Using Depleted Uranium to Shield Vitrified High-Level Waste Packages

H. R. Yoshimura, P. D. Gildea, and E. A. Bernard

Sandia National Laboratories, Albuquerque, New Mexico, 87185-0718

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

INTRODUCTION

For more than 50 years, the U.S. Department of Energy (DOE) has been enriching uranium for commercial nuclear fuel and defense purposes. Natural uranium must be enriched to sustain the fissioning process required for nuclear power production. The uranium enrichment process generates large quantities of depleted uranium (DU) as a byproduct. DU contains less than 0.7% of its U^{235} isotope. (The assay of most of the DU in the inventory is 0.2 to 0.5%.) Throughout the DOE complex, there are presently approximately 555,000 metric tons of UF_6 (375,000 metric tons of uranium metal) in 50,000 cylinders, most of which are stored at the three uranium enrichment sites in 10-ton and 14-ton steel cylinders (Martin Marietta Energy Systems 1993). Approximately 2,500 of these 10- and 14-ton cylinders are added to this inventory annually. Since July 1, 1993, the UF_6 generation has been the responsibility of US Enrichment Corporation.

Until the end of the Cold War, DU was being stored by the DOE until it could be used as fuel for breeder reactors, mixed with more highly enriched uranium for reactor fuel, or used as armor protection or armor-piercing penetrators on artillery shells. With the collapse of the Soviet Union and other changes in the geopolitical arena, most of these intended uses are no longer necessary. Rather than direct disposal, alternative uses for the stored DU are being sought by the DOE. End products must be developed that use the specific properties of DU.

The underlying report for this paper evaluates options for using depleted uranium as shielding material for transport systems for disposal of vitrified high-level waste (VHLW). In addition, economic analyses are presented to compare costs associated with these options to costs associated with existing and proposed storage, transport, and disposal capabilities. A more detailed evaluation is provided elsewhere. (Yoshimura et al. 1995).

DU is one of the most dense materials known; it is more dense than lead. Like lead, DU provides efficient protection from radioactive exposures, but DU is slightly less toxic than lead. These properties of DU led the DOE Office of Technology Development to than lead. These properties of DU led the DOE Office of Technology Development to begin exploration of the use of DU as radiation shielding in all or parts of containers for storage, transport, and/or disposal systems for defense or commercial high-level nuclear waste or spent fuel. Using DU as shielding material provides the potential benefit of disposing of significant quantities of DU during the high-level waste disposal process. Several significant potential benefits associated with this use of DU are identified.

SYSTEM DESCRIPTION AND APPLICATION

The DU-shielded transport systems evaluated provide for the storage, transport, and disposal of high-level waste along with significant quantities of DU. These DU-shielded systems were designed to store, transport, and dispose of high-level waste in stainless steel canisters with DU as shielding. The DU-shielded transport systems considered were evaluated for storage and transport costs and other factors associated with the goal of efficient disposal of VHLW and DU at the permanent geologic repository. Potential problem issues and costs associated with using depleted uranium for those systems are reviewed.

DU is an excellent gamma radiation-shielding material; it can provide equivalent gamma shielding with less thickness than other materials such as lead and stainless steel. In shipping container applications, DU has been used to provide gamma shielding for spent fuel casks. Another advantageous attribute of DU is that it can provide structural strength similar to stainless steel, although this characteristic of DU has not yet been recognized by regulatory agencies.

Depleted uranium shielding in the following applications were evaluated:

1. DU-shielded waste containers for the dual-use function of storage and disposal in a transport system that uses separate transport packages for canistered high-level waste from facilities producing VHLW. This system is identified as S/D+T.

2. DU-shielded waste containers for the multipurpose function of storage, transport, and disposal of canistered high-level waste for direct emplacement into a geologic repository. This system is identified as S/T/D.

While both these transport systems use DU shielding, the disposal process that begins in the waste-producing facility and ends at the geologic repository is somewhat different for each system.

In the S/D+T system, the waste canister with enclosed waste form is loaded into a DU-shielded storage/disposal container and stored at the processing facility until such time as the repository is ready to accept that material. The storage/disposal container is then loaded into a truck or rail transport overpack, impact limiters are installed on the ends of the overpack, and the overpack is loaded onto either a truck trailer or railcar and moved to the final repository. The storage/disposal container is removed from the transport overpack and prepared for emplacement. The transport overpack with impact limiters is returned to the processing facility to transport additional storage/disposal containers. The waste form, the waste canister, the DU-shielded storage/disposal container, the transport package, and the truck or rail conveyance are the primary components of the S/D+T system.

