A Multi-Functional Cermet Spent-Nuclear-Fuel Super Cask

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Preparation Date: June 11, 2003
File Name: Supercask.INMM.2003.Paper.June9
Paper Due Date: June 23, 2003

Paper Number 81
Session E: Packaging and Transportation-Packaging Design & Transport Operations
Paper Presentation: Wednesday July 16, 2003
Institute of Nuclear Materials Management 44th Annual Meeting
Phoenix, Arizona.
July 13–17, 2003

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

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ABSTRACT

The issue of safeguards and security of spent nuclear fuel (SNF) is of increased international concern. Recent technical developments may enable construction of a multi-functional cermet cask with enhanced security features. The multi-functional cask is loaded with SNF at the reactor and then used for SNF storage, transport, and disposal. The SNF is handled only once—when the cask is loaded—minimizing handling of SNF and allowing the cask to be welded shut after loading. The cask weight (70 to 100 tons) and the sealing system act as major physical barriers to theft or diversion. The size of the cask allows surveillance from orbit, and transponders can be attached to each cask to confirm that no tampering has occurred.

The viability of a multi-functional cask depends upon meeting the multiple requirements for storage, transport, and disposal. This objective is accomplished by using casks constructed of cermets. The cermet cask contains various ceramics embedded in a continuous steel matrix. Depleted uranium dioxide (DUO_2) in the cermet maximizes shielding efficiency, which maximizes cask capacity (i.e., the number of fuel assemblies per cask) and improves the economics. Hard ceramics (such as Al_2O_3, which is used in traditional cermet armor) are added to the cermet to maximize resistance to military weapons, cutting tools, and other devices.

A new cermet fabrication method (patents applied for) creates the potential to produce a low-cost thick-walled variable-composition cermet cask. The variable composition allows different ceramics to be located in different locations within the cask body and thus maximize both economics and assault resistance. The combination of the new cermet cask fabrication technology and the systems design creates the potential for an SNF super cask. This paper describes the basis for the system, the cask, and the enabling fabrication technologies.

INTRODUCTION

During the initial development of nuclear energy, it was thought that uranium resources were extremely limited; thus, designs for early fuel cycles assumed that SNF would be quickly recycled. With the discovery of large quantities of low-cost uranium resources, in much of the world the light-water-reactor fuel cycle has evolved into a once-through fuel cycle. Because of this history, large quantities of SNF are stored in pools at reactors. This form of storage, the use of separate transport casks, and the use of separate disposal casks result in a system that is highly dependent upon active safeguards and security measures (e.g., guns, gates, and guards). With increased concerns [1] about terrorism, security, and proliferation, it is appropriate to rethink our approach to SNF management.

There are several requirements for a robust, "no-regrets" once-through fuel cycle that is designed for an uncertain future. First, the SNF should be retrievable should SNF processing again become desirable. SNF contains (1) fissile materials that can be used to construct nuclear weapons and

(2) radioactive materials that can be used to construct radiological weapons. To minimize the risks of diversion, the SNF should be handled the minimum number of times. The SNF should also be in a secure system that makes assault, diversion, or theft extremely difficult. Last, the total system costs should be minimized. An advanced system to meet these goals is proposed.

SYSTEM DESCRIPTION

The proposed system [2] consists of a multi-functional cermet cask, a storage overpack, a transportation overpack, and a repository overpack (Fig. 1). At the reactor, the SNF is loaded into the heavy cask, which is then used for at-reactor storage, transport, and disposal. Once SNF is loaded into the cask, the cask is sealed and never reopened. The cermet cask consists of DUO_2 and other ceramic particulates embedded in a steel matrix (described below). The use of overpacks addresses conflicting storage and disposal requirements that cannot easily be met by the multi-functional cask. For management of SNF, the system consists of the following components.

1. *Multi-functional cask.* The multi-functional cask performs several functions: (1) serving as a handling package for SNF from the reactor to the repository and during any future retrieval operations, (2) providing primary radiation shielding, (3) offering physical protection against assault and accidents, and (4) functioning as a sealed safeguards package.

