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Use of Depleted Uranium Metal as Cask Shielding in High-Level Waste Storage, Transport, and Disposal Systems

H. Richard Yoshimura, John S. Ludwigsen, Mark E. McAllaster, Anthony J. Trennel, Michael C. Brady, Paul E. McConnell, Kevin D. Seager, Kenneth H. Eckelmeyer, Patrick D. Gildea, Davina M. Kim, William L. Uncapher, Stephen Wix

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**USE OF DEPLETED URANIUM METAL AS CASK SHIELDING
IN HIGH-LEVEL WASTE STORAGE, TRANSPORT, AND DISPOSAL SYSTEMS**

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ABSTRACT

The U.S. Department of Energy has amassed over 555,000 metric tons of depleted uranium from its uranium enrichment operations. Rather than dispose of this depleted uranium as waste, this study explores a beneficial use of depleted uranium as metal shielding in casks designed to contain canisters of vitrified high-level waste produced at Department of Energy vitrification facilities. Two high-level waste storage, transport, and disposal shielded cask systems are analyzed. The first system employs a shielded storage and disposal cask having a separate reusable transportation overpack. The second system employs a shielded combined storage, transport, and disposal cask. Conceptual cask designs that hold one, three, four, and seven high-level waste canisters are described for both systems. In all cases, cask design feasibility was established and analyses indicate that these casks meet applicable thermal, structural, shielding, and contact-handled requirements. Depleted uranium metal casting, fabrication, environmental, and radiation compatibility considerations are discussed and found to pose no serious implementation problems. About one-fourth of the depleted uranium inventory would be used to produce the casks required to store and dispose of the nearly 15,400 high-level waste canisters that would be produced. This study estimates the Department of Energy total-system cost for the preferred seven-canister storage and disposal configuration having a separate transportation overpack would be \$6.3 billion. When credits (\$0.8 billion to \$2.5 billion) are taken for depleted uranium disposal cost, a cost that would be avoided if depleted uranium were used as cask shielding material rather than disposed of as waste, total system net costs are between \$3.8 billion and \$5.5 billion. Compared with the \$5.8 billion cost of a reference system for separate high-level waste and depleted uranium disposal, total-system cost savings range from \$0.3 billion to \$2.0 billion. Possible repository overpack and waste storage cost decreases, together could increase these savings by another \$0.4 billion.

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ACRONYMS AND ABBREVIATIONS

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
cn	canister
CRWMP	Civilian Radioactive Waste Management Program
CRWMS	Civilian Radioactive Waste Management System
Ci	curie
D&E	development and evaluation
DHLW	defense high-level waste
DOE	U.S. Department of Energy
DU	depleted uranium
DWPF	Defense Waste Processing Facility
GWSB	glass waste storage building
HLW	high-level waste
LLW	low-level waste
LWT	legal weight truck
MPC	multi-purpose canister
MRS	Monitored Retrievable Storage
MSC	Manufacturing Sciences Corporation
MTHM	metric tons of heavy metal
NMI	Nuclear Metal, Inc.
NRC	U.S. Nuclear Regulatory Commission
OCRWM	U.S. DOE Office of Civilian Radioactive Waste Management
PWR	pressurized water reactor
RCRA	Resource Conservation and Recovery Act
S/D+T	storage/disposal plus transport
S/T/D	storage/transport/disposal
SARP	Safety Analysis Report for Packaging
SCT	shielded canister transporter
SNF	spent nuclear fuel
SRS	Savannah River Site

ACRONYMS AND ABBREVIATIONS (Concluded)

TSLCC	total-system life-cycle cost
U	uranium
UF ₆	uranium hexafluoride
VW-MPC	vittrified waste - multi-purpose canister

EXECUTIVE SUMMARY

For more than 50 years, enriched uranium has been used for defense and commercial nuclear applications. The uranium enrichment process generates large quantities of depleted uranium (DU) as a byproduct. In 1994 throughout the U.S. Department of Energy (DOE) complex there were ~555,000 metric tons of DU, most of which was stored at the three uranium enrichment sites in 10- and 14-ton steel cylinders containing uranium hexafluoride (UF_6). Approximately 2,500 of these 10- and 14-ton cylinders are added to this inventory annually.

DU was being stored by the DOE until it could be used for 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. Most of these intended uses no longer remain. Uses for the stored DU are being sought by the DOE as an alternative to disposal as waste.

DU is one of the densest materials known; it is more dense than lead. Like lead, DU provides efficient shielding from radiation exposures. While slightly radioactive, DU is slightly less toxic than lead. These properties of DU led the DOE Office of Technology Development to explore using DU in place of lead as radiation shielding in all or parts of casks for storage, transport, and/or disposal systems for defense or commercial high-level waste (HLW) or spent nuclear fuel. Several significant potential benefits associated with this use of DU were identified.

The metal DU-shielded HLW management systems evaluated in this report provide for the storage, transport, and disposal of vitrified HLW in stainless-steel canisters. These systems use significant quantities of DU as shielding in the system casks. Figure ES-1 shows the flow and components of the two DU-shielded systems considered in this analysis.

As described in this report, DU shielding is emplaced with the HLW canisters in both a storage/disposal plus transport (S/D+T) system and a storage/transport/disposal (S/T/D) system. While both these HLW management systems use DU shielding, the disposal process that begins at the waste-producing facility and ends at the geologic repository is somewhat different.

In the S/D+T system, the waste canister is loaded into a DU-shielded storage/disposal cask and stored at the processing facility until the repository is ready to accept the waste material. The storage/disposal cask is then loaded into a truck or rail transportation 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 geologic repository. At the repository, the storage/disposal cask is removed from the transportation overpack and prepared for emplacement. The reusable transportation overpack and impact limiters are returned to the processing facility to transport additional storage/disposal casks. The waste form, the waste canister, the DU-shielded storage/disposal cask, the transport packaging (which includes the transportation overpack and impact limiters), and the truck or rail conveyance are the primary components of the S/D+T system.

Figure ES-1. A Comparison of Depleted-Uranium-Shielded High-Level Waste Management Systems

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

Of the ~385,000 metric tons of DU in the 1991 DOE inventory, ~335,000 metric tons were in temporary storage as UF_6 . If this UF_6 is declared to be a waste, it cannot be accepted directly by the disposal facilities because of its reactive capability to release hydrofluoric acid in the presence of water or water vapor. Conversion to oxide or metal yields an inert form that is more directly disposable. Current manufacturers can convert approximately 5,000 metric tons of UF_6 into DU per year for each site.

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 advantage of DU metal is that it can provide structural strength similar to stainless steel, although this characteristic of DU has not yet been recognized by regulatory agencies.

Both HLW management systems considered in this evaluation allow storage of HLW canisters in DU-shielded casks at a designated site before transport to a repository for disposal. Both systems provide storage, transport, and disposal of HLW and significant quantities of DU as shielding. Both systems provide two levels of containment to meet transportation requirements. Both systems involve direct emplacement of DU-shielded casks at the repository. An emplacement overpack may be added at the repository based on future repository criteria for long-term containment of HLW in canisters. For comparative evaluation, four parallel configurations have been developed for each of these DU-shielded systems: one-canister, three-canister, four-canister, and seven-canister configurations.

Because the metal form of DU has not yet been accepted as a structural material in certified transport packages, 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. Both systems use the Defense Waste Processing Facility HLW canister as the baseline canistered waste form. Both systems are based on current regulatory requirements for Type B packages. Federal regulations (Title 10, Code of Federal Regulations, Parts 60, 71, and 72) govern disposal, transportation, and on-site storage requirements (NRC, 1995).

The thermal analysis in this study used a two-dimensional thermal model to calculate the temperature distribution in the seven-canister configuration of the S/D+T system. The seven-canister configuration was selected for the preliminary thermal analysis 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 (300°C), to verify that the O-ring temperature of the transportation overpack does not reach a temperature that results in a loss of seal integrity (204°C), and to calculate the maximum surface temperature of the S/D+T system transportation overpack. For both the normal condition of transport and hypothetical accident environments, the preliminary thermal analysis indicates that component temperatures do not exceed temperature limits.

The preliminary structural analysis of the DU-shielded HLW management systems evaluated two scenarios which constitute limiting design basis events for structural integrity:

- Tip-over loadings of the storage/disposal cask (of the S/D+T system) and the storage/transport/disposal cask (of the S/T/D system) with a handling impact limiter attached.
- A 9-m (30-ft) impact of the transportation overpack (of the S/D+T system) and the storage/transport/disposal cask (of the S/T/D system) with both 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 features in any of the canister configurations of the S/D+T or the S/T/D systems that would preclude acceptance of a design for certification.

The preliminary shielding analysis performed a series of calculations using simple point-kernel techniques to determine adequate DU shield thicknesses for storage/disposal casks designed to store either one or seven HLW canisters. The calculations considered the effects of varying the DU shield thickness on the predicted dose rates at the surface of the cask and at 2 m from the cask, both radially and axially. Based on previous analyses performed for a cask design similar to the model used for the one-canister configuration, it was assumed that the neutron dose would be comparable in magnitude to the calculated gamma doses. The preliminary shielding analysis calculations indicate the proposed DU thicknesses of 2.0 to 3.0 in. for the one-canister configuration and 3.0 to 4.0 in. for the seven-canister configuration should provide adequate radiation shielding.

Three commercial manufacturers, Manufacturing Sciences Corp. in Oak Ridge, TN, Aerojet Ordnance 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 casks or S/T/D system storage/transport/disposal casks, although currently limited, could be developed if there is a defined need.

Problems could arise from using DU as a shielding material in casks used for long-term storage or disposal of HLW. They affect both long-term integrity of the cask and interaction of cask materials with cask environments. Problems identified include the following:

- Chemical reactions of DU with oxygen that could possibly cause decreases in effective shielding thickness due to flaking effects or compromise cask integrity resulting from formation and wedging effects of less dense, higher specific volume of uranium oxide.
- Radiation-induced changes in the dimensions of the DU or embrittlement of the DU may cause structural stress development that could result in compromise of cask integrity.

Threats to shielding capability or cask integrity from the oxidation of DU can be easily overcome. Remedies include surrounding the DU with structural steel, coating the DU metal, alloying the DU metal, or allowing the self-limiting process to create barriers of uranium oxide between the DU and the oxygen or moisture. By ensuring that the cask 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 behavior of enriched uranium fuel elements. The application of DU to shielding is a much-different situation and requires further investigation that is beyond the scope of this preliminary assessment. To date, no problems have been encountered with other DU-shielded packages.

A non-DU-shielded reference case HLW management system is evaluated for uniform application to all waste sites and, to the extent data are available, associated total-system costs are developed. Total-system costs are also estimated for the comparable DU-shielded HLW management systems. These cost estimates are then compared to the Civilian Radioactive Waste Management Program (CRWMP) authorized radioactive waste management system cost estimate of \$3.9B (DOE, 1990).

The non-DU-shielded reference case was developed considering data from three major areas: DOE Office of Civilian Radioactive Waste Management defense waste assumptions, defense waste site planning and activities, and relevant CRWMP planning. The major difference between the reference case and the DU-shielded systems is that DU provides radiation shielding to the levels required for Type B packages. Thus DU-shielded casks containing vitrified HLW canisters can be contact-handled; i.e., shielded transporters, shielded vault storage facilities, and shielded transportation overpacks are not required.

The costing analysis attempts to quantify the effects of using DU-shielded casks within the Civilian Radioactive Waste Management System (CRWMS) by

- Determining the total-system costs resulting from codisposal of DU (as shielding) with HLW in the geologic repository.
- Estimating the total quantity of DU that can be codisposed (as shielding) with HLW.
- Estimating any cost benefit to DOE from DU codisposal (as shielding) as opposed to separate DU disposal as low-level or Resource Conservation and Recovery Act (RCRA) waste.

The non-DU-shielded reference case, which employs a variation of the multi-purpose canister (MPC) concept of the CRWMS and the Savannah River Site (SRS) dry storage planning, is compared with four DU-shielded system configurations. The four DU-shielded configurations, which include different design and capacity variations, were selected to explore cost advantages and DU usage benefits resulting from larger cask capacity and an integral transportation overpack. In addition, truck transport costs were generated for the West Valley Site for comparison with rail transport. Results of these comparisons are presented on both a total-system and site-specific basis where appropriate. Total-system cost estimates for the DU-shielded system configurations range between \$6.1B and \$8.7B.

Any cost benefit resulting from codisposal of DU (as shielding) with HLW in the geologic repository is determined by applying a credit, equal to the cost of separate DU disposal, to the total-system cost for the DU-shielded system. Low-level and RCRA-controlled waste disposal costs represent the minimum and maximum estimates, respectively, for separate DU disposal. The resulting net DU-shielded total-system costs, ranging from \$3.8B and \$7.6B, are compared with the non-DU-shielded reference case total cost of \$5.8B. When the net DU-shielded system cost is less than the reference case, there is a positive cost benefit to DOE from codisposal of DU as shielding with HLW. The seven-canister S/D+T system is the preferred system because of its lower total cost (\$6.1B total and \$3.8B net) and better HLW canister loading configuration.

Although a caution is necessarily issued concerning the preliminary nature of the data used in this study, several conclusions are reached in the costing analysis.

- Defense waste total-system costs are 1.5 to 2.2 times higher for the configurations developed for this study than the authorized waste management system (DOE, 1990). These differences are primarily the result of much larger canister, cask, and emplacement overpack costs.
- The non-DU-shielded reference case, which employs a variation of the CRWMS MPC concept and SRS dry storage planning, is the lowest cost disposal process when a DU disposal credit is not taken for the DU-shielded configurations.
- The actual cost benefit realized from codisposal of DU with HLW can vary from a positive to a negative benefit. This results from the factor of three uncertainty (\$30.19/kg to \$9.50/kg) in the separate disposal cost because it is unclear whether DU falls under RCRA or low-level waste regulation.

- The DU-shielded system becomes competitive (i.e., exceeds break-even) when the separate DU disposal costs exceed \$6.43/kg for the seven-canister configurations, \$14.34/kg for the four-canister configuration, and \$25.62/kg for the single-canister configuration.
- A positive cost benefit results for all configurations by applying the present cost estimate for separate RCRA DU disposal (\$30.19/kg) as a credit for the DU-shielded configuration. The savings range from about \$260M to \$1.9B depending on the DU-shielded system configuration.
- The seven-canister DU-shielded configuration provides the largest cost advantage from codisposal of HLW and DU metal. It results in a break-even disposal credit that is \$3.07/kg lower than the minimum LLW DU disposal cost estimate of \$9.50/kg.
- The total quantity of DU that would be codisposed (as shielding) with HLW in the geologic repository ranges from 81 to 113 million kilograms (178 to 248 million pounds) for the configurations used in this study.
- Larger container or cask capacities result in lower total-system cost. This cost reduction results from lower transportation, repository, and waste site costs. The seven-canister DU-shielded configuration probably represents a realistic upper capacity due to transportation and emplacement handling limits.
- Reusable transportation overpacks used with storage/disposal casks are less costly than combined storage/transport/disposal casks.
- The use of Incoloy cladding in place of a separate geologic repository emplacement overpack shows the potential for significant cost reduction. However, a better understanding of long-term material corrosion is required to fully assess this approach. Incoloy clad systems are as much as \$0.5B less in total-system cost than equivalent stainless-steel systems.
- The use of multiple HLW canister storage, transport, and disposal casks that can be contact handled may result in repository cost reduction. However, repository facilities and operations costs will remain one of the important intangibles of the HLW management system until the repository design concept is further developed and costed.
- A cost saving on the order of \$170M could be achieved at the SRS by substituting the DU-shielded waste management system pad storage concept for the second glass waste storage building.
- The truck transport option for West Valley provides a cost saving of about 10% over rail transport.

Supporting costing analysis data are provided in Appendix D. Appendix D was assembled during July and August 1993 and used the waste site HLW canister production schedule provided

by the DOE Integrated Data Base for 1992, and the repository waste acceptance schedule from the 1990 addendum to the CRWMP TSLCC (DOE, 1992 and 1990). For a first order approximation, relative system element and total-system costs developed in this study should remain completely acceptable for comparison purposes as inventories and costs are updated. Similarly, the site-specific cost comparisons should remain viable.

1.0 INTRODUCTION

1.1 Depleted Uranium and Its Use as Shielding Material

In 1992, the U.S. Department of Energy (DOE) Office of Science and Technology (formerly the Office of Technology Development) began to explore beneficial alternatives for using the large quantity of depleted uranium (DU) stored in its inventory. Among the alternatives recognized was the use of DU as radiation shielding material in spent nuclear fuel or high-level waste (HLW) management systems. This study addresses, specifically, the use of DU as shielding in casks designed for vitrified HLW storage, transport, and disposal systems. This analysis concludes that this is a beneficial use of DU versus disposal of DU as a radioactive or Resource Conservation and Recovery Act (RCRA) waste.

The DU inventories and properties of interest in this study are provided in Section 2.0. The two HLW storage, transport, and disposal systems analyzed are described in Section 3.0. The components, canister configurations, capabilities, similarities, and distinguishing characteristics of the DU-shielded HLW management systems are discussed. Preliminary thermal, structural, and shielding analyses and component development considerations are presented in Sections 4.0 and 5.0, respectively. Total-system cost estimates and comparisons are developed in Section 6.0. Results are provided to assist DOE in addressing and resolving the challenge of managing the large inventory of DU that now exists.

1.2 High-Level Waste Considered

The HLW considered in this study is canistered borosilicate glass logs produced by DOE vitrification facilities at Savannah River, Hanford, and West Valley. At these facilities, HLW feeds are mixed with glass frit and melted. The molten borosilicate glass waste is poured into a stainless-steel, pipe-like canister where it solidifies in place into a borosilicate glass log. The canister is large, approximately 9 ft long and 2 ft in diameter. When filled with vitrified waste it weighs about 4,200 lb. After the poured waste solidifies, a domed top plug is seal-welded to the open end to confine the "glass log" in its individual canister.

The specific canister considered in this study is the Savannah River Site (SRS) Defense Waste Processing Facility (DWPF) canister. It was selected by SRS in 1982 and used as the design basis canister for the DWPF and its processes. This canister is similar to canisters to be used at the Hanford and West Valley vitrification facilities.

SRS researchers have acquired extensive data on the vitrified waste form in the stainless-steel canister, i.e., HLW canister. As produced, the HLW canisters can be safely stored at the SRS for an extended period, up to 40 years. Within this time, construction of the geologic repository, and preparation for repository waste acceptance and disposal should be completed.

1.3 High-Level Waste Management Systems Considered

Two HLW (DU-based) management systems are considered for storage, transport, and disposal of HLW canisters for comparison with the baseline system. The two systems are illustrated in Figure 1-1.

- The storage/disposal plus transport (S/D+T) system employs a nontransportable DU-shielded cask for storage and disposal. This cask is placed in a separate, reusable transportation overpack for transport. The added transportation overpack for transport of the storage/disposal cask leads to the S/D+T designation.
- The storage/transport/disposal (S/T/D) system employs a transportable DU-shielded cask for storage, transport, and disposal. A transportation overpack is not required for transport. This cask meets storage, transport, and disposal requirements, thus the S/T/D designation.

As shown in Figure 1-1, the contents of both the S/D+T and S/T/D systems are the waste form (the solidified HLW borosilicate glass log) in its HLW canister. In the S/D+T system, the HLW canister (or canisters) is placed in a storage/disposal cask. When filled, the cask is seal-welded closed to make up the S/D+T storage unit. In the S/T/D system, the HLW canister (or canisters) is placed in a waste container, which is seal-welded closed. The sealed container is then placed in a storage/transport/disposal cask. When filled, the cask is seal-welded closed to make up the S/T/D storage unit.

Cask designs holding one, three, four and seven HLW canisters are developed for each system. In both systems, the storage units (including the storage impact limiters) can be stored outdoors on a concrete pad within a securely fenced and lighted storage area. The units can be stored up to 40 years until it is time for transport to the repository for disposal.

When the geologic repository is ready to accept waste, transport packaging must be added to both the S/D+T and S/T/D storage units for off-site transport. In the S/D+T system, the storage/disposal cask is placed in a transportation overpack. The overpack lid with its O-ring seal is bolted in place to seal the cask inside the overpack. Transport impact limiters are then attached to both ends of the transportation overpack to complete the S/D+T transport package. In the S/T/D system, only transport impact limiters are attached to both ends of the storage/transport/disposal cask to complete the S/T/D transport package. With the addition of the transport packaging, the respective transport packages are then ready to be placed on the conveyance (truck or rail) for transport to the repository.

DU metal is used as shielding material in either the storage/transport cask (S/D+T system) or the storage/transport/disposal cask (S/T/D system). DU is not considered a structural material (refer to Section 2.0); the DU metal is sandwiched between the inner and outer stainless-steel structural shells of the casks.

Storage/Disposal Plus Transport (S/D+T) System

Storage/Transport/Disposal (S/T/D) System

- High-level Waste Form and Canister
- Reusable Components
- DU-Shielded Components

Figure 1-1. A Comparison of Depleted-Uranium-Shielded High-Level Waste Management Systems

1.4 Terminology

Contents: The HLW vitrified waste form (a borosilicate glass log) and the individual, seal-welded stainless-steel, pipe-like canister that confines and encloses the waste form. HLW canisters refers to the sealed canister and the enclosed borosilicate glass log waste form.

Contact-Handled (CH) Waste: Radioactive material that has been shielded and packaged so that external exposures are less than 200 mrem/h at the surface of the package and less than 10 mrem/h at a 2 m distance from the surface. DU-shielded casks are designed to meet these requirements when filled with HLW canisters.

Dedicated Train: A train composed of a locomotive and a specific number of railcars that transports a specific cargo, such as DU-shielded transport packages. The train and its cargo move as a unit. Railcars are neither added nor dropped until the train reaches its final destination. Sometimes a security escort railcar is part of the dedicated train.

Depleted Uranium: Depleted uranium (DU) is a byproduct of uranium enrichment operations. It is uranium with less than the natural ^{235}U concentration of 0.7%. The ^{235}U concentration of most of the DU inventory is between 0.2% and 0.5%.

High-Level Waste (HLW): HLW is generally defined as the highly radioactive liquid or solid materials resulting from the reprocessing of spent nuclear fuel. For the purpose of this study, HLW is the canistered, borosilicate glass log waste form produced by DOE vitrification facilities at the Savannah River Site, Hanford site, and West Valley Demonstration Project.

High-Level Waste Canister: A stainless-steel, seal-welded canister that confines vitrified HLW, a single solidified borosilicate glass log. "HLW canister" is equivalent to Contents above.

High-Level Waste Management System: The hardware, components, and operations required to store, transport, and dispose HLW canisters.

Remote-Handled Waste: Radioactive waste, either packaged or not packaged, that emanates unsafe levels of radiation exposures. This waste cannot be handled directly and requires shielding, robotic equipment, and/or standoff distances for safe handling.

Shielded Cask: A cask that has the property of mitigating or reducing radiation coming from waste within the cask. The shielding can be intrinsic to the material used to construct the cask or it may be a distinct material added specifically to lower external radiation exposures.

Storage/Disposal Cask: A DU-shielded cask that contains HLW canister(s). This cask is used in the S/D+T system for both waste storage at the waste processing facility and waste disposal in the geologic repository. This cask does not meet off-site transportation requirements.

Storage/Transport/Disposal Cask: A DU-shielded cask that holds the HLW canister seal-welded stainless steel container(s). This transportable cask is used in the S/T/D system for waste storage at

the waste processing facility and waste disposal in the geologic repository. This cask meets off-site transportation requirements.

Storage/Disposal Plus Transport (S/D+T) System: A HLW management system that employs a storage/disposal cask for HLW canister storage and disposal, and a separate reusable transportation overpack with transport impact limiters for HLW canister transport. The system includes preparation and emplacement capabilities at the repository.

Storage/Transport/Disposal (S/T/D) System: A HLW management system that employs a combined storage/transport/disposal cask for HLW canister storage, transport, and disposal. This system requires only the attachment of impact limiters for transport.

Storage Unit: In the S/D+T system, the storage unit is the seal-welded storage/disposal cask with its full complement of HLW canister(s). In the S/T/D system, the storage unit is the seal-welded storage/transport/disposal cask with its full complement of HLW canister(s) in their individual waste containers. Storage units include storage impact limiters and are designed to be stored outdoors on a securely fenced, perimeter lighted, concrete pad.

Transport Impact Limiter: A externally attached pair of metallic honeycombed-structured devices that protects the HLW canister contents and cask during transport. The impact limiter is designed to deform on impact, thus absorbing energies generated during accidents or incidents. This protects the cask and its contents against damage that might otherwise occur.

Transportation Overpack: In the S/D+T System, a separate non-DU-shielded component designed to protect the storage/disposal cask and HLW canister(s) from heat, fire, and physical impact that may occur during handling and shipping accidents, or security incidents. The storage/transport/disposal cask in the S/T/D system is designed to provide equivalent protection without the transportation overpack.

Transport Package: In both the S/D+T and S/T/D systems, the transport package consists of the transport packaging and its contents, the HLW canister(s).

Transport Packaging: In the S/D+T system, transport packaging includes the storage/disposal cask, the transportation overpack, and the transport impact limiters. In the S/T/D system, transport packaging includes the waste container, the storage/transport/disposal cask, and the transport impact limiters.

Waste Canister: A large, sealable, pipe-like stainless-steel assembly into which molten HLW is poured and solidified into a solid borosilicate glass log. An end plug is seal-welded on the top end to confine the solidified borosilicate glass log.

Waste Container: A thin-walled, seal-welded stainless-steel container that provides the first level of containment for the HLW canister in the S/T/D system.

Waste Form: The HLW borosilicate glass logs produced at DOE vitrification facilities at the Savannah River Site, Hanford site, and West Valley Demonstration Project that meet waste acceptance criteria for disposal in the geologic repository.

1.5 Assumptions

The following assumptions are made for this study.

- The proposed Hanford site and West Valley site vitrification plants will have capabilities similar to the DWPF at the SRS.
- High-level canistered waste may be stored up to 40 years, as stated in the *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE, 1992).
- Vitrified HLW processing facilities, both current and planned (such as the Hanford and West Valley), will have hot cells, cranes, and other equipment to handle DU-shielded casks and the storage and transport packages.
- The proposed repository, such as the site currently being evaluated at Yucca Mountain, can properly accept and handle DU-shielded casks that contain HLW canisters. (It should be acknowledged that the use of DU-shielded casks has not been studied by the repository designers.)
- The DU metal used for the HLW cask shielding can be acquired by converting depleted UF_6 , currently stored at DOE uranium processing plants, to DU metal.
- The costs incurred for the DU-shielded HLW management systems include costs for both conversion of depleted UF_6 to the metal form (at \$10.00/kg) and fabrication of the metal to finished product (at \$11.00/kg).
- The costs for separate disposal of depleted UF_6 as a waste material range from \$9.50/kg as low-level waste to \$30.19/kg as RCRA-controlled waste.
- The DU metal is provided in a form that can be either directly used or alloyed to produce DU rings or segments that are used as shielding material for the casks.
- The repository emplacement overpack for the S/D+T storage/disposal and the S/T/D storage/transport/disposal casks, if required, will be similar to the emplacement overpack designed for the multi-purpose canister (MPC) now being considered by the DOE Office of Civilian Radioactive Waste Management (OCRWM).
- The stainless-steel, seal-welded waste canister provides confinement, but not containment (with respect to transportation requirements), for the HLW borosilicate glass log enclosed in the canister.

- Transportation weight restrictions are 80,000 lb for a legal weight truck shipment and 263,000 lb gross railcar weight for a rail shipment.
- The transportation size restriction is a 10 ft-8 in. (width) by 15 ft-1 in. (height) cross section for rail shipment.
- The HLW canisters will require two levels of containment to meet transportation requirements as defined in 10 CFR 71.63.

1.6 Limitations

This study is limited to the conceptual design, design evaluation, and cost estimates of the DU-shielded S/D+T and S/T/D HLW management systems. Relative S/D+T and S/T/D system design and costs differences are based on the non-DU-shielded reference case developed in Section 6.0. In the reference case, HLW canisters and DU are disposed separately; the HLW in the geologic repository and DU in a low-level waste disposal facility. The DU-shielded S/D+T and S/T/D systems and the reference case costs are also compared with the Civilian Radioactive Waste Management Program (CRWMP) system cost (DOE, 1990).

The vitrification facilities considered are the DWPF at SRS and proposed vitrification facilities at the Hanford site and West Valley Demonstration Project. The S/D+T, S/T/D, and reference case systems are based on the storage, transport, and disposal of about 15,400 HLW canisters; the total number currently planned for production by these facilities.

The conceptual designs of the S/D+T and S/T/D systems are developed to establish the feasibility of using DU-shielded casks for the storage, transport, and disposal of HLW canisters. Limited detail is provided on these designs beyond conceptual development. Follow-on studies will evaluate these systems in greater detail and develop preliminary designs.

Cost information provided in this report is a first-order estimate for the storage, transport, and disposal of HLW canisters. Disposal costs are limited to the HLW canister delivery, preparation, and emplacement costs. Capital cost of the geologic repository itself is not considered in the cost estimate.

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2.0 DEPLETED URANIUM INVENTORIES AND PROPERTIES

2.1 Production and Disposition of Depleted Uranium

Since the 1940s, DOE and its predecessors have been enriching uranium for defense and commercial nuclear fuel applications. These applications require uranium with higher ^{235}U isotopic concentrations than the 0.7% concentration in natural uranium. Some applications require ^{235}U isotopic concentrations of several percent and others require 10% and higher. Enrichment processes, in addition to producing uranium with the required ^{235}U isotopic concentrations, produce DU, uranium with less than the natural 0.7% concentration of ^{235}U .

About 200 kg of DU are produced for each kilogram of enriched uranium processed for defense applications. For commercial applications, about 5 to 10 kg of DU are produced for each kilogram enriched. Over the decades of enriched uranium production at these ratios, DOE has generated and stores (as of March 31, 1994) about 555,000 metric tons of DU (DOE, 1995). Most of this DU is in the form of UF_6 and is stored outdoors in about 50,000 steel storage cylinders at SRS, the Hanford site, and the West Valley Demonstration Project. About 2,500 cylinders of UF_6 are added to the stored inventory each year.

The original intent was to retain DU in storage until it was used for further enrichment or as fertile blanket material for breeder reactors. Other uses include DU armor for tanks and DU armor piercing artillery shells. Actual usage is now far below expectations. Presently, the demand for DU is limited and decreasing. At the same time, the DU inventory continues to increase.

Questions are being raised whether DU is a radioactive waste and whether DU can be designated a "recyclable material" by RCRA standards. In addition, a small number (less than ten) of the storage cylinders are reported to be leaking, a number of them are rusting, and the public perception is that DU cylinders are yet another DOE pollution threat. Unless a beneficial use of DU is soon identified, DOE may have to consider disposal of DU as a radioactive or RCRA waste.

A number of benefits could result from the use of DU metal as shielding material in casks for HLW storage, transport, and disposal systems.

- Maintenance, repackaging, and future DU storage costs would be reduced, current cylinder storage sites could be remediated and released, and the empty cylinders could be made available to the U.S. Enrichment Corporation for other uses.
- DOE vitrified HLW would be stored in contact handled (CH) DU-shielded casks until the geologic repository is ready to accept waste.
- A more robust, long-term DU storage (as shielding) system would be provided for a part of the inventory until a decision is made to place the DU-shielded casks in the geologic repository.

- Future decontamination and decommissioning (D&D) costs for DU-shielded cask storage facilities would be negligible compared to projected D&D costs for current storage cylinder sites.
- The manufacture of DU-shielded casks would foster a viable new industry at reduced DOE total-system cost.

