DEPLETED URANIUM APPLICATIONS IN GEOLOGICAL REPOSITORIES

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ABSTRACT

The world inventory of depleted uranium (DU) exceeds 10^6 metric tons. *All of this inventory* could potentially be used to improve the operations and performance of geological repositories that are designed for disposal of spent nuclear fuel (SNF). The DU in the form of depleted uranium dioxide (DUO_2) could serve as a particulate fill of void spaces in repository waste packages (WPs). Alternatively, the WPs could be constructed of a DUO_2-steel cermet. The cermet would consist of DUO_2 particulates embedded in steel with clean layers of steel on the exterior surfaces of the cermet. The cermet packages could also be used as multipurpose packages designed to transport, storage, and dispose of SNF or high-level waste (HLW).

The use of DU in repository applications assures its safe disposal. The DU in these forms can improve repository performance by (1) reducing the long-term potential for nuclear criticality in the repository; (2) reducing the radionuclide release rate from the WP; and (3) providing radiation shielding during SNF storage, transport, and disposal. The use of DU and the status of research on these applications are described.

I. INTRODUCTION

Most nuclear power plants require fuel with low-enriched uranium (-3% ^{235}U). To obtain the low-enriched uranium, natural uranium containing -0.7 wt % ^{235}U is separated into (1) a product stream enriched in ^{235}U and (2) a stream depleted in ^{235}U. For the production of light-water reactor (LWR) fuel, 5 to 7 tons of DU is generated for every ton of low-enriched fuel. The world inventory exceeds 10^6 tons, over 500,000 tons of DU which is in storage in the United States.

Methods are needed to use, store, or dispose of this DU. One possible option is in geological repositories designed for disposal of SNF. This option provides three potential benefits.

- *Safe disposal*. DU is a long-lived, chemically toxic, slightly radioactive material. Disposal in a repository ensures its safe isolation from humans. The United States is currently evaluating the construction of a repository for SNF and HLW at Yucca Mountain (YM). Studies (Owen 1999, Leeds 2000) indicate that this site would be suitable for disposing of all the DU in the United States.

- *Improved repository performance*. The use of DU in a geological repository can improve the repository performance by reducing the potential for release of radionuclides from the WP and site (Sect. 3.2).

- *Long-term strategy*. At the current time, uranium resources are sufficient to meet all demands. Sometime in the future, however, it may be necessary to process SNFs to recover fissile materials and recycle DU into advanced reactors. Use of DU in SNF WPs provides a means of safely disposing of both materials as well as co-locating them should future generations require these fissile and fertile materials.

Many of the benefits of using DU in a repository are somewhat unrelated to the way in which the DU is placed in the repository. For this reason, the various methods used to add DU to a repository are described first, followed by a discussion of the benefits of DU addition. Nonrepository applications of cermets are also briefly described. Finally, potential areas of research and development (R&D) for international cooperation are defined.

2. APPLICATIONS OF DU IN A REPOSITORY

DU can be used in any repository. However, our studies have focused on the use of DU at the proposed YM repository. A repository description is provided herein to assist with understanding of the DU applications. The proposed repository is located near Las Vegas, Nevada, in an unsaturated rock environment in which oxidizing chemical conditions exist. Figure 1 shows a cross section of a repository tunnel.

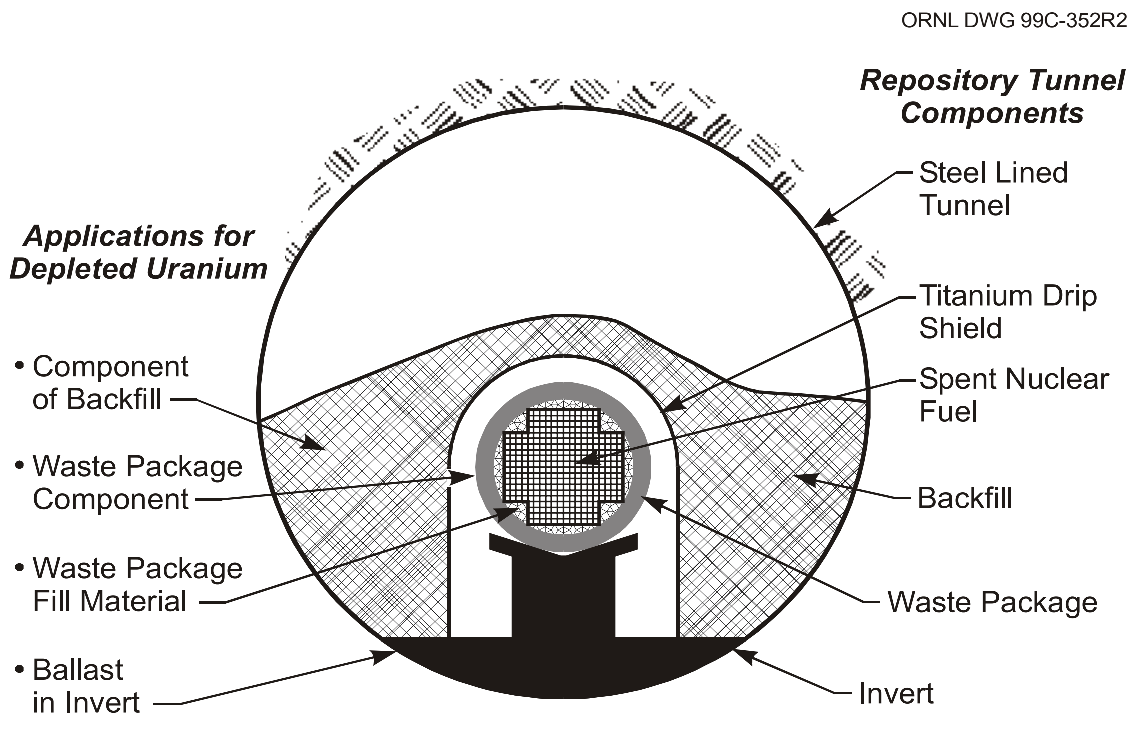

Fig. 1. Potential applications of DU in the proposed YM Repository.