2. *Dry storage overpack.* Conflicting design requirements apply to high-capacity-cask storage of short-cooled SNF at the reactor and to disposal of SNF. For storage of short-cooled SNF at the reactor, the primary design constraint is the need to avoid high in-cask temperatures, which would degrade the SNF. The storage cask requires a high ratio of surface area to volume (i.e., the use of small casks or fins) to dissipate heat. For disposal, the primary design constraint is to ensure long-term waste package (WP) integrity. (Decay heat levels will have significantly decreased by the time the waste is to be disposed of.) The WP should have a low ratio of surface area to volume to minimize (1) the interactions between groundwater and the WP and (2) the cost of an expensive corrosion-resistant repository overpack. This later requirement implies the use of a bare cylinder with smooth surfaces. The use of a removable storage overpack with heat removal features (e.g., fins) during storage can resolve these conflicting performance requirements and thus allow transfer of short-cooled SNF from the reactor SNF pool to the cask.

3. *Transport overpack.* The transport overpack provides the added protection required for transport.

4. *Disposal overpack.* The repository overpack ensures compatibility of the cask and the repository. The overpack is constructed of a corrosion-resistant alloy. In the U.S. repository system, the overpack would consist of 2 or more centimeters of C-22 metal alloy.

The multi-functional cask system offers major advantages in terms of safeguards and security. SNF is handled only once. Hot SNF at the reactor is transferred into casks that may weigh >100 tons. While an individual SNF assembly weighs less than a ton and can be transported by helicopter or other methods, only railroads or heavy-haul vehicles (on roads with high weight limits) can move a large cask. The large casks are easily observed from orbit, and the option exists for a separate transponder to be placed on each cask to continuously monitors its status. Welded sealing systems ensure significant delay in opening such a cask.

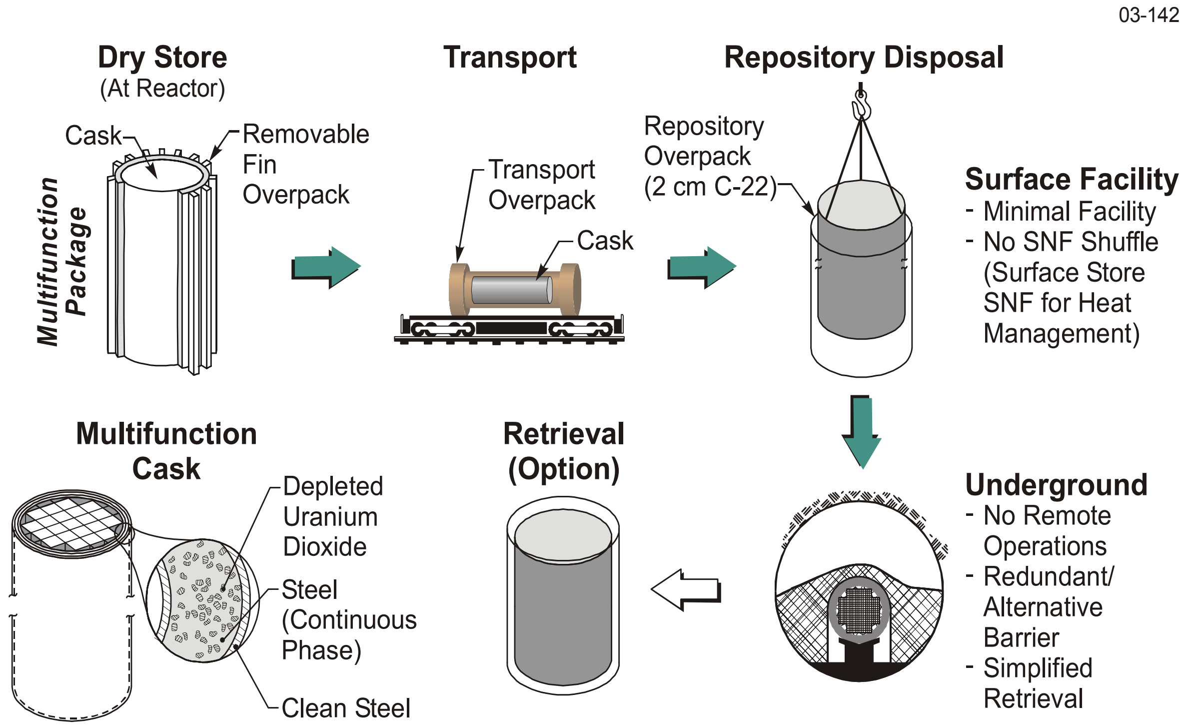

Fig.1. DUO_2–steel cermet multi-functional cask system, including optional SNF repository retrieval.