These benefits, in part, are the basis for studying DU-shielded casks for HLW management system applications.

2.2 Inventories

The 555,000-metric-ton inventory of DU is now stored in about 50,000 steel storage cylinders throughout the DOE complex (DOE, 1995). Mostly, these are 10- and 14-ton capacity cylinders. Table 2-1 shows the approximate percentages of DU inventories by site as of 1991. This inventory is mostly UF_6 and is equivalent to about 375,000 metric tons of DU metal.

Table 2-1. DOE Depleted Uranium Inventory in 1991 (WSRC, 1992)

Site Name	Percentage of DU Inventory
Martin Marietta, Uranium Enrichment Activity, Paducah	54.4
Martin Marietta, Uranium Enrichment Activity, Portsmouth Gaseous Diffusion Plant	25.7
Martin Marietta, Uranium Enrichment Activity, K-25 Site	9.6
Westinghouse Savannah River Company, Savannah River Site	5.8
Westinghouse Environmental Management Company of Ohio, Fernald Environmental Management Project	2.0
Martin Marietta, Paducah Gaseous Diffusion Plant	0.8
Martin Marietta, Y-12	0.6
U.S. DOE Albuquerque Field Office	0.2
Hanford, Defense Reactor Division	0.2
Mason & Hanger-Silas, Pantex	0.1
Total of other sites (each with <0.1% of grand total DU)	0.6

Uranium enrichment plants are still in operation. Currently they produce enriched uranium for domestic and international commercial nuclear power customers. These enrichment operations result in DU inventory increases of about 5% per year.

In July 1993, DOE contracted with the U.S. Enrichment Corporation to assume responsibility for uranium enrichment operations. The corporation continues to operate these facilities under that contract.

2.3 Characteristics

The concentration of ^{235}U in DU varies between 0.2% and 0.5%, slightly less than the 0.7% concentration found in natural uranium. DU is primarily a fertile, not fissile, source material. Accordingly, there are no significant criticality concerns associated with DU.

DU is one the densest materials known. At a metal density of 18.7 g/cm^3 , it is more dense than lead (11.3 g/cm^3). The high density of DU makes it attractive for radiation shielding applications. The material thickness required for effective gamma ray shielding is significantly less for DU than for other materials, such as lead and stainless steel. The mechanical properties of DU, stainless steel, and lead are provided in Table 2-2 (Becker, 1992).

Table 2-2. Mechanical Properties of Depleted Uranium, Stainless Steel, and Lead

	Depleted Uranium (α phase)	Stainless Steel (annealed)	Lead
Thermal expansion coefficient (β), $^{\circ}\text{F}$	13.8×10^{-6}	9.6×10^{-6}	16.4×10^{-6}
Yield strength, psi	20,000	30,000	1,900
Tensile strength, psi	50,000	80,000	2,500
Tensile modulus of elasticity, psi	2.8×10^7	2.8×10^7	2.0×10^6
Density, lb/in.^3	0.689	0.279	0.410

The American Society for Testing and Materials has not established material standards for uranium metal as a structural material and DU is not included as a code material by the American Society of Mechanical Engineers. Thus, the structural strength of DU metal was not considered in the conceptual HLW cask designs. The inherent mechanical/structural properties of alloyed DU are comparable to some stainless steels. However, DU is not accepted as a structural component in the design of transport packages. Although high in strength, DU and some of its alloys do exhibit undesirable fracture toughness properties.

Additional work to certify DU as a structural material should be considered for future work. If successful, DU-shielded cask weights would be less and standard railcars (versus the possibility of using heavy-duty railcars) could be used for conveyance.

The structural analyses reported in Section 4.0 take no credit for DU structural properties. DU only adds weight to the transport package. This approach adds conservatism to the designs and falls within current regulatory interpretations of structural materials.

2.4 Conversion of Uranium Hexafluoride to Uranium Oxide and Metal

UF₆ in its produced form is not a useable material. UF₆ must be converted to uranium oxide (U₃O₈) for disposal. For metal DU shielding material, UF₆ must be converted further to the metallic form. These conversions are costly, about \$4.20/kg for U₃O₈ and \$10.00/kg for uranium metal (DOE, 1995).

Newly developed DU metal conversion processes may reduce DU metal material costs (DOE, 1995). Idaho National Engineering Laboratory and Los Alamos National Laboratory plasma processes are possible candidates for reducing DU metal conversion costs. A continuous reduction process developed for the Advanced Vapor Laser Isotope Separation program at Oak Ridge National Laboratory is another. Martin Marietta Molten Metals (M4) Environmental Limited Partnership is reported to have still another DU metal conversion cost reduction process. While these processes have not been proven on a production scale, they do hold promise of reducing DU metal conversion costs. Nevertheless, the \$10.00/kg conversion is used to develop the cost estimates reported in Section 6.0.

Current commercial DU metal conversion capabilities exist, but generally, are not in operation at this time. A survey of these companies shows interest in restarting these operations if a significant demand for DU metal exists (DOE, 1995). These companies include Cameco Corporation (Port Hope, Canada), Nuclear Metal, Inc. (Concord, MA), Aerojet Ordnance Tennessee, Inc. (Jonesborough, TN), and Manufacturing Sciences Corp. (Oak Ridge, TN). Together, their DU metal production capacity, perhaps several thousand tons per year, is sufficient to support implementation of metal DU-shielded casks in the HLW management system.

3.0 HIGH-LEVEL WASTE STORAGE, TRANSPORT, AND DISPOSAL SYSTEMS

3.1 Overview

Two HLW storage, transport, and disposal systems are considered in this study:

- The storage/disposal plus transportation overpack (S/D+T) system and
- The storage/transport/disposal (S/T/D) system.

The two systems are introduced in Section 1.3 and shown in Figure 1-1. In some ways, the S/D+T and S/T/D systems are similar:

- Both systems employ a thick-walled metal DU-shielded cask.
- Both systems provide for the joint storage, transport, and disposal of HLW canisters and significant quantities of DU as shielding.
- Both systems allow for long-term (up to an estimated 40 years) outdoor storage of HLW canisters and DU as shielding in a robust storage unit.

In other ways, the S/D+T and S/T/D systems are different:

- The S/D+T system requires a separate transportation overpack for transport while the S/T/D system does not.
- The S/T/D system requires a separate, thin-shelled, stainless-steel waste container for each HLW canister while the S/D+T system does not.

The added S/T/D waste container is required to provide a second level of containment that is assumed to be needed for transport of the HLW canisters.

Generally, the two systems are similar in concept, but the specific components associated with the storage, transport, and disposal of HLW canisters are different. The components that make up the contents, storage unit, transport packaging, transport package, and waste (repository emplacement) package are shown in Figure 3-1. The S/D+T system is shown at the top and the S/T/D system at the bottom. The components of each system are identified in the far left-hand column. The succeeding columns show which components make up various parts of the storage, transport, and disposal system.

Note that the waste (repository emplacement) package in the far right-hand column in the S/D+T system does not include the transportation overpack or impact limiters. In the S/T/D system, the

System Components	S/D+T System				
	Contents	Storage Unit	Additional Transport Packaging	Transport Package	Waste (Repository Emplacement) Package
Repository Overpack					Repository Overpack
Waste Form	Waste Form	Waste Form		Waste Form	Waste Form
HLW Canister	HLW Canister	HLW Canister		HLW Canister	HLW Canister
Storage/Disposal Cask		Storage/Disposal Cask*		Storage/Disposal Cask	Storage/Disposal Cask
Transportation Overpack			Transportation Overpack	Transportation Overpack	
Impact Limiters			Impact Limiters	Impact Limiters	
Conveyance				Conveyance	

System Components	S/T/D System				
	Contents	Storage Unit	Additional Transport Packaging	Transport Package	Waste (Repository Emplacement) Package
Repository Overpack					Repository Overpack
Waste Form	Waste Form	Waste Form		Waste Form	Waste Form
HLW Canister	HLW Canister	HLW Canister		HLW Canister	HLW Canister
Waste Container		Waste Container		Waste Container	Waste Container
Storage/Transport/Disposal Cask		Storage/Transport/Disposal Cask*		Storage/Transport/Disposal Cask	Storage/Transport/Disposal Cask
Impact Limiters			Impact Limiters	Impact Limiters	
Conveyance				Conveyance	

*Includes storage impact limiters.

Figure 3-1. S/D+T and S/T/D System Components, Contents, and Packages

impact limiters are not included. These components are removed during preparations for disposal at the repository and returned to the respective DOE vitrification facility for reuse with future cask shipments.

Conceptual designs are developed for a one-canister cask for truck trailer conveyance, and three-, four-, and seven-canister casks for railcar conveyance. The different canister capacities are selected based on geometrical constraints. Two-, five-, and six-canister configurations are excluded because they are uneconomical because of excess void space within these casks. The seven-canister cask provides a configuration with a minimum void fraction (apart from the one-canister cask). The seven-canister cask size and weight are estimated to be the largest and heaviest permitted by railcar size (nominal 10 ft width by 15 ft height) and gross weight transportation restrictions.

Cask designs for the S/D+T and S/T/D systems are based on the SRS DWPF HLW canister (du Pont de Nemours & Co., 1988). As discussed in Section 1.0, similar canistered waste forms are expected to be used at planned DOE vitrification facilities at the Hanford site and West Valley Demonstration Project. The West Valley canister is expected to have a larger neck section for filling and a thinner canister wall, but the canister envelope is expected to be the same as the DWPF canister. It is assumed that the seal-welded canister, in each case, provides confinement, but not containment (with respect to transportation requirements) for the HLW borosilicate glass log it holds.

3.2 General System Design

The HLW management systems, excluding the conveyance, considered for this study are based on current regulatory requirements for Type B packages. Title 10, Code of Federal Regulations, Parts 71 and 72 (10 CFR 71 and 72) (NRC, 1995) are used as the governing documents for meeting regulatory transportation and on-site storage requirements. The containment requirements for disposal are defined in 10 CFR 60 (NRC, 1995).

Because the HLW canister will contain more than 20 curies (Ci) of plutonium, the HLW management systems for this study were assumed to require double containment of the waste form as defined in 10 CFR 71.63. The first level of containment is the seal-welded lid on the storage/disposal cask in the S/D+T system and the seal-welded stainless-steel waste container in the S/T/D system. The second level of containment is the elastomeric O-ring sealed and bolted closure on the transportation overpack in the S/D+T system and the seal-welded lid on the storage/transport/disposal cask in the S/T/D system. The bolted closure on the transportation overpack is a conventional closure design that is typically used on current-generation transport system designs. The closure seal would be comparable to current transport package practices.

Large honeycomb impact limiters are attached to both ends of the transport package to mitigate hypothetical transportation accident environments. In both systems, the package is shipped horizontally on either a dedicated truck trailer or railcar. The maximum truck transport weight is assumed to be 80,000 lb for a legal weight truck shipment. The railcar gross weight limit is assumed to be 263,000 lb (using a standard four-axle railcar). A heavier railcar may be needed to

carry the seven-canister configuration. If so, the net weight allowed for the transport package will be less by the additional weight of the heavier railcar.

The DU shielding material used in this study was assumed to be available in metallic form and alloyed to optimize the structural characteristics of the material. The DU will be cast into rings or segments and used as shielding material in the casks. Generally, the DU rings or segments will be sandwiched between the inner and outer structural steel layers. The structural strength of the DU was not considered in the design, but should be evaluated in follow-on studies. Stainless steel (type 304) was used for all major structural components in the HLW management systems. Stainless steel is a material recognized and accepted by the regulatory agencies. The economic benefits of these systems are discussed in Section 6.0.

3.3 Storage/Disposal Plus Separate Transport System

The S/D+T HLW management system consists of two major components: a DU-shielded storage/disposal cask and a transportation overpack. The storage/disposal cask is used as an on-site storage and repository disposal container for HLW canisters (see Figure 3-2). The storage/disposal cask can be constructed from a combination of stainless or high nickel alloy steel and DU. The DU provides radiation shielding for the canistered waste and the steel provides the structural integrity for the container. High nickel alloy steel is one of the corrosion-resistant materials being considered for the repository emplacement overpack material.

Appendix A provides conceptual drawings of the one-, three-, four-, and seven-canister storage/disposal plus transport system components. The one-canister cask is intended for truck transport, while the three-, four-, and seven-canister casks are intended for rail transport. Each storage/disposal cask is designed to provide primary containment of the HLW canister and sufficient shielding to meet transport regulatory radiation exposure limits of 10 mrem/h at 2 m from the cask surface and 200 mrem/h at the cask surface.

The storage/disposal casks are designed to be loaded at the waste processing facility with HLW canisters, seal welded, and stored on outdoor concrete pads, up to 40 years, until the geologic repository is completed and ready to receive HLW. When the repository is ready, the storage/disposal cask is loaded into a transportation overpack, and an elastomeric sealed, bolted closure is installed. Transport impact limiters are installed, and the transport package is loaded on either a truck trailer or railcar for transport to the repository.

The truck and railcar loading configurations for the one- and seven-canister transport packages, respectively, are shown in Appendix B. At the repository, the transport package is removed from the truck trailer or railcar, and the storage/disposal cask is removed from the transportation overpack and prepared for repository emplacement. The empty transportation overpack with impact limiters is loaded onto either the truck trailer or railcar and returned to the waste processing facility, where it is prepared to transport additional storage/disposal casks.

Figure 3-2. Storage/Disposal Plus Transport (S/D+T) System

The total weight of each S/D+T system configuration is shown in Table 3-1. The one-canister truck-transportable configuration uses ~8 tons (7 metric tons) of DU, while the seven-canister rail-transportable configuration uses ~40.5 tons (37 metric tons) of DU.

Table 3-1. Total Weight of Storage/Disposal Cask Plus Transportation Overpack Configurations

One-Canister Storage/Disposal Cask Plus Transportation Overpack Configuration	
Transportation overpack	20,300 lb
Transport impact limiters	3,070 lb
Storage/disposal cask	6,500 lb
Depleted uranium	16,200 lb
High-level waste canister with waste form	<u>5,400 lb</u>
	51,470 lb
Three-Canister Storage/Disposal Cask Plus Transportation Overpack Configuration	
Transportation overpack	46,500 lb
Transport impact limiters	5,840 lb
Storage/disposal cask	20,500 lb
Depleted uranium	46,700 lb
High-level waste canister with waste form	<u>16,200 lb</u>
	135,740 lb
Four-Canister Storage/Disposal Cask Plus Transportation Overpack Configuration	
Transportation overpack	52,800 lb
Transport impact limiters	6,482 lb
Storage/disposal cask	23,600 lb
Depleted uranium	53,000 lb
High-level waste canister with waste form	<u>21,600 lb</u>
	157,482 lb
Seven-Canister Storage/Disposal Cask Plus Transportation Overpack Configuration	
Transportation overpack	70,200 lb
Transport impact limiters	7,642 lb
Storage/disposal cask	31,500 lb
Depleted uranium	81,000 lb
High-level waste canister with waste form	<u>37,800 lb</u>
	228,142 lb

The S/D+T system has two advantages in addition to the disposal of large quantities of DU. The transportation overpack is designed as a thick-walled, stainless-steel structure with a conventional bolted closure. After the storage/disposal cask is closed, the closure assembly can be easily tested to verify containment before transport. This type of closure design is commonly used for large transportation overpacks and is understood and accepted by regulatory organizations.

The other major advantage of the separate transportation overpack is that the overpack is reusable for transporting storage/disposal casks. The total number of transportation overpacks needed to conduct a repository shipping campaign from a specific processing facility may be as small as five to ten units, thereby reducing the capital investment (compared to the S/T/D system) for the HLW management system.

The three- and four-canister S/D+T configurations were developed to determine if there are any economic or facility-handling benefits to be gained by reducing the number of canisters per cask. The three- and four-canister waste configurations have no transport benefit as far as total railcar capacity. However, there may be handling benefits (ease in emplacement) at the repository due to the somewhat lower storage/disposal cask weights and smaller package envelope. In either case, only a single three-canister cask or a single four-canister cask can be transported per standard four-axle railcar. Using these configurations would increase the total number of storage/disposal casks required to store and dispose of the HLW canisters and increase the total number of shipments. The most economical configuration is the larger seven-canister configuration (refer to Section 6.0).

The S/D+T system configurations considered most viable are the one-canister, truck-transportable configuration if the facility does not have rail access, or the seven-canister configuration for rail transport.

3.4 Combined Storage/Transport/Disposal System

The S/T/D HLW management system features a combined DU-shielded storage/transport/disposal cask (see Figure 3-3). The thin-walled inner stainless-steel container with welded closure and lifting attachment is used as the first level of containment for the canistered waste. The seal-welded HLW canister containing the vitrified borosilicate, glass log is not credited for containment.

The outer storage/transport/disposal cask provides the shielding and its seal-welded lid provides secondary containment for the HLW canisters. This cask can be constructed from a combination of stainless or high nickel alloy steel and DU. The DU provides radiation shielding and the steels provide the structural integrity for the cask. Appendix C provides conceptual drawings of

Figure 3-3. Storage/Transport/Disposal (S/T/D) System

the four S/T/D system configurations considered. These configurations include one-, three-, four-, and seven-canister configurations. The one-canister configuration is intended for truck transport, while the three-, four-, and seven-canister configurations are intended for rail transport. Each S/T/D cask is designed to meet transport radiation exposure limits of 10 mrem/h at 2 m from the cask surface and 200 mrem/h at the cask surface.

The S/T/D process for loading and storage is somewhat different than the loading and storage process in the S/D+T system. Here the canistered waste is loaded into the inner thin-walled waste container and a closure assembly with a lifting attachment is welded to the container. This waste container could be fabricated using stainless steel or a high nickel alloy steel. The waste container is loaded into the DU-shielded storage/transport/disposal cask, and the cask closure assembly is welded to the cask. The storage/transport/disposal cask is then stored on outdoor concrete storage pads, up to 40 years, at the vitrification facility until the geologic repository is completed and ready to receive HLW.

When the repository is ready, the storage/transport/disposal cask is prepared for transfer to the repository. Transport impact limiters are installed and the package is loaded onto a truck trailer or railcar. The truck trailer and railcar loading configurations for the one- and seven-canister transport packages, respectively, are shown in Appendix C. (Conceptually, these configurations are the same as the S/D+T configuration.) At the repository, the impact limiters are removed and returned to the processing facility, and the cask is prepared for repository emplacement. In this system, the transport impact limiters are the only reusable component.

The total weight of each S/T/D system configuration is shown in Table 3-2. In addition to disposal of HLW, the one-canister truck-transportable configuration will dispose of ~9 tons (~8 metric tons) of DU, while the seven-canister rail transportable cask uses ~47 tons (~43 metric tons) of DU as shielding.

The S/T/D system has some disadvantages. In this system, both primary and secondary closures are welded to the inner waste container and the storage/transport/disposal cask, respectively. The ability to verify seal weld integrity of both weldments after a long storage period is not a straightforward process. Access to the inner waste container is limited by the storage/transport/disposal cask closure assembly. This closure provides the primary end shielding and the welded assembly eliminates direct access to the inner container. This could be an operational verification process that may add significant effort to storage and transport operations. Also, the transportation overpack is constructed as an integral part of the storage/transport/disposal cask and is emplaced with the HLW at the repository. Thus the capital cost of each storage/transport/disposal cask is higher because it must be built to withstand the transportation certification standards.

The three- and four-canister S/T/D system configurations were developed to determine whether economic benefit resulted from reducing the total number of canisters. The three- and four-canister configurations have no transportation benefit as far as total railcar capacity. Despite the reduced size and weight, only a single three-canister or a single four-canister could be

Table 3-2. Total Weight of Storage/Transport/Disposal Cask Configurations

One-Canister Storage/Transport/Disposal Cask Configuration	
Storage/transport/disposal cask	13,300 lb
Depleted uranium	18,500 lb
Transport impact limiters	2,820 lb
Inner waste container	1,650 lb
High-level waste canister with waste form	<u>5,400 lb</u>
	41,670 lb
Three-Canister Storage/Transport/Disposal Cask Configuration	
Storage/transport/disposal cask	40,400 lb
Depleted uranium	53,600 lb
Transport impact limiters	5,010 lb
Inner waste container	5,000 lb
High-level waste canister with waste form	<u>16,200 lb</u>
	120,210 lb
Four-Canister Storage/Transport/Disposal Cask Configuration	
Storage/transport/disposal cask	46,300 lb
Depleted uranium	61,000 lb
Transport impact limiters	6,446 lb
Inner waste container	6,600 lb
High-level waste canister with waste form	<u>21,600 lb</u>
	141,946 lb
Seven-Canister Storage/Transport/Disposal Cask Configuration	
Storage/transport/disposal cask	72,600 lb
Depleted uranium	95,300 lb
Transport impact limiters	7,428 lb
Inner waste container	11,600 lb
High-level waste canister with waste form	<u>37,800 lb</u>
	224,728 lb

transported on a standard four-axle railcar. The use of these configurations would increase the total number of casks required, as well as increase the total number of shipments. As with the S/D+T system, the most economical S/T/D configuration is the large seven-canister configuration (refer to Section 6.0).

3.5 Incoloy-Clad Casks

As discussed in Section 1.0, a repository emplacement overpack is required for disposal of the DU-shielded cask. As an option to the repository emplacement overpack, a conceptual design was developed for an Incoloy-clad cask in both the S/D+T and the S/T/D systems. In this option, the outer steel structural shell is made of Incoloy rather than stainless steel. It is believed that the Incoloy design meets requirements set for the repository emplacement overpack. However, its acceptance for disposal without the separate repository overpack has not been approved. If it is approved, total-system cost will be lower by approximately \$0.2B for the seven-canister configuration in the S/D+T system (refer to Section 6.0). Additional work to gain acceptance of Incoloy-clad by the repository for disposal without the need for the separate repository emplacement overpack should be considered in future tasks.

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4.0 THERMAL, STRUCTURAL, AND SHIELDING ANALYSES

4.1 Introduction

Thermal, structural, and shielding analyses of both the S/D+T and S/T/D HLW management systems were conducted for this report. The preliminary thermal analysis indicates that system component temperatures do not exceed the established temperature limits. The preliminary structural analysis found no structural feature in either system that would preclude acceptance at this time. The results of the preliminary shielding analyses show the proposed DU thicknesses should provide adequate radiation shielding.

4.2 Thermal Analysis

A thermal analysis was performed to evaluate the preliminary conceptual design of the seven-canister configuration of the S/D+T system. A two-dimensional thermal model was used to calculate the temperature distribution in the seven-canister configuration. The seven-canister configuration was selected because this configuration had the highest total heat generation.

The thermal evaluation of the seven-canister configuration had three objectives. The first objective was to verify that the centerline temperature of the center waste canister did not exceed published maximum permissible temperatures for the canistered waste form. The second objective was to verify that the O-ring temperature of the transportation overpack did not reach a temperature resulting in a loss of seal integrity. The third objective was to calculate the maximum surface temperature of the S/D+T system.

4.2.1 Thermal Model

The thermal analysis was performed using PATRAN to generate the thermal model and P/THERMAL to calculate temperatures (PDA Engineering Associates, 1991). Figure 4-1 presents the thermal model. Because the model was two-dimensional, end effects were not considered.

The model consisted of a one-twelfth section of the seven-canister configuration. Air was used as a fill gas between the waste canisters in the storage/disposal cask. Helium was used as a fill gas between the storage/disposal cask and the transportation overpack. Type 304 stainless steel was used in the transportation overpack and the storage/disposal cask.

Figure 4-1. Depleted Uranium Thermal Model

The seal region of the transportation overpack was not modeled. The temperature of the transportation overpack/inner storage/disposal cask interface was used as the seal temperature. This is a conservative assumption because the actual seal region is closer to the exterior surface than the transportation overpack/inner storage/disposal cask interface, and thus could be expected to be cooler.

Boundary Conditions

Normal Conditions of Transport. The boundary conditions on the exterior of the seven-canister S/D+T configuration consisted of radiation, convection, and solar loads. The ambient air surrounding the transportation overpack was at 38°C. The solar load was for a curved surface, in accordance with 10 CFR 71, and was 387.5 W/m². The heat dissipation was 690 W per waste canister, assuming that the canister is filled with oxides from 5-year-old sludge and precipitates from 15-year-old supernate. The emissivity for the stainless-steel surfaces was assumed to be 0.5.

Hypothetical Accident Environment. The hypothetical thermal accident environment follows the 9-m (30-ft) impact and 1-m puncture, and is defined in the regulations as a thermal environment fully surrounding the package with an 800°C temperature for 30 minutes. The emissivity of the package surface was 0.8 and the emissivity of the environment was 0.9, in accordance with 10 CFR 71.

The initial temperature distribution was taken from the normal condition of transport analysis. A cool-down period of 4 hours is used to ensure that maximum temperatures are obtained in the hypothetical accident environment.

Material Properties

The material and thermal properties for the waste material and DU were taken from the defense HLW cask described in the Safety Analysis Report for Packaging (SARP) (GA Technologies, 1987). The waste material thermal properties are

$$k = 0.845 + 0.00125T(^{\circ}\text{C}) \text{ W/m-}^{\circ}\text{C} , \quad (4.1)$$

and

$$\rho c_p = 0.195 + 0.000425T(^{\circ}\text{C}) \text{ cal/cm}^3\text{-}^{\circ}\text{C} . \quad (4.2)$$

The DU material thermal properties are

$$k = 25.6 \text{ W/m-}^{\circ}\text{C} , \quad (4.3)$$

and

$$\rho c_p = 0.609 \text{ cal/cm}^3\text{-}^{\circ}\text{C} . \quad (4.4)$$

The thermal conductivity for air, helium, and type 304 stainless steel was taken from the PATRAN materials data base.

Component Temperature Limits

The component temperature limits used in this analysis are presented in Table 4-1. The temperature limit for the waste form was taken from the defense HLW cask SARP, although

subsequent reports publish a lower anneal temperature (of 407°C). The temperature limit for the surface temperature was also taken from the defense HLW cask SARP. The seal temperature limit used in this analysis is referenced in manufacturer's data.

Table 4-1. Component Temperature Limits

Component	Temperature Limit (°C)
Seals	204
Waste Canister	300
Surface	82 ^a

^aNo solar load (shaded surface).

4.2.2 Results and Conclusions

Normal Conditions of Transport

The maximum component temperatures calculated for the normal conditions of transport environment are presented in Table 4-2.

Table 4-2. Component Maximum Temperatures for Normal Conditions of Transport

Component	Temperature (°C)	Limit (°C)
Seals	106	204
Waste Canister	293	300
Surface	65 ^a	82
Surface	102 ^b	N/A

^aNo solar load.
^bSolar load.

Hypothetical Accident Environment

The maximum component temperatures calculated for the hypothetical accident environment are presented in Table 4-3.

Table 4-3. Component Maximum Temperatures for the Hypothetical Accident Environment

Component	Temperature (°C)	Limit (°C)
Seals	198	204
Waste Canister	293	300

The calculated temperatures for the hypothetical accident environment are below the component limits presented in Table 4-1. The waste canister temperature did not change because of the large thermal mass of the cask.

Conclusions

For both the normal condition of transport and hypothetical accident environments, the preliminary thermal analysis indicates that component temperatures do not exceed maximum temperature limits. This thermal analysis was performed on the seven-canister S/D+T system configuration. Other configurations, such as three- and four-canister casks, are feasible options. To ensure regulatory compliance, a thermal analysis of these other configurations would need to be performed if they were selected for further evaluation.

The on-site storage environment should be examined to ensure the casks will be compliant with the appropriate regulations. Geometric orientation of the casks will affect both centerline waste temperature and surface temperature. The question of elevated temperatures and personnel barriers should be addressed in the next program phase. Likewise, the method of emplacement must be specified to perform the thermal calculations that ensure waste centerline temperatures do not exceed component temperature limits.

4.3 Structural Analysis

A preliminary structural analysis of the two proposed DU-shielded HLW management systems was performed. The first system is a DU-shielded and stainless-steel storage/disposal cask with a separate stainless-steel transportation overpack (S/D+T). This system is proposed in four different configurations: one-, three-, four-, and seven-waste canister casks. The second system is a stainless-steel and DU-shielded combined storage/transport/disposal cask (S/T/D). This system was developed in the same four configurations. (A more complete description of the systems is found in previous sections of this document.)

The preliminary structural analyses of these transportation systems evaluated tip-over loadings of the storage/disposal cask (of the S/D+T system illustrated in Figure 1-1) and the storage/transport/disposal cask (of the S/T/D system) with a handling (or storage) impact limiter attached. The analyses also evaluated a 9-m (30-ft) impact of the transportation overpack (of the S/D+T system

illustrated in Figure 1-1) and the storage/transport/disposal cask (of the S/T/D system) with transport impact limiters. The tip-over analysis evaluates loads that may be imposed during handling and storage operations. The 9-m (30-ft) impact analysis evaluates partial performance during hypothetical transport accident conditions.

Because this is a preliminary analysis, elaborate finite-element modeling has not been performed on these systems. Instead, simplified analytical methods were used to predict the dynamic response of the systems during the tip-over and 9-m (30-ft) impact events.

4.3.1 Storage/Disposal Plus Transport System

The first system analyzed consists of a waste canister, a sealed stainless-steel storage/disposal cask that includes DU shielding, and a separate stainless-steel reusable transportation overpack (S/D+T). The sealed stainless-steel, DU-shielded storage/disposal cask is designed to store the canistered waste at the processing facility up to 40 years. This storage/disposal cask will be evaluated for tip-over loads that simulate possible severe handling conditions. The subsequent 9-m (30-ft) impact analysis will be applied to the storage/disposal cask and the transportation overpack with impact limiters. The structural properties of the four S/D+T system configurations are shown in Table 4-4.

Table 4-4. Structural Properties of Storage/Disposal Cask Plus Transportation Overpack System Configurations

Storage/Disposal Cask and Transportation Overpack Configuration	Inner Storage/ Disposal Cask Weight* (lb)	Storage/Disposal Cask: Center of Gravity From Base (in.)	Storage/Disposal Cask Plus Transportation Overpack Weight* (lb)	Storage/Disposal Cask Plus Transportation Overpack: Center of Gravity From Base (in.)
One-Canister	28,310	64.8	47,251	74.6
Three-Canister	86,070	65.4	127,370	74.6
Four-Canister	101,640	65.4	148,280	74.7
Seven-Canister	156,933	65.2	216,250	73.7

*Preliminary weights used in the structural analysis.

Tip-Over Analysis of the Storage/Disposal Cask

The tip-over analysis of the storage/disposal cask used the following procedure. The maximum potential energy of the cask was calculated with the cask oriented such that the center of gravity was over the corner. The potential energy of the cask on its side was calculated and subtracted from the maximum potential energy. The difference in energy was used to determine how much the handling (or storage) impact limiter would be crushed during the tip-over event. The average force needed to crush the storage impact limiter was then calculated and applied as a static load with an appropriate dynamic amplification factor. The stresses in the cask could then be determined using simple static bending stress calculations.

For the seven-canister configuration, the center of gravity is located ~78.24 in. above the corner when the storage/disposal cask is in this orientation. The center of gravity is located at a height of ~43.25 in. when the cask is on the side. The potential energy from the difference in height is

$$\Delta PE = W\Delta H = 156,933 (78.24 - 43.25) = 5.5E+06 \text{ in.-lbs} . \quad (4.5)$$

The volume of 4,000-psi material that must be crushed to absorb the impact is

$$V = 5.5E+06 / 4,000 = 1,375 \text{ in.}^3 . \quad (4.6)$$

This equates to a crush depth of just over 4 in. on the side of the impact limiter. An approximation of the forces generated from the crushing can be calculated by assuming that a rectangular box of crushable material with dimensions of 4 in. by 12 in. and an average width of 28 in. is fully crushed during the tip-over event. This results in an average force of

$$\text{Average Force} = 28 \times 12 \times 4,000 = 1.34E+06 \text{ lbs} . \quad (4.7)$$

Assuming a dynamic amplification factor of 2 (theoretical maximum for a single mass, single spring system) and the static loading configuration shown in the free body diagram (Figure 4-2), an estimate of the maximum bending stresses in the cask wall can be made.

