RETRIEVABLE DEPLETED URANIUM DIOXIDE–STEEL CERMET SNF MULTIPURPOSE CASKS

Charles W. Forsberg
Oak Ridge National Laboratory*
P.O. Box 2008
Oak Ridge, Tennessee 37831-6179
Tel: (865) 574-6783; Fax: (865) 574-9512
E-mail: forsbergcw@ornl.gov

Preparation Date: November 1, 2002
File Name: Cermet: Retrievable.HLW.Conference.2003.paper

Paper Prepared for
2003 International High-Level Radioactive Waste Management Conference
Las Vegas, Nevada
March 30–April 2, 2003

Subject Categories
5.9 Approaches to the Retrievability/Reversibility Option
Alternative: 2.3. Repository Surface Facilities (Including Retrievability)

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*Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

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Charles W. Forsberg
Oak Ridge National Laboratory
P.O. Box 2008; Oak Ridge, TN 37831-6179
Tel: (865) 574-6783; E-mail: forsbergcw@ornl.gov

Abstract—*Depleted uranium dioxide (DUO_2)–steel cermet casks are being investigated for use as multipurpose casks for spent nuclear fuel (SNF). The cermet cask body is made of DUO_2 embedded in the steel. The multipurpose cask (1) is loaded at the reactor with SNF and used for on-site storage, (2) is used for SNF transport, and (3) serves as part of the final repository waste package (WP). These high-capacity self-shielded casks offer several potential benefits in terms of long-term retrievability of SNF from the repository. First, the multipurpose self-shielded WP minimizes retrieval difficulties (involves no remote-handling operations) and avoids the need to build a storage facility for any SNF that is retrieved (provides a suitable cask for SNF surface storage). Second, the high-performance cermet minimizes cask weight per unit of SNF compared with other cask shielding materials, thus reducing handling difficulties or reducing the number of casks by increasing the capacity of each cask. Third, if the SNF is ever recovered for recycle of fissile fuels for use in reactors, the DU necessary for the fuel is located within the same WP. This paper describes the multipurpose cask system, the potential benefits, and the placement and retrieval operations for this high capacity cask. Technical and economic uncertainties are identified.*

I. INTRODUCTION

Significant policy, institutional, and technical advantages favor the construction of repositories from which recovery of the spent nuclear fuel (SNF) can be accomplished with reasonable efficiency.

- *Future energy resources*. Retrievability allows recovery of the SNF if future generations require the fissile isotopes for energy production.
- *Confidence in the repository.* Public acceptance is improved by the knowledge that unforseen repository problems can be resolved by SNF retrieval.
- *Increased repository capacity*. Repository capacity is generally limited by the SNF decay heat load, however, the decay heat limits per unit area of the repository are not well known. Consequently, conservative limits on decay heat load are required. During repository operation, much will be learned about the ultimate repository capacity. If higher decay heat loadings in the repository are possible, cask retrievability would allow casks to be removed from a disposal drift and the drift to be reloaded with more casks or those with higher decay heat levels, thereby increasing repository capacity. There have also been proposals[1] to ventilate the repository. In each disposal drift, the heat removal near the cold air inlets results in "cold spots" in the repository. After a few decades of ventilation, it may be feasible to add hotter waste packages (WPs) to these locations. Limited research and development has been done on the potential gains in repository capacity by such shuffling of WPs over time. The viability of such options strongly depends upon the ease of WP retrievability.

While retrievability is a desirable characteristic, the question is how to obtain this capability at acceptable costs. One potential option is to dispose of the SNF in retrievable multipurpose self-shielded casks constructed of a depleted uranium dioxide (DUO_2)–steel cermet.[2] The cask shells would be constructed of a cermet (DUO_2 embedded in the steel), which, in turn, would be contained between clean layers of steel. Multipurpose cermet casks (Fig. 1) would be loaded with SNF at the reactor or at interim storage locations. These casks would then be used for interim storage, long-term storage, transport, and final geological disposal—with no additional handling of the SNF itself. The characteristics of this system, its additional retrieval benefits compared with those offered by other systems, its operational features, and some of the uncertainties are described herein.