Because of their intrinsic characteristics, casks have high resistance to assault and accidents. The SNF inventory of each cask is limited, thus (1) limiting the consequences of any single incident and (2) allowing passive decay-heat cooling. In aircraft collisions, fire is a primary threat to the cask. The high thermal inertia of a cask protects against very high external heat fluxes experienced over a finite (or short) period of time, while the modular characteristics of casks limit the duration of any fire. In refineries and other facilities, the ground is (1) sloped to allow liquid fuels to drain away from equipment to burn pits or (2) covered with crushed rock to allow drainage of fuel underground (away from air, thus extinguishing the fire). The same approach is applicable to casks in storage.

Thick walls, required for shielding, provide significant protection against aircraft impacts. In Germany, the resistance of metal casks to aircraft collisions has been successfully tested against aircraft collisions by firing 1-tonne heavy metal poles, the size of jet engine rotors—the strongest and most damaging component in an aircraft—into SNF casks at 300 m/s [3]. Casks do not have foundations and thus will move under high-impact loadings. This process dissipates the energy in severe events and makes it more difficult to destroy a cask than to destroy a building with an equivalent wall structure.

CERMET CASKS

The cermet cask wall (Fig. 2) consists of various ceramic particulates embedded in a steel matrix between two clean layers of steel. The fundamental characteristic of a cermet—the ability to encapsulate variable quantities of different ceramic particulates into a high-integrity monolithic metal matrix—creates the potential for a cask with superior performance compared to casks constructed of traditional materials. Ceramic components have outstanding properties to address specific cask requirements. The DUO_2 is the highest-performance gamma-radiation shielding material compatible with repository operation that has acceptable costs. The improved gamma shielding enables construction of casks with greater capacity (i.e., more SNF assemblies per cask) for the same given weight and size constraints. This significantly improves the economics. The oxygen, carbon, silicon, and other additives provide enhanced neutron shielding. Hard ceramics such as Al_2O_3 have excellent capabilities to breakup certain types of military projectiles. However, all of these ceramics have poor physical properties. The traditional weaknesses (low thermal conductivity, low ductility) of ceramics in a SNF cask are avoided by the use of metal matrix.