In Figure 4-2, all downward forces are assumed to be acting at the center of gravity of the cask. This is a very conservative assumption because in reality, a disproportionate amount of the mass is located at each end of the cask. Also assumed is that the corner of the cask away from the impact is just lifted off the ground and is not imposing any forces on the cask. The bending moment can then be calculated as

$$\text{Bending Moment} = 68 \times 2.68E+06 = 1.8E+08 \text{ in.-lbs.} \quad (4.8)$$

Figure 4-2. Free Body Diagram Showing Assumed Force Locations During Tip-Over

The calculated static bending forces, which assumes that only the outer stainless-steel wall takes all of the bending loads, results in a material stress of 25,000 psi. This stress is still below the yield stress of ~28,000 psi for 304 stainless steel. Given the very conservative assumptions used (stressing only the outer wall and placing all the mass at the center of gravity), the seven-canister storage/disposal cask should have no trouble surviving a tip-over impact. The results for the one-, three-, and four-canister systems also resulted in acceptable performance in the tip-over analysis.

Nine-Meter (Thirty-Foot) Impact of the Storage/Disposal Cask and Transportation Overpack

The calculation of average stresses in the wall of the storage/disposal cask and transportation overpack (S/D+T) is very straightforward. An end-on impact was selected for analysis. In an end-on impact, virtually all kinetic energy is adsorbed in the crushable impact limiters. A crush strength of 3,000 psi is assumed for the transport impact limiters. An average acceleration required to bring the storage/disposal cask plus transportation overpack to a stop from the 9-m (30-ft) drop can be calculated using a simple equation of motion. A 9-m (30-ft) drop results in a velocity of 13.4 m/s (528 ips). The kinetic energy in the seven-canister storage/disposal cask and transportation overpack configuration is

$$KE = 0.5 MV^2 = 0.5 \times 216,250 / (32.2 \times 12) \times 528^2 = 7.8E+07 \text{ in.-lbs} \quad (4.9)$$

The depth of crush can be calculated by assuming all energy goes into crushing the impact limiter on the end of the package.

$$\text{Depth of Crush} = 7.8E+07 / (\text{Area of End} \times \text{Crush Strength}) = 3.8 \text{ in.} \quad (4.10)$$

The average acceleration during the impact is calculated to be ~95g.

The axial stresses in the wall of the transportation overpack of the S/D+T system seven-canister configuration can be calculated by assuming that 80% of the weight of the transportation overpack contributes to the load in the wall. (The other 20% is based on the assumption that the weight of one end does not contribute to the load in the wall.) Using a dynamic amplification factor of 2 and 80% of the weight accelerating at ~95g results in a wall stress of only 5,400 psi. This is well below the 28,000-psi yield strength of the material. The axial stresses from the 9-m (30-ft) impact in the transportation overpack wall are small and should not challenge the integrity of the package. The results for the one-, three-, and four-canister S/D+T configuration calculations also result in acceptable performance in the 9-m (30-ft) impact analysis.

4.3.2 Combined Storage/Transport/Disposal System

The combined S/T/D system consists of waste canisters sealed in an inner thin-walled waste container and a heavier outer DU-shielded storage/transport/disposal cask. The differences between the four configurations of this system are determined by how many individual waste canisters with their own inner waste containers are placed in the heavier DU-shielded cask. The weights of the four systems are shown in Table 4-5.

Table 4-5. Weights of Combined Storage/Transport/Disposal System Configurations

Combined Storage/Transport/ Disposal System Configurations	Total System Weight (lb)
One-Canister	41,670
Three-Canister	120,210
Four-Canister	141,946
Seven-Canister	224,728

Tip-Over Analysis of the Combined Storage/Transport/Disposal System

For a true failure to occur during a tip-over incident, the inner waste container must be compromised. Because the inner waste container is protected by the heavy outer DU-shielded cask, the chance of rupture to the inner waste container is very small during handling operations.

Although the outer cask could conceivably receive some damage during handling, this would not create a failure to the inner waste container. The one-, three-, four-, and seven-canister configurations should have acceptable behavior concerning leakage to the inner waste container during handling operations, including tip-over loadings.

Nine-Meter (Thirty-Foot) Impact of the Storage/Transport/Disposal Cask

During shipping the combined storage/transport/disposal cask will be fitted with transport impact limiters on each end. The weight and dimensions of the cask will be similar to the storage/disposal cask plus transportation overpack analyzed previously. The impact limiter will perform in much the same manner and impose about the same levels of acceleration to the package.

The axial stresses in the wall of the storage/transport/disposal cask should be similar to the stresses in the storage/disposal cask plus transportation overpack previously analyzed. Those stresses were only 5,400 psi, which was well below the yield strength of the 304 stainless steel. Axial stresses from the impact should not be a problem in any of the configurations considered. The one-, three-, four-, and seven-canister configurations of the S/T/D system should have acceptable behavior during a 9-m (30-ft) impact.

4.3.3 Conclusions

Within the limitations of the analyses performed, there are no structural features in either the S/D+T system or the S/T/D system that would preclude acceptance at this time. A more detailed analysis of all system configurations will be required to predict more accurately the behavior of these systems. There is sufficient flexibility in these designs that should potential structural concerns become apparent, straightforward design changes can be applied to correct the condition.

4.4 Shielding Analysis

A series of preliminary calculations was performed using simple point-kernel techniques to determine adequate DU shield thicknesses for storage/disposal casks designed to store one HLW canister and another to store seven HLW canisters. The calculations considered the effects of varying the DU shield thickness on the predicted dose rates at the surface of the cask and at 2 m from the centerline, both radially and axially. This energy spectrum and the strength of the gamma radiation source used in the calculations are described below. No calculations were performed to evaluate neutron shielding in the conceptual cask designs. Based on analyses performed for a cask design similar to the model being used for the one-DHLW-canister configuration (GA Technologies, 1987), it is reasonable to assume that the neutron dose will be comparable in magnitude to the calculated gamma doses. The QADS code used to perform the analyses is briefly described (in detail in Broadhead, 1990). Modeling assumptions and descriptions of the geometry models used in the analyses are presented as well as the calculated results. A reference waste density of 2.69 g/cm^3 was assumed in the shielding analyses.

4.4.1 Source Description

The photon source in the waste form (HLW glass) is a result of the radioactive decay of both activation and fission products contained in the wastes. Table 4-6 lists the major contributors to the photon source (excerpted from GA Technologies, 1987). Gamma-line data for these nuclides (taken from Brown and Firestone, 1986) were combined and binned into an 18-group energy structure required for the shielding calculations. The normalized gamma source spectrum is given in Table 4-7. GA Technologies (1987) also gives the gamma source strength as $8.9070\text{E-}02\text{ Ci/cm}^3$. Based on a fill height of 106 in. and a canister inner diameter of 23.25 in., a total source strength of $2.4306\text{E+}15$ photons/sec was used for each HLW canister.

**Table 4-6. Principal Photon Sources in the Waste Form (High-Level Waste Glass)
(GA Technologies, 1987)**

Nuclide	Activity	
	(Ci/lb)	(Ci/cm ³) ^a
Co-60	4.58E-02	2.72E-04
Zr-95	2.71E-06	1.61E-08
Nb-95	5.70E-06	3.38E-08
Rh-106	6.09E-01	3.61E-03
Ag-110m	3.39E-05	2.01E-07
Sb-125	2.29E-01	1.36E-03
Cs-134	9.09E-02	5.40E-04
Ba-137m	1.12E+01	6.65E-02
Pr-144	2.66E+00	1.58E-02
Eu-152	9.94E-04	5.90E-06
Eu-154	1.67E-01	9.91E-04

^aBased on 2.69 g/cm^3 waste density.

4.4.2 Method of Dose Evaluation

The code QADS was used in this preliminary study to evaluate the effect of various thicknesses of DU shielding. QADS, a multidimensional point-kernel code utilizing the simplified free-form input of the SCALE system (Broadhead, 1990), was developed under U.S. Nuclear Regulatory Commission (NRC) sponsorship. The point-kernel method is an approximate, but very economical, approach for evaluating photon responses in shielding materials (Parks et al., 1988).

The point-kernel method provides reasonable results for cases in which the shield is made of one solid material and the source can be approximated as one homogeneous material. The method does not account for radiation scattering from structures external to the shield

Table 4-7. Normalized Gamma Energy Spectrum

Group Number	Upper Energy Limit (eV)	Normalized Group Strength ^a
1	1.00E+07	0.000E+00
2	8.00E+06	0.000E+00
3	6.50E+06	0.000E+00
4	5.00E+06	0.000E+00
5	4.00E+06	0.000E+00
6	3.00E+06	0.000E+00
7	2.50E+06	0.000E+00
8	2.00E+06	2.182E-03
9	1.66E+06	1.732E-02
10	1.33E+06	4.018E-02
11	1.00E+06	2.051E-02
12	8.00E+05	8.314E-01
13	6.00E+05	7.387E-02
14	4.00E+05	2.776E-03
15	3.00E+05	4.606E-03
16	2.00E+05	5.920E-03
17	1.00E+05	0.000E+00
18	5.00E+04	1.303E-03
	1.00E+04 ^b	

^aA gamma source of 2.4306E+15 photons/sec was used for the one-HLW-canister configuration and

1.70142E+16 photons/sec was used for the seven-HLW-canister configuration.

^bLower limit of energy spectrum.

(walls, floors, ceilings, etc.). The method as implemented in QADS provides a dose on the basis of direct line-of-sight attenuation from source to detector. Parks et al. (1988) also provide comparison data for calculations using the QADS point-kernel methodology versus discrete ordinates and Monte Carlo calculations.

The analyses performed utilized the geometrical progression approximation option in QADS (Broadhead, 1990). This option represents improvements in the point-kernel technique. The infinite-medium buildup factors used by QADS should result in an overestimate of the dose rate at a surface external to the source region, because it implies that reflecting material is located beyond the surface. However, the error will usually not be more than a few percent. The buildup factors used in these analyses were those designated IRON_EXP, indicating the air exposure response with penetration through iron. Iron buildup factors were used to yield conservative results. The effect of this assumption is illustrated in the discussion of the results.

4.4.3 Geometry Models and Assumptions

This section describes the geometry specifications used in the shielding calculations. The multidimensional point-kernel computer code QADS (Broadhead, 1990) was used to perform shielding analyses of one-canister and seven-canister storage/disposal casks.

One-Canister Configuration

The DU-shielded one-canister S/D+T system configuration was modeled as a series of concentric right-circular cylindrical bodies as shown in Figure 4-3. Specific zones, or regions, were defined as shown in Figure 4-4. Surrounding internal and external voids were constructed to facilitate QADS dose estimations external to the package. Although a DU shield thickness of 6 in. is shown in Figure 4-4, calculations were performed for DU shield thicknesses ranging from 1 in. to 6 in.

As shown in Figure 4-4:

- The waste form (a glass log) is 106 in. long with a diameter of 23.25 in.
- The HLW canister has a wall thickness of 0.375 in. and outer diameter of 24 in.
- There is a 0.5-in. void around the sides of the waste canister, a 13.25-in. void at the top of the canister (on the closure end), and no void at the bottom of the canister.

Figure 4-3. Top View and Modeling of One-Canister Depleted-Uranium-Shielded Storage/Disposal Cask

Figure 4-4. Profile of One-Canister Depleted-Uranium-Shielded Storage/Disposal Cask Showing Zones

- The shield liner has a steel thickness of 1 in.
- The DU shield has a thickness of 6 in.
- The storage/disposal cask body has a thickness of 2 in., except at the closure end where it is 12 in.
- The waste canister, shield liner, and the storage/disposal cask body are made of stainless steel.

Seven-Canister Configuration

The seven-canister DU-shielded S/D+T system configuration contains seven waste forms (glass logs), each contained within a waste canister and a basket, as shown in Figure 4-5. The basket is a thin-walled stainless-steel pipe used to guide and separate the waste canisters during the loading process. However, the seven-canister S/D+T system configuration was modeled by smearing the outer six waste logs over the volume between the basket containing the inner waste form and the DU shield liner, as shown in Figure 4-6. The source density of the outer six waste forms was reduced by the ratio of the volume of the six waste forms (each 106 in. long and having a diameter of 23.25 in.) to the volume between the inner basket and the DU shield liner.

Figure 4-5. Top View of Seven-Canister Depleted-Uranium-Shielded Storage/Disposal Cask

Figure 4-6. Modeling of Seven-Canister Depleted-Uranium-Shielded Storage/Disposal Cask With Smeared Outer Six Waste Forms

(This volume had a length of 106 in., an outer diameter of 78 in., and an inner diameter of 26 in.) The canisters and the baskets for the outer six waste forms were neglected. Specific zones for this case are shown in Figure 4-7. Surrounding internal and external voids were constructed to facilitate QADS dose estimations external to the package. Although a DU shield thickness of 6 in. is shown in Figure 4-7, calculations were performed for DU shield thicknesses ranging from 2 in. to 6 in. A change in the DU shield thickness would only change the dimensions of the storage/disposal cask body, not the geometry of the inner waste form, the inner waste canister, the inner basket, the smeared outer six waste forms, or the DU shield liner.

Figure 4-7. Profile of Seven-Canister Depleted-Uranium-Shielded Storage/Disposal Cask Showing Modeling Zones

As shown in Figure 4-7:

- The inner waste form is 106 in. long and has a diameter of 23.25 in.
- An inner stainless-steel waste canister has a wall thickness of 0.375 in. and an outer diameter of 24 in.

- There is a basket around the inner waste canister with a wall thickness of 0.5 in., an outer diameter of 26 in., and an inner diameter of 25 in.
- There is a 0.5-in. void between the basket and the sides of the waste canister, a 13.25-in. void to the left of the canister, and no void to the right of the canister.
- The DU shield liner has a steel thickness of 1 in. all around.
- The DU shield has a thickness of 6 in. all around.
- The storage/disposal cask body has a thickness of 2 in., except at the closure end where it is 12 in.
- The storage/disposal cask body, the basket, the DU shield liner, and the waste canister body are made of stainless steel.

In the materials specifications for the shielding analyses, a density of 18.9 g/cm^3 was assumed for the DU shield material. All other materials (waste canister, shield liners, etc.) were assumed to be type 304 stainless steel. The composition of the HLW form (glass) (GA Technologies, 1987) as used in the shielding calculations is given in Table 4-8.

**Table 4-8. Elemental Densities in High-Level Waste Form (Glass)
(GA Technologies, 1987)**

Element	Atom Density (atoms/barn-cm)
Oxygen, O	0.0158
Silicon, Si	0.0184
Sodium, Na	0.00682
Boron, B	0.00467
Lithium, Li	0.00762
Magnesium, Mg	0.00040
Zirconium, Zr	0.00013

4.4.4 Results

Results from the preliminary calculations are presented in this section. Table 4-9 contains the calculated dose rates for the waste package containing a single HLW form (glass log). Iron buildup factors were used for these calculations. In Table 4-9, dose rates were calculated at seven detector locations; radially at cask mid-length (surface, 1 m from the surface, and 2 m from the surface), two at the top center of the storage/disposal cask (surface and 2 m from the surface), and two at the bottom center of the cask (surface and 2 m from the surface). At 3.0 inches or more of DU,

Table 4-9. Calculated Dose Rates^a (rem/h) for Single-Canister High-Level Waste Form Storage/Disposal Cask

Detector Location	Thickness of DU Shield (inches)					Limit
	1.0	2.0	3.0	4.0	6.0	
Radially at mid-length:						
Surface	3.476E+00	1.888E-01	1.303E-02	9.657E-04	5.914E-06	2.0E-01
Surface + 1 m	9.947E-01	5.686E-02	4.106E-03	3.167E-04	2.077E-06	-
Surface + 2 m	5.240E-01	3.108E-02	2.312E-03	1.823E-04	1.233E-06	1.0E-02
Top center:						
Surface	1.326E-04	1.067E-05	8.880E-07	7.541E-08	5.659E-10	2.0E-01
Surface + 2 m	2.053E-06	1.492E-06	1.325E-07	1.195E-08	9.954E-11	1.0E-02
Bottom center:						
Surface	3.414E+01	2.203E-01	1.560E-02	1.185E-03	7.586E-06	2.0E-01
Surface + 2 m	1.889E+00	1.840E-02	1.558E-03	1.369E-04	1.093E-06	1.0E-02

^aUsing iron buildup factors.

the highest surface dose rates are generally at the bottom of the waste cask, whereas the highest 2-m dose rate is radially at cask mid-length. Results indicate that the point of concern should be the 2-m dose that is limited by regulations to 10 mrem/h. In order to support the assumption that the iron dose factors would yield conservative results, the case with the 3-in. DU shield was recalculated using uranium buildup factors.

The effect of using iron buildup factors versus uranium buildup factors is seen in Table 4-10. Iron buildup factors produced results that were about 4 to 4.5 times greater than the uranium doses for all detector locations on the surface of the storage/disposal waste container. At the 2-m locations, the dose values based on uranium buildup factors are about one-fourth to one-fifth of those predicted using iron buildup factors. Of course the system has both iron and DU, so both factors will come into play in a detailed analysis. This amount of conservatism should be adequate to cover the additional dose from neutrons, which was not explicitly calculated in these preliminary studies but could effectively double the values calculated.

Table 4-11 shows results for the storage/disposal cask designed to carry seven HLW canisters. Calculations were performed for the three critical detector positions: the surface plus 2-m positions radially at mid-length, the top center of the storage/disposal cask, and the bottom center of the storage/disposal cask. In this case, the highest calculated 2-m dose rates are those at the bottom center of the waste cask.

Table 4-10. Effect of Using Iron vs. Uranium Buildup Factors

Detector Location	Dose Rate (rem/h ^a)	
	Iron Buildup Factor	Uranium Buildup Factor
Radially at mid-length:		
Surface	1.303E-02	3.253E-03
Surface + 1 m	4.106E-03	1.027E-03
Surface + 2 m	2.312E-03	5.792E-04
Top center:		
Surface	8.880E-07	1.933E-07
Surface + 2 m	1.325E-07	2.895E-08
Bottom center:		
Surface	1.560E-02	3.887E-03
Surface + 2 m	1.558E-03	3.956E-04
^a Dose results (rem/h) are for a single-canister configuration containing one HLW form (glass log) with a 3-in. DU shield.		

Table 4-11. Calculated Dose Rates^a (rem/h) for the Seven-Canister Storage/Disposal Cask

Detector Location	Thickness of DU Shield (inches)				Limit
	2.0	3.0	4.0	6.0	
Radially at mid-length:					
Surface + 2 m	3.940E-02	7.203E-03	5.569E-04	3.641E-06	1.0E-02
Top center:					
Surface + 2 m	8.824E-06	1.018E-06	8.770E-08	6.903E-10	1.0E-02
Bottom center:					
Surface + 2 m	1.269E-01	1.343E-02	1.097E-03	7.698E-06	1.0E-02
^a Using iron buildup factors.					

Based on the results presented in this section, the proposed DU thicknesses of 2.0 in. for the single-canister configuration and 3.0 in. for the seven-canister configuration should provide adequate radiation shielding. In the next phase of transport system design, more sophisticated methods of evaluating the shielding performance of the seven-canister configuration will need to be implemented to avoid the geometry modeling assumptions used in this study. The dose from neutrons should also be explicitly evaluated in the next phase of design.

4.5 Criticality

Criticality was not evaluated because of the low fissile material content of the vitrified HLW.

5.0 COMPONENT DEVELOPMENT

5.1 Depleted Uranium Fabrication Facilities

Three commercial manufacturers were surveyed for current uranium casting capabilities. The results are summarized below. Based on recent conversations, the processing capability to cast large-diameter DU rings for shielding in casks could be developed if there is a defined need.

- Manufacturing Sciences Corp. (MSC), Oak Ridge, TN, has two vacuum-induction melting furnaces in which they can cast uranium. The geometry of their existing vacuum chamber limits the outside diameter of their castings to ~38 in. and the height to ~48 in. Typical crucible loadings are ~2180 kg, but this limitation results from inefficient packing of the solid starting material in the crucible. The ultimate capacity of 3630 kg could be realized by double melting (casting two 1815-kg solid cylinders that would fit efficiently in the crucible, then remelting them). The MSC furnaces are very modern and have excellent controls.
- Aerojet Ordnance Tennessee, Inc., Jonesborough, TN, has six vacuum-induction melting furnaces in which they can cast uranium. Their furnaces consist of an upper (crucible) chamber and lower (mold) chamber, thus providing more flexibility than the MSC furnace in terms of casting geometry. Their current arrangement would permit production of castings with outside diameters up to ~75 in. and heights up to ~60 in. This diameter could be increased still more by constructing a larger mold chamber. Typical crucible loadings are ~1815 kg, but a higher ultimate capacity of 2720 kg could be realized by double melting, as outlined above. Note that even this larger ultimate capacity would severely limit the heights of very large diameter (~75 in.) castings. They believe that they could increase this ultimate capacity by structural modifications to the furnace, but it remains to be shown whether sufficient increases could be made to permit ~75-in. outside-diameter castings to be made in useful heights.
- Nuclear Metal, Inc. (NMI), Concord, MA, has furnaces much smaller than those at either MSC or Aerojet. Their current chambers limit casting an outside diameter to ~22 in. and casting height to ~24 in. Their typical charges are 860 kg, and their ultimate weight limitation is slightly over 2000 kg.

5.2 Depleted Uranium Environmental Considerations

This section addresses the factors pertinent to the use of DU as shielding material in containers used for long-term storage or disposal of HLW. The long-term response of DU under repository conditions has not been evaluated and should be addressed in future studies.

The following discussion is based on the assumption that the primary issues are long-term integrity of the container and interaction of the container materials with the interior

environments. Inherent in this is the assumption that the uranium shielding will not be a structural member of the container during transport and handling, and that the container will be designed to ensure that the uranium shielding will not be highly stressed during either normal or abnormal transport or handling events; i.e., that mechanical properties need only to be adequate to ensure that the shielding maintains its integrity under conditions of external loading applied to the container structural components (i.e., containment shells).

The following appear to be the most important potential problems:

1. Environmental compatibility—Problems caused by chemical reaction of the uranium with oxygen, such as
 - Decreases in shielding capacity due to oxidation of the uranium and flaking of the oxide.
 - Development of structural stresses and possible disruption of container integrity due to the formation and wedging effects of the high-volume uranium oxide.
2. Radiation compatibility—Development of structural stresses and possible disruption of container integrity due to
 - Radiation-induced changes in the dimensions of the uranium.
 - Radiation-induced embrittlement of the uranium.

This section provides a discussion of three chemistry-related issues and an introduction to the radiation-related issues. Additional investigations are needed in the area of radiation-induced changes affecting long-term containment integrity.

5.2.1 Environmental Compatibility

Metallic uranium is more chemically reactive than most structural metals. It reacts with gaseous oxygen to form solid uranium oxide,

This reaction occurs as long as oxygen is present in the environment. Once the oxygen has been consumed in the volume containing the DU, the reaction stops.

The uranium oxide produced by reaction with oxygen does not provide an impermeable layer that isolates the underlying metal from the atmosphere, thereby self-limiting the oxidation

process. Instead, oxidation occurs approximately linearly with time. The rates of these reactions have been characterized as functions of temperature and are summarized in Weirick (1987).

This reaction is the basis for the first three strongly interrelated chemistry-related issues to be discussed. Thus several considerations relating to reaction rates and container conditions will be discussed prior to the more specific discussions of loss of shielding due to the formation and flaking of oxide and possible loss of integrity due to stresses induced by oxide formation and wedging.

The effects of temperature and atmosphere on the kinetics of uranium oxidation reactions are reflected in Figures 5-1 and 5-2. It can be seen that the reaction rate increases with increasing temperature.

In a sealed container that contains only oxygen and small amounts of water vapor, both gases will be quickly consumed and all reaction will then cease. The result will be a small amount of uranium oxidation and conversion of the water vapor to an equal amount of hydrogen gas.

Loss of Shielding Effectiveness Due to Oxidation of Uranium

The effects of temperature and atmosphere on the thickness of uranium converted to oxide per year are shown in Figures 5-1 and 5-2.

In a hermetically sealed container containing only oxygen and water vapor, all gases will be quickly consumed. No significant amount of the uranium will be oxidized as long as the container remains intact.

The uranium oxide produced by the reaction with oxygen is initially adherent, but flakes off as the oxide layer grows thicker. If the oxide remained in place, the shielding effectiveness would not be degraded. One possible way to overcome the problem of loss of shielding capability is to surround the DU with structural steel, as is the case of the systems being proposed herein.

Possibility of Self-Limitation of the Oxidation Reactions

It is possible that the oxide growth process could be self-limiting because the uranium oxide so tightly fills the space between itself and the inner and outer structural container walls that it forms an effective barrier that prevents the oxygen and moisture from coming in contact with the uranium, thus stopping the oxidation reactions. The potential problems of oxidation-induced loss of shielding and the resultant stressing, distortion, and loss of integrity could be easily overcome.

Other Methods for Decreasing the Rates of Oxidation and Hydrogen Production

Coatings. Uranium is frequently coated to help overcome oxidation and corrosion (Weirick, 1987). Electroplating with nickel and ion plating with aluminum both have shown to provide

Figure 5-2. Effects of Atmosphere on the Kinetics of Uranium Oxide Reactions

Figure 5-1. Effects of Temperature on the Kinetics of Uranium Oxide Reactions

effective protection to certain engineering components. From a long-term perspective, however, coatings provide only transient protection and should not be viewed as dependable ways to protect uranium shielding in storage applications involving many centuries or millennia.

Alloying. Uranium can also be alloyed to increase resistance to oxidation. The effects of alloying and heat treatment on corrosion resistance and mechanical behavior are described in Weirick (1987) and Eckelmeyer (1990). For the maximum increases in oxidation resistance to be realized, however, the alloying additions must be in solid solution in the uranium. Because only small amounts of alloying elements can be dissolved in alpha-uranium (the equilibrium phase below $\sim 667^{\circ}\text{C}$), alloys in equilibrium heat treatment conditions rarely exhibit more than an order of magnitude decrease in the rates of reaction with oxygen compared to unalloyed uranium. To obtain more dramatic decreases, elevated temperature heat treatments are frequently used to dissolve larger amounts of alloying elements into the higher solubility gamma phase (which forms above $\sim 771^{\circ}\text{C}$). These heat treatments are followed by rapid cooling to promote the formation of metastable phases that are supersaturated with alloying elements and, therefore, exhibit reaction rates up to two to three orders of magnitude lower than those for unalloyed uranium.

Several problems could be associated with using highly corrosion-resistant uranium alloys in storage containers. First, the alloying elements [most commonly niobium (Nb) and molybdenum (Mo)] could add to the materials and manufacturing costs of the shielding. Second, the high cooling rates required to realize maximum increases in oxidation resistance would be difficult to achieve in the thick sections required for the shields. This might be overcome by using a concentrated alloy, such as U-6%Nb or U-10%Mo, that can tolerate relatively slow cooling and still retain the alloying elements in supersaturated solution. Third, nonequilibrium cooling can result in high residual stresses that can cause delayed cracking in some uranium alloys. This might be overcome by using a low-yield-strength alloy, such as U-6%Nb, that cannot sustain high residual stresses. Unfortunately, such alloys are usually subject to time-dependent property changes (increases in yield strength and decreases in ductility and resistance to stress corrosion cracking) in the vicinity of room temperature. Hence, it does not seem desirable to employ highly corrosion-resistant uranium alloys in these storage containers.

An alternate approach would be to use a diluted uranium alloy, such as U-1%Nb, in the annealed (equilibrium) heat treatment condition. This would probably result in only an order of magnitude decrease in oxidation rate, but it would overcome the need for rapid cooling and the associated delayed cracking problems. In addition, by virtue of its equilibrium heat treatment, this material would be free from time-dependent changes in mechanical properties. Other methods for decreasing the rates of oxidation and hydrogen production will be evaluated in the next phase of the program.

5.2.2 Radiation Compatibility

Under certain conditions, radiation can cause dramatic dimensional changes in, and embrittlement of, uranium (Holden, 1958). Based on the information examined to date, it does not appear that the mechanisms of these effects are well understood. Thus it is difficult to assess the degree to which radiation effects may be important considerations in the shielding application.

Two broad categories of radiation effects are possible with uranium.

1. Those that result from fission events occurring within the uranium; i.e., fissioning of the remaining ^{235}U atoms.
2. Those that result strictly from exposure to external radiation; i.e., interactions between neutrons produced by HLW and the ^{238}U atoms in the DU shield.

The current dilemma is that most of the information on radiation effects in uranium has been generated in studies of enriched uranium ($>0.7\%$ ^{235}U) fuel elements, where both mechanisms can occur but where the former mechanism might logically be expected to dominate. For the DU being used as radiation shielding, however, only approximately 0.2% to 0.5% of the uranium atoms will be ^{235}U . While both mechanisms will occur to some extent, radiation effects are expected to be dominated by the latter mechanism. This makes it difficult to apply the available information directly to the problem at hand.

The following phenomena have been observed from studies of metallic uranium fuel elements.

1. Dramatic radiation-induced changes in linear dimensions can occur. These linear dimension changes are very dependent on:
 - Grain size (maximum in large-grained polycrystalline materials, much smaller in single crystals of fine-grained polycrystalline materials),
 - Preferred crystallographic orientation (increases with degree of texture),
 - Temperature (maximum from 0° to 200°C), and
 - Applied stress (mechanical constraint suppresses linear dimension changes, at least in the early stages).
2. Severe losses of ductility occur.

Thus it seems possible that long-term exposure to the radiation produced by the adjacent HLW could cause dimensional changes. Such changes could result in:

1. High internal stresses in the uranium shielding,
2. Embrittlement of the uranium and possible cracking due to embrittlement plus high internal stresses, and
3. High stresses applied to the external container shell, possibly resulting in disruption of container integrity.

The key unanswered questions are:

1. How does externally irradiated DU behave? Are data available on this? What inferences can be made from previous work on enriched uranium fuel elements?
2. Do applied stresses suppress dimensional changes, even changes in volume?

Further information is required to answer these questions and is beyond the scope of the current program.

5.3 Summary

Problems related to chemical reactions with the uranium shielding can best be avoided by ensuring that the container is completely sealed. Potential problems related to oxide formation appear to be amenable to solution by engineering design.

Potential problems related to radiation exposure include dimensional changes, which could result in high internal stresses in the uranium shielding and/or the outer container, and embrittlement of the uranium, which could (in conjunction with the internal stresses) result in cracking of the shielding. These potential problems are inferred from previous studies and the literature on enriched uranium fuel elements. The much-different situation of DU shielding requires further investigation. Commercial use of DU for shielded containers suggests no problems.

6.0 COSTING AND TOTAL-SYSTEM COST COMPARISONS

Employing DU shielding in casks used for disposal of HLW canisters in the Civilian Radioactive Waste Management System (CRWMS) will allow DOE to codispose large quantities of DU with vitrified HLW in the geologic repository. Codisposal of DU with HLW provides DOE the important benefit of using large quantities of DU that otherwise would require separate disposal as low-level waste (LLW), or possibly as RCRA-controlled waste. This study, which attempts to quantify the effects of using DU-shielded casks within the CRWMS, has three specific goals:

- To determine the total-system costs required to codispose of DU (as shielding) with HLW canisters in the geologic repository,
- To estimate the total quantity of DU that can be codisposed (as shielding) with HLW canisters, and
- To estimate any cost benefit to the DOE from DU codisposal (as shielding) in the geologic repository (as opposed to separate DU disposal as LLW or RCRA-controlled waste).