The SNF or HLW is packed in WPs that contain up to 21 pressurized-water reactor (PWR) SNF assemblies or 5 HLW canisters. The filled WPs are transported by rail from the surface packaging facilities into the disposal tunnels and are placed horizontally in the tunnels. The WPs sit on an invert with titanium drip shields located above. Groundwater flows vertically from the surface and past the WPs to the saturated groundwater zone located several hundred meters under the WPs. Because of the direction of groundwater flow, the titanium drip shield acts as a secondary barrier to keep water away from the WPs. A backfill may be placed over the drip shield when the repository is closed. The backfill prevents falling rocks from damaging the WP or the drip shields.

2.1 USES

DU can be added to the repository in four forms (Fig. 1).

- *Fill*. DUO_2 particulates can be used to fill the void spaces within the WP—including the coolant channels within the SNF.
- *Waste Package*. The package can be constructed of uranium in various forms.
- *Invert.* The invert, the structure that supports the WP in the repository tunnel, can be constructed of uranium in various forms.
- *Backfill.* The backfill can contain DU as a component.

Associated with each use of DU is a set of constraints on the chemical form of the uranium. As will be discussed later, for most applications, the DU must be in the form of an oxide. The use of uranium oxides in repositories is accepted (Leeds 2000).

Our studies have focused on the use of DU as a fill and WP material. These two applications have the greatest potential benefits in terms of improving repository performance and have the least impact on repository operations. The use of uranium in invert and backfill applications, where the uranium is not as fully contained, increases the potential for contamination control problems during repository operations.

2.2 DUO_2 PARTICULATE FILLS

DUO_2 particulate fills are being investigated for use in repository WPs containing SNF. The use of fills would be expected to (1) improve the long-term WP performance and (2) beneficially use excess DU. The WP containing DUO_2 fill would be similar to those currently proposed for the repository. The WP would be first filled with SNF and then 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. 2).

If a small range of particulate sizes is used, fill efficiencies of ~65 vol % DUO_2 and ~35 vol % void space can be obtained when filling packages with complex internals, such as SNF. If an appropriate binary-size mixture is used with appropriate fill procedures, fill efficiencies >80 vol % can be obtained. For a YM WP with 21 PWR SNF assemblies, about 33 tons of DUO_2 with a 65% fill density can be added (Forsberg September 2000a). This results in 3.46 kgs of DU in the WP for every kg of uranium originally in the fuel. Significant experimental and engineering data on fill technologies are available, including the following:

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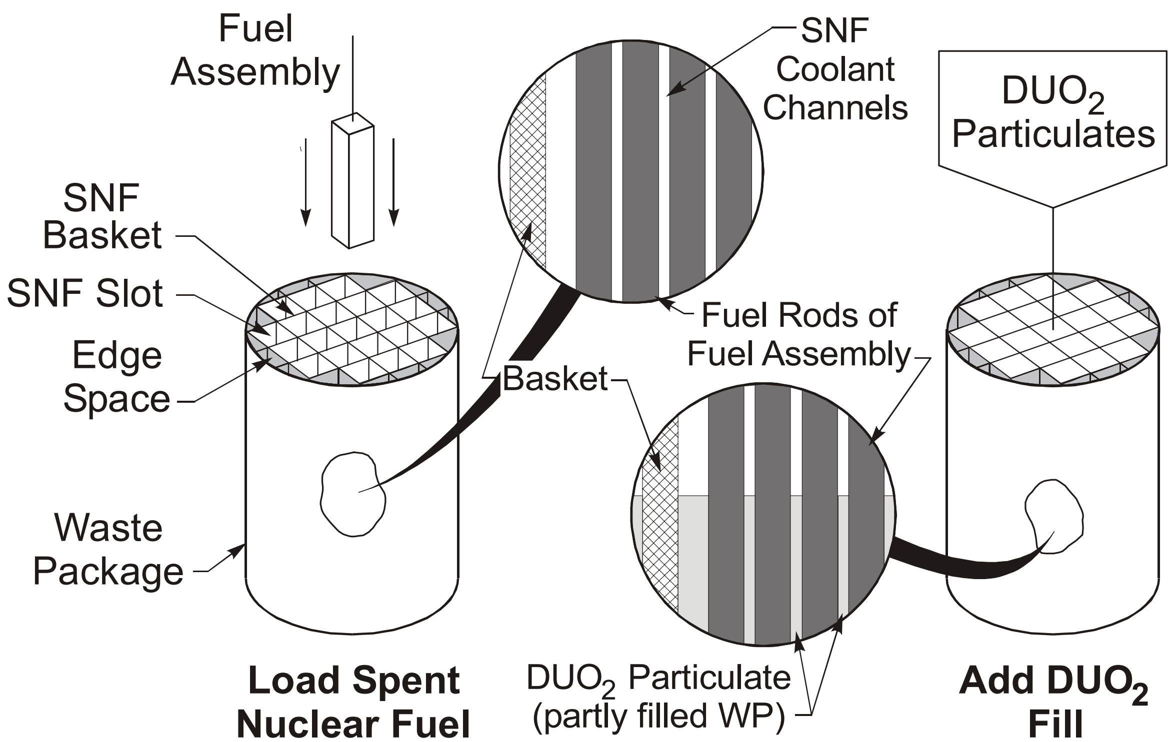

Fig. 2. Loading of DUO_2 fill into a WP.

- *Particulate properties*. Experimental property measurements exist for many fills, including UO_2 particulates (Hirose 1970). Most of the work on UO_2 particulate fills has been in support of developing (1) fuel fabrication processes and (2) particulate fuels, where a UO_2 particulate is packed into a fuel pin. Analysis and experiments also indicate that the use of a fill does not significantly impact the thermal behavior of a WP (Forsberg May 2001).

- *LWR assembly tests with steel shot*. The United States has successfully conducted limited fill experiments with dummy 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).

- *Full-package fill tests.* The Canadian repository program (Forsberg 1997) has proposed disposal of SNF in thin-walled titanium WPs with an inert particulate fill to support the outside WP wall against external pressures and thus prevent wall collapse. A large-scale development program was initiated, and the fill concept has been successfully demonstrated on full-scale WPs. While this program did not examine DUO_2 fill, many other fill materials were shown to be viable for this application. The clearances between fuel pins of SNF assemblies in CANDU SNF are less than those in an LWR fuel assembly; thus, particulate filling of a WP with LWR SNF assemblies is expected to be a simpler operation than particulate filling of a WP with CANDU SNF assemblies.