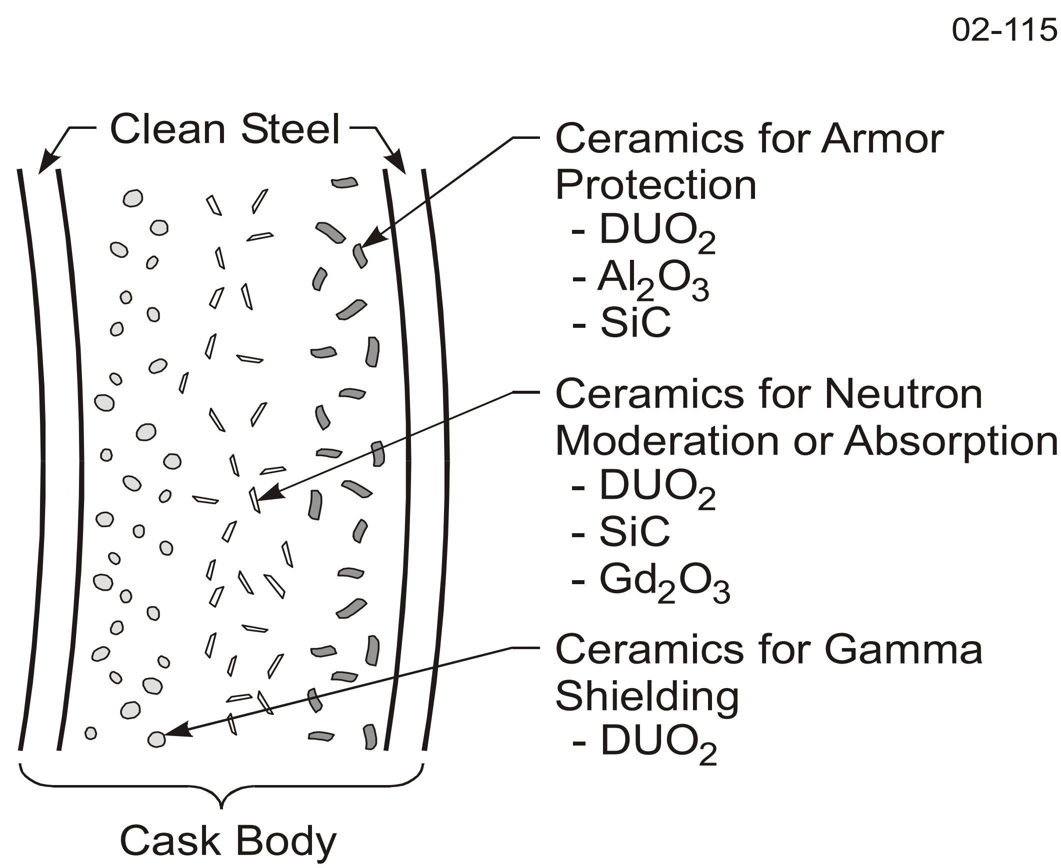

Fig. 2. Cermet cask cross section.

Traditionally, cermets are used in very severe operating environments: (1) tank and vault armor, (2) brake shoes, (3) tool bits, and (4) nuclear fuel in some test reactors. Because UO_2 cermets have been used as nuclear fuels and their properties [4] are understood, there is reasonable confidence in the technical capabilities of cermet SNF casks.

Many types of military armor are cermets. Armor design [5–7] involves tradeoffs to provide good resistance to multiple types of threats: high-speed long-rod projectiles (military shells and tornado-driven poles), explosive shaped charges, high temperatures (thermite bombs and fires), and cutting tools. In a ceramic/metal composite armor system, the hard ceramic pieces are backed by a ductile metal. The ceramic (1) erodes the front of the projectile (or shape-charge jet) and thus reduces its kinetic energy and mass and (2) spreads the force of the projectile over a wider area so the energy can be absorbed by the metal. The metal holds the ceramic in place as long as possible to allow erosion of the projectile. A cermet in which the ceramic is incorporated into the metal provides increased toughness and greatly improves the ballistic resistance and multi-hit capabilities of the system. SNF casks are substantially heavier than the U.S. or Russian main battle tanks and are also much smaller. As a consequence, cermet casks have the potential to be significantly more resistant to assault than any military vehicle.

CASK MANUFACTURING

Large quantities of cermets are manufactured each year. However, the existing techniques are unsuitable for manufacture of thick-walled casks because no methods exist to weld thick sections of cermets. Consequently, a new manufacturing method (Fig. 3) has been invented [8, 9] for cask fabrication. While the fabrication technique is new, on a microscopic scale (temperatures, pressures, material compositions), the cermet-forming processes are the same as those associated with the traditional processes. The new process consists of the following steps.

1. *Preform fabrication*. A hollow preform, slightly larger than the final annular cask body, is constructed of steel. The annular, U-cross-section preform consists of (1) the outside cylindrical cask wall, (2) the inside cylindrical cask wall, and (3) an annular steel piece at one end of the preform between the inner and outer walls.

2. *Preform filling*. The preform is filled with a particulate mixture of DUO_2, other ceramics, and steel powder. The composition of the particulate mix can varied between the inner and outer walls.

3. *Welding, heating, and gas evacuation*. After the preform is filled, an annular ring is welded to the end of the preform that was open during the particulate fill process. This creates a sealed cylinder with a steel exterior and filled with a mixture of ceramic particulates and steel powder. The preform is then evacuated while being heated, which removes gases in the void spaces in the particulate mixture and gases sorbed on the particulates.

4. *Forging.* The preform is heated and compressed to (1) eliminate all void spaces and (2) weld the metal particles together to form a continuous, strong steel matrix containing various ceramic particulates. There are two standard industrial processes that can be used to consolidate the preform and particulate mixture into a cermet. With traditional forging, the

hot, heated perform can be hammered to consolidate the particulate mixture into a cermet and produce the final cask form. In one method, a cylindrical anvil, the size of the interior of the final cask, is placed inside the preform. The forge then strikes the exterior to consolidate the particulate mixture. Alternatively, with ring-rolling forging, the hot loaded preform can be placed in a ring-rolling machine and rolled into its final form.

5. *Finishing*. Because of the difficulty in welding and machining cermets, the manufacturing process is designed to avoid these operations. The cask bottom is welded onto the cylindrical cask body. After completion of this step, a vertical boring mill is used to obtain the final dimensions and to drill holes in the top of the cask body for the lid bolts. While the thickness of the steel preform inner and outer circular shells may be 1 to 2 cm, the thickness of the annular top of the preform may be 10 to 20 cm to allow for bolt holes and attachment of other hardware to mate with the lid of the cask. By design, the preform ensures that all welding and cutting operations are completed on the steel in the preform. No cutting or welding of the cermet is required.