These goals are addressed by developing the S/D+T and S/T/D DU-shielded cask configurations, applying them in the CRWMS, and comparing their total-system costs with that of present DOE unshielded vitrified HLW management system planning. As DU-shielded cask configuration system costs were developed, no non-DU-shielded HLW management system costs could be identified as a basis for cost assessment and comparison. Cost elements of the HLW management system are available in CRWMP documents (DOE, 1989 and 1990) and in documents of defense waste management system activities at the SRS (WSRC, 1991). Therefore, a non-DU-shielded HLW management system reference case was developed for comparison with the S/D+T and S/T/D DU-shielded cask total-system costs for HLW disposal.

Thus this costing analysis defines a non-DU-shielded HLW management system reference case for uniform application to all HLW sites. This reference case applies the Savannah River dry storage concept and uses the CRWMS 125-ton, 21 pressurized water reactor (PWR) multi-purpose canister (MPC) configuration modified for HLW canisters. The DU-shielded S/D+T and S/T/D HLW management systems proposed for comparison to the reference case include four separate configurations. These configurations provide a direct cost comparison with the reference case and explore the effects of cask capacity, integral transportation overpack, and DU shielding on total-system costs.

Total-system costs were developed for both the DU-shielded system and non-DU-shielded reference case system and then compared to defense waste management system costs published in the 1990 addendum to the Civilian Radioactive Waste Management Program (CRWMP) Total-System Life-Cycle Cost (TSLCC) analyses (DOE, 1989 and 1990). As requested by DOE EM-50, this costing analysis considers only the HLW canisters from Savannah River, Hanford, and West Valley sites. Thus the total-system costs developed in this study include both defense HLW and West Valley HLW.

Providing a detailed estimate of total-system costs for a defense HLW management system is very uncertain. Total-system cost estimates for defense HLW disposal have been described in the CRWMP TSLCC (DOE, 1990); however, such estimates are considered first-order estimates.

In summary, the life-cycles of three HLW management systems are used in this costing analysis.

- The defense HLW management system costs published in the CRWMP TSLCC (DOE, 1990).
- The non-DU-shielded HLW management system reference case costs developed from the defense HLW TSLCC, other CRWMP documents, and documentation of activities at the SRS.
- The DU-shielded S/D+T and S/T/D HLW management systems developed in Section 3.0. Results provide estimates of the total-system cost required to codispose of DU (as shielding) with HLW in the geologic repository, estimation of the total quantity of DU that can be codisposed (as shielding) with HLW, and identification of cost benefit to the DOE from DU shielding codisposal in the geologic repository compared to separate DU disposal as LLW or RCRA-controlled waste.

6.1 Development Constraints for a Non-Depleted-Uranium-Shielded High-Level Waste Management System Reference Case

The non-DU-shielded HLW management system reference case was developed consistently with past and ongoing planning, assumptions, and activities of both the civilian spent nuclear fuel and defense HLW management systems. Data from three major sources were included in the development of the reference case.

- DOE OCRWM defense HLW assumptions.
- HLW site planning and activities.
- Relevant CRWMP planning and activities.

6.1.1 Department of Energy Office of Civilian Radioactive Waste Management Defense High-Level Waste Assumptions

A waste management system for both civilian reactor spent nuclear fuel and defense HLW was developed and used as the basis for total-system life-cycle cost analysis of the CRWMP (DOE, 1989 and 1990; Roy F. Weston, Inc., 1989 and 1991). To determine a first-order estimate of costs for the defense HLW portion of the total-system life cycle, various assumptions about the amounts and characteristics of defense HLW were made by DOE with the full realization that the actual conditions at the time of disposal are likely to be different. The defense HLW assumptions contained in the CRWMP TSLCC are summarized below.

1. Defense HLW will be accepted by the OCRWM at the waste storage locations and transported directly to the repository in transportation casks developed by the CRWMP. The design of these transportation casks will be certified by the NRC.
2. Defense HLW quantities and characteristics are based on the Integrated Data Base for 1992 (DOE, 1992). (Note: The TSLCC estimates [DOE, 1989] were based on the Integrated Data Base for 1988.)
3. The total defense HLW quantity (complex-wide) is 17,750 canisters or ~8,875 metric tons of heavy metal (MTHM), and the West Valley HLW consists of 300 canisters (~640 MTHM), for a total quantity of 9,515 MTHM (DOE, 1989 and 1990). (This is greater than the 15,402 Savannah River, Hanford, and West Valley HLW canisters considered in this analysis.)
4. Each canister of defense HLW is equivalent to 0.5 MTHM.
5. Defense HLW acceptance for disposal at the geologic repository is assumed to be prioritized in the order of "oldest canister first" and acceptance is in integer package loads. The West Valley HLW is accepted at the repository following acceptance of defense HLW.
6. Defense HLW shipments are made by rail on dedicated five-car trains. Each car carries one transportation cask with a capacity of five defense HLW canisters.

When exception is taken to any of the above assumptions in the development of the waste management system reference case, it will be noted and reasons for the deviation provided.

6.1.2 High-Level Waste Site Planning and Activities

Planning for stabilization and disposal of HLW has been ongoing for several years and much progress has been made, particularly at SRS. The SRS has completed construction of the Defense Waste Processing Facility (DWPF) for vitrification of HLW. With geologic repository acceptance of defense HLW canisters now scheduled to begin in the year 2015, SRS proposed and completed construction of an interim dry storage glass waste storage building (GWSB) (WSRC, 1991). To provide adequate storage capacity until the repository opens, SRS has also requested authorization to construct a second GWSB.

Although past concepts for transport and disposal of HLW canisters are based primarily on those for spent nuclear fuel, DOE is assessing new concepts for storage, transport, and disposal of defense HLW to ascertain costs and address other defense HLW management system issues. The inclusion of DU-shielding in casks used for HLW disposal in the CRWMS is one such initiative.

6.1.3 Relevant Civilian Radioactive Waste Management Program Planning and Activities

As stated in Section 6.1.1, the CRWMP developed a waste management system for storage, transport, and disposal of both HLW and spent nuclear fuel, that was used to estimate the total-system life-cycle costs for the CRWMP. Since the 1989 TSLCC and its 1990 addendum were published, the DOE OCRWM has been pursuing the assessment of the multi-purpose canister (MPC) concept for spent nuclear fuel storage and disposal. The MPC represents a new handling and packaging philosophy. The MPC approach is expected to foster standardization among the various civilian reactor sites, reduce the number of spent nuclear fuel handlings, simplify facilities at both the monitored retrievable storage (MRS) and repository, and increase radiological safety (CRWMS, 1993a; EPRI, 1993).

6.2 Non-Depleted-Uranium-Shielded High-Level Waste Management System Reference Case

The non-DU-shielded HLW management system reference case, illustrated in Figures 6-1 and 6-2, includes the appropriate OCRWM defense HLW assumptions, the disposal activities already implemented at defense waste sites (primarily SRS), and the latest CRWMP thinking on the MPC approach for spent nuclear fuel storage, transport, and disposal. It defines a non-DU-shielded HLW management system that can be uniformly applied to DOE sites for disposal of HLW. The hardware complement proposed for supporting this system is described below.

- The container proposed for shipping HLW canisters from the waste sites to the geologic repository is the CRWMP 125-ton, 21 PWR MPC. This MPC configuration, designated vitrified waste MPC (VW-MPC) in this report, is modified to accept four HLW canisters. Modifications include the addition of a compatible four-canister basket and, possibly, a 4- to 6-in. enlargement of the MPC diameter.
- The shielded transportation overpack for shipping the VW-MPC to the geologic repository is the CRWMP 125-ton transportation overpack appropriately modified to accept the VW-MPC.
- The repository emplacement overpack for the VW-MPC is the CRWMP 125-ton, 21 PWR emplacement overpack appropriately modified to accept the VW-MPC.

The modifications required for the 125-ton, 21 PWR MPC and transportation and emplacement overpacks are, to the first order, assumed to be minor and should have no significant effect on the size, weight, or cost of the hardware as defined in the CRWMS M&O document (CRWMS, 1993c).

The four-canister VW-MPC is an exception to the five-canister TSLCC assumption. It was chosen for the non-DU-shielded HLW management system reference case because the weight, size, and cost characteristics are known and it appears to be consistent with current DOE planning.

Figure 6-1. The Non-Depleted-Uranium-Shielded High-Level Waste Management System Reference Case

Figure 6-2. Unshielded Vitrified Waste-Multi-Purpose Canister (VW-MPC) Transport System

The handling, loading, and seal welding facilities and operations proposed for the CRWMP MPC are used for similar VW-MPC operations. The costs cited in the CRWMS document (CRWMS, 1993b) for these facilities and operations were used for developing the total-system costs for the proposed four-canister VW-MPC. These costs include the canister handling facility (referred to as cask-to-cask transfer facility in CRWMS, 1993b) and welding equipment used for loading and sealing operations at the defense waste sites.

The non-DU-shielded reference case process, illustrated in Figure 6-1, is described as follows. HLW canisters produced in a DWPF are moved from the DWPF to the GWSB by a robotic shielded canister transporter (SCT). These HLW canisters are stored on an interim basis in a GWSB (WSRC, 1991), until the year 2015, when the geologic repository will begin accepting defense HLW.

When the repository is ready to accept waste, the vitrified HLW canisters will be moved from the GWSB to the canister handling facility by the robotic SCT. Four HLW canisters are loaded into a VW-MPC, which has already been assembled into its transportation overpack. After loading, the VW-MPC cover is added and seal-welded closed. The transportation overpack cover is then put in place and bolted closed to form the transport package. The VW-MPC transport package is now loaded onto a railcar for shipment to the repository. It should be noted that all canister handling and assembly operations must be performed remotely until the transportation overpack cover has been installed. After cover installation, the assembly can be contact-handled.

The five, four-canister, VW-MPC transport packages are transported by dedicated five-car train to the repository. At the repository, the VW-MPC transport packages are offloaded at the waste package preparation facility and moved into the VW-MPC remote handling cell. In the remote handling cell, the VW-MPC is removed from the transportation overpack in reverse order of loading. The transportation overpack and impact limiters are reloaded on the train that returns to the HLW site for reloading. The VW-MPC is then assembled into its emplacement overpack and the overpack is seal-welded closed for repository emplacement. The VW-MPC/emplacement overpack assembly (called the waste package) is now placed on a shielded transporter for movement into and emplacement in the repository. It should be noted that all repository operations require the use of shielded handling and transportation equipment.

6.3 Depleted-Uranium-Shielded High-Level Waste Management System

The major difference between the non-DU-shielded reference case and the DU-shielded HLW management system is that DU provides radiation shielding to the levels required for Type B packages. [Title 10, Code of Federal Regulations, Parts 71 and 72 (10 CFR Parts 71 and 72) (NRC, 1995) are used as the governing criteria for transportation and on-site storage (see Sections 3.2 and 4.4).] This means that when the HLW canisters are loaded into a DU-shielded cask, the cask can be contact-handled; i.e., shielded transportation overpacks, transporters, and storage facilities are not required.

Two basic DU-shielded HLW management systems have been defined (see Sections 3.3 and 3.4). The Storage/Disposal plus Transport (S/D+T) system design consists of two major components: a storage/disposal cask and a transportation overpack. In contrast, the Storage/Transport/Disposal (S/T/D) system design includes an inner waste container and a combined storage, transport, and disposal cask. Four different configurations (which include design and capacity variations) within these systems are considered for costing in this study. The proposed DU-shielded HLW management system process is described below and illustrated in Figure 6-3.

Defense vitrified HLW is produced in the DWPF and moved in canisters to the canister handling facility. In the canister handling facility, the HLW canisters are loaded directly into the DU-shielded cask. When a cask is fully loaded with the appropriate number of HLW canisters (depending on the configuration), it is seal-welded closed and transported from the canister handling facility over a paved road to an outdoor temporary storage site within 2 miles of the DWPF. Single-canister casks can be moved by truck, while the three-, four-, and seven-canister configurations will require a "heavy hauler" for transport. Since the DU-shielded cask configurations provide shielding levels for Type B packages, the truck and heavy hauler do not require shielding. The casks will be stored at this temporary storage site, consisting of a fenced, perimeter-lighted concrete pad, until they can be transported to the repository. The three-canister DU-shielded S/D+T and S/T/D configurations (see Sections 3.3 and 3.4) are not included in the system cost study because of their closeness in capacity to the four-canister design.

When the repository begins accepting waste, two disposal processes are possible, depending on which specific DU-shielded HLW management system (S/D+T or S/T/D) disposal cask design is being used. These options are discussed below.

6.3.1 Storage/Disposal Plus Transport System Transport and Disposal Process

When the repository is ready to accept waste material, the DU-shielded storage/disposal casks (or storage units) are moved back to the canister handling facility. At the canister handling facility, each cask will be assembled with its transportation overpack and impact limiters and subsequently placed on a railcar for transport to the repository. It should be noted that the canister handling facility is not required for radiation protection, but rather provides a way to handle the storage/disposal cask for loading in the transportation overpack. It is also assumed that the equipment for loading the transport package onto the railcar exists at the canister handling facility and that this is a normal part of the HLW site equipment. Thus it will not be costed as part of the DU-shielded S/D+T HLW management system.

Five S/D+T transport packages are shipped by dedicated five-car train to the repository. At the repository, the S/D+T transport packages are offloaded at the waste package preparation facility. The DU-shielded storage/disposal casks are removed from their transportation overpacks. The transportation overpacks and impact limiters are then reloaded on the train for return to the

Figure 6-3. Depleted-Uranium-Shielded High-Level Waste Management Systems

waste site. The DU-shielded storage/disposal casks are assembled into emplacement overpacks (this assembly is the waste package; see Figure 6-3) and moved into the repository for emplacement. It should be noted here that the DU-shielded storage/disposal casks do not require a remote handling cell at the waste package preparation facility and can be contact-handled for all repository operations. The casks do not require the use of shielded handling or transporter equipment.

6.3.2 Storage/Transport/Disposal System Transport and Disposal Process

When the repository is ready to accept waste material, the DU-shielded storage/transport/disposal casks (or storage units) are moved back to the canister handling facility where the transport impact limiters are attached. These transport packages are then loaded onto railcars for transport to the repository. Five S/T/D transport packages are shipped by a dedicated five-car train to the repository. At the repository, the S/T/D transport packages are offloaded at the waste package preparation facility. The impact limiters are removed from the storage/transport/disposal casks and loaded on the train for return and reuse at the waste site. The DU-shielded storage/transport/disposal casks are assembled with emplacement overpacks (this assembly is the waste package) and moved into the repository for emplacement. Once again, the DU-shielded storage/transport/disposal casks do not require a remote handling cell at the waste package preparation facility and can be contact-handled for all repository operations.

6.3.3 Depleted-Uranium-Shielded Configurations Selected for Cost Analysis

To explore cost advantages and DU usage benefits, four DU-shielded system configurations, which include different design and capacity variations, have been selected for cost analysis.

- Configuration 1—Four-canister stainless-steel S/D+T system design to provide direct cost comparison with the reference case four-canister VW-MPC.
- Configuration 2—Seven-canister stainless-steel S/D+T system design to assess cost benefit and DU usage with larger-capacity storage/disposal casks.
- Configuration 3—Seven-canister stainless-steel S/T/D system design to assess cost benefit of not having a separate transportation overpack.
- Configuration 4—One-canister stainless-steel S/D+T system design to assess the maximum HLW disposal cost. A subset of this configuration, applying truck transport to only the West Valley HLW, is costed to determine the cost differences between rail and truck transport.

6.4 Total-System Cost Analysis

The HLW total-system cost analysis performed in this section includes costs for the CRWMP system elements plus costs for two additional system elements (waste acceptance and defense

waste site) that were not considered in the CRWMP TSLCC analysis. As a result, this analysis develops costs for six HLW system elements: waste acceptance, transportation, monitored retrievable storage (MRS), repository, other defense waste, and defense waste site. System element costs are estimated and compared for both the non-DU-shielded reference case and the selected DU-shielded HLW management systems. The CRWMP TSLCC estimate provides a secondary basis for cost comparisons. All total-system cost estimates include subtotals for each cost element. A more detailed description of costs is presented in Appendix D.

The major cost items identified within each HLW management system element are listed in Table 6-1. These are the principal cost categories by which the non-DU-shielded reference case and each of the DU-shielded configurations were evaluated. The cost evaluation of each system element is presented in the following section.

Table 6-1. Defense High-Level Waste System Element Cost Items

System Element	Cost Item
Waste acceptance	<ul style="list-style-type: none"> • Welding equipment • Canister handling facility
Transportation	<ul style="list-style-type: none"> • Overpack fleet • Shipping • Overpack maintenance
MRS	<ul style="list-style-type: none"> • Not applicable
Repository	<ul style="list-style-type: none"> • Waste packages • Surface facilities and operations • Subsurface facilities and operations
Other defense waste	<ul style="list-style-type: none"> • Development and evaluation (D&E) • Benefits
Defense waste site	<ul style="list-style-type: none"> • Receiving and handling facilities/balance of plant • Preparations for waste acceptance • Waste canister interim storage

6.4.1 System Element Cost Evaluation

The system element costs estimated by this study employed an aggregate of quantities of items or activities (i.e., numbers of packages, pieces of equipment, sealing operations, etc.) multiplied by the individual costs associated with each item or activity (i.e., capital, maintenance, mileage rates, etc.). The individual costs were generated as presented in Appendix D. The Integrated Data Base for 1992 provided the numbers of waste canisters and production schedules for each HLW site (DOE, 1992). The TSLCC 1990 addendum was used for the repository waste acceptance schedule (DOE, 1990). These data formed the basis for generation of the quantities of applicable items, equipment, facilities, and activities required to specify both the reference case and DU-shielded HLW management systems.

Transportation overpack fleet requirements and repository shipment costs were generated using the TSLCC transportation model and algorithms (DOE, 1989 and 1990), companion cost estimating methods (Roy F. Weston, 1989 and 1991), and site mileage data from the Transportation System Data Base provided by Roy F. Weston, Inc. The evaluation of the system element costs listed in Table 6-1 is described below.

Waste Acceptance

Waste acceptance consists of OCRWM accepting HLW at the defense waste site for disposal in the geologic repository. The Waste Acceptance system element includes the capital equipment to perform the operations necessary to meet DOE OCRWM acceptance requirements. The waste acceptance cost items for the non-DU-shielded reference case and DU-shielded systems include welding equipment and a canister handling facility.

Welding Equipment. The automated welding equipment required to seal the reference case VW-MPC and the various DU-shielded S/D+T and S/T/D configurations is expected to be equivalent to that proposed for sealing the CRWMS MPC. Each of the HLW sites will require one piece of this equipment. The estimated \$500K cost per machine is considered to be a good first-order estimate and is used for the welding equipment cost in this study (CRWMS, 1993b). Decommissioning costs are estimated at 20% of capital or \$100K each.

Canister Handling Facility. Each of the HLW sites will require a canister handling facility for loading vitrified HLW canisters into the VW-MPC or DU-shielded transport/disposal casks. In the reference case, the VW-MPC will be loaded when the repository begins accepting defense waste. The HLW canisters will be removed from dry storage by the SCT and loaded into the VW-MPC, which has already been placed in its transportation overpack. The VW-MPC cover is then put in place and seal-welded closed. The overpack cover is installed and bolted in place, and the VW-MPC transport package is loaded onto a railcar for transport to the repository.

For DU-shielded configurations, the HLW canisters will be loaded into the storage/disposal cask or storage/transport/disposal cask as they are produced in the DWPF. When a cask has been filled with the appropriate number of canisters, it is seal-welded closed and transported as the storage unit to an interim outdoor storage site within 2 miles of the DWPF. In the S/D+T

system, the storage/disposal cask (storage unit) must be assembled into a transportation overpack for shipment to the repository. Though not needed for radiation protection, the canister handling facility will provide a ready means for assembling the storage/disposal casks and transport packages.

The size, weight, sealing/bolting and handling requirements for all DU-shielded configurations appear to be equivalent to those described for the CRWMS MPC. As a result, the facility capital and decommissioning costs of \$6.0M and \$1.5M respectively are considered appropriate as a first-order approximation for both the reference case and DU-shielded HLW management system canister handling facility costs. A summary of waste acceptance charges is provided in Table 6-2.

Table 6-2. Waste Acceptance Costs (millions of 1993 dollars)

Cost Item	Item Cost (M\$)					
	Reference	DU-Shielded System Configuration				
	Case	1	2	3	4	
	4-cn VW-MPC	4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T all sites	WV truck
Welding equipment	1.8	1.8	1.8	1.8	1.8	0.6
Canister handling equipment	22.8	22.8	22.8	22.8	22.8	7.6
Total Waste Acceptance Cost	24.6	24.6	24.6	24.6	24.6	8.2

Transportation

The Transportation system element includes the infrastructure needed to transport HLW from the waste site directly to the geologic repository. The transportation cost items are the overpack fleet, shipping, and overpack fleet maintenance.

Transportation Overpack Fleet. The number of transportation overpacks for the reference case and the various DU-shielded HLW management system configurations were derived using the transportation models and algorithms in the CRWMP TSLCC and accompanying cost-estimating methods documents (DOE, 1989; Roy F. Weston, Inc., 1989). One-way rail and truck distance miles were provided by Roy F. Weston, Inc. from the Transportation System Data Base. It was assumed that shipment would occur at the rate of 400 canisters per year from both SRS and Hanford, beginning in the year 2015. While this may be an exception to the TSLCC assumption of "oldest canister first," this study interprets "oldest canister first" on a site-by-site basis and not on a "global" defense HLW basis. It does not seem sensible to ship 800 canisters from SRS until canister age catches up with Hanford and then ship 400 from each site. Shipment to the repository would continue at the 400-canister rate until all SRS canisters are shipped in the year 2028. At that time, the Hanford rate would increase to 800 canisters. It was also assumed that, starting in 2028, the SRS transportation overpack fleet would be transferred to Hanford for use

until all Hanford canisters were shipped to the repository. Thus Hanford would not accrue any additional overpack fleet charges to support the increased shipment rate to the repository.

Shipping. Transportation shipping costs include shipping, security, and inspection charges. Shipping costs were derived for each site using the transportation models and algorithms in the CRWMP TSLCC and companion cost estimating methods (DOE, 1989; Roy F. Weston, Inc., 1989). One-way rail and truck distance miles were provided by Roy F. Weston, Inc. from the Transportation System Data Base. Dedicated train rail transportation was assumed for all HLW sites. However, West Valley truck transportation costs were also calculated for the one-canister S/D+T design (Configuration 4) to provide a comparison with rail shipment costs.

It was assumed that all HLW sites had both rail transportation and railcar loading capabilities at their canister handling facilities. Thus there are no heavy-haul costs accrued for shipment of defense HLW to the repository. The total number of transport package miles (in millions) calculated for the configurations are as follows:

System Configuration and Transport Package Miles

Configuration	Description	Transport Package Miles (million)
Reference case	4-cn VW-MPC	7.1
DU-Shielded Systems		
Configuration 1	4-cn S/D+T	7.1
Configuration 2	7-cn S/D+T	4.0
Configuration 3	7-cn S/T/D	4.0
Configuration 4	1-cn S/D+T	28.2
	1-cn WV- S/D+T	8.2

Transportation Overpack Maintenance. The CRWMP TSLCC estimated yearly defense HLW package maintenance costs at \$90,000 based on the total number of package miles required to ship defense HLW to the repository. For all practical purposes, the S/T/D casks designated for this study do not require maintenance because they are not reused but buried in the repository. The transportation overpacks for the reference case VW-MPC and DU-shielded S/D+T configurations will require some maintenance. However, this cost will probably be less than projected by the CRWMP TSLCC because the reference case and DU-shielded S/D+T configurations will not contain bare fuel assemblies. Because actual maintenance requirements have not been developed, the \$90,000-per-year TSLCC estimate will be used as a first-order

approximation for both the reference case VW-MPC and DU-shielded S/D+T configurations in this study. Assuming that defense HLW shipments will begin in 2015 and that the last Hanford waste will be shipped in 2034, the total maintenance cost of \$1.71M is applied to the reference case and DU-shielded configurations 1, 2, and 4 (all sites). Configuration 3 does not require a transportation overpack, and the maintenance cost for the West Valley truck transport option is \$0.1M. A summary of transportation costs is provided in Table 6-3.

Table 6-3. Transportation Costs (millions of 1993 dollars)

Cost Item	Item Cost (M\$)					
	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration				
		1	2	3	4	
		4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T all sites	WV truck
Overpack Fleet						
VW-MPC	72					
S/D+T		20	12		25	3
Overpack Maintenance						
VW-MPC	2					
S/D+T		2	2		2	0.1
Impact limiter fleet (S/T/D)				6		
Shipping	171	165	96	95	650	11
Total Transportation Cost	245	187	110	101	677	14

Monitored Retrievable Storage

The MRS system element is the cost of providing interim storage for spent nuclear fuel and does not apply to HLW. The system element without a cost assignment is carried along in this study for completeness and consistency with the CRWMP TSLCC.

Repository

The Repository system element covers the engineering, construction, operation, and closure and decommissioning costs for the repository. The repository cost items include the capital costs for the DU-shielded casks, non-DU-shielded canisters (VW-MPC) and emplacement overpacks, and both surface and subsurface facilities and operations.

Waste Package. The repository waste package is the unit that is emplaced in the repository. It is the assembly of the VM-MPC or DU-shielded cask and the emplacement overpack. The number of casks and MPCs required for each configuration was calculated from the total number of HLW canisters to be emplaced from each HLW site and the capacity of the various

configurations (i.e., one, four, and seven HLW canisters). The number of emplacement overpacks is the same as the number of casks and MPCs. The DU-shielded cask and MPC costs provided in Table 6-4 are based on large quantity pricing.

Table 6-4. Storage, Transport, and Disposal Cask; Multi-Purpose Canister; and Emplacement Overpack Cost Estimate (thousands of 1993 dollars)

Cask or Canister Type	Reference Case VW-MPC	Stainless-Steel S/D+T	Stainless-Steel S/T/D	Incoloy S/D+T	Incoloy S/T/D	Emplacement Overpack
1-cn		218	287	235	322	71
4-cn	202	726	966	787	1,085	182
7-cn		1,087	1,517	1,168	1,703	182

A side issue of this analysis was to explore any cost benefit that could result from substituting Incoloy for stainless-steel cladding on the DU-shielded casks (refer to Section 3.5). The potential cost advantage of Incoloy cladding is the possibility of eliminating the separate repository emplacement overpack required for each cask.

A breakdown of the costs for the DU-shielded configurations is provided in Appendix D, Tables D-21, D-22, D-24, and D-25. Similar costs for the reference case VW-MPC are found in Table D-26. Unit material and fabrication costs were derived from the CRWMS (CRWMS, 1993b) and DOE (DOE, 1995) documents and applied to the specific DU-shielded configurations considered for this study. The reference VW-MPC cost was assumed to be equivalent to the 125-ton 21 PWR canister as costed in the CRWMS document (CRWMS, 1993b) with a four-canister basket substituted for the fuel assembly basket.

Surface Facilities and Operations. Because of the formative status of the repository surface facilities design, this study did not attempt to estimate incremental cost changes for repository surface facilities and operations. It is likely that valid arguments could be made for potential cost savings. Decreased surface operations compared to the CRWMP TSLCC estimates should result from not having to handle bare canisters for any defense HLW configurations. All of the DU-shielded configurations can be contact-handled. Quantification of these advantages as specific cost reductions would be very difficult considering the present formative state of the repository design concept. As a result, the published TSLCC costs are used as the first-order estimates for all configurations considered in this study (DOE, 1989).

Subsurface Facilities and Operations. For reasons similar to those presented above, no attempt was made to estimate incremental cost changes in repository subsurface facilities and operations from those provided in the CRWMP TSLCC. Arguments similar to those made for surface facility and operations cost savings can be made for repository subsurface facilities and operations. However, handling differences between MPCs and DU-shielded casks make cost savings for subsurface facilities and operations less certain than for surface facilities and

operations. Several reasons for expecting such cost reductions are discussed in EPRI, 1993. For this study, the published CRWMP TSLCC costs are used as the first-order cost estimates for all configurations considered. A summary of repository costs is provided in Table 6-5.

Table 6-5. Repository Costs (millions of 1993 dollars)

Cost Item	Item Cost (M\$)					
	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration				
		1	2	3	4	
		4-cn	7-cn	7-cn	1-cn S/D+T	
		S/D+T	S/D+T	S/T/D	all sites	WV truck
Waste Packages						
VW-MPC + emplacement overpack	1,482					
Stainless-steel DU-shielded cask + emplacement overpack		3,502	2,796	3,741	4,460	87
Incoloy DU-shielded cask		3,035	2,574	3,752	3,623	
Surface/subsurface facilities and operations	1,373	1,373	1,373	1,373	1,373	
Total Repository Cost						
Non-DU-shielded reference case	2,855					
Stainless-steel DU-shielded system		4,875	4,169	5,114	5,833	87
Incoloy DU-shielded system		4,408	3,947	5,125	4,996	

^aTSLCC estimate: 1988 cost = 1,330. Escalating factor for 1993 = 3.2%, (DOE 1993),
Therefore, 1993 cost = (1,330)(1.032) = 1,373.

Other Defense High-Level Waste

The Other Defense Waste system element contains two cost items: development and evaluation (D&E) and benefits. The D&E cost item covers all the siting, preliminary design development, testing, and regulatory and institutional activities associated with the repository, the MRS, and the transportation system. It also includes the cost of administration by the federal government, and the NRC charges for licensing the waste-management facilities and certifying the transportation casks. The benefits cost item covers payments to States, Indian Nations, and affected units of local government for the mitigation of socioeconomic impacts (as authorized by the Nuclear Waste Policy Amendments Act of 1987).

Development and Evaluation. The cost of D&E for defense HLW disposal was not considered. Determination of D&E cost differences between the TSLCC, the reference case, and DU-shielded configurations is beyond the scope of this study. The 1990 addendum to the TSLCC estimated the D&E costs for the defense HLW portion of the TSLCC at \$1,765M (DOE, 1990). This cost is included in this analysis for completeness.

Benefits. The cost of benefits for defense HLW disposal was not considered in this analysis for the same reasons that D&E costs were not considered. The 1990 addendum to the TSLCC estimated the defense HLW portion of benefits costs at \$78M. This cost is included in this summary for completeness.

The D&E and benefits costs, escalated to 1993, are summarized below and assumed to be the same for all configurations considered in this study.

- D&E \$1,821M
- Benefits \$81M
- Total other \$1,902M

Defense Waste Site

The Defense Waste Site system element includes operations required of the defense waste site and West Valley in preparation for waste acceptance by OCRWM, and costs and operations associated with storage of vitrified waste canisters from the time they were produced to repository acceptance. The cost items included in this element are receiving and handling facilities and balance of plant, preparation for waste acceptance, and interim storage.

Receiving and Handling Facilities/Balance of Plant. It was assumed for this study that all HLW sites had in place the necessary receiving and handling facilities and balance of plant required to support the HLW disposal program. Thus no costs are accrued for this item.

Preparations for Waste Acceptance. Waste acceptance operations for the reference case consist of loading HLW canisters into the VM-MPC, which has been assembled with its transportation overpack, installing the canister cover and seal welding it in place. After completion of the cover seal welding operation, the transportation overpack cover is put in place and bolted closed to form the transport package. For the DU-shielded S/T/D system configurations, the HLW canisters are loaded into individual waste containers, which are seal-welded closed to provide the primary containment boundary. The waste containers are assembled into the combined storage/transport/disposal cask and the cask cover is installed and seal-welded in place to form the S/T/D storage unit. In the DU-shielded S/D+T system configurations, the HLW canisters are assembled into the S/D+T storage/disposal cask and the cask cover is installed and seal-welded in place to form the S/D+T storage unit.

