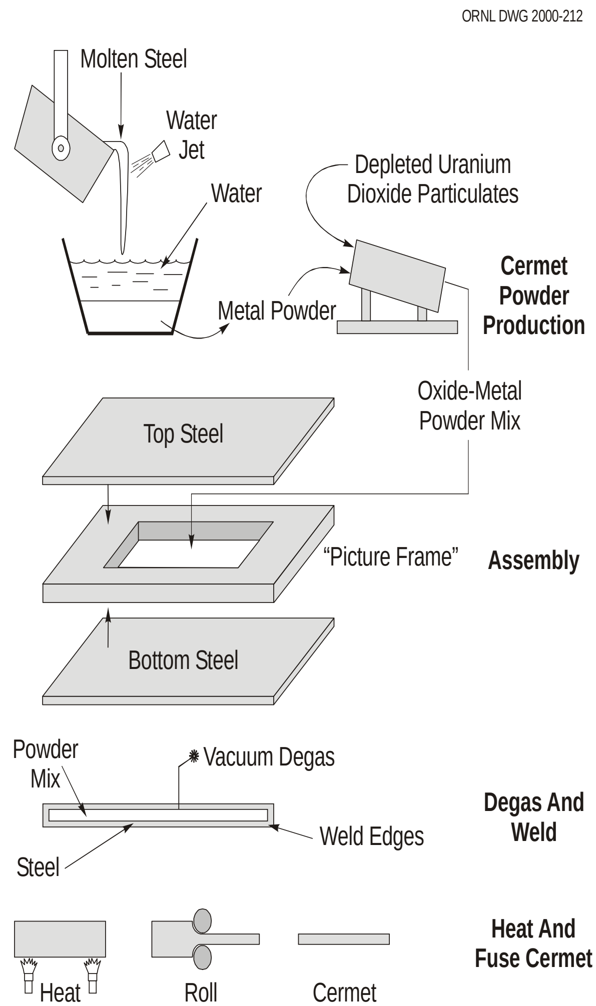

Fig. 2. Example Method for Cermet Production.

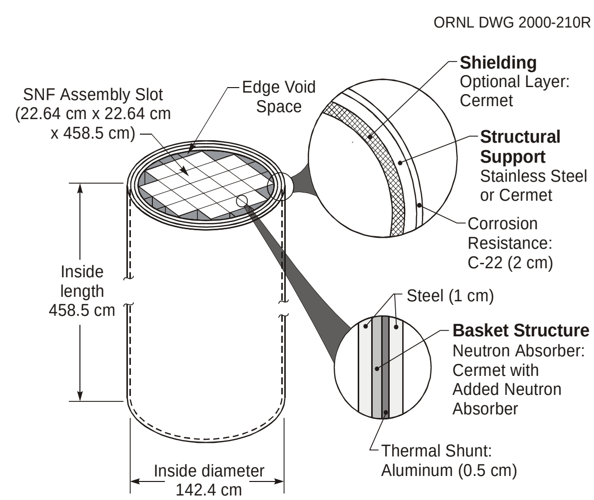

Fig. 3. Uses of Cermets in PWR Spent Nuclear Fuel WPs.

- *Waste basket*. The basket can be made from a cermet. In this application, rare-earth oxides or other good nuclear absorbers may be added to the DUO_2 ceramic particulate during the manufacturing process to create a cermet that meets all waste basket criticality-control requirements.

IV. LONG-TERM IMPROVEMENTS IN REPOSITORY PERFORMANCE

Cermets may create added chemical and nuclear barriers to slow the migration of radionuclides from the SNF to the accessible environment. These mechanisms are initiated after WP failure, the entry of oxidizing air and groundwater into the WP, and the start of corrosion of the cermet. Steel, which is the continuous phase, will oxidize before the DUO_2 does. Consequently, the initial degradation of the interior basket and WP will result in the cermet being converted to a mixture of iron oxides and DUO_2 particulates. The degradation products of the WP will surround the SNF with this mixture. This has several potential benefits[6].

- *Slowing the degradation of SNF*. SNF UO_2 does not degrade under chemically reducing conditions. Radionuclides are trapped in the UO_2 pellets and can not escape until the SNF UO_2 is oxidized and dissolved in groundwater. The UO_2 must be oxidized to UO_2^{+2} for rapid degradation to occur. Chemically reducing conditions may be maintained after WP failure by adding materials to the WP that remove oxygen from the groundwater. Oxygen is removed from groundwater as the iron oxidizes to rust and the DUO_2 oxidizes to a mixture of U_3O_8 and $UO_3 \cdot xH_2O$. Iron oxidizes before the DUO_2 does. As long as metallic iron or DUO_2 remains, chemically reducing conditions will remain in the WP with slow SNF degradation.

- *Removing radionuclides from groundwater*. Recent SNF leaching experiments show that certain long-lived radionuclides (e.g., neptunium) are retained by hydrated uranium oxides—such as those created by oxidation of DUO_2. Hydrated iron oxides (hydroxides) will also retain a variety of radionuclides by several mechanisms. In addition, the various degradation products will filter various radioactive colloids (small particulates) from the groundwater.

- *Ensuring nuclear criticality control*. The average enrichment of light-water-reactor SNF is equivalent to ~1.5 wt % ^{235}U in ^{238}U. There are two sources of ^{235}U: (1) ^{235}U originally in the SNF and (2) ^{235}U from the decay of ^{239}Pu. Many other SNFs have higher enrichments. At Okla, Gabon, Africa, prehistoric natural reactors operated at enrichments as low as 1.3 wt %. As the WP degrades, the DU is expected to mix with the SNF enriched uranium through dissolution, ion-exchange, and co-precipitation of the different uranium isotopes in the WP. By lowering the assay of fissile ^{235}U, the long-term potential of nuclear criticality in the repository is reduced.

  Cermets may be particularly useful for the disposal of higher-enriched SNF where long-term nuclear criticality control is a major design constraint[7]. DU is the ideal long-term neutron absorber because it has the same chemistry as does enriched uranium and thus follows the same pathways. The cermet allows the incorporation of both DUO_2 and other selected neutron absorbers into the WP structure.

V. DISPOSAL OF EXCESS DU

The United States[8] has ~500,000 tons of excess DU. Using the DU as a cermet in the WP avoids the disposal costs for this material. If self-shielded WPs are used, there is the potential to use half[5] or more of the entire DU inventory.

VI. OTHER APPLICATIONS

The cermet could be used in a SNF multipurpose canister system, in which the same package is used for multiple missions (storage, transport, and disposal). Compared to metals, many cermets have better properties to withstand severe events (fire, etc.); thus, they may be useful for some types of radioactive waste transport packages. Cermets have been proposed[9] for some Waste Isolation Pilot Plant WPs to provide radiation shielding and assure long-term criticality control in the repository. Slightly contaminated steel can be used in the manufacturing of the inner cermet and thus allow for the disposal of a secondary waste stream that is currently growing.

VII. CONCLUSIONS

Scoping evaluations indicate the potential value of a DUO_2-steel cermet WP: improved repository performance, reduction in the potential for long-term nuclear criticality in the repository, and avoidance of disposal costs for DU and contaminated steel. The use of a cermet allows the introduction of UO_2 into the WP with minimal impact on the operational characteristics of the WP—no external contamination and a ductile WP. However, significant uncertainties must be addressed before definitive conclusions can be drawn: (a) the trade-offs between cermet properties and production costs, (b) the economic benefits of avoiding disposal costs for DUO_2, and (c) the value of improvements in repository performance.

ACKNOWLEDGMENT

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