2.3 CERMET WPs

In this DU application, the steel components of repository WPs are replaced with a DUO_2-steel cermet. The cermet consists of DUO_2 particulates embedded in a continuous-steel phase (Fig. 3). The high-temperature cermet fabrication processes (Appendix A) limit the form of uranium to DUO_2—the stable high-temperature oxide. Typical cermets use a sandwich-type construction with clean uncontaminated steel layers on both sides of the cermet. The cermet becomes the structural component of the WP. The WP basket can also be made from a cermet. In this application, rare-earth oxides or other good nuclear absorbers may be added to the DUO_2 particulate during the manufacturing process to create a cermet that meets WP criticality-control requirements. Depending upon design goals, cermet WPs could consume 3 to 8 kgs of DU per kg of SNF-potentially the entire DU inventory.

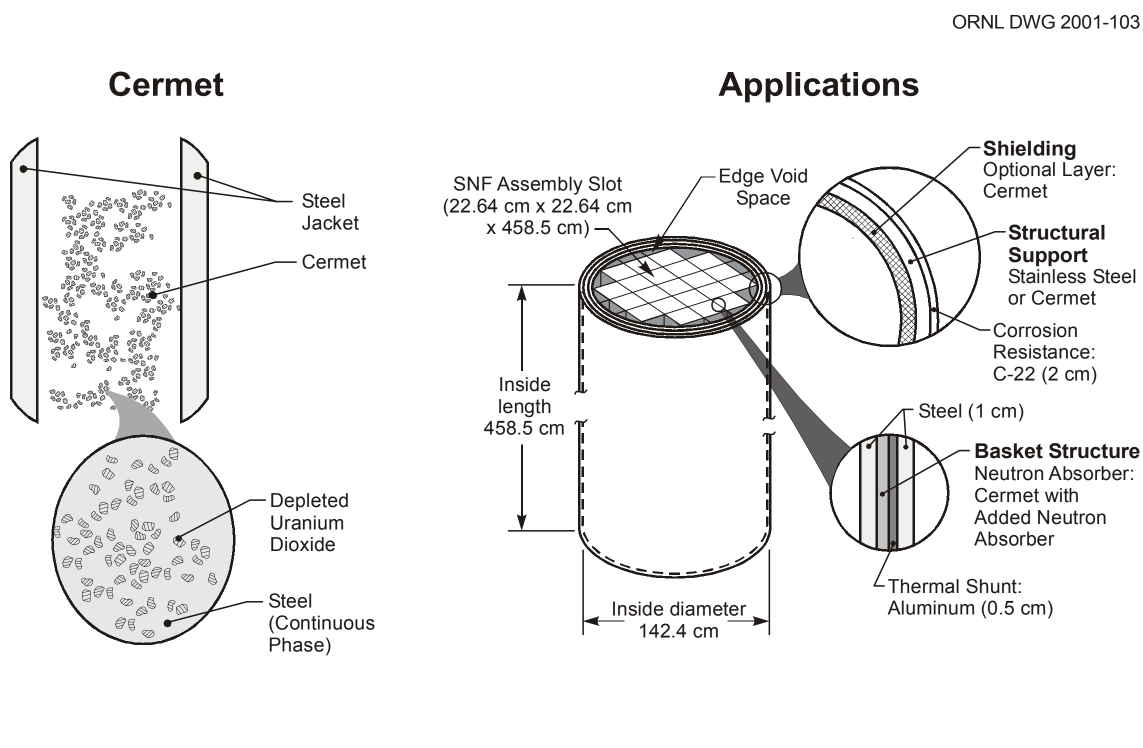

Fig. 3. Characteristics and uses of cermets in SNF WPs.

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. 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- or second-generation WP.

Cermet properties depend primarily upon the choice of metal and the ratio of DUO_2 to metal (Forsberg September 2001). Cermets are strong, tough materials that can operate at high temperatures and under severe conditions. The specific application determines the type of cermet to be used. In the 1950s, cermet fuels were investigated and used in 11 research and test reactors in the United States (Keller 1960, Arthur 1964). Uranium dioxide stainless steel (SS) cermets have been produced with loadings up to 90 vol % UO_2. Cermets are currently being investigated in Europe (Porta 1999) for use as very-high-burnup power-reactor fuels. As a consequence, the properties of cermets are reasonably well understood.

This application of DU in the repository provides major operational advantages. The DU is contained, and thus, no potential exits for uranium contamination in surface or underground facilities. For the repository operator, the use of DU is invisible and requires no special considerations.

Uranium metal is used in some SNF transport casks; however, the requirements for a repository are very different and extend for many thousands of years. Current information (Leeds 2000) indicates that oxides offer significant repository performance advantages over metal. The economics of this application must also be considered. The current evidence indicates that if many WPs are being fabricated, uranium metal is expected to be more expensive than an equivalent cermet because of the lower costs associated with making DUO_2 compared with those for DU metal.

3. REPOSITORY BENEFITS OF USING DU

3.1 SHIELDING

Repository designers in the United States have considered both shielded and unshielded WPs. Shielded WPs have major advantages: (1) the WPs can be used to store SNF to allow the radioactive decay heat to decrease before placement in the repository, (2) the WPs provide lag storage between surface and underground facilities to decouple these two operations, (3) underground operations are simplified, and (4) radiation interactions between the waste form and the geology are minimized. The primary penalty is the higher cost associated with shielded WPs. If low-cost methods to fabricate shielded WPs can be developed, there would be strong incentives to use such packages.

Although unshielded WPs are the baseline design for YM, the use of shielded WPs is also being considered. Proposed changes in the repository design are creating new incentives for considering shielded WPs. The YM project is evaluating alternative designs in which the repository remains open and is ventilated for 50 to 300 years. Ventilated repositories allow for the removal of the decay heat during the initial period when the decay heat is high. Ventilation during this time reduces the peak temperatures in the repository. Reducing the temperatures also reduces the degree of uncertainty associated with long-term repository behavior, may simplify licensing, and may allow design simplifications that result in significant cost reductions. With an extended maintenance and inspection period, incentives exist for reconsidering shielded WPs.