For both DU-shielded configurations, the S/D+T storage/disposal and S/T/D storage/transport/disposal casks (or storage units) are temporarily stored until the repository begins accepting defense HLW. At that time, the casks are removed from storage. The S/T/D storage/transport/disposal cask is assembled with its transport impact limiters for shipment to the repository. Similarly, the S/D+T storage/disposal cask is assembled with its transportation overpack for shipment to the repository.

The canister loading, cask seal-welding, and overpack cover-bolting operations are considered to be equivalent to those estimated to cost \$4,300 for the CRWMS Cask-to-Cask Transfer Facility (CRWMS, 1993a). For the reference case and DU-shielded S/T/D system configurations, a \$4,300 operations cost is charged once. For the DU-shielded S/D+T system configurations, a

\$4,300 operations cost is charged twice because the storage/disposal cask must be returned to the canister handling facility for assembly with its transportation overpack.

Interim Storage. Because HLW canisters are scheduled for production well before the repository will begin accepting defense HLW, a means must be provided for safely storing the waste canisters until they can be shipped to the repository beginning in the year 2015. Two potential storage methods are considered in this study:

- The concept that applies to the non-DU-shielded reference case is currently being implemented at SRS. This method uses the GWSB to provide dry storage for the 5,242 HLW canisters scheduled for production. Present planning (1993 data) calls for two GWSBs at a cost of \$111M each and two robotic SCTs at \$20.6M each; decommissioning costs at 20% would be \$22.2M and \$4.1M each, respectively. Operating costs for each GWSB are estimated at \$750K per year. Assuming a 20-year operating life for the facilities, the total operating cost for the two buildings is \$30M. The system cost for a GWSB is \$172.9M.
- The interim storage concept for the DU-shielded waste management system configurations is to use a fenced, perimeter-lighted concrete pad located within 2 miles of the HLW vitrification facility (see Figure D-1). For this method, the vitrified HLW canisters are loaded directly into the DU-shielded casks as they are produced. Because the DU-shielded cask can be contact-handled after assembly, the loaded cask (or storage unit) is hauled to the temporary storage site either by truck, for the single-canister storage/disposal cask, or by a special heavy hauler for the four- and seven-canister configurations. The cost of the fenced, lighted storage pad is estimated by Sandia National Laboratories at \$34.00 per square foot. The DU-shielded cask pad area requirements are 133 square feet for the single-canister configuration, 304 square feet for the four-canister configuration, and 256 square feet for the seven-canister configurations. The road connecting the pad to the vitrification site will cost about \$700K per mile. Two heavy haulers with service lives of 20 years will be required for each site at a cost of \$250K each. Because these facilities and equipment will not be radioactively contaminated, the decommissioning costs are estimated at 10% of cost. It should be noted that actual temporary outside storage facility costs will be very site-specific. For this analysis, it is assumed that a storage facility site that requires minimal site preparation and is in relatively close proximity to roads and electrical power can be located at each of the defense HLW sites. A summary of defense HLW sites costs is provided in Table 6-6.

6.4.2 Cost Analysis Summary

The costing analysis in this report evaluates the cost advantages and disadvantages that result from using DU as shielding material for defense HLW canister storage, transport, and disposal. Four DU-shielded configurations were developed and compared to a non-DU-shielded reference case employing a CRWMS MPC-like vitrified HLW canister container, referred to as the VW-MPC, and SRS dry storage planning. The one-canister S/D+T configuration, using truck

Table 6-6. Defense High-Level Waste Site Costs (millions of 1993 dollars)

Cost Item	Item Cost (M\$)					
	Reference	DU-Shielded System Configuration				
	Case	1	2	3	4	
	4-cn VW-MPC	4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T all sites	WV truck
Receiving and handling facilities/balance of plant	0	0	0	0	0	0
Preparation for waste acceptance	17	34	19	10	134	3
Waste canister interim storage	719	69	47	47	102	5
Total HLW Site Cost	736	103	66	57	236	8

transport, was applied specifically to the West Valley site to explore costs associated with a truck transport option. With the exception of West Valley truck transport, the results of these comparisons are presented on both a total-system and site-specific basis.

The DU-shielded cask costs reported in this summary (see Table 6-4) are based on large quantity pricing and include costs for both conversion of UF_6 to metal and hardware fabrication. The DU costs are based on unit costs cited in DOE, 1995. Cost breakdowns for the DU-shielded cask configurations are provided in Appendix D, Tables D-21, D-22, D-24, and D-25.

Total-System Costs

The aggregated system costs are shown in Table 6-7 and Figures 6-4 and 6-5 in 1993 dollars. The CRWMP TSLCC estimates, provided in 1988 dollars (DOE, 1989 and 1990), have been escalated by 3.2% to achieve the 1993 costs. Similarly, the CRWMS MPC-related costs, provided in 1992 dollars (CRWMS, 1993a), have been escalated by 1.2% to achieve 1993 dollars.

The cost-comparison discussions that follow use the stainless-steel storage/disposal cask configurations as the basis for DU-shielded system cost comparison with the non-DU-shielded reference case VW-MPC. Costs for similar Incoloy-clad DU-shielded storage/disposal casks are included in Table 6-7 for comparison. The potential benefit of Incoloy cladding is that it may be possible to directly emplace the storage/disposal cask in the geologic repository without the need for an additional emplacement overpack. However, the licensing impacts of such a design on the geologic repository are uncertain because the design bases of the final emplacement overpack have not been developed.

Table 6-7. Aggregated Total-System Life-Cycle Costs (millions of 1993 dollars)

System Element	HLW System Element Cost (M\$)					
	CRWMP TSLCC Estimate ^a	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration			
			1 4-cn S/D+T	2 7-cn S/D+T	3 7-cn S/T/D	4 1-cn S/D+T
Transportation	358	245	187	110	101	677
MRS	N/A	N/A	N/A	N/A	N/A	N/A
Repository ^b	1,685					
Non-DU-shielded reference case		2,855				
Stainless-steel DU-shielded system			4,875	4,169	5,114	5,833
Incoloy DU-shielded system			4,408	3,947	5,125	4,996
Other Defense Waste (D&E and Benefits)	1,902	1,902	1,902	1,902	1,902	1,902
Subtotal for comparison with the TSLCC	3,945					
Non-DU-shielded reference case		5,002				
Stainless-steel DU-shielded system			6,964	6,181	7,117	8,412
Incoloy DU-shielded system			6,497	5,959	7,128	7,575
Waste Acceptance	0	25	25	25	25	25
Defense Waste Site	0	736	103	66	57	236
Total-System Cost	3,945					
Non-DU-shielded reference case		5,763				
Stainless-steel DU-shielded system			7,092	6,272	7,199	8,673
Incoloy DU-shielded system			6,625	6,050	7,210	7,836
Total DU disposal (kg x 1,000,000)	N/A	N/A	93	81	95	113
Min. DU disposal credit (LLW @ \$9.50/kg) ^c			884	770	903	1,074
Max. DU disposal credit (RCRA @ \$30.19/kg) ^c			2,808	2,445	2,868	3,411
Net DU-shielded total-system cost	N/A	5,763				
Stainless-steel DU-shielded system						
Maximum cost ^d			6,208	5,502	6,296	7,599
Minimum cost ^e			4,284	3,827	4,331	5,262
Incoloy DU-shielded system						
Maximum cost ^d			5,741	5,280	6,307	6,762
Minimum cost ^e			3,817	3,605	4,342	4,425

^a1988 TSLCC costs have been escalated to 1993 using costs 3.2% escalation factor (DOE, 1993).

^bRepository costs include surface/subsurface facilities and operations cost = \$1,373M for all disposal options; balance is canister, cask, and emplacement overpack cost.

^cDOE, 1995.

^dMaximum net total-system cost = (total-system cost) - (minimum DU disposal credit).

^eMinimum net total-system cost = (total-system cost) - (maximum DU disposal credit).

Figure 6-4. Total-System Costs for the CRWMP TSLCC, Reference Case, and Depleted-Uranium-Shielded Configurations (millions of 1993 dollars)

Figure 6-5. Net Total-System Costs Showing Credit for Depleted Uranium Disposal (millions of 1993 dollars)

The minimum and maximum DU disposal credits in Table 6-7 were determined by multiplying the total quantity of DU that would be codisposed with HLW for each of the DU-shielded configurations by the separate DU disposal cost as LLW and RCRA waste, respectively (DOE, 1995).

Recognizing the uncertainties associated with the cost estimates used, the following comparisons based on the system element cost analysis presented in Section 6.4.1 can be made with respect to the CRWMP TSLCC estimate (DOE, 1989), the non-DU-shielded reference case, and the four DU-shielded configurations.

CRWMP TSLCC Estimate. The CRWMP TSLCC estimate is \$3,945 M. The total-system life-cycle costs for the non-DU-shielded reference case and four DU-shielded system configurations developed in this study (Table 6-7) are 1.5 to 2.2 times higher (\$1,818M to \$4,730M) than the CRWMP TSLCC estimate. This difference is driven by higher (five to fourteen times) canister, cask, and emplacement overpack costs. The next largest contributor is the defense waste site cost that was not included as part of the TSLCC estimate. Waste acceptance costs, also not included in the TSLCC estimate, are minor contributors.

There are valid reasons to believe that repository surface and subsurface facilities and operations costs (Table 6-5) will be lower as a result of using multiple-canister disposal packages, particularly those that can be contact-handled. These cost savings can be expected to mitigate, somewhat, the increased canister, cask, and emplacement costs. However, repository facilities and operations costs will remain one of the important intangibles of the defense HLW disposal total-system cost analysis until the repository design concept is further developed and facilities and operations are defined and costed.

Non-DU-Shielded HLW Management System Reference Case. The total-system cost estimate for the non-DU-shielded reference case is \$5,763M. The reference case, which applies the Savannah River dry storage concept and uses the CRWMP 125-ton, 21 PWR MPC configuration (CRWMS, 1993a), as modified for vitrified defense HLW, is the lowest cost waste management system when a DU disposal credit is not taken for the DU-shielded configurations. The DU-shielded waste management system becomes competitive when the DU disposal cost exceeds \$6.43/kg for the seven-canister configuration, \$14.34/kg for the four-canister configuration, and \$25.62/kg for the single-canister configuration.

It should be noted here that the CRWMP 125-ton transportation cask (CRWMS, 1993b) cost is used for the non-DU-shielded reference case estimate, and no attempt has been made to determine whether defense HLW shielding requirements/costs would be the same as those for spent nuclear fuel.

DU-Shielded HLW Management Systems. Total-system costs were developed for a DU-shielded HLW management system to evaluate cost benefits that might accrue from codisposal of DU as shielding with defense HLW in the geologic repository as opposed to separate disposal as LLW or RCRA waste. Additionally, four separate DU-shielded configurations were identified to provide a direct cost comparison with the non-DU-shielded reference case, and also to assess the

effects of cask capacity, integral (i.e., nonreusable) transportation overpack, and DU usage on total-system life-cycle costs. The results of this analysis are provided below.

- The four stainless-steel DU-shielded configurations show that the potential exists for achieving a net cost savings from codisposal of DU as shielding with defense HLW in the geologic repository. The amount of savings depends on the actual cost of disposing DU as either LLW or RCRA waste. Applying the RCRA disposal cost (\$30.19/kg) as a credit reduces the total-system cost in all cases below the non-DU-shielded reference case total-system cost. This results in a potential cost benefit ranging from about \$500M to \$1.9B depending on the configuration. At the LLW disposal cost (\$9.50/kg), only the seven-canister S/D+T design drops below the non-DU-shielded reference case cost over the full range of DU disposal cost, providing a minimum savings of about \$260M at the \$9.50/kg DU disposal cost.
- Three S/D+T configurations indicate larger package capacities result in lower total-system cost. The bounding one-canister configuration has the highest total cost at \$8.7B. Using four- and seven-canister configurations results in \$1.6B and \$2.4B reductions in total-system costs, respectively. The cost reduction for larger package capacity results from lower waste site, transportation, and repository costs.
- The comparison of one-, four-, and seven-canister capacities demonstrates that larger cask capacity results in lower transportation costs. This is particularly evident when comparing the one- and four-canister designs where the difference is a savings of about \$490M. This results primarily from the dedicated train mileage charge that becomes the controlling shipping cost factor. The larger cask capacity results in fewer trainloads required to move the waste containers and thus lower total shipping costs. The seven-canister capacity configuration, which provides an additional \$77M savings, probably represents a realistic upper limit for storage, transport, and disposal casks, because its loaded weight approaches transportation and emplacement handling capacity limits.
- System Configurations 2 and 3 compare costs associated with using the seven-canister integral (S/T/D) and reusable (S/D+T) transportation overpacks. The analysis shows the total-system costs are \$927M larger for the S/T/D system combined storage, transport, and disposal cask. This results primarily from the need to build each S/T/D system cask stronger than the S/D+T system cask to meet the structural requirements of the transportation environment. Because the resulting larger S/T/D system capital cost is not offset by reductions in any other cost items, the S/T/D configuration is not cost-competitive with systems employing reusable transportation overpacks.
- Depending on package configuration, 81 to 113 million kilograms (178 to 248 million pounds) of DU would be used for shielding in the one-, four-, and seven-canister DU shielded designs costed in this study. Corresponding to the quantity of DU used in the design, there is a break-even disposal cost/credit for each of the configurations, generally somewhere between the LLW and RCRA waste disposal costs. These break-even disposal costs are \$25.62/kg, \$14.34/kg, and \$6.43/kg for the one-, four-, and seven-canister S/D+T

configurations, respectively. Thus the seven-canister S/D+T configuration provides the largest cost advantage with a break-even disposal credit below the present estimate of \$9.50/kg for disposal as LLW.

- The effect on cost using Incoloy cladding was not one of the specific comparison goals for this study. However, the costing results show the potential for significant S/D+T system cost reductions accruing from Incoloy cladding if its use will eliminate the need for a separate emplacement overpack. Costs for the Incoloy-clad, S/D+T system four-canister configuration (Configuration 1) are \$467M less than the stainless-steel clad package. Using the seven-canister S/D+T configuration results in a further reduction of \$575M making it the lowest cost configuration for the study, \$6,050M. These results indicate that using Incoloy cladding in place of a separate repository emplacement overpack should be investigated further. However, future repository licensing uncertainties cloud this approach.

Site-Specific Costs

The aggregated site-specific costs are presented in Tables 6-8, 6-9, and 6-10 for Savannah River, Hanford, and West Valley, respectively. Appropriate TSLCC and CRWMP costs were escalated to 1993 dollars as described in the total-systems cost summary (DOE, 1989; CRWMS, 1993a). The bases for site-specific comparisons are identical to those identified for the systems comparisons. The major system elements (Table 6-1) evaluated for each site included waste site costs, waste acceptance costs, transportation costs, and repository costs. D&E and benefits were not considered appropriate for site-specific analysis, and MRS costs are not applicable to defense HLW.

The comparisons made for the total-system analysis of the non-DU-shielded reference case and the various DU-shielded system configurations are directly supported by the site-specific data. For this reason, those comparisons will not be repeated, and this section will be limited to other site-specific observations.

Savannah River. The most significant difference between the non-DU-shielded reference case and the four DU-shielded configurations is the interim storage cost using the GWSB dry storage approach. This cost exceeds the directly comparable four-canister DU-shielded system storage cost by approximately \$320M and indicates that a cost saving on the order of \$170M could be achieved by substituting the DU-shielded system pad storage concept for the second GWSB.

Hanford. When comparing the Hanford non-DU-shielded reference case cost with SRS, it appears that Hanford's waste disposal cost is about 146% as high as the SRS cost for disposal of about twice as much HLW. Hanford does not begin to generate vitrified waste canisters until the year 2000 and begins shipping canisters out of interim storage about halfway through canister production. Thus Hanford requires only the same dry storage space as SRS for twice as many canisters. Hanford shipping costs also contribute to this cost difference because the Hanford shipping distance is about half that for SRS.

Table 6-8. Savannah River Site Aggregated Total Disposal Costs
(millions of 1993 dollars)

System Element/Cost Item	Element/Item Cost (M\$)				
	Reference	DU-Shielded System Configuration			
	Case	1	2	3	4
	4-cn VW-MPC	4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T
Waste Acceptance					
Welding equipment	0.6	0.6	0.6	0.6	0.6
Canister handling facility	7.6	7.6	7.6	7.6	7.6
Transportation					
Overpacks	24.0	6.6	4.2	0.0	8.5
Overpack maintenance	1.8	1.8	1.8	0.0	1.8
Impact limiters (S/T/D)	0.0	0.0	0.0	1.9	0.0
Shipping	85.4	83.0	47.9	47.5	327.6
Repository					
VW-MPC (non-DU-shielded reference case)	264.7				
Stainless-steel DU-shielded cask		952.2	814.2	1,135.9	1,145.9
Emplacement overpacks	238.6	238.6	136.3	136.3	372.2
Waste Site					
Preparation for waste acceptance	5.7	11.4	6.5	3.3	45.6
Interim storage	345.8	25.7	17.9	17.9	36.8
SRS Total					
Non-DU-shielded reference case	975.5				
Stainless-steel DU-shielded system		1,328.8	1,038.3	1,347.8	1,946.6
Total DU disposal (kg x 1,000,000)	N/A	31.5	27.5	32.4	38.5
Minimum DU disposal credit (LLW @ \$9.50/kg) ^a		299.3	261.3	307.8	365.8
Maximum DU disposal credit (RCRA @ \$30.19/kg) ^a		951.0	830.2	978.2	1,162.3
SRS Net Cost	975.5				
Stainless-steel DU-shielded disposal process					
Maximum cost ^b		1,029.5	777.0	1,040.0	1,580.6
Minimum cost ^c		377.8	208.1	369.6	784.3

^aDOE, 1995.

^bMaximum net SRS cost = (SRS total cost) - (minimum DU disposal credit).

^cMinimum net SRS cost = (SRS total cost) - (maximum DU disposal credit).

Table 6-9. Hanford Aggregated Total Disposal Costs (millions of 1993 dollars)

System Element/Cost Item	Element/Item Cost (M\$)				
	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration			
		1 4-cn S/D+T	2 7-cn S/D+T	3 7-cn S/T/D	4 1-cn S/D+T
Waste Acceptance					
Welding equipment	0.6	0.6	0.6	0.6	0.6
Canister handling facility	7.6	7.6	7.6	7.6	7.6
Transportation					
Overpacks	24.0	6.6	4.2	0.0	8.5
Overpack maintenance	1.8	1.8	1.8	0.0	1.8
Impact limiters (S/T/D)	0.0	0.0	0.0	1.9	0.0
Shipping	80.6	77.9	45.2	44.7	305.4
Repository					
VW-MPC (non-DU-shielded reference case)	500.1				
Stainless-steel DU-shielded cask		1,790.3	1,531.6	2,136.7	2,155.4
Emplacement overpacks	448.6	448.6	256.4	256.4	700.1
Waste Site					
Preparation for waste acceptance	10.7	21.5	12.3	6.1	85.8
Interim storage	353.3	39.1	24.5	24.5	60.1
Hanford Total					
Non-DU-shielded reference case	1,424.9				
Stainless-steel DU-shielded system		2,394.0	1,884.2	2,478.5	3,325.3
Total DU disposal (kg x 1,000,000)	N/A	59.2	51.8	60.9	72.4
Minimum DU disposal credit (LLW @ \$9.50/kg)^a		562.4	491.2	578.6	687.8
Maximum DU disposal credit (RCRA @ \$30.19/kg)^a		1,787.2	1,563.8	1,838.6	2,185.8
Hanford Net Cost	1,424.9				
Stainless-steel DU-shielded system					
Maximum cost ^b		1,831.6	1,392.1	1,899.9	2,637.5
Minimum cost ^c		606.8	320.4	636.9	1,139.5

^aDOE, 1995.

^bMaximum net Hanford cost = (Hanford total cost) - (minimum DU disposal credit).

^cMinimum net Hanford cost = (Hanford total cost) - (maximum DU disposal credit).

Table 6-10. West Valley Aggregated Total Disposal Costs (millions of 1993 dollars)

System Element/Cost Item	Element/Item Cost (M\$)					
	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration				
		1	2	3	4	
		4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T Train	Truck
Waste Acceptance						
Welding equipment	0.6	0.6	0.6	0.6	0.6	0.6
Canister handling facility	7.6	7.6	7.6	7.6	7.6	7.6
Transportation						
Overpacks	24.0	6.6	4.1	0.0	8.5	2.8
Overpack maintenance	1.8	1.8	1.8	0.0	0.1	0.8
Impact limiters	0.0	0.0	0.0	1.9	0.0	0.0
Shipping	4.5	4.3	2.5	2.5	17.0	10.9
Repository						
VW-MPC (non-DU-shielded reference case)	15.2					
Stainless-steel DU-shielded cask		54.5	46.8	65.3	65.6	65.6
Emplacement overpacks	13.7	13.7	7.8	7.8	21.3	21.3
Waste Site						
Preparation for waste acceptance	0.3	0.7	0.4	0.2	2.6	2.6
Interim storage	19.8	4.6	4.1	4.1	5.2	5.2
West Valley Total Cost						
Non-DU-shielded reference case	87.5					
Stainless-steel DU-shielded system		94.4	75.7	90.0	128.5	117.4
Total DU disposal (kg x 1,000,000)	N/A	1.80	1.57	1.86	2.20	2.20
Minimum DU disposal credit (LLW @ \$9.50/kg) ^a		17.1	14.9	17.7	20.9	20.9
Maximum DU disposal credit (RCRA @ \$30.19/kg) ^a		54.3	47.7	56.2	66.4	66.4
West Valley Net Cost	87.5					
Stainless-steel DU-shielded system						
Maximum cost ^b		77.3	60.8	72.3	107.6	96.5
Minimum cost ^c		40.1	28.0	33.8	62.1	51.0

^aDOE, 1995.

^bMaximum net West Valley cost = (West Valley total cost) - (minimum DU disposal credit).

^cMinimum net West Valley cost = (West Valley total cost) - (maximum DU disposal credit).

West Valley. Because it did not seem appropriate to consider building a GWSB at West Valley for storing 300 canisters, the SRS storage cost per canister was prorated for the 300 canisters to provide complete costs for the total-system cost analysis. In the event that a dry storage approach is used at West Valley, the actual cost will be determined at that time. The major cost study difference between West Valley and the other sites was the inclusion of a truck transport configuration using the one-canister DU-shielded S/D+T configuration (System Configuration 4).

A comparison of the truck transport option to the rail transported configurations shows it to cost about 90% of rail transport for the one-canister S/D+T configuration, resulting in about an \$11M saving. As expected, the rail transported one-canister configuration results in the highest transportation cost. However, all of the multiple-canister cask and package configurations that use rail shipment are more cost effective than truck transport. The cost savings for these configurations range from about \$23M to \$42M or from 64% to 80% of the truck transport option. The seven-canister S/D+T configuration (System Configuration 2) is the least costly alternative, even without application of a DU disposal credit.

6.5 Conclusions

Defense HLW system elements have been identified and their major cost items determined. The costs of these principal cost categories were estimated and used to evaluate the various non-DU-shielded and DU-shielded HLW management systems. The resulting total-system costs were compared to the CRWMP TSLCC estimates. They were also used to estimate specific waste site costs and explore the cost advantages and disadvantages of using DU-shielded storage/disposal casks for codisposal of DU along with defense HLW in the geologic repository.

The following conclusions are based on the analysis of Section 6.4. A caution is issued concerning the preliminary nature of the data used in this study.

- The actual disposal cost of DU as waste is very uncertain. This results from uncertainty whether DU waste management and disposition falls under the regulatory requirements of the Resource Conservation and Recovery Act. The actual cost benefit accrued from codisposal of DU along with defense HLW in the geologic repository can vary from a positive to a negative benefit depending on the assumed disposal cost.
- Defense HLW total-system costs are 1.5 to 2.2 times higher (\$1.818M to \$4.730M) for the configurations developed in this study than the CRWMP TSLCC estimate (DOE, 1989). These cost differences are primarily the result of larger canister, cask, and emplacement overpack costs.
- The potential exists for a net cost saving from codisposal of DU with defense HLW in the geologic repository. The amount of savings depends on the actual DU disposal cost and ranges from \$260M to \$1.9B. Applying the RCRA disposal cost (\$30.19/kg) as a credit reduces the total-system cost in all cases below the non-DU-shielded reference case total-system cost. Using the LLW disposal cost (\$9.50/kg), only the seven-canister S/D+T configuration drops below the reference case total-system cost.
- The use of multiple HLW canister storage, transport, and disposal casks and multi-purpose canisters, particularly those that can be contact-handled (i.e., those that are DU-shielded), should result in reduction of repository surface and subsurface facilities and operations costs. However, specific repository facilities and operations costs will remain an important

intangible of waste disposal system costing until the repository design concept is further developed.

- The non-DU-shielded reference case, which applies the Savannah River dry storage concept and uses the CRWMS 125-ton, 21 PWR MPC configuration (CRWMS, 1993a), as modified for vitrified defense HLW, is the lowest cost scenario when a DU disposal credit is not taken for the shielded configurations. The DU-shielded configurations become competitive when the DU disposal costs exceed \$6.43/kg for the seven-canister configuration, \$14.34/kg for the four-canister configuration, and \$25.62 for the one-canister configuration.
- The three S/D+T configurations indicate larger system capacities (multiple canisters per cask) result in lower total-system cost. The reduction for larger capacity results from lower transportation, repository, and waste site costs. A cost benefit results from the ability to contact-handle and store the waste on relatively inexpensive open concrete pads.
- Larger container or cask capacity (whether DU-shielded or not) provides lower transportation costs. The dedicated train mileage charge becomes the controlling shipping cost factor. Larger capacity results in fewer train miles needed to move the waste to the repository and thus lower shipping costs.
- The seven-canister DU-shielded configuration is cost-effective and probably represents a realistic upper capacity for HLW canister storage, transport, and disposal because its loaded weight and size approaches present transportation and emplacement handling capacity limits.
- Integral transport package systems (S/T/D) are more costly and are not competitive with reusable transportation overpack systems (S/D+T). Each integral transport package unit must be built stronger to meet the structural requirements of the transportation environment. The resulting larger capital cost is not appreciably offset by any cost reductions.
- The use of Incoloy cladding in place of a separate geologic repository emplacement overpack shows the potential for significant cost reduction. Costs for the Incoloy-clad DU-shielded four-canister S/D+T configuration are \$467M less than the stainless-steel-clad package. However, a better understanding of long-term material corrosion under repository emplacement conditions is required.
- This study shows that 81 to 113 million kilograms (178 to 248 million pounds) of DU could be disposed as shielding in the one-, four-, and seven-canister DU-shielded designs. Corresponding to the quantity of DU used in the design, there is a break-even disposal cost/credit for each of the configurations, generally somewhere between the LLW and RCRA waste disposal costs. The seven-canister S/D+T configuration provides the largest cost advantage with a break-even disposal credit of \$6.43/kg or \$3.07/kg below the present estimate of \$9.50/kg for LLW disposal.
- A cost saving on the order of \$170M could be achieved at the SRS by substituting the DU-shielded system pad storage concept for the second GWSB.

- The West Valley truck transport option costs about 90% of the rail transport option for the one-canister S/D+T configuration, and results in about an \$11M saving. All of the multiple DU-shielded cask and multipurpose canister configurations using rail transport are more cost effective than truck shipment with cost savings from 64% to 80% of the truck transport option. The seven-canister S/D+T configuration is the least costly alternative, even without application of a DU disposal credit.

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7.0 CONCLUSIONS

7.1 Metal Depleted-Uranium-Shielded Casks for High-Level Waste Canisters

Metal DU-shielded casks can be used for the storage, transport, and disposal of HLW canisters as produced by the Savannah River, Hanford, and West Valley HLW vitrification facilities. Design feasibility has been established for two types of metal DU-shielded casks: (1) a nontransportable storage/disposal cask that requires a separate transportation overpack for off-site transport (the S/D+T system), and (2) a transportable storage/transport/disposal cask that does not require a transportation overpack (the S/T/D system). Conceptual designs of both casks that are configured to hold one, three, four, and seven HLW canisters show that they meet applicable structural, thermal, and shielding requirements. Current transportation size and weight restrictions will probably limit cask capacity to seven HLW canisters, the preferred configuration. A 3-in. layer of DU sandwiched between the inner and outer structural steel shells of the cask provides a contact handled cask for the seven-canister cask. Conceptual designs developed in this study provide the needed basis for development of preliminary design(s) for a DU-shielded cask for HLW canisters.

7.2 Implementation Considerations

DU metal fabrication facilities will have to be restarted to provide the parts needed to make DU-shielded casks. Options, associated primarily with DU alloys, need to be investigated to resolve problems related to oxide formation, radiation-induced dimension changes, radiation embrittlement, and the acceptance of DU as a structural material. Each of the metal DU-shielded casks considered in this study can be employed in the HLW storage, transport, and disposal system that conforms with current DOE OCRWM assumptions, assessments, and planning activities.

7.3 Dispositioning of Excess Depleted-Uranium Inventories

About one-fourth of the current DU inventory would be used for shielding material in the DU-shielded casks. A more substantial storage system would be provided for DU than the stainless-steel storage tanks now being used. Using DU as shielding in casks for HLW canisters is a beneficial use that counters some thoughts that DU should be disposed as a waste. Disposal of HLW canisters in DU-shielded casks in the geologic repository would eliminate separate disposal of DU as a waste in either a LLW or RCRA-controlled repository.

7.4 Total-System Cost

Total-system cost estimates for systems employing the DU-shielded cask are higher than the estimated cost of a reference system for the separate disposal of DU and HLW canisters, at least \$0.5B more. However, when credited with DU disposal costs (costs that are avoided by using

DU-shielded casks) the estimated cost is at least \$0.3B less for the preferred seven-canister S/D+T configuration proposed in this analysis. In this case, estimated costs could be as much as \$2B less, depending on the assumed cost of separate DU disposal. The cost decreases with increased HLW canister capacity. Estimated costs will be less by an additional amount if DU hexafluoride (the predominant form of stored DU) to metal conversion costs prove to be less than the currently estimated \$10/kg-U.

8.0 RECOMMENDATIONS

The following recommendations are made as a result of this analysis.

- Develop a preliminary design for a nontransportable metal DU-shielded cask for storage and disposal of HLW canisters.
- Initiate DU alloy studies to identify an optimum alloy of DU, both type and concentration, that resolves oxide formation, radiation-induced dimension changes, radiation embrittlement, and DU structural acceptance problems.
- Form a combined venture with the DOE OCRWM and Environmental Management Office of Nuclear Material and Facility Stabilization to assess and validate the concept to employ metal DU-shielded casks in HLW management systems, and prioritize development needs.
- Inform commercial manufacturers and vendors of the conclusions of this study, and provide an opportunity for participation in preliminary cask design, DU alloy studies, concept assessment and validation, and prioritization of development needs.

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APPENDIX A
CONCEPTUAL DRAWINGS OF THE
FOUR STORAGE/DISPOSAL PLUS
TRANSPORT SYSTEM CONFIGURATIONS

This appendix presents the conceptual drawings of the four configurations of the Storage/Disposal Plus Transport (S/D+T) system. These conceptual drawings were developed during the early stages of the program to determine the feasibility of using depleted uranium as a shielding material for the storage, transportation, and disposal of high-level waste canisters. The terminology used to describe specific components of the systems changed over the course of the development activity. The drawings reflect the nomenclature assigned to the system components and assemblies at the time the conceptual drawings were developed. In an attempt to clarify the individual S/D+T configuration figures, titles have been added to aid in understanding the differences among these configurations.