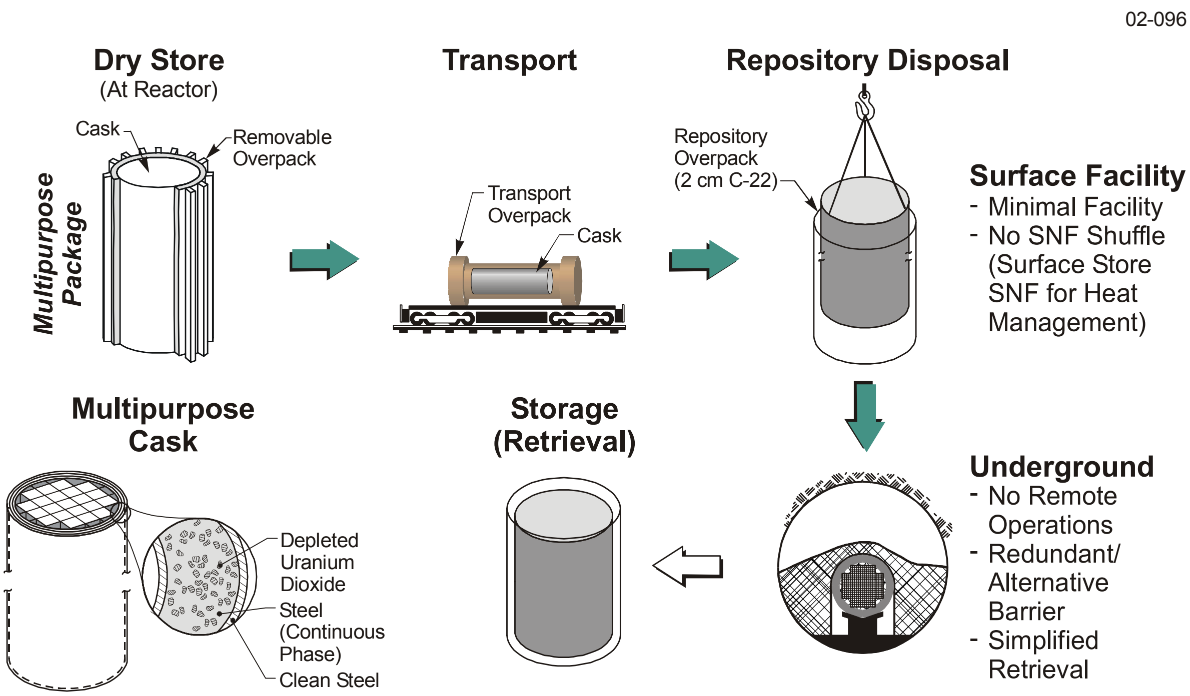

Fig. 1. DUO_2–steel cermet multipurpose cask system, including SNF retrieval.

II. SYSTEM DESCRIPTION

The proposed system consists of a multipurpose cask (constructed of a DUO_2–steel cermet), a storage overpack, a transportation overpack, and a repository overpack. The overpacks address conflicting storage and disposal requirements that cannot be easily met by the multipurpose cask.

- *Multipurpose cask.* The multipurpose cask performs several functions: (1) serving as a handling package for SNF from the reactor to the repository and during any retrieval operations, (2) providing primary radiation shielding, (3) offering physical protection against assault and accidents—including handling during retrieval, and (4) functioning as a sealed safeguards package. Multipurpose casks simplify surface operations at the repository. To ensure long-term repository performance, decay-heat limits are imposed on each WP. WP heat loads at the proposed repository are to be controlled by selection of hot and cold SNF for each WP, which involves sorting and handling of the SNF. In a multipurpose cask system, casks with high heat loads would be stored until the decay heat in each cask has decreased to the allowable repository WP limits. Thus storage, not SNF sorting and handling, would be used to control WP heat loads. In terms of retrievability, shielded multipurpose casks offer major advantages. Any cask recovered from the repository can again be used for surface SNF storage; thus, no storage facility would need to be built if it was decided to recover SNF.

- *Dry storage overpack.* Conflicting functional design requirements apply to high-capacity cask storage of short-cooled SNF and disposal of SNF. In storage, the primary design constraint is the need to avoid high temperatures, which would degrade the SNF. The storage cask requires a high ratio of surface area to volume (the use of small casks or fins) to dissipate heat. For disposal, the primary design constraint is to ensure long-term WP integrity. (Decay heat levels are lower.) Thus the disposal WP should have a low ratio of surface area to volume to minimize both (1) the interactions between groundwater and the WP and (2) the cost of expensive corrosion-resistant materials. This requirement implies a bare cylinder with smooth surfaces. The use of a removable overpack with heat removal features (fins) during storage of short-cooled SNF can resolve these conflicting performance requirements.