Both fills and cermets provide radiation shielding. If a fill is used, the shielding requirements for the WP are reduced. Waste packages containing DUO_2-steel cermets can provide full radiation shielding and better shielding (lighter and smaller packages) than most other WP materials.

- *Gamma shielding*. The gamma-shielding performance of the cermets is up to 30+ % better than that of steel because of the higher densities of the cermet. The densities of the different materials are as follows: 7.92 g/cm^3 for SS, 9.44 g/cm^3 for a cermet containing 50 vol % DUO_2, 10.66 g/cm^3 for a cermet containing 90 vol % DUO_2, and 10.96 g/cm^3 for DUO_2.

- *Neutron shielding*. Cermets have better neutron-shielding capability than steel. The high oxygen content (1.3 g/cm^3) in DUO_2 provides a neutron moderator to slow down fast neutrons and allow capture by thermal neutron absorbers. This quality is unique among high-density shielding materials.

A preconceptual design for a shielded YM WP was developed (Fig. 4) using the same design assumptions (when possible) as those used with the existing unshielded YM WP design. The WP is designed for 21 PWR SNF assemblies. The SNF has an average burnup of 40,000 MWd and is loaded into the WP 25 years after discharge from the reactor. The basket diameter is 1.424 m and the internal cavity length is 4.585 m. The radiation from the basket is 14,700 R/hour. The metal is 316 SS, the same as that used in the existing WP design. The inner WP is placed into a closely fitting 2-cm-thick outer WP, which is made of a corrosion-resistant nickel alloy (C-22) to ensure long-term integrity in the repository environment.

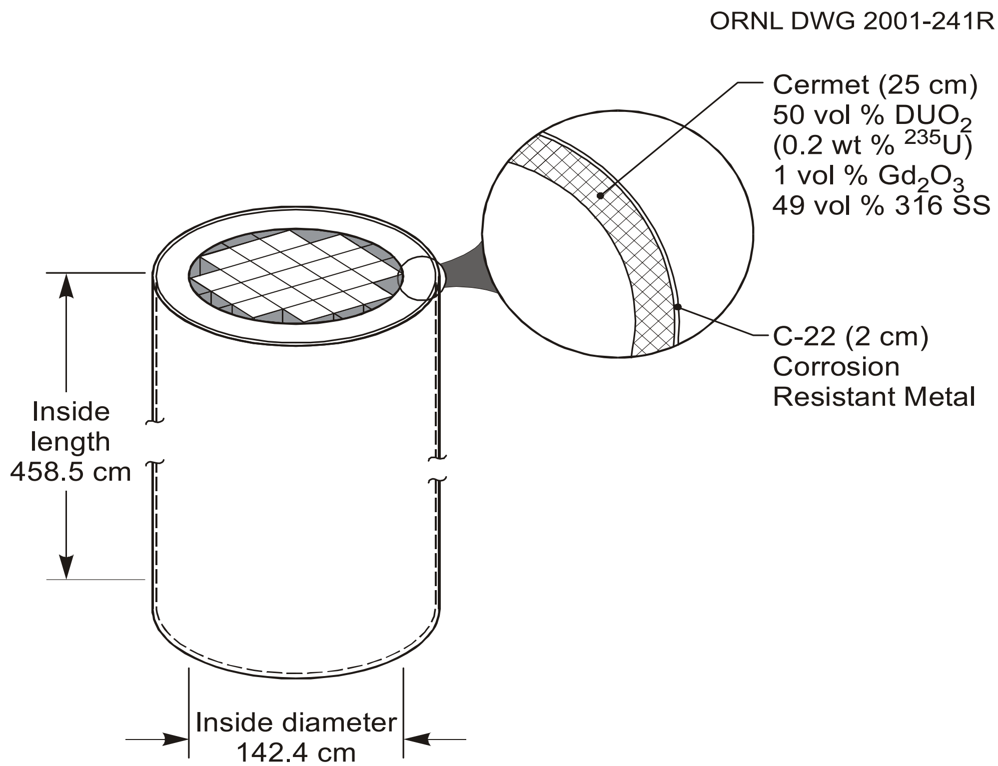

Fig. 4. Shielded cermet WP for 21 PWR SNF assemblies.

The inner shielded cermet WP is assumed to average 50 vol % DUO_2 with 0.2 wt % ^{235}U, 1 vol % Gd_2O_3, and 49 vol % 316 SS. This average cermet composition includes the cermet and its bonded clean-steel surface layers. The outer WP is composed of 2 cm of C-22 and is identical in composition, thickness, and function to the outer WP of the current YM WP design. For an external surface radiation dose of 200 mrem/h, the WP would consist of -25 cm of cermet and 2 cm of C-22. The cermet shell (with end pieces) weighs -70 metric tons. The WP design was chosen to meet the technical requirements (U.S. DOE March 6, 1999) but has not been optimized. An optimized design may use alternative neutron absorbers and different DUO_2 loadings in the cermet.

3.2 CRITICALITY

Over geological time, the SNF and the WP will degrade. Fissile materials will change chemical form and migrate. During these processes, fissile materials can become sufficiently concentrated to cause nuclear criticality to take place, as has happened the past (Forsberg September 2000b). At Okla, Gabon, Africa, prehistoric natural reactors operated at enrichments as low as 1.3 wt % ^{235}U in ^{238}U. The average enrichment of LWR 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.

Nuclear criticality should be avoided in a repository because it generates heat that may degrade repository performance and increases the amount of radioactive materials. Equally important, the potential for nuclear criticality may create uncertainties regarding the performance of a repository. Two strategies may be used to ensure that nuclear criticality does not degrade repository performance: (1) conduct a performance assessment of the long-term repository behavior in sufficient detail to show that either nuclear criticality cannot occur or it will not significantly impact repository performance or (2) add DU.