ONE-CANISTER CONFIGURATION OF THE STORAGE/DISPOSAL
PLUS TRANSPORT SYSTEM

DESIGN/REVISION		REVISIONS				
REV	DATE	REVISION BY	DESCRIPTION	DATE	CHK	APP
A		R. STRINGFELLOW, 2003/ D. UNCAS, 0542				

REV	1	2	3	4	5	6	TITLE
REV	A	A	A	A	A	A	SINGLE CANISTER STORAGE /DISPOSAL PKG W/TRANS- PORTATION OVERPACK (U)
CLASSIFICATION	UNCLASSIFIED						
CLASSIFICATION	UNCLASSIFIED						
DATE	05/14/03						SCALE 1/8" = 1'-0"
DATE	05/14/03						SCALE 1/8" = 1'-0"

ONE-CANISTER CONFIGURATION
OF THE STORAGE/DISPOSAL CONTAINER

DESIGN NUMBER	
R4-1076	
DESIGN CLASSIFICATION	
UNCLASSIFIED	
REV	CHG-4213
E	DATE 1/8
DATE A	DATE 2 6-4
TABLE 5A-OK-3-18-05

SECTION C-C

ONE-CANISTER CONFIGURATION OF THE STORAGE/DISPOSAL
CONTAINER WITH STORAGE IMPACT LIMITERS INSTALLED

DRAWING NUMBER		
RR41076		
DRAWING CLASSIFICATION		
UNCLASSIFIED		
SIZE	ORIGIN	SCALE
E	1/8"	1/8"
SHEET A	SHEET 3	OF 4
FORM SA-OR-3-18-05

DESIGN ASPECT		REVISIONS					
PART NUMBER	REV	PREPARED BY	DESCRIPTION	DATE	CHK	APP	
R41077-000	A	R. STRINGFELLOW, 2083/ D. UNKAPEN, 0542					

THREE-CANISTER CONFIGURATION OF THE
STORAGE/DISPOSAL PLUS TRANSPORT SYSTEM

DATE	1	2	3	4	5	6	TITLE	
DATE	A	A	A				THREE CANISTER STORAGE /DISPOSAL PKG W/TRANS- PORTATION OVERPACK (U)	
PART CLASSIFICATION							UNCLASSIFIED	
DESIGN CLASSIFICATION							UNCLASSIFIED	
							E R41077	
DRAWN SA-OK-3-18-63							CHECKED BY SA-45-42.1

THREE-CANISTER CONFIGURATION OF THE
STORAGE/DISPOSAL CONTAINER

DRAWING NUMBER			
R41077			
DRAWING CLASSIFICATION			
UNCLASSIFIED			
SIZE	DMC14213	SCALE	1/8
E	REV A	SHEET	2 OF 3
DRAWING NO. SA-OK-3-1B-05			

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SECTION C-C

THREE-CANISTER CONFIGURATION OF THE STORAGE/DISPOSAL
CONTAINER WITH STORAGE IMPACT LIMITERS INSTALLED

DRAWING NUMBER		
R41077		
DRAWING CLASSIFICATION		
UNCLASSIFIED		
SIZE	OMC 4213	SCALE 1/8"
E	ISSUE A	SHEET 3 OF 3
REVISION SA-OR-3-18-53

DESIGN AGENCY PART NUMBER		REVISIONS					
REV	DATE	PREPARED BY	DESCRIPTION	CHKD	CHG	APPD	
R41078-000	A	R. STRINGFELLOW, 2983/ D. UNDAFER, 6542

FOUR-CANISTER CONFIGURATION OF THE
STORAGE/DISPOSAL PLUS TRANSPORT SYSTEM

SHEET	1	2	3	4	5	6	DATE
FILE	A	A	A				FOUR CANISTER STORAGE /DISPOSAL PKG W/TRANS- PORTATION OVERPACK (U)
FILE CLASSIFICATION	UNCLASSIFIED						
DESIGN CLASSIFICATION	UNCLASSIFIED						DESIGN NUMBER E R41078
SHEET 1 OF 3							
SCALE SA-OK-3-18-63							SCALE SA-45-Y2.1

FOUR-CANISTER CONFIGURATION OF THE
STORAGE/DISPOSAL CONTAINER

DRAWING NUMBER		
FR4-1078		
DRAWING CLASSIFICATION		
UNCLASSIFIED		
VIEW	DATE/REV	SCALE
E	10/1/21	1/8"
REV. A	10/1/21	1/8"
SCALE SA-OK-3-18-03

SECTION C-C

FOUR-CANISTER CONFIGURATION OF THE STORAGE/DISPOSAL
CONTAINER WITH STORAGE IMPACT LIMITERS INSTALLED

DRAWING NUMBER		
R41078		
DRAWING CLASSIFICATION		
UNCLASSIFIED		
REV	DESCRIPTION	DATE
E	CHG 4213	NOV 1/8
	ISSUE A	NOV 3 1983
SERIAL SA-OK-3-18-63

SECTION D-D

SEVEN-CANISTER CONFIGURATION OF THE
STORAGE/DISPOSAL PLUS TRANSPORT SYSTEM

DESIGN PROJECT		REVISIONS				
PROJECT NUMBER	DATE	REVISION BY	DESCRIPTION	DATE	CHKD	APVD
R41079-000	A	R. STRINGFELLOW, 2883/ B. UNCIPHER, 0542				

DATE	1	2	3	4	5	6	TITLE
FILE	A	A	A	A	A	A	SEVEN CANISTER STORAGE /DISPOSAL PKG W/TRANS- PORTATION OVERPACK (U)
PROJECT CLASSIFICATION	UNCLASSIFIED						
DESIGN CLASSIFICATION	UNCLASSIFIED						PROJECT NUMBER R41079
DRAWING NUMBER SA-OK-3-18-03							SCALE 1/8" = 1'-0"
SHEET SA-W5-V2.1							SHEET 1 OF 4

SEVEN-CANISTER CONFIGURATION OF THE
STORAGE/DISPOSAL CONTAINER

DRAWING NUMBER			
R41079			
DRAWING CLASSIFICATION			
UNCLASSIFIED			
SIZE	0864213	SCALE	1/8"
E	DATE A	DATE 2	OF 4
SHEET SA-OK-S-18-93

SEVEN-CANISTER CONFIGURATION OF THE STORAGE/DISPOSAL
CONTAINER WITH STORAGE IMPACT LIMITERS INSTALLED

DRAWING NUMBER		
R41079		
DRAWING CLASSIFICATION		
UNCLASSIFIED		
SIZE	ORIGIN	SCALE
E	4213	1/8
	ISSUE A	SHEET 3 OF 4
REVISION		
SA-OK-3-18-05

APPENDIX B
STORAGE/DISPOSAL PLUS TRANSPORT SYSTEM TRUCK
AND RAIL TRANSPORTATION CONFIGURATIONS

This appendix presents the conceptual drawings of the proposed truck and rail conveyance components of the Storage/Disposal Plus Transport (S/D+T) system. These conceptual drawings were developed during the early stages of the program to determine the feasibility of using truck or rail transport. The terminology used to describe specific components of the transport conveyance changed over the course of the development activity. The drawings reflect the nomenclature assigned to the transport conveyance components and assemblies at the time the conceptual drawings were developed. In an attempt to clarify the S/D+T transport options, titles have been added to aid in understanding the differences between the truck and rail configurations.

FIGURATION OF THE STORAGE/DISPOSAL
SYSTEM WITH TRUCK CONVEYANCE

Drawing Number		R41076	
Drawing Classification		UNCLASSIFIED	
Scale	Drawn	Check	Date
E	04-02-13	1/20	
Rev. A	04-04-13	04-04	
Issue: SI-OK-3-1B-25			

B-1

ION OF THE STORAGE/DISPOSAL
 EM WITH RAIL CONVEYANCE

DRAWING NUMBER		
R41079		
DRAWING CLASSIFICATION		
UNCLASSIFIED		
SIZE	SHEET 2 OF 4	SHEET 20/1
E	NAME A	SHEET 4 OF 4
SHEET SA-04-3-18-93

APPENDIX C
CONCEPTUAL DRAWINGS OF THE
FOUR STORAGE/TRANSPORT/DISPOSAL
SYSTEM CONFIGURATIONS

This appendix presents the conceptual drawings of the four configurations of the Storage/Transport/Disposal (S/T/D) system including conveyance configurations for truck and rail. These conceptual drawings were developed during the early stages of the program to determine the feasibility of using depleted uranium as a shielding material for the storage, transportation, and disposal of high-level waste canisters. The terminology used to describe specific components of the systems changed over the course of the development activity. The drawings reflect the nomenclature assigned to the system components and assemblies at the time the conceptual drawings were developed. In an attempt to clarify the S/T/D configuration figures, titles have been added to aid in understanding the differences among these configurations.

5		2		1				
		REVISED						
		DESIGN AGENCY PART NUMBER		REVISION BY	DESCRIPTION	DATE	CHK	APP
		R41080-000		A	R. STRINGFELLOW, 2583/ B. UNKAPEN, 0542

ONE-CANISTER CONFIGURATION OF THE
STORAGE/TRANSPORT/DISPOSAL SYSTEM

SHEET	1	2	3	4	5	6	TITLE
SCALE	A	A	A	A	A	A	SINGLE CANISTER STORAGE /TRANSPORT/DISPOSAL PACKAGE (U)
PART CLASSIFICATION UNCLASSIFIED							
DESIGN CLASSIFICATION UNCLASSIFIED							
DESIGN NUMBER E R41080							
DATE 12-21-83 SCALE 1/8" = 1'-0"							
SHEET SA-08K-S-17-93							

D

SECTION B-B

C

B

SECTION B-B

A

ALL
DIM

CONTAINMENT
SEAL WELD

WASTE CONTAINER CONFIGURATION OF THE STORAGE/TRANSPORT/DISPOSAL SYSTEM

DRAWING NUMBER	
R41080	
DRAWING CLASSIFICATION	
UNCLASSIFIED	
SIZE	DATE: 12/13/83
E	SCALE: 1/8"
REVISION A	SHEET 2 OF 3
DRAWING: SA-OR-3-17-83

SECTION C-C

WASTE CONTAINER CONFIGURATION OF THE
STORAGE/TRANSPORT/DISPOSAL SYSTEM

Drawing Number	
R41091	
Drawing Classification	
UNCLASSIFIED	
Size	08x14x213 1/8
E	Sheet 2 of 2
Scale SA-OK-3-17-03

DESIGN AGENCY PWS-KLASER		REVISIONS				
REV	DATE	PREPARED BY	DESCRIPTION	SIZE	CHK	APP
A		R. STRINGFELLOW, 2983/ S. UNKAPFER, 6642				
R41082-000

FOUR-CANISTER CONFIGURATION OF THE
STORAGE/TRANSPORT/DISPOSAL SYSTEM

REV	1	2	3	4	5	6	TITLE
REV	A	A					FOUR CANISTER STORAGE /TRANSPORT/DISPOSAL PACKAGE (U)
UNCLASSIFIED							
UNCLASSIFIED							
E R41082							
CNS 14219 SCALE 1/8 SHEET 1 OF 2							
SHEET SA-OK-3-17-63 SHEET SA-ANS-42.1

CONTAINMENT
SEAL WELD

WASTE CONTAINER CONFIGURATION OF THE STORAGE/TRANSPORT/DISPOSAL SYSTEM

DRAWING NUMBER			
R41082			
DRAWING CLASSIFICATION			
UNCLASSIFIED			
SIZE	OVERALL DIMS	SCALE 1/8"	
E			
	SHEET A	SHEET 2	OF 2
TITLE SA-OK-3-17-83

SEVEN-CANISTER CONFIGURATION OF THE
STORAGE/TRANSPORT/DISPOSAL SYSTEM

REV	1	2	3	4	5	6	TITLE
REV	A	A	A				SEVEN CANISTER STORAGE /TRANSPORT/DISPOSAL PACKAGE (U)
CLASSIFICATION	UNCLASSIFIED						
CLASSIFICATION	UNCLASSIFIED						REV R41083
DATE	1983-12-13						SCALE 1/8" = 1'-0"
DATE	1983-12-13						REV 1 OF 3
DATE	1983-12-13						REV SA-48-V2.1

WASTE CONTAINER CONFIGURATION OF THE STORAGE/TRANSPORT/DISPOSAL SYSTEM

Drawing Number		
R41083		
Drawing Classification		
UNCLASSIFIED		
Size	Sheet 1 of 3	
E	Sheet A	Sheet 2 of 3
Revised SA-OR-3-17-93

ER CONFIGURATION OF THE
OSAL SYSTEM WITH TRUCK CONVEYANCE

DRAWING NUMBER			
R41080			
DRAWING CLASSIFICATION			
UNCLASSIFIED			
SIZE	ORIG 4213	SCALE	1/20
E	REV A	DATE	3 OF 3
BRN: SA-OK-3-17-83

SINGLE CANIS
STORAGE/TRANSPORT/DIS

CONFIGURATION OF THE
SYSTEM WITH RAIL CONVEYANCE

DRAWING NUMBER		
R41083		
DRAWING CLASSIFICATION		
UNCLASSIFIED		
REV	DATE	BY
E	08/14/21	WALE 20/1
SHEET A		SHEET 3 OF 3
SHEET 5A-08-3-17-03

APPENDIX D

**ABBREVIATED CASE STUDIES
AND SYSTEM COST ANALYSIS**

APPENDIX D

ABBREVIATED CASE STUDIES AND SYSTEM COST ANALYSIS

Appendix D was assembled during July and August 1993 and used the waste site HLW canister production schedule provided by the DOE Integrated Data Base for 1992, and the repository waste acceptance schedule from the 1990 addendum to the CRWMP TSLCC (DOE, 1992 and 1990). Since that time the solidification schedules for Hanford and Savannah River have undergone major changes caused by changes in DOE funding guidance. Similarly, the 1995 analysis of the CRWMP TSLCC has reduced the repository HLW canister acceptance rate by 50 canisters (from 800 to 750) per year between the years 2015 and 2037 (DOE, 1995). However, the total number of HLW canisters planned for disposal has not changed appreciably and the initial HLW acceptance date for the repository is still planned for the year 2015.

For a first order approximation, the system element and total-system life-cycle costs developed in this study should remain completely acceptable for comparison purposes. Similarly, the site-specific cost comparisons should remain viable. However, the Savannah River, Hanford, and West Valley site production and shipment schedules, provided in Sections D.1, D.2, and D.3 and discussed in the text, retain the 1992 Integrated Data Base and 1990 TSLCC production and acceptance rates and do not reflect the latest Integrated Data Base (i.e., 1994) and TSLCC (1995) projections.

D.1 ABBREVIATED CASE STUDY FOR SAVANNAH RIVER

The Savannah River Site (SRS) was scheduled to begin vitrified waste production in 1993 and complete vitrification of 5,242 waste canisters in the year 2010 (DOE, 1990). The geologic repository will begin accepting defense high-level waste (HLW) in the year 2015 at the rate of 800 canisters per year (DOE, 1989). For this cost analysis, the total repository acceptance rate will be equally split between SRS and Hanford until the year 2028 when all of the SRS waste will have been shipped.

The assumption is also made for this study that all 300 canisters of West Valley HLW will be shipped to the repository the first year and the 500-canister balance will be equally divided between Savannah River and Hanford sites. Note that this is an exception to the Civilian Radioactive Waste Management Program Total-System Life-Cycle Cost (CRWMP TSLCC) assumption that West Valley waste will be shipped after all of the defense HLW has been accepted by the repository. It does not appear sensible to store the 300 canisters of West Valley HLW for an additional 29 years while the defense HLW is being shipped at 800 canisters per year. In any case, the SRS waste canisters must be temporarily stored for 15 years until the repository is ready to start accepting defense HLW. The projected SRS canister production/shipment schedule is provided in Table D-1.

Two approaches are developed for storing, transporting, and disposing of the 5,242 waste canisters produced at SRS. These approaches include a variation of the CRWMS multi-purpose canister (MPC) concept (CRWMS, 1993a; EPRI, 1993) which will be referred to as the non-DU-shielded HLW management system reference case (described in Section 6.2 of this report). The second approach, called the DU-shielded HLW management system, uses a DU-shielded cask (as described in Section 6.3 of this report).

Non-DU-Shielded HLW Management System Reference Case

As described in Section 6.2 and illustrated in Figure 6-1, 5,242 waste canisters are produced in the Defense Waste Processing Facility (DWPF) and dry stored in two glass waste storage buildings (GWSBs) (WSRC, 1991) that together are assumed to have sufficient capacity for all of the canisters produced at SRS. The highly radioactive canisters are handled remotely by a robotic shielded canister transporter (SCT). The SCT is used to move the canisters from the DWPF to the GWSB and from the GWSB to the canister handling facility as required.

When the repository is ready to accept defense HLW, the waste canisters are moved from the GWSB to the canister handling facility where they are loaded into the four-canister vitrified waste multi-purpose canister (VW-MPC). In preparation for canister loading, the VW-MPC has been preassembled with its transportation overpack. The transportation overpack is a reusable shielded package for rail shipment of waste canisters to the repository. When the assembly of four waste canisters is complete, the VW-MPC cover is put in place and seal-welded closed. The

Table D-1. Projected Savannah River Site Canister Production/Shipment Schedule

Year	Annual		Cumulative Total	Cumulative Store	Cumulative	Cumulative	Cumulative	Cumulative
	Create	Ship			4-cn	4-cn	7-cn	7-cn
					System Store	System Ship	System Store	System Ship
1993	17	0	17	17	5	0	3	0
1994	205	0	222	222	56	0	32	0
1995	307	0	529	529	133	0	76	0
1996	410	0	939	939	235	0	135	0
1997	410	0	1,349	1,349	338	0	193	0
1998	410	0	1,759	1,759	440	0	252	0
1999	410	0	2,169	2,169	543	0	310	0
2000	379	0	2,548	2,548	637	0	364	0
2001	369	0	2,917	2,917	730	0	417	0
2002	363	0	3,280	3,280	820	0	469	0
2003	307	0	3,587	3,587	897	0	513	0
2004	307	0	3,894	3,894	974	0	557	0
2005	307	0	4,201	4,201	1051	0	601	0
2006	307	0	4,508	4,508	1127	0	644	0
2007	239	0	4,747	4,747	1187	0	679	0
2008	205	0	4,952	4,952	1238	0	708	0
2009	205	0	5,157	5,157	1290	0	737	0
2010	85	0	5,242	5,242	1311	0	749	0
2011		0	5,242	5,242	1311	0	749	0
2012		0	5,242	5,242	1311	0	749	0
2013		0	5,242	5,242	1311	0	749	0
2014		0	5,242	5,242	1311	0	749	0
2015		255	4,987	4,987	1247	64	713	37
2016		399	4,588	4,588	1147	164	656	94
2017		399	4,189	4,189	1048	264	599	151
2018		399	3,790	3,790	948	364	542	208
2019		399	3,391	3,391	848	564	485	265
2020		399	2,992	2,992	748	664	428	322
2021		399	2,593	2,593	649	764	371	379
2022		399	2,194	2,194	549	864	314	436
2023		399	1,795	1,795	449	964	257	493
2024		399	1,396	1,396	349	1,064	200	550
2025		399	997	997	250	1,164	143	607
2026		399	598	598	150	1,264	86	664
2027		399	199	199	50	1,364	29	721
2028		199	0	0	0	1,414	0	750
2029		0	0	0	0	0	0	0
2030		0	0	0	0	0	0	0
2031		0	0	0	0	0	0	0
2032		0	0	0	0	0	0	0
2033		0	0	0	0	0	0	0
2034		0	0	0	0	0	0	0
2035		0	0	0	0	0	0	0
2036		0	0	0	0	0	0	0
2037		0	0	0	0	0	0	0
2038		0	0	0	0	0	0	0

transportation overpack cover is then bolted in place and the VW-MPC transport package is loaded onto a railcar for shipment to the repository. The VW-MPC transport package is fully shielded and can be contact-handled.

At the repository, the VW-MPC transport package is offloaded at the waste package preparation facility and moved into the VW-MPC remote handling cell. In the handling cell, the VW-MPC is disassembled from the transportation overpack in reverse order of loading. The empty overpack and impact limiters are reloaded on the dedicated train, which returns to SRS, for reuse. In the handling cell, the VW-MPC is assembled with its emplacement overpack. The emplacement overpack is seal-welded closed and the VW-MPC/emplacement overpack assembly (or waste package; see Figure 6-1) is placed on a shielded transporter for movement into and emplacement in the repository. All operations in the VW-MPC handling cell and repository are performed remotely because of the lack of shielding provided by the VW-MPC and emplacement overpack.

DU-Shielded HLW Management System

As described in Section 6.3 and illustrated in Figure 6-3, the vitrified waste canisters are moved from the DWPF directly into the canister handling facility and are loaded into a DU-shielded cask at the same rate as they are produced. Four DU-shielded system configurations are considered for SRS in this study. They include the one-, four-, and seven-canister storage/disposal plus transport (S/D+T) configurations and a seven-canister storage/transport/disposal (S/T/D) configuration. The S/D+T system entails a reusable transportation overpack and impact limiter assembly where the S/T/D system includes an integral transport/disposal system with reusable impact limiters. When a cask is fully loaded, the cover is put in place and seal-welded closed. Once the cover is in place, the loaded cask is fully shielded by the DU liner and can be contact-handled. Thus, the GWSB is no longer needed for radiation protection during canister storage, and the loaded DU-shielded cask (storage unit) can be stored on an outdoor concrete pad.

The loaded one-, four-, and seven-canister casks (storage units) are moved from the canister handling facility over a paved road to a temporary storage site within 2 miles of the DWPF. With the exception of the one-canister cask that can be truck transported, a special heavy hauler is required for this transport. This interim storage site consists of a fenced, lighted concrete pad. The storage site sizes required for the one-, four-, and seven-canister configurations are approximately 35, 20, and 10 acres, respectively.

When the repository begins accepting defense HLW, the loaded S/D+T casks (storage units) are moved by heavy hauler back to the canister handling facility. At the canister handling facility, each cask will be assembled with its transportation overpack and then loaded onto a railcar for shipment to the repository. Since the S/T/D configuration does not require a transportation overpack, it is returned by heavy hauler to the canister handling facility where it is assembled with transportation impact limiters and then loaded onto a railcar for shipment to the repository.

At the repository, the S/D+T transport packages are offloaded at the waste package preparation facility. The DU-shielded casks are removed from their transportation overpacks, which are reloaded on the dedicated train for return and reuse at SRS. The S/D+T cask is then assembled with its emplacement overpack and the waste package (refer to Figure 6-3) is moved into the repository for emplacement.

For the S/T/D configuration, the S/T/D transport packages are offloaded from the train at the waste package preparation facility. The impact limiters are removed and reloaded on the train for return and reuse at SRS. The S/T/D cask is assembled with its emplacement overpack and the waste package is moved into the repository for emplacement. Since the S/D+T and S/T/D casks are fully shielded, remote handling is not required for any repository operations.

Cost Evaluation

Four major system elements (described in Section 6.4 of this report) are associated with the disposal of HLW. These system elements and their associated cost items are listed below as they apply to SRS HLW disposal.

- Waste site costs
 - Preparations for waste acceptance
 - Interim storage
- Waste acceptance costs
 - Welding equipment
 - Canister handling facility
- Transportation costs
 - Overpack fleet
 - Overpack maintenance
 - Shipping
- Repository costs
 - Waste packages (which include VW-MPCs, S/D+T and S/T/D casks, and emplacement overpacks)

A summary of these cost items as they apply to SRS waste disposal is provided in Table D-2 for each of the system configurations considered.

Table D-2. Savannah River Site Aggregated Total Disposal Costs
(millions of 1993 dollars)

System Element/Cost Item	Element/Item Cost (M\$)				
	Reference	DU-Shielded System Configuration			
	Case	1	2	3	4
	4-cn VW-MPC	4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T
Waste Acceptance					
Welding equipment	0.6	0.6	0.6	0.6	0.6
Canister handling facility	7.6	7.6	7.6	7.6	7.6
Transportation					
Overpacks	24.0	6.6	4.2	0.0	8.5
Overpack maintenance	1.8	1.8	1.8	0.0	1.8
Impact limiters (S/T/D)	0.0	0.0	0.0	1.9	0.0
Shipping	85.4	83.0	47.9	47.5	327.6
Repository					
Waste Packages					
VW-MPC (reference case)	264.7				
Stainless-steel DU-shielded cask		952.2	814.2	1,135.9	1,145.9
Emplacement overpacks	238.6	238.6	136.3	136.3	372.2
Waste Site					
Preparation for waste acceptance	5.7	11.4	6.5	3.3	45.6
Interim storage	345.8	25.7	17.9	17.9	36.8
SRS Total					
Non-DU-shielded reference case	975.5				
Stainless-steel DU-shielded system		1,328.8	1,038.3	1,347.8	1,946.6
Total DU disposal (kg x 1,000,000)	N/A	31.5	27.5	32.4	38.5
Min. DU disposal credit (LLW @ \$9.50/kg) ^a		299.3	261.3	307.8	365.8
Max. DU disposal credit (RCRA @ \$30.19/kg) ^a		951.0	830.2	978.2	1,162.3
SRS Net Cost	975.5				
Stainless-steel DU-shielded system					
Maximum cost ^b		1,029.5	777.0	1,040.0	1,580.6
Minimum cost ^c		377.8	208.1	369.6	784.3

^aDOE, 1995.

^bMaximum net SRS cost = (SRS total cost) - (min. DU disposal credit).

^cMinimum net SRS cost = (SRS total cost) - (max. DU disposal credit).

D.2 ABBREVIATED CASE STUDY FOR HANFORD

The Hanford site is scheduled to begin vitrified waste production in the year 2000 and will complete vitrification of 9,860 waste canisters in the year 2030 (DOE, 1990). The geologic repository will begin accepting defense HLW in the year 2015 at the rate of 800 canisters per year (DOE, 1989). For this cost study, the total repository acceptance rate will be equally split between SRS and Hanford until the year 2028 when all of the SRS waste will have been shipped. At this time, the Hanford shipping rate will jump to the 800-canister repository acceptance rate.

The assumption is also made for this study that all 300 canisters of West Valley HLW will be shipped to the repository the first year and the 500-canister balance will be equally divided between Hanford and SRS. Note that this is an exception to the TSLCC assumption that West Valley waste will be shipped after all of the defense HLW has been accepted by the repository. It does not appear sensible to store the 300 canisters of West Valley HLW for an additional 29 years while the defense HLW is being shipped at 800 canisters per year. In any case, about half (4,815) of the Hanford waste canisters must be temporarily stored for 16 years until the repository is ready to start accepting defense HLW. With the exception of the year 2015, the acceptance rate at the repository will exceed the Hanford canister production rate. The year 2015 is an exception because of the assumption that all 300 canisters of West Valley HLW will be shipped that year. The projected Hanford canister production/shipment schedule is provided in Table D-3.

Two approaches are developed for storing, transporting, and disposing of the 9,860 waste canisters produced at Hanford. These approaches include a variation of the CRWMS multi-purpose canister concept (CRWMS, 1993a; EPRI, 1993) that will be referred to as the non-DU-shielded HLW management system reference case (described in Section 6.2 of this report). The second approach, called the DU-shielded HLW management system, uses a DU-shielded cask (as described in Section 6.3 of this report).

Non-DU-Shielded HLW Management System Reference Case

As described in Section 6.2 and illustrated in Figure 6-1, 9,860 waste canisters are produced in the DWPF and dry stored in two GWSBs (WSRC, 1991) that together are assumed to have sufficient capacity for all of the canisters produced at Hanford, realizing that storage capacity is only needed for 4,815 canisters. The highly radioactive canisters are handled remotely by a robotic SCT, i.e., moved from the DWPF to the GWSB and from the GWSB to the canister handling facility as required.

When the repository is ready to accept defense HLW, the waste canisters are moved from the GWSB to the canister handling facility where they are loaded into the four-canister VW-MPC. In preparation for canister loading, the VW-MPC has been preassembled with its transportation overpack. The transportation overpack is a reusable shielded package for rail shipment of waste canisters to the repository. When the assembly of four waste canisters is complete, the

Table D-3. Projected Hanford Site Canister Production/Shipment Schedule

Year	Annual		Cumulative Total	Cumulative Store	Cumulative	Cumulative	Cumulative	Cumulative
	Create	Ship			4-cn System Store	4-cn System Ship	7-cn System Store	7-cn System Ship
1993		0	0	0	0	0	0	0
1994		0	0	0	0	0	0	0
1995		0	0	0	0	0	0	0
1996		0	0	0	0	0	0	0
1997		0	0	0	0	0	0	0
1998		0	0	0	0	0	0	0
1999		0	0	0	0	0	0	0
2000	290	0	290	290	73	0	42	0
2001	290	0	580	580	145	0	83	0
2002	320	0	900	900	225	0	129	0
2003	320	0	1,220	1,220	305	0	175	0
2004	320	0	1,540	1,540	385	0	220	0
2005	320	0	1,860	1,860	465	0	266	0
2006	320	0	2,180	2,180	545	0	312	0
2007	320	0	2,500	2,500	625	0	358	0
2008	320	0	2,820	2,820	705	0	403	0
2009	320	0	3,140	3,140	785	0	449	0
2010	320	0	3,460	3,460	865	0	495	0
2011	320	0	3,780	3,780	945	0	540	0
2012	320	0	4,100	4,100	1,025	0	586	0
2013	320	0	4,420	4,420	1,105	0	632	0
2014	320	0	4,740	4,740	1,185	0	678	0
2015	320	245	4,815	4,815	1,204	62	688	35
2016	320	399	4,736	4,736	1,184	162	677	92
2017	320	399	4,657	4,657	1,165	262	666	149
2018	320	399	4,578	4,578	1,145	362	654	206
2019	320	399	4,499	4,499	1,125	462	643	263
2020	320	399	4,420	4,420	1,105	562	632	320
2021	320	399	4,341	4,341	1,086	662	621	377
2022	320	399	4,262	4,262	1,066	762	609	434
2023	320	399	4,183	4,183	1,046	862	598	491
2024	320	399	4,104	4,104	1,026	962	587	548
2025	320	399	4,025	4,025	1,007	1,062	575	605
2026	320	399	3,946	3,946	987	1,162	564	662
2027	320	399	3,867	3,867	967	1,262	553	719
2028	320	595	3,592	3,592	898	1,411	514	804
2029	320	798	3,114	3,114	779	1,611	445	918
2030	320	798	2,636	2,636	659	1,811	377	1,032
2031		798	1,838	1,838	460	2,011	263	1,146
2032		798	1,040	1,040	260	2,211	149	1,260
2033		798	242	242	61	2,411	35	1,374
2034		242	0	0	0	2,472	0	1,409
2035			0	0	0	0	0	0
2036			0	0	0	0	0	0
2037			0	0	0	0	0	0
2038			0	0	0	0	0	0

VW-MPC cover is put in place and seal-welded closed. The transportation overpack cover is then bolted in place and the VW-MPC transport package is loaded onto a railcar for shipment to the repository. The VW-MPC transport package is fully shielded and can be contact-handled.

At the repository, the VW-MPC transport packages are offloaded at the waste package preparation facility and moved into the VW-MPC remote handling cell. In the handling cell, the VW-MPC is disassembled from the transportation overpack in reverse order of loading. The empty overpack is reloaded on the dedicated train, which returns to Hanford, for reuse. In the handling cell, the VW-MPC is assembled with its emplacement overpack. The emplacement overpack is seal-welded closed and the waste package is placed on a shielded transporter for movement into and emplacement in the repository (refer to Figure 6-1). All operations in the VW-MPC handling cell and repository are performed remotely because of the lack of shielding provided by the VW-MPC and emplacement overpack.