In the S/T/D system, the primary components are the waste form, the waste canister, the waste container, the DU-shielded storage/transport/disposal package, and the truck or rail conveyance. The waste canister is loaded into a thin shelled waste container, and a closure assembly is installed and welded. The waste container is loaded into a DU-shielded storage/transport/disposal package, impact limiters are installed on the ends of the package, and the package is loaded onto either a truck trailer or railcar and moved to the final repository. The impact limiters are removed from the storage/transport/disposal package, and the package is prepared for final emplacement. In this system, the impact limiters are the only reusable component.

Both systems allow storage of high-level waste canister(s) in DU-shielded containers at a designated site before transport to a repository for final disposal. Both systems provide storage, transport, and disposal of high-level waste and significant quantities of DU. Both systems provide two levels of containment. Both systems propose direct emplacement at the repository of DU-shielded packages. (An emplacement overpack may be added at the repository if required by future repository criteria for long-term containment of high-level waste.)

In the S/D+T transport system, the transport overpack is a reusable system component that can be returned to the originating facility storage site to transport additional DU-shielded storage/disposal containers. In the S/T/D system, the transport package is neither separate nor reusable; for the most part it is the same as the final disposal package. For comparative evaluation, four parallel configurations have been developed for each of these DU-shielded transport systems: one-canister, three-canister, four-canister, and seven-canister configurations.

Both systems use the Defense Waste Processing Facility high-level waste canister as the baseline canistered waste form. Both systems are based on current regulatory requirements for Type B packages. Federal regulations (10 CFR Parts 60, 71, and 72) govern disposal, transportation, and on-site storage requirements. Because the metal form of DU has not yet been certified as a structural material, the structural strength of DU was not considered in the package designs. This adds additional conservatism to the design because DU is comparable to stainless steel in structural strength.

STRUCTURAL, THERMAL, AND SHIELDING ANALYSES

Preliminary structural, thermal, and shielding analyses of DU-shielded transport systems were conducted. For the thermal analyses, the seven-canister configuration was selected because this configuration has the highest total heat dissipation. This analysis was performed to verify that the centerline temperature of the waste canister does not exceed published maximum permissible temperatures for the canistered waste form, to verify that the O-ring temperature of the transport overpack does not reach a temperature that results in the loss of seal integrity, and to calculate the maximum surface temperature of the S/D+T system transport overpack. For both the normal condition of transport and hypothetical accident environments, the preliminary thermal analysis indicates that component temperatures do not exceed the temperature limits.

The preliminary structural analysis of the DU-shielded transport systems evaluated

- Tip-over loadings onto an unyielding surface of the storage/disposal container (of the S/D+T system) and the storage/transport/disposal package (of the S/T/D system) with a handling impact limiter attached.

- A 9-m (30-ft) impact onto an unyielding surface of the transport package (of the S/D+T system) and the storage/transport/disposal package (of the S/T/D system) with transport impact limiters attached.

The tip-over analysis evaluates loads that may be imposed during handling and storage operations. The 9-m (30-ft) impact analysis evaluates performance during hypothetical transport accident conditions. Simplified analytical methods were used to predict the dynamic response of the systems during tip-over and impact events in this preliminary structural analysis of all canister configurations of both systems. The preliminary structural analysis indicates there are no design features in any of the considered canister configurations of either the S/D+T or the S/T/D system that would preclude acceptance.

The preliminary shielding analysis consists of a series of calculations using simple point-kernal techniques to determine adequate DU shield thicknesses for storage/disposal containers designed to store one high-level waste canister and another to carry seven high-level waste containers. The calculations considered the effects of varying the DU shield thickness on the predicted dose rates at the surface of the container and at 2.0 m (6.6 ft) from the centerline, both radially and axially. Based on previous analyses performed on a cask design similar to the model used for the one-canister configuration, it is assumed that the neutron dose will be comparable in magnitude to the calculated gamma doses. The preliminary shielding analysis calculations indicate the proposed DU thicknesses of 5.0 cm (2.0 in.) for the single-canister configuration and the 8.0 cm (3.0 in.) for the seven-canister configuration should provide adequate radiation shielding.

MANUFACTURING OF DU-SHIELDED COMPONENTS AND LONG-TERM SYSTEM INTEGRITY

Potential issues of developing and using DU-shielded components were evaluated. The first issue considered is the availability of fabrication facilities. Three commercial manufacturers, Manufacturing Sciences Corp. in Oak Ridge, TN; Aerojet Ordinance Tennessee, Inc. in Jonesborough, TN; and Nuclear Metal, Inc. in Concord, MA, were surveyed for current uranium casting capabilities. The results of the survey and follow-on conversations indicate the processing capability to cast large-diameter DU rings for shielding S/D+T system storage/disposal containers or S/T/D system storage/transport/

disposal packages, although currently limited, could be developed if there is a defined need.