If DU is added to the WP, as the WP and SNF degrade, the DU is expected to mix with the SNF-enriched uranium through dissolution, ion exchange, and coprecipitation of the different uranium isotopes in the WP (Fig. 5). The uranium enrichment will be lowered sufficiently that nuclear criticality can no longer occur (Forsberg September 2000b). For criticality control, fills perform somewhat better than a cermet WP because of better intermixing of the fill and SNF assemblies.

3.3 SLOW RELEASE OF RADIONUCLIDES FROM THE REPOSITORY

Natural ore bodies containing UO_2, in the same uranium chemical form as that found in SNF, have remained intact for millions of years. In naturally occurring nuclear reactors, many fission products have not migrated from the original locations of the reactors. In some cases, the UO_2 has remained, although the particular geological environment would be expected to quickly degrade the UO_2. These different lines of evidence suggest that the UO_2 on the outer edges of the ore deposit may have acted as a sacrificial material to preserve the UO_2 in the interior zones of the deposits and that various other mechanisms associated with uranium chemistry helped preserve the deposits. The same approach may be used to help ensure the long-term preservation of SNF until most radionuclides have decayed to very low levels (Fig. 6). The mechanisms (Forsberg September 2000b) that can assist in the isolation of radionuclides in SNF are complex. A partial list and descriptions of the important beneficial effects are provided below:

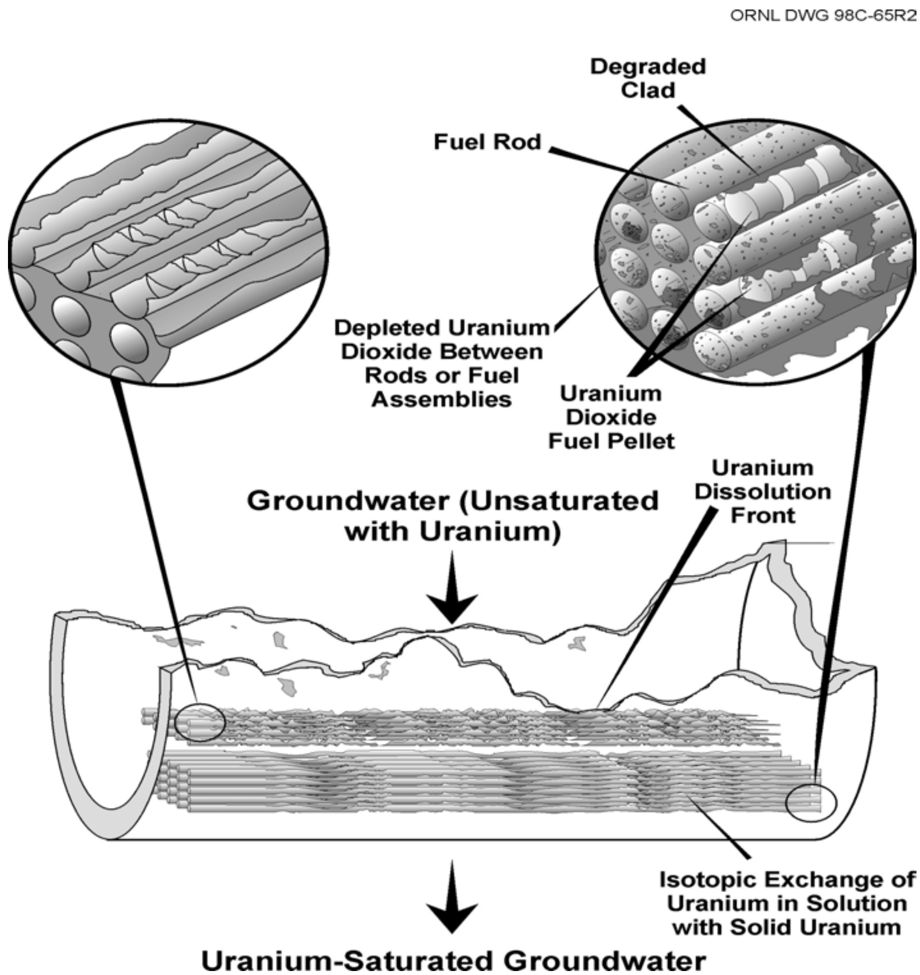

Fig. 5. Uranium isotopic exchange between DU and SNF eliminates the long-term potential for nuclear criticality as the WP and SNF degrade.

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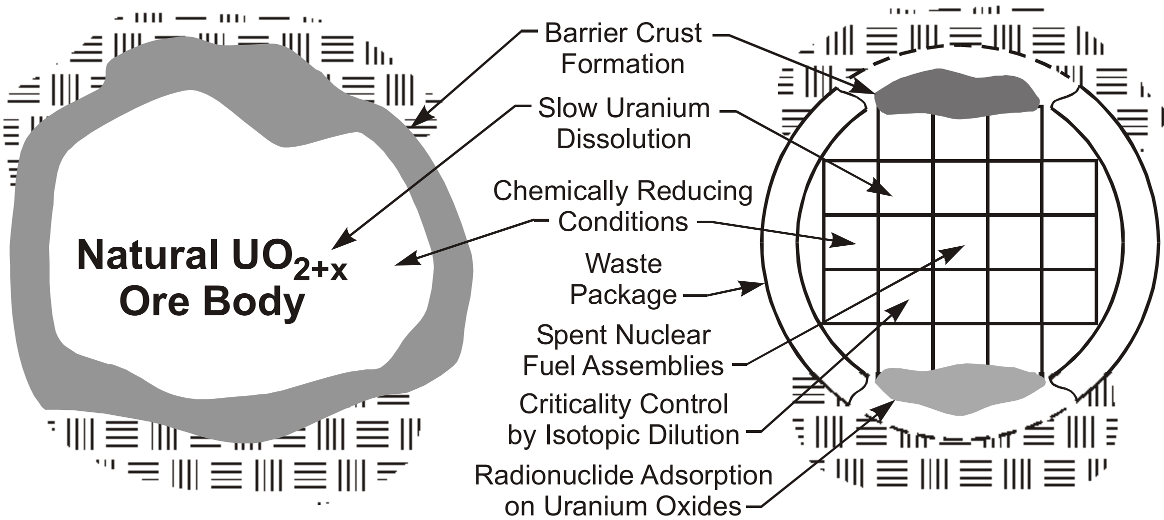

Fig. 6. Similarities in long-term behavior exist between uranium ore bodies and SNF WPs with DU.