DU-Shielded HLW Management System

As described in Section 6.3 and illustrated in Figure 6-3, the HLW canisters are moved from the DWPF directly into the canister handling facility and are loaded into a DU-shielded cask at the same rate as they are produced. Four DU-shielded system configurations are considered for Hanford in this study. They include the one- and four-canister S/D+T configurations and both of the S/D+T and S/T/D seven-canister configurations. When a cask is fully loaded, the cover is put in place and seal-welded closed. Once the cover is in place, the loaded cask is fully shielded by the DU liner and can be contact-handled. Thus, the GWSB is no longer needed for radiation protection during canister storage, and the loaded DU-shielded casks (storage units) can be stored on an outdoor concrete pad.

The loaded one-, four-, and seven-canister casks (storage units) are moved from the canister handling facility over a paved road to an interim storage site within 2 miles of the DWPF. With the exception of the one-canister cask that can be truck transported, a special heavy hauler is required for this transport. This interim storage site consists of a fenced, lighted concrete pad. The storage site sizes required for the one-, four-, and seven-canister configurations are approximately 66, 38, and 18 acres, respectively.

When the repository begins accepting defense HLW, the loaded S/D+T casks (storage units) are moved by heavy hauler back to the canister handling facility. There, each cask will be assembled with its transportation overpack and then loaded onto a railcar for shipment to the repository. Since the S/T/D configuration does not require a transportation overpack, it is returned by heavy hauler to the canister handling facility where it is assembled with transportation impact limiters and then loaded onto a railcar for shipment to the repository.

At the repository, the S/D+T transport packages are offloaded at the waste package preparation facility. The DU-shielded casks are removed from their transportation overpacks, which are reloaded on the dedicated train for return and reuse at Hanford. The S/D+T cask is assembled with its emplacement overpack and the waste package is moved into the repository for emplacement (refer to Figure 6-3). For the S/T/D configuration, the S/T/D transport packages

are offloaded from the train. The impact limiters are removed and reloaded on the train for return and reuse at Hanford. The S/T/D cask is assembled with its emplacement overpack and the waste package is moved into the repository for emplacement. Since the S/D+T and S/T/D casks are fully shielded, remote handling is not required for any repository operations.

Cost Evaluation

Four major system elements (described in Section 6.4 of this report) are associated with the disposal of HLW. These system elements and their associated cost items are listed below as they apply to Hanford site HLW disposal.

- Waste site costs
 - Preparations for waste acceptance
 - Interim storage
- Waste acceptance costs
 - Welding equipment
 - Canister handling facility
- Transportation costs
 - Overpack fleet
 - Overpack maintenance
 - Shipping
- Repository costs
 - Waste packages (which include VW-MPCs, S/D+T and S/T/D casks, and emplacement overpacks)

A summary of these cost items as they apply to Hanford waste disposal is provided in Table D-4 for each of the system configurations considered.

Table D-4. Hanford Aggregated Total Disposal Costs (millions of 1993 dollars)

System Element/Cost Item	Element/Item Cost (M\$)				
	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration			
		1	2	3	4
		4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T
Waste Acceptance					
Welding equipment	0.6	0.6	0.6	0.6	0.6
Canister handling facility	7.6	7.6	7.6	7.6	7.6
Transportation					
Overpacks	24.0	6.6	4.2	0.0	8.5
Overpack maintenance	1.8	1.8	1.8	0.0	1.8
Impact limiters (S/T/D)	0.0	0.0	0.0	1.9	0.0
Shipping	80.6	77.9	45.2	44.7	305.4
Repository					
Waste Packages					
VW-MPC (reference case)	500.1				
Stainless-steel DU-shielded cask		1,790.3	1,531.6	2,136.7	2,155.4
Emplacement overpacks	448.6	448.6	256.4	256.4	700.1
Waste Site					
Preparation for waste acceptance	10.7	21.5	12.3	6.1	85.8
Interim storage	353.3	39.1	24.5	24.5	60.1
Hanford Total					
Non-DU-shielded reference case	1,424.9				
Stainless-steel DU-shielded system		2,394.0	1,884.2	2,478.5	3,325.3
Total DU disposal (kg x 1,000,000)	N/A	59.2	51.8	60.9	72.4
Minimum DU disposal credit (LLW @ \$9.50/kg) ^a		562.4	491.2	578.6	687.8
Maximum DU disposal credit (RCRA @ \$30.19/kg) ^a		1,787.2	1,563.8	1,838.6	2,185.8
Hanford Net Cost	1,424.9				
Stainless-steel DU-shielded system					
Maximum cost ^b		1,831.6	1,392.1	1,899.9	2,637.5
Minimum cost ^c		606.8	320.4	636.9	1,139.5

^aDOE, 1995.

^bMaximum net Hanford cost = (Hanford total cost) - (min. DU disposal credit).

^cMinimum net Hanford cost = (Hanford total cost) - (max. DU disposal credit).

D.3 ABBREVIATED CASE STUDY FOR WEST VALLEY

The West Valley site is scheduled to begin vitrified waste production in 1996 and will complete vitrification of 300 waste canisters in 1998 (DOE, 1990). The geologic repository will begin accepting defense HLW in the year 2015 at the rate of 800 canisters per year (DOE, 1989). For this cost study, the assumption is made that all 300 West Valley canisters will be shipped to the repository the first year that it accepts HLW. The 500-canister balance for the year 2015 will be equally split between SRS and Hanford. Note that this is an exception to the TSLCC assumption that West Valley waste will be shipped after all of the defense HLW has been accepted by the repository. It does not appear sensible to store the 300 canisters of West Valley HLW for an additional 29 years while the defense HLW is being shipped at 800 canisters per year. In any case, the West Valley waste canisters must be temporarily stored for 19 years until the repository is ready to start accepting defense HLW. The projected West Valley canister production/shipment schedule is provided in Table D-5.

Two approaches are developed for storing, transporting, and disposing of the 300 waste canisters produced at West Valley. These approaches include a variation of the CRWMS multi-purpose canister concept (CRWMS, 1993a; EPRI, 1993) that will be referred to as the non-DU-shielded HLW management system reference case (described in Section 6.2 of this report). The second approach, called the DU-shielded HLW management system, uses a DU-shielded cask (as described in Section 6.3 of this report).

Non-DU-Shielded HLW Management System Reference Case

As described in Section 6.2 and illustrated in Figure 6-1, 300 waste canisters are produced in the DWPF and dry stored in a GWSB (WSRC, 1991). The highly radioactive canisters are handled remotely by a robotic SCT, i.e., moved from the DWPF to the GWSB and from the GWSB to the canister handling facility as required.

When the repository is ready to accept HLW, the waste canisters are moved from the GWSB to the canister handling facility where they are loaded into the four-canister VW-MPC. In preparation for canister loading, the VW-MPC has been preassembled with its transportation overpack. The transportation overpack is a reusable shielded package for rail shipment of waste canisters to the repository. When the assembly of four waste canisters is complete, the VW-MPC cover is put in place and seal-welded closed. The transportation overpack cover is then bolted in place and the VW-MPC transport package is loaded onto a railcar for shipment to the repository. The VW-MPC transport package is fully shielded and can be contact-handled.

At the repository, the VW-MPC transport packages are offloaded at the waste package preparation facility and moved into the VW-MPC remote handling cell. In the handling cell, the VW-MPC is disassembled from the transportation overpack in reverse order of loading. The empty overpack is reloaded on the dedicated train, which returns to West Valley, for reuse. In the handling cell, the VW-MPC is assembled with its emplacement overpack. The emplacement

Table D-5. Projected West Valley Canister Production/Shipment Schedule

Year	Annual		Cumulative Total	Cumulative Store	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative
	Create	Ship			1-cn	1-cn	4-cn	4-cn	7-cn	7-cn
					System Store	System Ship	System Store	System Ship	System Store	System Ship
1993		0	0	0	0	0	0	0	0	0
1994		0	0	0	0	0	0	0	0	0
1995		0	0	0	0	0	0	0	0	0
1996	100	0	100	100	100	0	25	0	15	0
1997	100	0	200	200	200	0	50	0	29	0
1998	100	0	300	300	300	0	75	0	43	0
1999		0	300	300	300	0	75	0	43	0
2000		0	300	300	300	0	75	0	43	0
2001		0	300	300	300	0	75	0	43	0
2002		0	300	300	300	0	75	0	43	0
2003		0	300	300	300	0	75	0	43	0
2004		0	300	300	300	0	75	0	43	0
2005		0	300	300	300	0	75	0	43	0
2006		0	300	300	300	0	75	0	43	0
2007		0	300	300	300	0	75	0	43	0
2008		0	300	300	300	0	75	0	43	0
2009		0	300	300	300	0	75	0	43	0
2010		0	300	300	300	0	75	0	43	0
2011		0	300	300	300	0	75	0	43	0
2012		0	300	300	300	0	75	0	43	0
2013		0	300	300	300	0	75	0	43	0
2014		0	300	300	300	0	75	0	43	0
2015	300		0	0	0	300	0	75	0	43
2016										
2017										
2018										
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overpack is seal-welded closed and the waste package is placed on a shielded transporter for movement into and emplacement in the repository (refer to Figure 6-1). All operations in the VW-MPC handling cell and repository are performed remotely because of the lack of shielding provided by the VW-MPC and emplacement overpack.

DU-Shielded HLW Management System

Four DU-shielded system configurations and both truck and rail transport are considered for West Valley waste disposal in this study. The rail transport configurations include the one- and four-canister S/D+T configurations and both of the S/D+T and S/T/D seven-canister configurations. For the truck transport option, the single-canister S/D+T configuration is used because the larger capacity casks exceed the truck load capacity of 25 tons.

As described in Section 6.3 and illustrated in Figure 6-3, the HLW canisters are moved from the DWPF directly into the canister handling facility and are loaded into a DU-shielded cask at the same rate as they are produced. When a cask is fully loaded, the cover is put in place and seal-welded closed. Once the cover is in place, the loaded cask is fully shielded by the DU liner and can be contact-handled. Thus, the GWSB is no longer needed for radiation protection during canister storage, and the loaded DU-shielded casks (storage units) can be stored on an outdoor concrete pad.

The loaded one-, four-, and seven-canister casks (storage units) are moved from the canister handling facility over a paved road to an interim storage site within 2 miles of the DWPF. The single-canister configuration can be truck transported to and from the storage pad; however, the four- and seven-canister configurations require a special heavy hauler for transport. This interim storage site consists of a fenced, lighted concrete pad. The storage site sizes required for the one-, four- and seven-canister configurations are approximately 2.0, 1.2, and 0.6 acres, respectively.

When the repository begins accepting defense HLW, the loaded S/D+T casks (storage units) are moved by heavy hauler back to the canister handling facility. At the canister handling facility, each cask will be assembled with its transportation overpack. The one-, four-, and seven-canister S/D+T casks are then loaded onto a railcar for shipment to the repository. To explore costs, the single-canister S/D+T cask is shipped by both rail and truck to the repository. Since the seven-canister S/T/D configuration does not require a transportation overpack, it is returned by heavy hauler to the canister handling facility where it is assembled with transportation impact limiters and then loaded onto a railcar for shipment to the repository.

At the repository, the S/D+T transport package are offloaded at the waste package preparation facility. The DU-shielded casks are removed from their transportation overpacks which are reloaded on the dedicated train or truck for return and reuse at West Valley. The S/D+T cask is assembled with its emplacement overpack and the waste package is moved into the repository for emplacement (refer to Figure 6-3). For the S/T/D configuration, the S/T/D transport packages are offloaded from the train at the waste package preparation facility. The impact limiters are removed and reloaded on the train for return and reuse at West Valley. The S/T/D cask is

assembled with its emplacement overpack and the waste package is moved into the repository for emplacement. Since the S/D+T and S/T/D casks are fully shielded, remote handling is not required for any repository operations.

Cost Evaluation

Four major system elements (described in Section 6.4 of this report) are associated with the disposal of HLW. These system elements and their associated cost items are listed below as they apply to West Valley site HLW disposal.

- Waste site costs
 - Preparations for waste acceptance
 - Interim storage
- Waste acceptance costs
 - Welding equipment
 - Canister handling facility
- Transportation costs
 - Overpack fleet
 - Overpack maintenance
 - Shipping
- Repository costs
 - Waste packages (which include VW-MPCs, S/D+T and S/T/D casks, and emplacement overpacks)

A summary of these cost items as they apply to West Valley waste disposal is provided in Table D-6 for each of the system configurations considered.

Table D-6. West Valley Aggregated Total Disposal Costs
(millions of 1993 dollars)

System Element/Cost Item	Element/Item Cost (M\$)					
	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration				
		1	2	3	4	
		4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T Train	Truck
Waste Acceptance						
Welding equipment	0.6	0.6	0.6	0.6	0.6	0.6
Canister handling facility	7.6	7.6	7.6	7.6	7.6	7.6
Transportation						
Overpacks	24.0	6.6	4.1	0.0	8.5	2.8
Overpack maintenance	1.8	1.8	1.8	0.0	0.1	0.8
Impact limiters	0.0	0.0	0.0	1.9	0.0	0.0
Shipping	4.5	4.3	2.5	2.5	17.0	10.9
Repository						
Waste Packages						
VW-MPC (reference case)	15.2					
Stainless-steel DU-shielded cask		54.5	46.8	65.3	65.6	65.6
Emplacement overpacks	13.7	13.7	7.8	7.8	21.3	21.3
Waste Site						
Preparation for waste acceptance	0.3	0.7	0.4	0.2	2.6	2.6
Interim storage	19.8	4.6	4.1	4.1	5.2	5.2
West Valley Total Cost						
Non-DU-shielded reference case	87.5					
Stainless-steel DU-shielded system		94.4	75.7	90.0	128.5	117.4
Total DU disposal (kg x 1,000,000)	N/A	1.80	1.57	1.86	2.20	2.20
Minimum DU disposal credit (LLW @ \$9.50/kg) ^a		17.1	14.9	17.7	20.9	20.9
Maximum DU disposal credit (RCRA @ \$30.19/kg) ^a		54.3	47.7	56.2	66.4	66.4
West Valley Net Cost	87.5					
Stainless-steel DU-shielded system						
Maximum cost ^b		77.3	60.8	72.3	107.6	96.5
Minimum cost ^c		40.1	28.0	33.8	62.1	51.0

^aDOE, 1995.

^bMaximum net West Valley cost = (West Valley total cost) - (min. DU disposal credit).

^cMinimum net West Valley cost = (West Valley total cost) - (max. DU disposal credit).

D.4 SYSTEM COST ANALYSIS

D.4.1 Waste Acceptance Costs

Welding Equipment. Each of the HLW sites will require one piece of automated welding equipment to seal the VW-MPC and the DU-shielded S/D+T and S/T/D casks. This equipment is expected to be equivalent to that proposed for sealing the CRWMS 125-ton MPC. An estimated cost of \$500K per machine and a decommissioning cost of \$100K each (20% of capital) were used to calculate the welding equipment costs.

Canister Handling Facility. Each of the HLW sites will require a canister handling facility to load vitrified waste canisters into the VW-MPCs and DU-shielded casks. The size, weight, and sealing/bolting and handling requirements for all the defense HLW system configurations appear to be equivalent to those described for the CRWMS 125-ton MPC. As a result, the facility capital and decommissioning costs of \$6.0M and \$1.5M, respectively, are used for the canister handling facility costs.

Table D-7 shows a summary of waste acceptance charges. The 1992 costs above have been escalated by 1.2% for 1993.

Table D-7. Waste Acceptance Costs (millions of 1993 dollars)

Cost Item	Item Cost (M\$)					
	Reference Case 4-cn VW-MPC	DU-Shielded System Configuration				
		1	2	3	4	
		4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T all sites	WV truck
Welding equipment	1.8	1.8	1.8	1.8	1.8	0.6
Canister handling equipment	22.8	22.8	22.8	22.8	22.8	7.6
Total Waste Acceptance Cost	24.6	24.6	24.6	24.6	24.6	8.2

Non-DU-Shielded Reference Case and DU-Shielded System Configurations 1, 2, 3, and 4 for All Sites

Welding Equipment

- $(\$500\text{K}/\text{machine}) \times (1.012) = \$506\text{K}/\text{machine}$
- Each HLW site requires one machine
 $\Rightarrow 3 \text{ sites} \times \$0.506\text{M} = \$1.518\text{M}$
- Decommissioning rate (@ 20% of capital)
 $\Rightarrow 3 \text{ sites} \times \$0.1012\text{M} = \$0.3036\text{M}$
 $\$1.8216\text{M}$

Canister Handling Facility

- Each HLW site requires one canister handling facility
- Facility capital of $(\$6.0M) \times (1.012) = \$6.072M$
 $\Rightarrow 3 \text{ sites} \times \$6.072M = \$18.216M$
- Decommissioning cost of $(\$1.5M) \times (1.012) = \$1.518M$
 $\Rightarrow 3 \text{ sites} \times \$1.518M = \underline{\$4.554M}$
 $\$22.77M$

DU-Shielded System Configuration 4 for the West Valley Site

Welding Equipment

- $(\$500K/\text{machine}) \times (1.012) = \$506K/\text{machine}$
- Each HLW site requires one machine
 $\Rightarrow 1 \text{ site} \times \$0.506M = \$0.506M$
- Decommissioning rate (@ 20% of capital)
 $\Rightarrow 1 \text{ site} \times \$0.1012M = \underline{\$0.1012M}$
 $\$0.6072M$

Canister Handling Facility

- Each HLW site requires one canister handling facility
- Facility capital of $(\$6.0M) \times (1.012) = \$6.072M$
 $\Rightarrow 1 \text{ site} \times \$6.072M = \$6.072M$
- Decommissioning cost of $(\$1.5M) \times (1.012) = \$1.518M$
 $\Rightarrow 1 \text{ site} \times \$1.518M = \underline{\$1.518M}$
 $\$7.59M$

D.4.2 Transportation Costs

Overpack Fleet. Transportation overpack fleet calculation for the non-DU-shielded reference case and the various DU-shielded system configurations were derived using the transportation models and algorithms in the CRWMP TSLCC and cost estimating methods document (DOE, 1989; Roy F. Weston, Inc., 1989). One-way rail and truck distance miles were provided by Roy F. Weston, Inc. from the Transportation System Data Base. The overpack fleet calculation mentioned above only applies to the VW-MPC reference case and the DU-shielded S/D+T configurations.

Overpack Maintenance. The CRWMP TSLCC has estimated yearly defense HLW package maintenance costs at \$90,000 based on the total number of package miles required to ship defense wastes to the repository. Because the actual maintenance requirements have not been developed, a \$93,000 per-year-estimate (an escalated cost of \$90,000 at 3.2%) will be used as a

first-order approximation for the VW-MPC reference case and DU-shielded S/D+T configurations.

Impact Limiter Fleet. Impact limiter fleet calculation was derived for the DU-shielded S/T/D configurations because the impact limiters are removed from the S/T/D cask at the repository and returned to the waste site for reuse.

Shipping. The shipping calculation was derived using the transportation models and algorithms in the CRWMP TSLCC and cost estimating methods document (DOE, 1989; Roy F. Weston, Inc., 1989). The shipping costs include security and inspection charges as well as the actual shipping charges. Table D-8 shows a summary of transportation costs.

Table D-8. Transportation Costs (millions of 1993 dollars)

Cost Item	Item Cost (M\$)					
	Reference	DU-Shielded System Configuration				
	Case	1	2	3	4	
	4-cn VW-MPC	4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T all sites	WV truck
Overpack Fleet						
VW-MPC reference case	72					
S/D+T		20	12		25	3
Overpack Maintenance						
VW-MPC reference case	2					
S/D+T		2	2		2	0.1
Impact limiter fleet (S/T/D)				6		
Shipping	171	165	96	95	650	11
Total Transportation Cost	245	187	110	101	677	14

Transportation Overpack Fleet Calculation

Cost of the transportation overpack fleet was calculated first by determining the total quantity of transportation overpacks required to support a given shipment rate at each waste site. It was assumed that the shipment would occur at the rate of 400 canisters each year from both SRS and Hanford beginning in the year 2015. The shipment rate for West Valley was assumed to be 300 canisters per year. Table D-9 shows a summary of transportation overpack fleet calculation.

Table D-9. Transportation Overpack Fleet

Waste Management System	Cask Capacity				Overpack Quantity			
	1	3	4	7	Savannah River Site	Hanford	West Valley ^a	Total
Reference case VW-MPC			X		10	10	10	30
DU-Shielded								
1-cn S/D+T	X				30	30	30	90
3-cn S/D+T		X			10	10	10	30
4-cn S/D+T			X		10	10	10	30
7-cn S/D+T				X	5	5	5	15

^aValues in the table are for train transport. Quantity for 1-canister S/D+T truck transport is 10.

Non-DU-Shielded Reference Case and DU-Shielded Configurations 1, 2, 3, and 4 for Savannah River and Hanford Sites

- Shipment rate for SRS and Hanford = 400 canisters/yr
- Number of dedicated trains required to support 400-canisters/yr rate
 - = 6 for 1-canister system
 - = 2 for 3- and 4-canister system
 - = 1 for 7-canister system
- Number of transportation overpacks required
 - = (# of trains) x (5) = 30 for 1-canister system
 - = 10 for 3- and 4-canister system
 - = 5 for 7-canister system

Non-DU-Shielded Reference Case and DU-Shielded Configurations 1, 2, 3, and 4 for the West Valley Site

- Shipment rate for West Valley = 300 canisters/yr
- Number of dedicated trains required to support 300-canisters/yr rate
 - = 6 for 1-canister system
 - = 2 for 3- and 4-canister systems
 - = 1 for 7-canister system
- Number of transportation overpacks required
 - = (# of trains) x (5) = 30 for 1-canister system
 - = 10 for 3- and 4- canister systems
 - = 5 for 7-canister system

Transportation Overpack Fleet Cost Calculation

Once the required transportation overpack fleet size was determined, cost of the transportation overpack fleet was then calculated by multiplying the quantity by its capital cost and adding the

appropriate decommissioning cost. The decommissioning cost was assumed to be 20% of its capital cost. Table D-10 shows a summary of the transportation overpack fleet cost.

Table D-10. Cost of Transportation Overpack Fleet (1993 dollars)

Waste Management System	Quantity	x (Capital (K\$)	+ Decommissioning (K\$)	= Total Cost ^a (M\$)
Reference case VW-MPC	30	1,997.0	399.40	71.9
DU-Shielded				
1-cn S/D+T				
Rail, all sites	90	236.1	47.22	24.5
Rail, West Valley	30	236.1	47.22	8.5
Truck, West Valley	10	236.1	47.22	2.8
3-cn S/D+T	30	494.0	98.80	17.8
4-cn S/D+T	30	553.9	110.78	19.9
7-cn S/D+T	15	691.1	138.22	12.4

^aCost of transportation overpack fleet = (total quantity of transportation overpacks) x (capital cost + decommissioning cost).

Table D-11 shows a summary of transportation overpack capital costs (used in Table D-10).

Transportation Overpack Maintenance

Rail shipment, all sites

- TSLCC estimated cost for transportation overpack maintenance
= (\$90,000/yr) x (1.0312) = \$92,880/yr = \$93,000/yr
- Operating life (from the year 2015 to 2034) = 19 yr
- Transportation overpack maintenance cost = (\$93,000/yr) x (19 yr) = \$1.767M

Rail shipment, West Valley site

- Operating life (from the year 2015 to 2016) = 1 yr
- Transportation overpack maintenance cost = (\$93,000/yr) x (1 yr) = \$0.1M

Truck shipment, West Valley site

- Annual cost for individual overpack maintenance
(Roy F. Weston, Inc., 1989) (\$75,000/yr) x (1.0132) = \$75,990/yr = \$76,000/yr
- Number of overpacks = 10
- Operating life (from the year 2015 to 2016) = 1 yr
- Transportation overpack maintenance cost
= (\$76,000/yr) x 10 overpacks x (1 yr) = \$0.8M

**Table D-11. Transportation Overpack Capital Costs for the DU-Shielded
S/D+T Design (1993 dollars)**

Cask	Item	Item Weight (lbs)	Unit Cost (\$/lb)		Item Cost (\$)		Total Cost (\$)
			Matl.	Fab.	Matl.	Fab.	
1-cn S/D+T	S.S. Container	20,300	2.10	2.10	42,630	42,630	85,260
	Impact Limiter Honeycomb	1,900	38.00	17.00	72,200	32,300	104,500
	0.125 S.S. Cladding	1,170	2.60	3.40	3,042	3,978	7,020
						Subtotal	196,780
						QA @ 20%	39,356
						Total Cost	236,136
3-cn S/D+T	S.S. Container	46,500	2.10	2.10	97,650	97,650	195,300
	Impact Limiter Honeycomb	3,700	38.00	17.00	140,600	62,900	203,500
	0.125 S.S. Cladding	2,140	2.60	3.40	5,564	7,276	12,840
						Subtotal	411,640
						QA @ 20%	82,328
						Total Cost	493,968
4-cn S/D+T	S.S. Container	52,800	2.10	2.10	110,880	110,880	221,760
	Impact Limiter Honeycomb	4,100	38.00	17.00	155,800	69,700	225,500
	0.125 S.S. Cladding	2,382	2.60	3.40	6,193	8,099	14,292
						Subtotal	461,552
						QA @ 20%	92,310
						Total Cost	553,862
7-cn S/D+T	S.S. Container	70,200	2.10	2.10	147,420	147,420	294,840
	Impact Limiter Honeycomb	4,800	38.00	17.00	182,400	81,600	264,000
	0.125 S.S. Cladding	2,842	2.60	3.40	7,389	9,663	17,052
						Subtotal	575,892
						QA @ 20%	115,178
						Total Cost	691,070

Impact Limiter Fleet Calculation

The impact limiter fleet calculation was based on the total quantity of impact limiters required to support a given shipment rate at each waste site. It was assumed that shipment would occur at the rate of 400 canisters per year from both SRS and Hanford. The shipment rate for West Valley was assumed to be 300 canisters per year.

Impact Limiter Fleet Cost Calculation

Once the required impact limiter fleet was determined, cost of the impact limiter fleet was then calculated by multiplying the quantity by its capital cost and adding the appropriate decommissioning cost. The decommissioning cost was assumed to be 20% of its capital cost. Table D-12 shows a summary of the impact limiter fleet cost. Table D-13 shows a summary of impact limiter capital costs used in Table D-12.

Table D-12. Cost of Impact Limiter Fleet (S/T/D)

Waste Management System	Quantity	x (Capital + Decommissioning)		Total Cost ^a
		(K\$)	(K\$)	(M\$)
DU-Shielded				
1-cn S/T/D (West Valley)	30	123.2	24.6	4.4
3-cn S/T/D	30	212.5	42.5	7.7
4-cn S/T/D	30	293.4	58.7	10.6
7-cn S/T/D	15	324.0	64.8	5.8

^aCost of impact limiter fleet = (total quantity of impact limiters) x (capital cost + decommissioning cost).

Table D-13. Impact Limiter Capital Costs for the DU-Shielded S/T/D Design (1993 dollars)

Cask	Item	Item Weight (lbs)	Unit Cost (\$/lb)		Item Cost (\$)		Total Cost (\$)
			Matl.	Fab.	Matl.	Fab.	
1-cn S/T/D	Honeycomb	1,750	38.00	17.00	66,500	29,750	96,250
	0.125 S.S. Cladding	1,070	2.60	3.40	2,782	3,638	6,420
						Subtotal	102,670
						QA @ 20%	20,534
						Total Cost	123,204
3-cn S/T/D	Honeycomb	3,000	38.00	17.00	114,000	51,000	165,000
	0.125 S.S. Cladding	2,010	2.60	3.40	5,226	6,834	12,060
						Subtotal	177,060
						QA @ 20%	35,412
						Total Cost	212,472
4-cn S/T/D	Honeycomb	4,200	38.00	17.00	159,600	71,400	231,000
	0.125 S.S. Cladding	2,246	2.60	3.40	5,840	7,636	13,476
						Subtotal	244,476
						QA @ 20%	48,895
						Total Cost	293,371
7-cn S/T/D	Honeycomb	4,600	38.00	17.00	174,800	78,200	253,000
	0.125 S.S. Cladding	2,828	2.60	3.40	7,353	9,615	16,968
						Subtotal	269,968
						QA @ 20%	53,994
						Total Cost	323,962

Shipping Cost

Shipping costs were derived for each site using the transportation models and algorithms in the CRWMP TSLCC and cost estimating methods documents (DOE, 1989; Roy F. Weston, Inc., 1989). One-way rail and truck distance miles were provided by Roy F. Weston, Inc. from the Transportation System Data Base. Rail transportation by dedicated train was assumed for all of the HLW sites. However, truck transportation costs were calculated additionally for the single-canister DU-shielded cask (DU-shielded System Configuration #4) for the West Valley site. The one-way distance miles from the Transportation System Data Base used for this study are shown in Table D-14.

Table D-14. One-Way Distance

Site	Rail (miles)	Truck (miles)
Savannah River Site	2,792	N/A
Hanford	1,302	N/A
West Valley	2,554	2,553

Table D-15 shows the shipping cost summary. The 1988 shipping costs calculated in Table D-16 have been escalated by 3.2% for 1993.

Table D-15. Shipping Cost Summary (1993 dollars)

Transport Package Type	Savannah River Site (M\$)	Hanford (M\$)	West Valley (M\$)	Shipping Cost ^a (M\$)
VW-MPC reference case	85.4	80.6	4.5	170.5
DU-shielded system configuration				
#1: 4-cn S/D+T	83.0	77.9	4.3	165.2
#2: 7-cn S/D+T	47.9	45.2	2.5	95.6
#3: 7-cn S/T/D	47.5	44.7	2.5	94.7
#4: 1-cn S/D+T				
All sites	327.6	305.4	17.0	650.0
WV Truck			10.9	10.9

^aShipping cost = (transporting cost + security cost + inspection cost) x (# of trips required).

In order to calculate the shipping costs, a transportation cost summary table was tabulated (see Table D-16).

- Cask capacity = (# of canisters)/(transport package)
- Canisters per trip = 5 x (transport package capacity)
- Mileage cost = (transporting cost) + (security cost) + (inspection cost)
- Number of trips required = (total canisters at site)/(canister per trip)
- Total rail cost = (round trip cost) x (# trips required)
- Package miles = (# of transport packages to be shipped) x (distance from waste site to repository)
= (total # of canisters)/(transport package capacity) x (distance from waste site to repository)
- Cost per mile = (total rail cost)/(# of transport package miles)

D.4.3 Repository Costs

Waste Packages. The repository waste package is the unit emplaced in the repository. It is the assembly of the VW-MPC or DU-shielded cask and emplacement overpack. The number of casks and MPCs required for each configuration was calculated from the total number of HLW canisters to be emplaced from each HLW site and the capacity of the various configurations (i.e., one-, four-, and seven-canisters). The size of the HLW package fleet equals the number of emplacement overpacks, which is the same as the number of casks or MPCs.

Surface/Subsurface Facilities/Operations. For this study, the published CRWMP TSLCC costs are used as the first-order estimates for all the HLW management systems considered (DOE, 1989). Table D-17 shows a summary of the repository costs.

Waste Package Fleet Calculation

To calculate the cost of the waste package fleet, the number of waste packages required for each waste site was first calculated by determining the quantity of VW-MPCs and DU-shielded casks required for each site. A summary of this calculation is shown in Table D-18.