- *Transport overpack.* The transport overpack provides the added protection required for shipment. If a multipurpose cask is shipped to the repository, it should also be possible to transport the SNF retrieved from the repository in the same cask.

- *Disposal overpack.* The proposed WP in the United States has an inner container for the SNF and an outer container of a corrosion-resistant alloy (2 cm of C-22). The inner container provides the structural support for the corrosion-resistant overpack. In this proposed system, a multipurpose cask replaces the inner container. The proposed outer container, which remains unchanged, is placed over the multipurpose cask at the repository.

Multipurpose casks have the potential to reduce waste management costs associated with SNF. The nuclear power system in the United States was originally designed for recycle of light-water-reactor SNF and evolved into a once-through fuel cycle. If the nuclear power system were designed specifically as a once-through fuel cycle, it might look very different from the current one. Recent terrorist events and limits to the pool storage capacity for SNF have resulted in greater use of dry storage casks. If utilities make the financial investment required for the transition to dry storage casks, the expected incremental cost of producing multipurpose casks would be small. Thus, the United States has the potential to adopt a multipurpose cask system for future SNF that simultaneously enhances retrievability and improves security.

As is true for any industrial facility that operates for decades, repository operations will change with time, based on experience. It is therefore logical to envision a second phase of repository operation that uses a multipurpose cask system for future SNF that is not already committed to other storage systems. A non disruptive pathway from the current system to the new proposed system exists. The multipurpose cask system provides the maximum versatility to address the uncertainties of the future—including the option for low-cost retrievability.

While multipurpose casks can be constructed of many materials, the use of DUO_2–steel cermets offers some potentially unique advantages. The DUO_2–steel cermets may be the highest-performance cask shielding material that can meet all the requirements. High-performance shielding materials minimize cask weight and wall thickness; this, in turn maximizes cask capacity for any given set of size and weight constraints during SNF loading at the reactor, in storage, during transport, and in the repository (restrictions of tunnel diameter). The greater the SNF capacity of each cask, the fewer the casks that must be built and handled.

Cermets provide better gamma shielding than steel because DUO_2 (10.9 g/cm^3) has a higher density than steel (7.8 g/cm^3). Because of the high oxygen content associated with the DUO_2, which moderates neutrons, cermets also have better neutron shielding capabilities than steel. The cermet would include a neutron absorber such as gadolinium oxide for efficient absorption of thermal neutrons.

The use of other more-efficient shielding materials is prohibited by one or more of the storage, transport, or disposal criteria. An examination of these criteria eliminates (1) chemically reactive materials, such as uranium metal; (2) materials that may impact repository performance, such as concretes or organics—the traditional materials for neutron shielding; (3) high-cost materials, such as tungsten; and (4) Resource Conservation and Recovery Act metals, such as lead.

III. RETRIEVABILITY BENEFITS OF A CERMET CASK SYSTEM

The use of a cermet self-shielded multipurpose cask has potentially significant strategic, engineering, and economic advantages compared with many other methods to ensure repository retrievability.

- *Strategic advantages.* The most likely scenario that would require recovery of SNF from a repository is a situation in which the price of uranium has increased and breeder reactor technology has become more economic. Under such circumstances, society will require the fissile materials from the SNF, as well as the DUO_2 itself, both for further extraction of ^{235}U and as a fertile material for reactors. With a WP made of DUO_2, the required fissile and fertile materials for such a fuel cycle are collocated in the same WP.

- *Engineering*. A cermet self-shielded cask is highly robust[3] and avoids the need for remote-operated equipment in the retrieval process. The conditions of retrieval are unknown and could vary from a repository in excellent condition to one that has experienced partial disruption. Recovery is greatly simplified and accelerated if the package is sufficiently robust that the impact of a mining machine or other equipment will not cause significant damage to the package. Recovery is also simplified if contact-handling procedures can be used and if there is confidence that high radiation levels will not be encountered. Use of a shelf-shielded package also avoids the need to build a storage facility for recovered SNF. The system is fully reversible in that any casks that are retrieved can be shipped to another site.