- *Slowing the degradation of SNF*. SNF UO_2 does not degrade under chemically reducing conditions. Radionuclides are trapped in the UO_2 pellets and cannot 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—subsequently—the DUO_2 oxidizes to a mixture of U_3O_8 and $UO_3 \cdot xH_2O$. As long as metallic iron or DUO_2 remains, chemically reducing conditions will be maintained 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.

- *Blocking the flow of groundwater*. The oxidation of DUO_2 to higher uranium oxides and the ultimate transformation to silicates result in volume expansion. This expansion can block the flow of groundwater through the WP and thus slow migration of radionuclides in groundwater from the WP. Although groundwater flow can be reduced by using either fill or cermet WP baskets, better results would be expected from using fill materials.

In general terms, evidence suggests that the more DU associated with the WP, the better is the performance.

3.4 PRESERVATION OF WP GEOMETRY

The use of fill has one special advantage: it helps maintain the WP geometry even as the WP degrades. If there are no void spaces inside the WP, it cannot collapse as it weakens because of WP corrosion (Fig. 7). The basic geometry remains intact and any exterior engineered barriers to radionuclide release are not compromised by collapse or consolidation of the WP (Forsberg October 1997, Forsberg September 2000b). As discussed earlier, the Canadian repository program has extensively investigated the specific advantages of fill materials. Such benefits apply to the use of any fill material, not just to the use of DUO_2 fill.

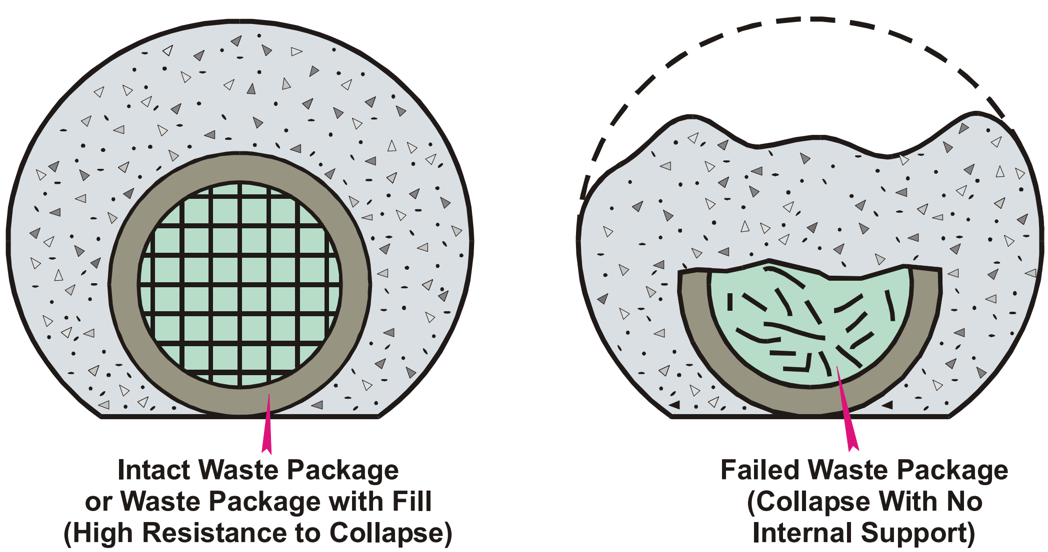

Fig. 7. Fill can prevent long-term WP collapse with full or partial preservation of exterior radionuclide barriers.

4. OTHER CERMET APPLICATIONS

The disposal of SNF from a nuclear reactor involves three activities (Forsberg October 2001): storage, transport to the repository, and disposal. Cermet storage, transport, and disposal casks can be used to meet each need.

SNF storage is required in all waste management systems. In a repository, high temperatures must be avoided to prevent reduction in the capability of the repository to isolate radionuclides. High temperatures could degrade the SNF, the WP, and the local geology. The heat from repository WPs is ultimately removed by conduction through the rock from repository depth to the surface of the earth. This is a slow process. To avoid high temperatures, the WPs are dispersed over many kilometers of tunnels. To minimize the size of the repository, all repository programs are planning to store SNF for years to decades to allow a reduction in the decay heat from the SNF before disposal.

The use of shielded cermet WPs, as described previously, makes possible the option for a combined storage, transport, and disposal packaging system (Fig. 8) using multipurpose canisters. The system includes the following components: (1) the SNF is loaded into a multipurpose canister at the reactor; (2) the loaded canister functions as a dry-storage cask at the reactor site or the repository; (3) the canister with a transportation overpack is used to transport the SNF to the repository; and (4) at the repository the transport overpack is replaced with a repository overpack that allows the canister and overpack to function together as a repository WP. The inner cermet WP, as described earlier, would function as the multipurpose canister and meet the functional requirements of (1) the basket (handling, criticality control, etc.), (2) radiation shielding, and (3) protection of the SNF natural forces and sabotage. For the proposed YM repository, the overpack would be the current 2-cm C-22 outer package.