Table D-16. Rail Transportation Cost Summary

Site	Transport Package Type	Transport Package Capacity	Canisters per Trip	Total Canisters at Site	Mileage Cost (K\$)	Number of trips Required	Total Rail Cost (M\$)	Transport Package Miles (mi)	Cost per Mile (K\$/mi)
Savannah River Site	VW-MPC	4	20	5,242	314.7	262	82.5	3,658,916	22.5
	S/D+T	1	5	5,242	301.4	1,048	316.0	14,635,664	21.6
	S/D+T	3	15	5,242	305.6	349	106.8	4,878,555	21.9
	S/D+T	4	20	5,242	306.7	262	80.4	3,658,916	22.0
	S/D+T	7	35	5,242	310.0	150	46.4	2,090,809	22.2
	S/T/D	1	5	5,242	300.2	1,048	314.7	14,635,664	21.5
	S/T/D	3	15	5,242	303.2	349	106.0	4,878,555	21.7
	S/T/D	4	20	5,242	304.1	262	79.7	3,658,916	21.8
	S/T/D	7	35	5,242	307.2	150	46.0	2,090,809	22.0
Hanford	VW-MPC	4	20	9,860	158.4	493	78.1	3,209,430	24.3
	S/D+T	1	5	9,860	149.8	1,972	295.4	12,837,720	23.0
	S/D+T	3	15	9,860	152.5	657	100.2	4,279,240	23.4
	S/D+T	4	20	9,860	153.2	493	75.5	3,209,430	23.5
	S/D+T	7	35	9,860	155.4	282	43.8	1,833,960	23.9
	S/T/D	1	5	9,860	149.1	1,972	294.0	12,837,720	22.9
	S/T/D	3	15	9,860	151.0	657	99.3	4,279,240	23.2
	S/T/D	4	20	9,860	151.6	493	74.7	3,209,430	23.3
	S/T/D	7	35	9,860	153.6	282	43.3	1,833,960	23.6
West Valley	VW-MPC	4	20	300	290.0	15	4.4	191,550	23.0
	S/D+T	1	5	300	277.3	60	16.6	766,200	21.7
	S/D+T	3	15	300	281.3	20	5.6	255,400	21.9
	S/D+T	4	20	300	282.3	15	4.2	191,550	21.9
	S/D+T	7	35	300	285.5	9	2.4	109,457	21.9
	S/T/D	1	5	300	276.2	60	16.6	766,200	21.7
	S/T/D	3	15	300	279.1	20	5.6	255,400	21.9
	S/T/D	4	20	300	279.9	15	4.2	191,550	21.9
	S/T/D	7	35	300	282.9	9	2.4	109,457	21.9

Table D-17. Repository Costs (millions of 1993 dollars)

Cost Item	Reference Case 4-cn VW-MPC	Item Cost (M\$)				
		DU-Shielded System Configuration				
		1	2	3	4	
		4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T all sites	WV truck
Waste Package						
VW-MPC + emplacement overpack	1,482					
Stainless-steel DU-shielded cask + emplacement overpack		3,502	2,796	3,741	4,460	87
Incoloy DU-shielded cask		3,035	2,574	3,752	3,623	
Surface/subsurface facilities and operations ^a	1,373	1,373	1,373	1,373	1,373	
Total Repository Cost						
Non-DU-shielded reference case	2,855					
Stainless-steel DU-shielded system		4,875	4,169	5,114	5,833	87
Incoloy DU-shielded system		4,408	3,947	5,125	4,996	

^aTSLCC estimate: 1988 cost = 1,330. Escalating factor for 1993 = 3.2%, (DOE, 1993),
Therefore, 1993 cost = (1,330)(1.032) = 1,373.

Table D-18. VW-MPC and DU-Shielded Cask Fleet Requirements

VW-MPC/DU-Shielded Cask	Canister Capacity				Quantity Required			Total
	1	3	4	7	Savannah River Site	Hanford	West Valley	
VW-MPC			X		1,311	2,465	75	3,851
S/D+T Cask	X				5,242	9,860	300	15,402
S/D+T Cask		X			1,747	3,287	100	5,134
S/D+T Cask			X		1,311	2,465	75	3,851
S/D+T Cask				X	749	1,409	43	2,200

The capital costs used in Table D-19 are calculated using VW-MPC and DU-shielded cask data and cost summary tables (see Tables D-21, D-22, D-24, D-25, and D-26).

- Number of waste packages = total canisters at waste site/VW-MPC or DU-shielded cask capacity
- Total canister at SRS = 5242 canisters
HANF = 9860 canisters
WV = 300 canisters

- Number of waste packages = number of emplacement overpacks

Waste Package Fleet Cost Calculation

Once the required waste package fleet size was determined, the costs of the VW-MPC, DU-shielded cask, and emplacement overpack fleets were calculated by multiplying the quantity by its capital cost. The VW-MPC, DU-shielded casks, and emplacement overpack fleet costs are summarized in Table D-19.

Emplacement overpack capital costs used in Table D-19 were determined using the following cost data, escalated by 1.2%.

- Emplacement overpack cost for
1-canister DU-shielded cask = $(\$70K) \times (1.012) = \$70.84K$
- Emplacement overpack cost for all others
(VW-MPC, S/D+T, and S/T/D) = $(\$180K) \times (1.012) = \$182.16K$

The physical characteristics of the various DU-shielded cask designs are provided in Tables D-20 and D-23.

Table D-19. Cost of the Waste Package Fleet (1993 dollars)

Waste Package Item	Quantity	Capital ^a (K\$)	Total Cost ^b (M\$)
VW-MPC	3,851	202.9	781.4
VW-MPC emplacement overpack	3,851	182.0	700.9
(1) S/D+T stainless-steel cask	15,402	218.6	3,366.9
(1) S/D+T Incoloy cask	15,402	235.2	3,622.6
(1) S/T/D stainless-steel cask	15,402	287.6	4,429.6
(1) S/T/D Incoloy cask	15,402	321.9	4,957.9
(1) S/D+T emplacement overpack	15,402	71.0	1,093.5
(3) S/D+T stainless-steel cask	5,134	639.1	3,281.1
(3) S/D+T Incoloy cask	5,134	692.0	3,552.7
(3) S/T/D stainless-steel cask	5,134	843.7	4,331.6
(3) S/T/D Incoloy cask	5,134	947.9	4,866.5
(3) S/D+T emplacement overpack	5,134	182.0	934.4
(4) S/D+T stainless-steel cask	3,851	727.3	2,800.8
(4) S/D+T Incoloy cask	3,851	788.2	3,035.4
(4) S/T/D stainless-steel cask	3,851	966.7	3,722.8
(4) S/T/D Incoloy cask	3,851	1,086.1	4,182.6
(4) S/D+T emplacement overpack	3,851	182.0	700.9
(7) S/D+T stainless-steel cask	2,200	1,088.8	2,395.4
(7) S/D+T Incoloy cask	2,200	1,170.1	2,574.2
(7) S/T/D stainless-steel cask	2,200	1,518.3	3,340.3
(7) S/T/D Incoloy cask	2,200	1,705.6	3,752.3
(7) S/D+T emplacement cask	2,200	182.0	400.4

^aCapital cost includes prorated NRC package certification cost of \$3.0M for the one- and three-canister casks and \$4.0M for the four- and seven-canister casks.

^bCost of waste package item = (number of items) x (capital cost).

Table D-20. Depleted-Uranium-Shielded Cask (S/D+T) Data Summary

Cask	Cask Size (diameter x length in inches)	Cask Weight Loaded (lb)	Cask Weight Empty (lb)	DU Weight lb (kg)	Vit. Waste Can. Weight (lb)	DU Disposal Credit (K\$)	
						Min. @\$9.50/kg	Max. @\$30.19/kg
1-cn S/D+T	31.5 x 132.5	50,300	44,900	16,200 (7,347)	5,400	69.8	221.8
3-cn S/D+T	64.0 x 132.5	133,600	117,400	46,700 (21,179)	16,200	201.3	639.3
4-cn S/D+T	70.5 x 132.5	155,100	133,500	53,000 (24,036)	21,600	228.4	725.6
7-cn S/D+T	86.5 x 133.0	225,300	187,500	81,000 (36,735)	37,800	349.1	1,108.9

**Table D-21. Depleted-Uranium-Shielded Stainless-Steel Cask (S/D+T)
Cost Summary (1993 dollars)**

Cask	Item	Item Wt. (lb)	Unit Cost ^a (\$/lb)		Item Cost (\$)		Subtotal Cost (\$)	QA @ 20% (\$)	Total Cost (\$)
			Matl.	Fab.	Matl.	Fab.			
1-cn	S.S. Cask	6,500	2.10	2.10	13,650	13,650	27,300	5,460	32,760
	DU Shielding	16,200	4.55	5.00	73,710	81,000	154,710	30,942	185,652
Total Cask Cost									218,412
3-cn	S.S. Cask	20,500	2.10	2.10	43,050	43,050	86,100	17,220	103,320
	DU Shielding	46,700	4.55	5.00	212,484	233,500	445,985	89,197	535,182
Total Cask Cost									638,502
4-cn	S.S. Cask	23,600	2.10	2.10	49,560	49,560	99,120	19,824	118,944
	DU Shielding	53,000	4.55	5.00	241,150	265,000	506,150	101,23	607,380
Total Cask Cost									726,324
7-cn	S.S. Cask	31,500	2.10	2.10	66,150	66,150	132,300	26,460	158,760
	DU Shielding	81,000	4.55	5.00	368,550	405,000	773,550	154,710	928,260
Total Cask Cost									1,087,020

^aUnit costs were derived from data in CRWMS, 1993b; DOE, 1995.

**Table D-22. Depleted-Uranium-Shielded Incoloy Cask (S/D+T)
Cost Summary (1993 dollars)**

Cask	Item	Item Wt. (lb)	Unit Cost ^a (\$/lb)		Item Cost (\$)		Subtotal Cost (\$)	QA @ 20% (\$)	Total Cost (\$)
			Matl.	Fab.	Matl.	Fab.			
1-cn	Inc. Cask	6,500	4.25	2.10	27,625	13,650	41,275	8,255	4,9530
	DU Shielding	16,200	4.55	5.00	73,710	81,000	154,710	30,942	185,652
Total Cask Cost									235,182
3-cn	Inc. Cask	20,500	4.25	2.10	87,125	43,050	130,175	26,035	156,210
	DU Shielding	46,700	4.55	5.00	212,484	233,500	445,985	89,197	535,182
Total Cask Cost									691,392
4-cn	Inc. Cask	23,600	4.25	2.10	100,300	49,560	149,860	29,972	179,832
	DU Shielding	53,000	4.55	5.00	241,150	265,000	506,150	101,230	607,380
Total Cask Cost									787,212
7-cn	Inc. Cask	31,500	4.25	2.10	133,875	66,150	200,025	40,005	240,030
	DU Shielding	81,000	4.55	5.00	368,550	405,000	773,550	154,710	928,260
Total Cask Cost									1,168,290

^aUnit costs were derived from data in CRWMS, 1993b; DOE, 1995.

Table D-23. Depleted-Uranium-Shielded Cask (S/T/D) Data Summary

Cask	Cask Size (diameter x length in inches)	Cask Weight Loaded (lb)	Cask Weight Empty (lb)	DU Weight lb (kg)	Vit. Waste Can. Weight (lb)	DU Disposal Credit (K\$)	
						Min. @\$9.50/kg	Max. @\$30.19/kg
1-cn S/T/D	41.5 x 140.5	40,600	35,200	18,500 (8,390)	5,400	79.7	267.6
3-cn S/T/D	76.3 x 142.3	118,200	102,000	53,600 (24,308)	16,200	230.9	775.4
4-cn S/T/D	83.4 x 142.3	139,700	118,100	61,000 (27,664)	21,600	262.8	882.5
7-cn S/T/D	102.0 x 144.0	221,900	184,100	95,300 (43,220)	37,800	410.6	1,378.7

Table D-24. Depleted-Uranium-Shielded Stainless-Steel Cask (S/T/D)
Cost Summary (1993 dollars)

Cask	Item	Item Wt. (lb)	Unit Cost ^a (\$/lb)		Item Cost (\$)		Subtotal Cost (\$)	QA @ 20% (\$)	Total Cost (\$)
			Matl.	Fab.	Matl.	Fab.			
1-cn	S.S. Cask	13,300	2.10	2.10	27,930	27,930	55,860	11,172	67,032
	S.S. Waste	1,650	2.10	2.10	3,465	3,465	6,930	1,386	8,316
	Container								
	DU Shielding	18,500	4.55	5.00	84,175	92,500	176,675	35,335	212,010
Total Cask Cost									287,358
3-cn	S.S. Cask	40,400	2.10	2.10	84,840	84,840	169,680	33,936	203,616
	S.S. Waste	5,000	2.10	2.10	10,500	10,500	21,000	4,200	25,200
	Container								
	DU Shielding	53,600	4.55	5.00	243,880	268,000	511,880	102,376	614,256
Total Cask Cost									843,072
4-cn	S.S. Cask	46,300	2.10	2.10	97,230	97,230	194,460	38,892	233,352
	S.S. Waste	6,600	2.10	2.10	13,860	13,860	27,720	5,544	33,264
	Container								
	DU Shielding	61,000	4.55	5.00	277,550	305,000	582,550	116,510	699,060
Total Cask Cost									965,676
7-cn	S.S. Cask	72,600	2.10	2.10	152,460	152,460	304,920	60,984	365,904
	S.S. Waste	11,600	2.10	2.10	24,360	24,360	48,720	9,744	58,464
	Container								
	DU Shielding	95,300	4.55	5.00	433,615	476,500	910,115	182,023	1,092,138
Total Cask Cost									1,516,506

^aUnit costs were derived from data in CRWMS, 1993b; DOE, 1995.

**Table D-25. Depleted-Uranium-Shielded Incoloy Cask (S/T/D)
Cost Summary (1993 dollars)**

Cask	Item	Item Wt. (lb)	Unit Cost ^a (\$/lb)		Item Cost (\$)		Subtotal Cost (\$)	QA @ 20% (\$)	Total Cost (\$)
			Matl.	Fab.	Matl.	Fab.			
1-cn	Inc. Cask	13,300	4.25	2.10	56,525	27,930	84,455	16,891	101,346
	S.S. Waste	1,650	2.10	2.10	3,465	3,465	6,930	1,386	8,316
	Container								
	DU Shielding	18,500	4.55	5.00	84,175	92,500	176,675	35,335	212,010
Total Cask Cost									321,672
3-cn	Inc. Cask	40,400	4.25	2.10	171,700	84,840	256,540	51,308	307,848
	S.S. Waste	5,000	2.10	2.10	10,500	10,500	21,000	4,200	25,200
	Container								
	DU Shielding	53,600	4.55	5.00	243,880	268,000	511,880	102,376	614,256
Total Cask Cost									947,304
4-cn	Inc. Cask	46,300	4.25	2.10	196,775	97,230	294,005	58,801	352,806
	S.S. Waste	6,600	2.10	2.10	13,860	13,860	27,720	5,544	33,264
	Container								
	DU Shielding	61,000	4.55	5.00	277,550	305,000	582,550	116,510	699,060
Total Cask Cost									1,085,130
7-cn	Inc. Cask	72,600	4.25	2.10	308,550	152,460	461,010	92,202	553,212
	S.S. Waste	11,600	2.10	2.10	24,360	24,360	48,720	9,744	58,464
	Container								
	DU Shielding	95,300	4.55	5.00	433,615	476,500	910,115	182,023	1,092,138
Total Cask Cost									1,703,814

^aUnit costs were derived from data in CRWMS, 1993b; DOE, 1995.

Table D-26. Four-Canister VW-MPC Cost Summary^a (1993 dollars)

VW-MPC Item	Item Weight (lb)	Unit Cost (\$/lb)		Matl. Cost (\$)	Fab. Cost (\$)	Subtotal Cost (\$)
		Matl.	Fab.			
S.S. Canister	16,434	2.12	2.48	34,840	40,756	75,596
S.S. Inner Basket	6,600	2.12	2.48	13,992	16,368	30,360
DU Plate ^b	3,481	4.55	5.00	15,839	17,405	33,244
S.S. Plate	2,181	2.12	2.69	4,264	5,867	10,491
S.S. Closure	3,676	2.12	2.49	7,793	9,153	16,946
Honeycomb	19	33.00	50.00	627	950	1,577
Subtotal						168,214
QA @ 20%						33,642
Total VW-MPC Cost						201,856

^aData for this table (other than DU cost) taken from CRWMS, 1993b.

^bDU cost data taken from DOE, 1995.

Table D-27 shows the DU usage summary.

Table D-27. Depleted Uranium Usage Summary

Cask	DU Weight per Cask (lb)	Number of Casks Required	Total DU Weight	
			(lb)	(kg)
1-cn S/D+T	16,200	15,402	249.5 M	113.4 M
1-cn S/T/D	18,500	15,402	284.9 M	129.5 M
3-cn S/D+T	46,700	5,134	239.8 M	109.0 M
3-cn S/T/D	53,600	5,134	275.2 M	125.1 M
4-cn S/D+T	53,000	3,851	204.1 M	92.8 M
4-cn S/T/D	61,000	3,851	234.9 M	106.8 M
7-cn S/D+T	81,000	2,200	178.2 M	81.0 M
7-cn S/T/D	95,300	2,200	209.7 M	95.3 M

D.4.4 Defense Waste Site Costs

Receiving and Handling Facilities/Balance of Plant. It was assumed for this study that all defense HLW sites and West Valley had in place the necessary receiving and handling facilities, and balance of plant required to support the HLW disposal program.

Preparation for Waste Acceptance. Waste acceptance operations for the non-DU-shielded reference case and DU-shielded system configurations consist of loading waste canisters into the VW-MPC and DU-shielded casks, installing the cover, and seal-welding the cover in place.

Interim Storage. Because vitrified waste canisters are scheduled for production well before the repository will begin accepting HLW, a means must be provided for safely storing the waste canisters until they can be shipped to the repository beginning in the year 2015. Two potential storage methods are considered in this study. A summary of the defense waste site costs is provided in Table D-28.

Table D-28. Defense High-Level Waste Site Costs (millions of 1993 dollars)

Cost Item	Item Cost (M\$)					
	Reference	DU-Shielded System Configuration				
	Case	1	2	3	4	
	4-cn VW-MPC	4-cn S/D+T	7-cn S/D+T	7-cn S/T/D	1-cn S/D+T all sites	WV truck
Receiving and handling facilities/balance of plant	0	0	0	0	0	0
Preparation for waste acceptance	17	34	19	10	134	3
Waste canister interim storage	719	69	47	47	102	5
Total HLW Site Cost	736	103	66	57	236	8

Preparation for Waste Acceptance Cost Calculation

The canister loading, cask seal-welding, and overpack cover-bolting operations are considered to be equivalent to those estimated to cost \$4300 for the CRWMS Package to Package Transfer Facility. For the reference case and DU-shielded S/T/D configurations, the \$4300 operations cost is charged once. For the DU-shielded S/D+T configurations, the \$4300 operations cost is charged twice because the DU-shielded S/D+T cask must be returned to the canister handling facility for assembly with its transportation overpack. A summary of the preparation for waste acceptance is shown in Table D-29. The 1992 operation costs have been escalated by 1.2% for 1993.

Table D-29. Preparation for Waste Acceptance Costs

Waste Management System	Number of Packages Assembled	Cost (M\$)
Reference case VW-MPC	3,851	16.8
DU-shielded system configuration		
#1: 4-cn S/D+T	3,851	33.5
#2: 7-cn S/D+T	2,201	19.2
#3: 7-cn S/T/D	2,201	9.6
#4: 1-cn S/D+T		
All sites	15,402	134.1
West Valley	300	2.6

Reference Case VW-MPC

- Operation cost = $(\$4300/\text{assembly}) \times (1.012) = \$4352/\text{assembly}$
- Waste acceptance cost = $3851 \times \$4352 = \16.8M

DU-Shielded System Configurations 1 and 2 (4- and 7-cn S/D+T)

- Operation cost = $(\$4300/\text{assembly}) \times (1.012) = \$4352/\text{assembly}$
- Waste acceptance cost = $2 \times 3851 \times \$4352 = \33.5M
= $2 \times 2201 \times \$4352 = \19.2M

DU-Shielded System Configuration 3 (7-cn S/T/D)

- Operation cost = $(\$4300/\text{assembly}) \times (1.012) = \$4352/\text{assembly}$
- Waste acceptance cost = $2201 \times \$4352 = \9.6M

DU-Shielded System Configuration 4 (1-cn S/D+T)

- Operation cost = $(\$4300/\text{assembly}) \times (1.012) = \$4352/\text{assembly}$
- Waste acceptance cost
All sites = $2 \times 15,402 \times \$4352 = \134.1M
West Valley = $2 \times 300 \times \$4352 = \$2.6.1\text{M}$

Interim Storage Cost Calculation for the Reference Case

Present planning for the non-DU-shielded reference case calls for two GWSBs at a cost of \$111M each, and two robotic SCTs at \$20.6M each. Decommissioning costs at 20% would be \$22.2M and \$4.1M each, respectively. Operating costs for each GWSB is estimated at \$750K per year. Assuming a 20-year operating life for the facilities, the total operating cost for the two buildings is \$30M. Costs cited above were provided by Savannah River (WSRC, 1991) and were assumed to be 1993 dollars.

**Table D-30. Waste Canister Interim Storage Cost Summary: Non-DU-Shielded
Reference Case (1993 dollars)**

Site	Facility/ Equipment Item	No. Required	Individual Item Cost			Total Item Cost ^a	Operating Life	Total Operating Cost ^b	Total Cost ^c
			Capital	Decom. @ 20%	Operating				
SRS	Glass Waste Storage Bldg.	2	\$111M	\$22.2M	\$750K/yr	\$266.4M	20 yr	\$30M	\$296.4M
	Shielded Canister Transporter	2	\$20.6M	\$4.1M	included above	\$49.4M	20 yr	included above	\$49.4M
	Savannah River Site total cost								\$345.8M
	Savannah River Site total cost/canister								\$66.0K
HANF	Glass Waste Storage Bldg.	2	\$111M	\$22.2M	\$750K/yr	\$266.4M	25 yr	\$37.5M	\$303.9M
	Shielded Canister Transporter	2	\$20.6M	\$4.1M	included above	\$49.4M	20 yr	included above	\$49.4M
	Hanford total cost								\$353.3M
	Hanford total cost/canister								\$35.8K
WV	Since it does not make sense to build a large glass waste storage building for 300 canisters, we will prorate the SRS total cost per canister and use it for the 300 WV canisters to provide complete costing data.								
	West Valley total cost								\$19.8M
	West Valley total cost/canister								\$66.0K

^aTotal item cost = (# required) x (capital cost + decommissioning cost).

^bTotal operating cost = (# required) x (operating life) x (operating cost).

^cTotal cost = total item cost + total operating cost.

Waste Canister Interim Storage Cost Calculation for the DU-Shielded System

For the DU-shielded configurations, a fenced, lighted concrete pad located within 2 miles of the waste vitrification facility will be used as the waste canister interim storage facility. The cost of the storage pad is estimated at \$34.00 per square foot and DU-shielded cask pad area requirements are 133 square feet for the single-canister, 304 square feet for the three- and four-canister, and 256 square feet for the seven-canister configurations. The road connecting the pad to the vitrification site will cost about \$700K per mile. The heavy hauler cost is \$250K and, with a service life of 20 years, two will be required for each site. The decommissioning costs for this facility are estimated at 10% of the cost. A representative storage pad layout and area requirements for each DU-shielded cask configuration is provided in Figure D-1.

Figure D-1. Depleted-Uranium-Shielded Cask Temporary Outside Storage Facility

It is important to note that actual outside storage facility costs will be very site specific. For purposes of this study, it is assumed that a storage location can be found at each waste site that requires minimal site preparation and is located in relatively close proximity to highways and power lines.

Depleted-Uranium-Shielded Cask Storage Pad Capital Costs

The DU-shielded cask storage pad capital costs are calculated in Tables D-31, D-32, and D-33.

Table D-31. DU-Shielded Cask Quantity

Cask Capacity	Savannah River Site	Hanford	West Valley
1-cn	5,242	9,860	300
3-cn	1,748	3,287	100
4-cn	1,311	2,465	75
7-cn	749	1,409	43

Table D-32. Storage Pad Area^a

Cask Capacity	Savannah River Site	Hanford	West Valley
1-cn	5,242 x 133 = 697,186	9,860 x 133 = 1,311,380	300 x 133 = 39,900
3-cn	1,748 x 304 = 531,392	3,287 x 304 = 999,248	100 x 304 = 30,400
4-cn	1,311 x 304 = 398,544	2,465 x 304 = 749,360	75 x 304 = 22,800
7-cn	749 x 256 = 191,744	1,409 x 256 = 360,704	43 x 256 = 11,008

^aStorage pad area = [(area/cask) x (# of casks)] square feet.

Table D-33. Storage Pad Capital Cost^a (1993 dollars)

Cask Capacity	Savannah River Site (M\$)	Hanford (M\$)	West Valley (M\$)
1-cn	23.7	44.6	1.4
3-cn	18.1	34.0	1.0
4-cn	13.6	25.5	0.8
7-cn	6.5	12.3	0.4

^aPad cost = \$34.00/square foot.

Interim storage cost summaries for the waste sites considered are shown in Tables D-34, D-35, and D-36.

Table D-34. Interim Storage Cost Summary: Depleted-Uranium-Shielded System for Savannah River Site (1993 dollars)

Cask Capacity	Facility/ Equipment Item	No. Required	Item Cost			Total Item Cost ^a	Operating Life	Total Operating Cost ^b	Total Cost ^c
			Capital	Decom. @ 10%	Operating				
1-cn	Storage Pad	1	\$23.7M	\$2.37M	\$120K/yr	\$26.1M	35 yr	\$4.2M	\$30.30M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	2	\$250K	\$25K	\$90K/yr	\$0.55M	20 yr	\$3.6M	\$4.15M
Savannah River Site 1-canister cask cost									\$36.8M
Savannah River Site cost/canister									\$7.0K
3-cn	Storage Pad	1	\$18.1M	\$1.81M	\$120K/yr	\$19.91M	35 yr	\$4.2M	\$24.11M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	2	\$250K	\$25K	\$90K/yr	\$0.55M	20 yr	\$3.6M	\$4.15M
Savannah River Site 3-canister cask cost									\$30.6M
Savannah River Site cost/canister									\$5.8K
4-cn	Storage Pad	1	\$13.6M	\$1.36M	\$120K/yr	\$14.96M	35 yr	\$4.2M	\$19.16M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	2	\$250K	\$25K	\$90K/yr	\$0.55M	20 yr	\$3.6M	\$4.15M
Savannah River Site 4-canister cask cost									\$25.7M
Savannah River Site cost/canister									\$4.9K
7-cn	Storage Pad	1	\$6.5M	\$0.65M	\$120K/yr	\$7.15M	35 yr	\$4.2M	\$11.35M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	2	\$250K	\$25K	\$90K/yr	\$0.55M	20 yr	\$3.6M	\$4.15M
Savannah River Site 7-canister cask cost									\$17.9M
Savannah River Site cost/canister									\$3.4K

^aTotal item cost = (# required) x (capital cost + decommissioning cost).

^bTotal operating cost = (# required) x (operating life) x (operating cost).

^cTotal cost = total item cost + total operating cost.

**Table D-35. Interim Storage Cost Summary: Depleted-Uranium-Shielded System
for Hanford Site (1993 dollars)**

Cask Capacity	Facility/ Equipment Item	No. Required	Item Cost			Total Item Cost ^a	Operating Life	Total Operating Cost ^b	Total Cost ^c
			Capital	Decom. @ 10%	Operating				
1-cn	Storage Pad	1	\$44.6M	\$4.5M	\$120K/yr	\$49.1M	35 yr	\$4.2M	\$53.30M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	3	\$250K	\$25K	\$90K/yr	\$0.825M	20 yr	\$3.6M	\$4.425M
Hanford 1-canister cask cost									\$60.1M
Hanford Site cost/canister									\$6.1K
3-cn	Storage Pad	1	\$34.0M	\$3.4M	\$120K/yr	\$37.4M	35 yr	\$4.2M	\$41.6M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	3	\$250K	\$25K	\$90K/yr	\$0.825M	20 yr	\$3.6M	\$4.425M
Hanford 3-canister cask cost									\$48.4M
Hanford cost/canister									\$4.9K
4-cn	Storage Pad	1	\$25.5M	\$2.55M	\$120K/yr	\$28.05M	35 yr	\$4.2M	\$32.25M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	3	\$250K	\$25K	\$90K/yr	\$0.825M	20 yr	\$3.6M	\$4.425M
Hanford 4-canister cask cost									\$39.1M
Hanford cost/canister									\$4.0K
7-cn	Storage Pad	1	\$12.3M	\$1.23M	\$120K/yr	\$13.53M	35 yr	\$4.2M	\$17.73M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	35 yr	\$0.84M	\$2.38M
	Heavy Hauler	3	\$250K	\$25K	\$90K/yr	\$0.825M	20 yr	\$3.6M	\$4.425M
Hanford 7-canister cask cost									\$24.5M
Hanford cost/canister									\$2.5K

^aTotal item cost = (# required) x (capital cost + decommissioning cost).

^bTotal operating cost = (# required) x (operating life) x (operating cost).

^cTotal cost = total item cost + total operating cost.

**Table D-36. Interim Storage Cost Summary: Depleted-Uranium-Shielded System
for West Valley Site**

Cask Capacity	Facility/ Equipment Item	No. Required	Item Cost			Total Item Cost ^a	Operating Life	Total Operating Cost ^b	Total Cost ^c
			Capital	Decom. @ 10%	Operating				
1-cn	Storage Pad	1	\$1.4M	\$0.14M	\$30K/yr	\$1.54M	20 yr	\$0.6M	\$2.14M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	20 yr	\$0.48M	\$2.02M
	Heavy Hauler	1	\$250K	\$25K	\$90K/yr	\$0.275M	20 yr	\$0.80M	\$1.075M
West Valley 1-canister cask cost									\$5.2M
West Valley cost/canister									\$17.5K
3-cn	Storage Pad	1	\$1.0M	\$0.1M	\$30K/yr	\$1.1M	20 yr	\$0.6M	\$1.7M
	2-mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	20 yr	\$0.48M	\$2.02M
	Heavy Hauler	1	\$250K	\$25K	\$90K/yr	\$0.275M	20 yr	\$0.80M	\$1.075M
West Valley 3-canister cask cost									\$4.8M
West Valley cost/canister									\$16.0K
4-cn	Storage Pad	1	\$0.78M	\$0.078M	\$30K/yr	\$0.858M	20 yr	\$0.6M	\$1.458M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	20 yr	\$0.48M	\$2.02M
	Heavy Hauler	1	\$250K	\$25K	\$90K/yr	\$0.275M	20 yr	\$0.80M	\$1.075M
West Valley 4-canister cask cost									\$4.6M
West Valley Cost/Canister									\$15.2K
7-cn	Storage Pad	1	\$0.37M	\$0.037M	\$30K/yr	\$0.407M	20 yr	\$0.6M	\$1.007M
	2-Mile Road	1	\$1.4M	\$0.14M	\$24K/yr	\$1.54M	20 yr	\$0.48M	\$2.02M
	Heavy Hauler	1	\$250K	\$25K	\$90K/yr	\$0.275M	20 yr	\$0.80M	\$1.075M
West Valley 7-canister cask cost									\$4.1M
West Valley cost/canister									\$13.7K

^aTotal item cost = (# required) x (capital cost + decommissioning cost).

^bTotal operating cost = (# required) x (operating life) x (operating cost).

^cTotal cost = total item cost + total operating cost.

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