- *Retrieval economics*. A self-shielded package greatly simplifies underground operations with significant cost reductions in any retrieval operation. Equally important, the self-shielded package avoids the costs to construct major surface facilities to handle the retrieved SNF. The recovered multipurpose casks containing SNF can simply be placed out in the open.

IV. OPERATIONS

The proposed system has many advantages. However, it requires the capability to place and recover heavy casks underground with access constraints, particularly during retrieval operations where tunnel drifts may be partly blocked and bypass tunnels with tight curves may have to used. Several underground cask-handling options exist.

One in-repository transport option is a modified Swedish SNF cask carrier system, which typically carries a 110-ton cask. A truck with the cask mounted on a transport frame (Fig. 2) is used to move the cask from the reactor to the ship and then from the ship to the monitored underground retrievable storage facility, Centralt Lager for Anvant Bransle—CLAB (www.skb.com). The vehicle is powered by diesel or overhead electric “trolley” lines for underground operations. At the reactor, the cask is mounded on a transport frame. The cask is loaded onto the frame from above by crane. The cask remains with the transport frame in all transport operations. When the cask and frame are to be moved, a special truck backs up under the upside-down “U” shaped frame. The truck bed rises and lifts the frame with its cask off the ground for transport. When the truck arrives at the drive-on/drive-off ship, M/S Sigyn, the truck drives onto the ship. Using the truck for precision positioning, the cask and frame are positioned over special frame lock-down mechanisms on the cargo floor of the transport ship. The truck bed is then lowered to position the frame with cask onto the ship floor. Each set of truck tires is mounted on a separate steerable axle; thus, the truck is very maneuverable compared with traditional wheeled vehicles.

A modified variant of this system could be used for a repository with tunnel access to the repository disposal drifts. The primary difference is the design of the frame (Fig. 3) to allow placement of the cask and recovery of the frame. The frame height would be raised, and the cask would be suspended from the top of the frame.

At the repository surface facility (Fig. 1), the transport overpack would be removed from each incoming multipurpose cask and be replaced by the repository overpack. The resultant WP would then be mounted to the upper support cradle that ultimately supports the WP in the repository disposal drift. A hydraulic table would be used to raise the WP and support cradle off the floor so that the transport frame can be lowered over them. After the support cradle is attached to the transport frame, the hydraulic table would be lowered so that the cradle (with its cask) is supported by the frame. The truck transporter would then back under the frame, raise its bed and the frame with cargo off the floor, and move the cask, upper support cradle, and frame to the repository.

At the repository, the truck would deliver its cargo to the proper location in the disposal drift and place the frame and its cargo over the final disposal location. The truck would then move away from the frame and its cargo. The cask and upper support cradle are then lowered vertically from the frame into the final disposal location. They are detached from the transport frame. The transport frame has a small set of wheels that would be lowered and used to move the frame away from the cask and support cradle. The transport frame wheels (used only to move the frame short distances) would be raised, the empty frame would be loaded back onto the truck, and the truck would return it to the surface facilities. For retrieval operations, these procedures would be undertaken in the reverse order.

Fig. 2. Swedish SNF cask carrier (Courtesy of the Swedish Nuclear Fuel and Waste Management Company, Photo by Bengt O. Nordin)