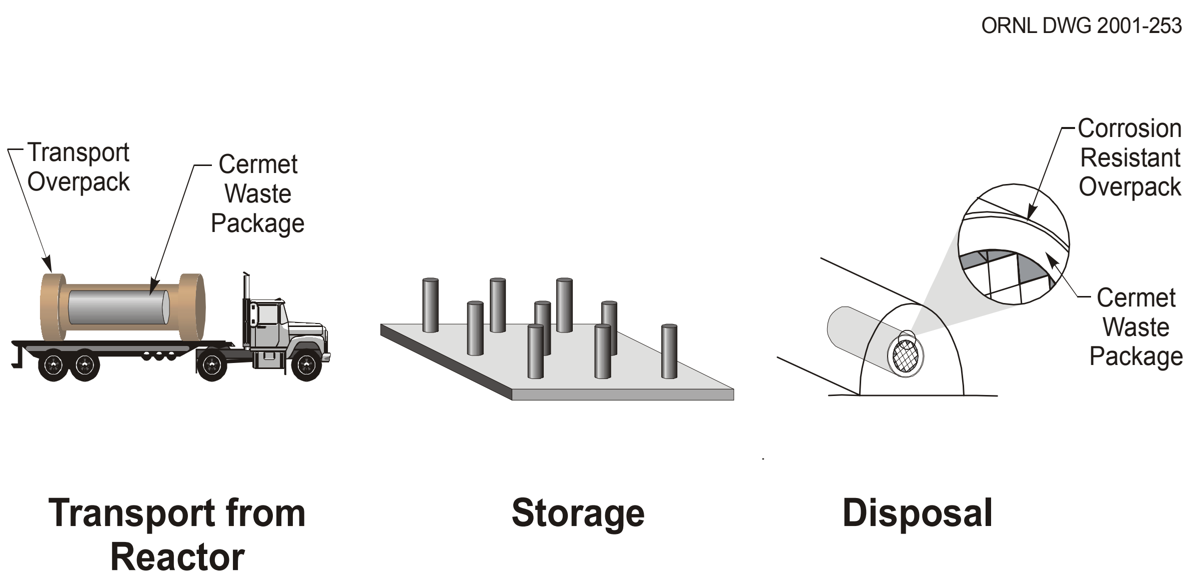

Fig. 8. Cermet WPs can be used as multipurpose packages.

The multipurpose canister makes it unnecessary to purchase separate storage, transport, and disposal packages for SNF. Furthermore, no transfer of SNF between storage, transport, and disposal packages is required. This reduces operating costs and risks. Recent events suggest that multipurpose canisters may be a very attractive concept for SNF management:

- *Defined repository requirements*. In the 1980s, the concept of a multipurpose canister for storage, transport, and disposal of SNF was investigated in the United States and elsewhere. The investigations determined that multipurpose canisters had economic and safety advantages. However, multipurpose canisters were not adopted because the requirements for repository WPs were not well understood or defined at that time. A multipurpose canister can not be designed until the basic requirements for the WP are known. In the last 20 years, the improved understanding of repository behavior has resulted in a better understanding of WP requirements. Consequently, it is an appropriate time to consider the use of multipurpose canisters.

- *Physical protection.* The destruction of the World Trade Center in New York City has resulted in a reevaluation of security requirements. Multipurpose canisters may offer significant economic advantages over competing methods for storage of SNF—with high levels of protection against sabotage. Such canisters are designed for transportation and, by design, (1) limit the SNF inventory at risk during any event to that of the cask capacity, (2) have passive cooling systems, (3) have robust walls that prevent consequences in most potential accident and sabotage scenarios, and (4) have extreme resistance to fire—the cause of the collapse of the World Trade Center towers. In a storage mode, fire duration from large aircraft impacts can be easily limited by sloping the storage yards to drain liquid fuels away from storage casks to burn pits (standard refinery practice to limit fire damage). In Germany (Droste 2001), metal casks have been successfully tested against aircraft collisions by firing heavy metal poles (1000 kg: the size of jet engine rotors—the strongest and most damaging component in an aircraft) at very-high speeds (300 m/s) into SNF casks.

5. R&D NEEDS

Several potential areas for cooperative R&D between the United States, Russia, and other countries in the area of DU applications in repositories have been identified. These areas address key technical issues associated with repository use of DU.

- *Sorption of radionuclides on hydrated uranium oxides*. Significant evidence (Forsberg September 2000b) indicates that hydrated uranium oxides sorb many of the radionuclides, including those that control repository performance (e.g., Np and Tc). If this sorption can be shown to occur under the full range of expected repository conditions, it could have a major impact (Rechard May 2001) on the expected performance of the repository and simplify licensing. This behavior applies to any use of DU in the repository and may be the single most important benefit to be gained from using DU. It may also apply to other waste forms containing these radionuclides; however, significant additional experimental data are needed to understand and quantify this behavior.

- *Cermet manufacture*. UO_2-steel cermets have been manufactured at significant expense on a small scale as nuclear fuels (Forsberg September 2001). Low-cost methods are used to manufacture nonnuclear cermets on a large scale (>100,000 tons/year). The incentives to use cermet WPs are strongly dependent upon total costs. Identification and evaluation of low-cost methods for manufacturing of DUO_2-steel cermets are needed. Low-cost fabrication methods could be potentially applied to WPs, transport casks, storage casks, and multipurpose canisters.

- *Fill behavior*. Much is known about the behavior of uranium oxides in repository environments, including the expected behavior of fills (Forsberg February 2001). However, additional experiments with DUO_2 fills are required to confirm the expected behavior and better understand (1) evolution of DUO_2 particulates in a bed and (2) changes in bed permeability to water and gas flow with time.

APPENDIX A: CERMET MANUFACTURE

Several methods of manufacturing cermets are possible (Forsberg September 2001). The traditional method for manufacturing of UO_2 cermets is to mix UO_2 and metal powder and press the mixture into a flat compact (Fig. 9). "Picture frames" are fabricated from 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 then heated to a high temperature and rolled into a thinner plate to produce the final cermet.