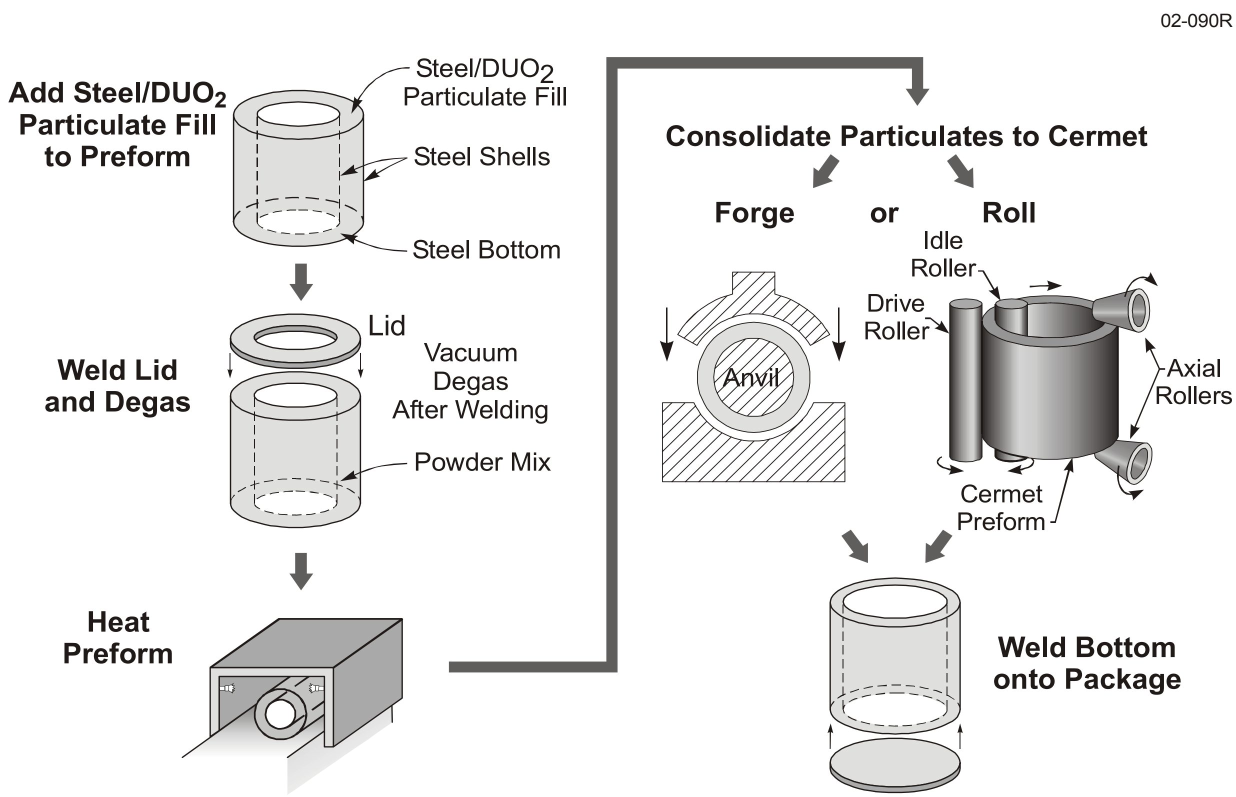

Fig. 3. New method for cermet cask fabrication.

CHALLENGES AND CONCLUSIONS

Because of changes in the nuclear fuel cycle and the increased potential threats to SNF, new approaches to SNF management should be considered. Multi-functional casks offer the benefit of minimum SNF handling—a potential security, safeguards, and economic advantage. New cask designs and fabrication techniques may allow production of a cermet cask with unique capabilities.

Significant technical and institutional development is required to develop a cermet multi-functional cask system. The new manufacturing technology is less than a year old. A series of fabrication studies and experiments are under way to develop and demonstrate the viability of the new method for cask fabrication. For safeguards purposes, appropriate security sealing, safeguards sealing, and transponder development is required. Separate from the technical developments is the need to develop appropriate institutional structures to implement the technology.

ACKNOWLEDGMENTS

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

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