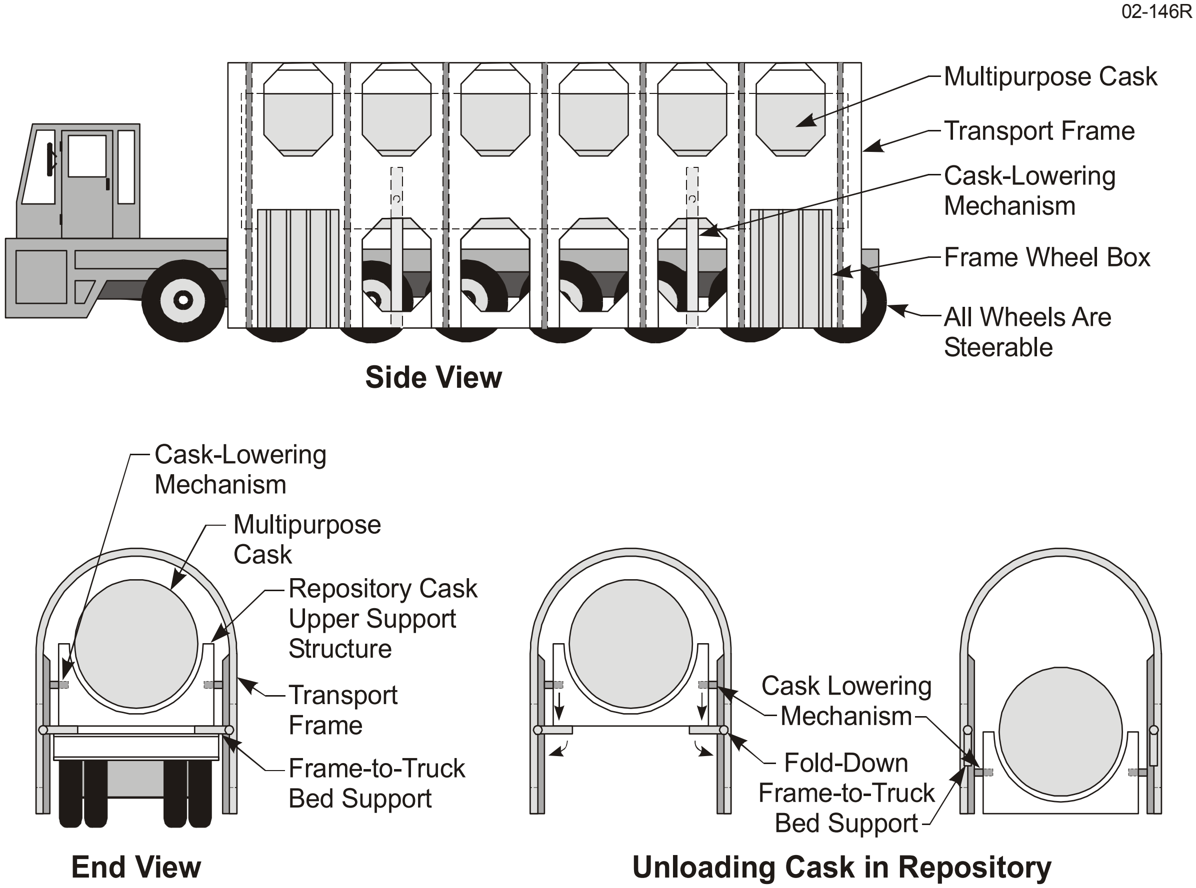

Fig. 3. Repository transport system for heavy cermet multipurpose cask.

This system has several attractions. The vehicle can navigate tight curves, precision place the cargo, and travel at a much higher travel speed than a tracked vehicle. The system requires very few support facilities beyond a road bed. Moreover, over a decade of operational experience exists in the Swedish configuration. The cask with cradle is lowered less than a meter, with the weight supported over short distances by the transport frame. Last, the system can move very heavy (>100-ton) WPs, including self-shielded WPs.

V. OBSERVATIONS

A DUO_2-steel cermet multipurpose cask system creates a new set of SNF management options and capabilities, potentially improving the once-through fuel cycle and simplifying repository retrieval of SNF at little or no additional costs. The cermet multipurpose cask has several advantages in terms of SNF retrievability: (1) co-disposal of fissile and fertile (^{238}U) material to allow co-recovery if required, (2) a high-performance shielding material that maximizes the amount of SNF per package, and (3) a shielded package that avoids the handling constraints of unshielded packages.

The potential economic viability is based on several considerations. The cost differential between storage and multipurpose casks is small; thus, there is the potential that multipurpose cask system savings in SNF handling and repository operations exceed the added costs of multipurpose casks. The higher capacity of cermet multipurpose casks reduce system costs.

Significant work is required to develop the system, including the critical requirement to develop a cost-effective system. Ongoing studies are directed at key economic issues, which include developing: (1) new methods to lower cask fabrication costs[4] and (2) the capability to allow storage of short-cooled SNF[5] in large casks. The capability to store short-cooled SNF allows the multipurpose cask to replace most at-reactor SNF storage facilities and has a major impact on system economics.

ACKNOWLEDGMENTS

This work was done under the auspices of the U.S. Department of Energy Depleted Uranium Uses Research and Development Program. Additional information (including technical reports) available at http//web.ead.anl.gov/uranium.

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