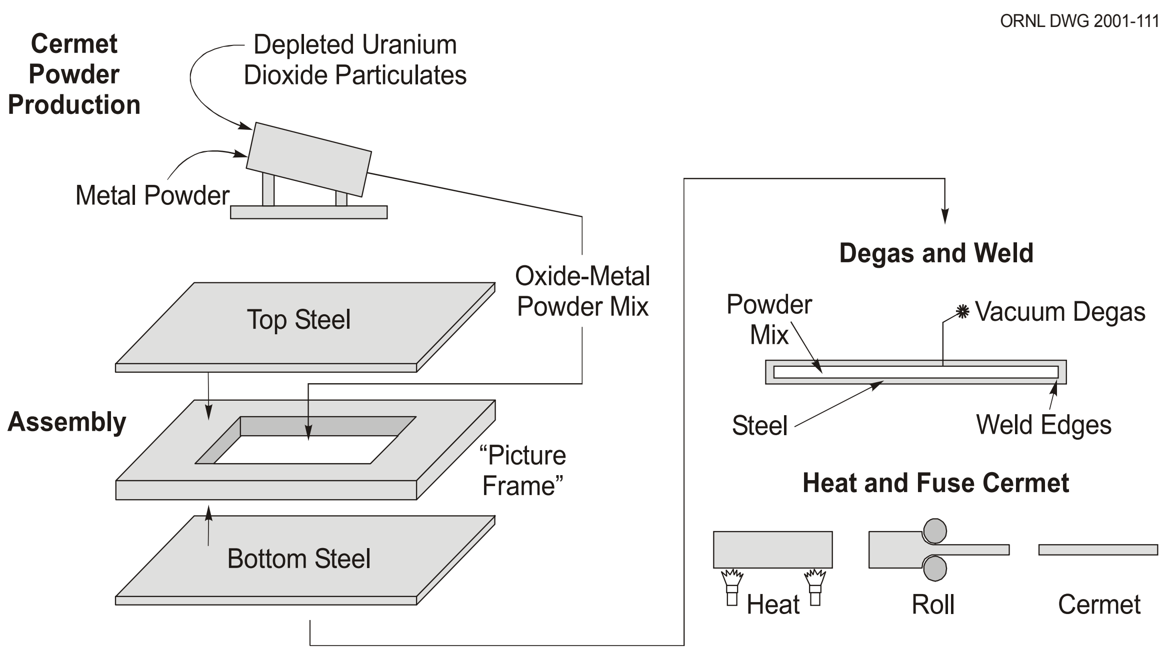

Fig. 9. Manufacture of cermets via the "picture frame" method.

This technique is used for fabrication of both nuclear and nonnuclear cermets. The picture frames can be many tens of centimeters in thickness. These operations are typical of many large industrial, steel-fabrication activities, and, in principle, are low-cost operations. Costs associated with cermet manufacture 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 cost of converting to uranium metal.

There are potentially very low cost methods for fabricating the shells of casks and WPs (Fig. 10). Aluminum-SiC cermets are made by casting molten aluminum with solid SiC particulates. The same approach may be viable for a DUO_2-steel cermet. For round objects, such as sewer pipe, centrifugal casting is the preferred method of casting. Molten metal is added to a cylindrical mold that is rotated at high speed. The metal is centrifugally held against the mold until the metal solidifies, and the final product is removed after cooldown. If the same process can be developed for casting both cermet cask and WP bodies, very low fabrication costs are possible. However, significant R&D is required before such methods can be considered viable.

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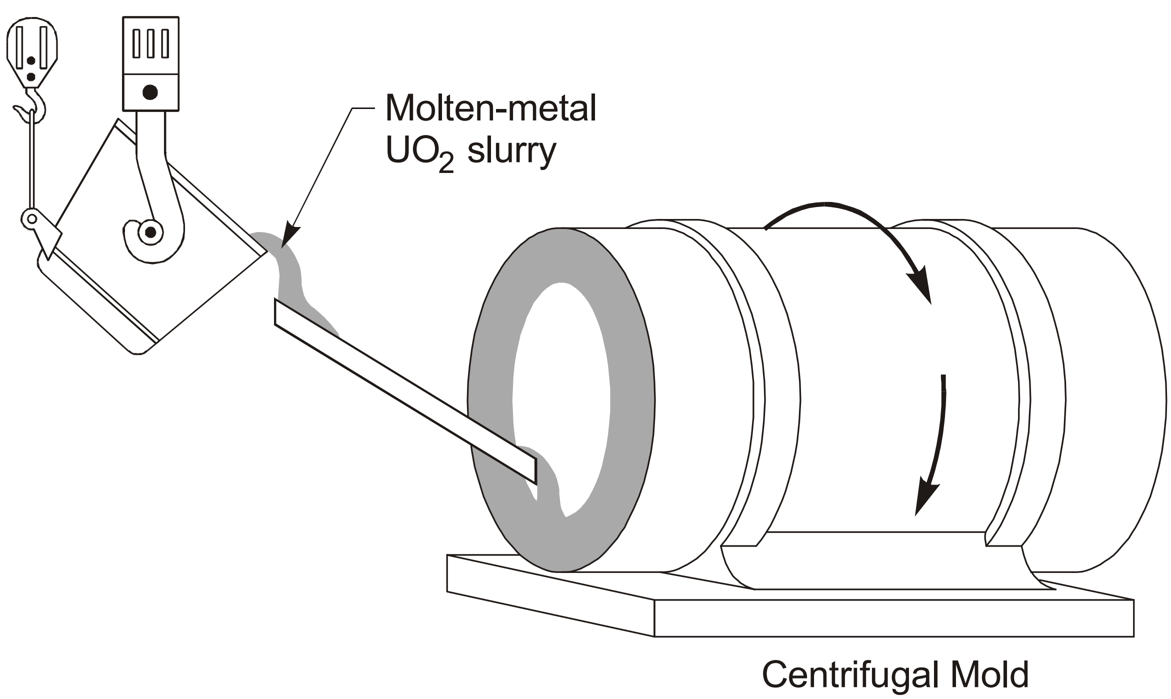

Fig. 10. Manufacture of cermet WP body by slurry spin casting.

In the United States, DOE has about 2,000,000 tons of metal for recycle, resulting from the decommissioning of gaseous-diffusion uranium-enrichment facilities. Because of unresolved issues associated with the recycle of metals from nuclear facilities into general commerce, it is unclear whether this material can be recycled in the open market. If the metal cannot be recycled, significant disposal costs will be incurred. In terms of DUO_2-steel cermet manufacture, the source of the material is not an issue. DOE's inventory includes large quantities of nickel and SSs. The potential availability of this inventory at low or negative costs may make it practical to use what have traditionally been considered "expensive, ductile high-performance" SSs for construction of cask bodies. The use of such steels may simplify fabrication (i.e., involve more-forgiving materials), improve cask performance, simplify licensing (i.e., reduce materials issues such as ductility), and facilitate quality assurance.

ACKNOWLEDGMENT

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WEBSITE

Additional information on DU applications in a geological repository can be found at the following "web.ead.anl.gov/uranium/uses/index.cfm." Copies of many of the references are also available at this site.

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