The second issue considered is the identification of any potential problems that could arise from using DU as a shielding material in containers used for long-term storage or disposal of high-level waste. It is assumed that the primary areas of concern are long-term integrity of the container and interaction of the container materials with the interior environments. Problems identified include

- Chemical reactions of DU with oxygen that could possibly cause decreases in shielding capacity due to flaking effects or disruption of container integrity due to structural stresses resulting from formation and wedging effects of high-volume uranium oxide; and

- Radiation-induced changes in the dimensions of the DU or embrittlement of the DU could cause development of structural stresses that could result in possible disruption of container integrity.

Threats to shielding capability or container integrity from the oxidation of the DU can be easily overcome. Recommendations include surrounding the DU with structural steel, coating the DU, alloying the DU, or allowing the self-limiting process to create barriers of uranium oxide between the DU and the oxygen or moisture. By ensuring that the container is sealed and applying engineering design, oxidation threats can be avoided.

The potential problems related to radiation exposure are inferred from previous studies and the literature on enriched-uranium fuel elements. The much-different situation of DU shielding requires further investigation that is beyond the scope of this preliminary assessment. No problems have been experienced with other DU-shielded packages to date.

COST ANALYSIS

The costing study develops and proposes an unshielded reference system (Figure 1) for high-level waste disposal for uniform application to all waste sites and, to the extent data are available, develops associated system costs. System costs are also developed for a comparable DU-shielded cask system (Figure 2). Both of these developed costs are then compared to the costs estimated by the Civilian Radioactive Waste Management Program for the authorized waste management system (DOE 1990).

The unshielded reference system was developed considering data from three major areas: total-system life-cycle cost defense waste assumptions, defense high-level waste site activities, and relevant Civilian Radioactive Waste Management System planning. The major difference between the unshielded reference system and the DU-shielded system is

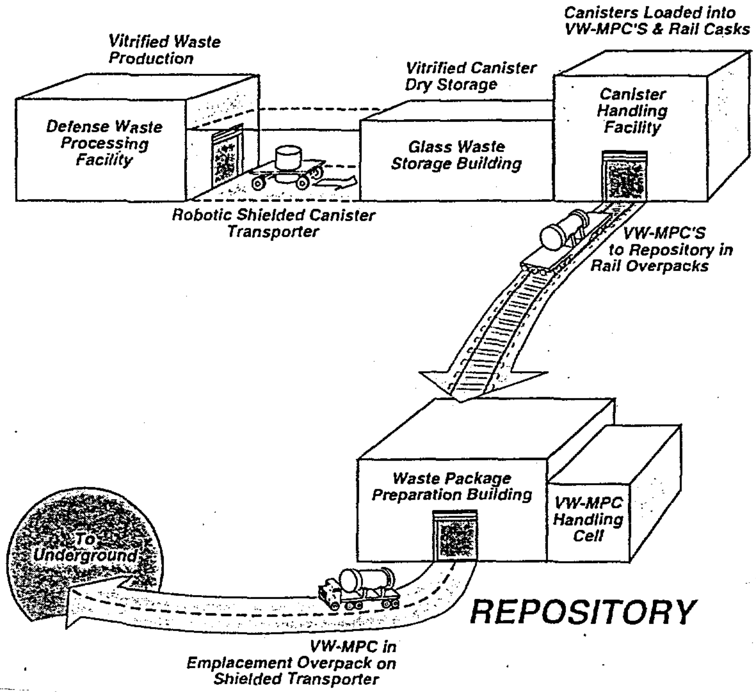

Figure 1. Baseline Scenario

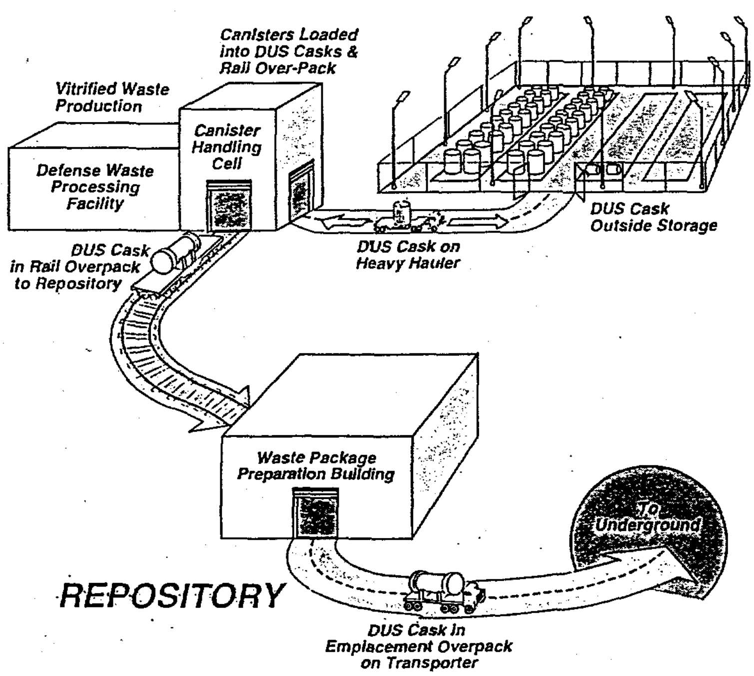

Figure 2. DU-Shielded Cask Scenario

that DU provides radiation shielding to the levels required for Type B packages, which means that once the VHLW canisters are loaded into a DU-shielded container or package, it can be contract-handled; i.e., shielded transporters, shielded vault storage facilities, and shielded transportation overpacks are not required.

The costing analysis evaluates the cost advantages and disadvantages that result from using DU as shielding material for high-level waste storage, transport, and disposal processes. Three DU-shielding system configurations were developed and compared to a baseline waste disposal process employing the multipurpose canister concept of the Civilian Radioactive Waste Management System and Savannah River Site dry storage planning. Results of these comparisons are presented on both a total system and site-specific basis.

Several conclusions are reached in the costing analysis, although a caution is necessarily issued concerning the preliminary nature of the data used in this study. The major cost intangible is the uncertainty of DU-shielded container and package fabrication cost estimates, which results from the lack of reliable future cost and availability data for metallic DU. Conclusions on the cost analysis of this study include:

- Defense waste total system costs are 1.5 to 1.8 times larger ($1,799M to $3,248M) for the scenarios developed for this study than the TSLCC estimate (DOE 1990), primarily the result of much larger cask and emplacement overpack costs.

- Multiple canister transportation/disposal casks, particularly those that can be contact-handled, will likely result in significant reduction of repository surface and subsurface facilities and operation costs. However, these costs cannot be quantified until the repository design concept is further developed.

- From 81 to 95 million kilograms (178 to 210 million pounds) of DU could be used in the seven-canister DU-shielded cask option. Applying DU disposal costs estimated to range from $9.50 to $30.19/kg, results in total cost savings for DU disposal of from $0.8B to $2.9B. Possible additional DU disposal savings, resulting from larger amounts of DU associated with one- and three-canister DU-shielded casks, will be offset because of higher transportation costs for the larger number of movements of these casks to the repository.

- The baseline DHLW scenario is the lowest cost scenario when a DU disposal credit is not taken. The DU-shielded cask scenarios become competitive when the DU disposal cost exceeds $6.44/kg for the seven-canister package and $14.40/kg for the four-canister package.

- With a $15.19/kg disposal credit, the three DU-shielded cask scenarios show it is less costly to use a DU-shielded cask of equivalent or larger capacity than the unshielded container. A cost benefit results from the ability to contact handle and store the waste on relatively inexpensive open concrete pads.

- *Larger cask capacity (seven canister) provides lower transportation costs due* primarily to the dedicated train mileage charge that becomes the controlling transportation cost element. Larger cask capacity results in fewer train miles needed to move the waste to the repository.

- It is more costly to use integral rather than reusable transportation overpacks. This results principally from the need to build each integral package stronger to meet the structural requirements of the transportation environment. This larger capital cost is not offset by reductions in any other cost items.

- The use of Incoloy cladding in place of a separate repository emplacement overpack should be investigated further. The costs for the Incoloy clad seven-canister reusable transport overpack system was the lowest cost configuration for the study.

REFERENCES

DOE (U.S. Department of Energy), *Preliminary Estimates of the Total-System Cost for the Restructured Program: An Addendum to the May 1989 Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program*, DOE/RW-0295P, Washington, DC, December 1990.

Martin Marietta Energy Systems, Inc., *Inventory Status and Requirements for Government-Owned Uranium*, Y/ES-009 (Draft), Oak Ridge, TN, August 1993.

Yoshimura, H. R., P. D. Gildea, E. A. Bernard, et al., *Use of Depleted Uranium for Shielding Material in Transport Systems for the Storage and Disposal of High-Level Waste*, SAND94-0826 (Draft), Albuquerque, NM, December 1995.