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WHC-SD-WM-ES-348
Revision 0

ALTERNATIVES FOR HIGH-LEVEL WASTE FORMS, CONTAINERS, AND CONTAINER PROCESSING SYSTEMS

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September 1995

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LIST OF TERMS

CCTV	Closed circuit television
CDC	Canister decontamination cell
CFR	Code of Federal Regulations
CS	Carbon steel
CSB	Canister storage building
CWBS	Contract work breakdown structure
DOT	Department of Transportation
DPM	Disintegrations per minute
He	Helium
HLW	High-level waste
HVAC	Heating, ventilation, and air conditioning
HWVP	Hanford Waste Vitrification Plant
lb	Pound mass
mrem	Milliroentgen-equivalent-man
mSv	Millisievert
MT	Metric ton
od	Outer diameter
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
rem	Roentgen-equivalent-man
SC	Safety class
SS	Stainless steel
STC	Smear test cell
Sv	Sievert
TEC	Total estimated cost
TIG	Tungsten inert gas
TOE	Total operating efficiency
TSD	Treatment, Storage, and Disposal
TWRS	Tank Waste Remediation System
WAC	Washington Administrative Code
WHC	Westinghouse Hanford Company

ALTERNATIVES FOR HIGH-LEVEL WASTE FORMS, CONTAINERS, AND CONTAINER PROCESSING SYSTEMS

1.0 OBJECTIVE

The objective of this study is to introduce and evaluate high-level waste (HLW) form alternatives. Information is presented that describes the technical features of alternate waste form configurations. All alternatives are evaluated and summary results are presented as a basis for comparison to support the selection of an HLW form configuration.

1.1 BACKGROUND AND SCOPE

In previous phases of the Tank Waste Remediation System (TWRS) facility configuration trade study effort, HLW form alternatives were identified and defined in the *Tank Waste Remediation System Facility Configuration Study* (Boomer et al. 1994). This report further defines these alternatives in detail. Additionally, new alternatives are introduced and discussed in this report.

Alternatives for HLW forms, containers, and container processing systems are illustrated in Figure 1-1 and summarized in Table 1-1. Four different glass HLW forms and twelve individual container cases are presented. Figure 1-1 depicts the preferred system configuration for each container case. Table 1-1 lists all of the system configurations that were considered and evaluated for each case. Glass waste form production processes include cullet, marbles, gems, and monolithic glass. Small and large containers configured with several combinations of overpack confinement and shield casks are presented for these waste forms. Conceptual designs have been prepared for each waste form container case and their respective processing systems. Each container configuration includes a discussion of its process systems, including: filling, closure, and inspection, onsite transportation, onsite interim storage, offsite transportation, and final storage.

To assess the features of each alternative, performance measures are utilized as a basis for evaluation. The set of performance measures selected for this study includes: process flowsheet/facility design impact, operability/complexity, maintainability, maturity of technology, schedule impact, regulatory impact, safety, and cost. Each alternative is subjected to a quantitative and/or qualitative assessment against the performance measures, then each alternative is evaluated against the performance measures relative to one another. This process provides a selection of favorable alternatives based on the above methods.

This study does not address melter feed system design, the melter itself, nor performance assessment characteristics for the glass waste forms. The scope of this study starts at the melter pour spout and ends with canisters in interim storage.

Figure 1-1. Configuration Options for High-Level Waste Form Study.

Table 1-1. Configuration Options for High-Level Waste Form Study.

Case	Waste form container	Waste form	Onsite transportation	Onsite storage	Offsite transportation	Final storage
1	Unshielded small canisters	Monolithic glass	Shielded transporter	Building or bore holes	Rail, truck, or barge	Repository
2	Unshielded 4-pack overpack canisters for unshielded small canisters	Monolithic glass	Shielded transporter	Building or bore holes	Rail, truck, or barge	Repository
3A	Metal shielded casks for unshielded 4-pack overpack canisters	Monolithic glass	Unshielded transporter	Pads	Rail, truck, or barge	Repository
3B	Concrete shielded casks for unshielded 4-pack overpack canisters	Monolithic glass	Unshielded transporter	Pads	Rail, truck, or barge	Repository
4	Large shielded casks	Cullet, marbles, or gems	Unshielded transporter	Pads	Rail, truck, or barge	Repository
5	Large unshielded canisters and metal overpack shielded casks	Cullet, marbles, or gems	Unshielded transporter	Pads	Rail, truck, or barge	Repository
6	Large unshielded canisters and concrete overpack shielded casks	Cullet, marbles, or gems	Unshielded transporter	Pads	Rail, truck or barge	Repository
7	Large unshielded canisters, unshielded overpack canisters, and metal overpack shielded casks	Cullet, marbles, or gems	Unshielded transporter	Pads	Rail, truck, or barge	Repository
8	Large unshielded canisters, unshielded overpack canisters, and concrete overpack shielded casks	Cullet, marbles, or gems	Unshielded transporter	Pads	Rail, truck, or barge	Repository
9	Large containers	Monolithic glass	Shielded transporter	Building	Rail, truck, or barge	Repository
10	Unshielded 7-pack overpack canisters for unshielded small canisters	Monolithic glass	Shielded transporter	Building or bore holes	Rail, truck, or barge	Repository
11	Unshielded 4-pack overpack canisters for unshielded HWVP-type canisters	Monolithic glass	Shielded transporter	Building or bore holes	Rail, truck, or barge	Repository

1.2 PURPOSE AND NEED

The development and evaluation of conceptual alternatives provide a basis required for the selection of favorable alternatives. The intent of this study is to select favorable alternatives based on an evaluation of alternatives and establish a framework for a future final decision process to recommend a preferred option. The report presents data that are specific to each alternative discussed in Section 1.1. The data presented describes and evaluates the alternatives against established performance measures and are used for relative comparison between the alternatives. The data presented in this report are considered supplemental, and shall support future decision processes in the selection of an HLW form concept.

2.0 SUMMARY

Sixteen configurations for HLW forms, waste containers and container processing systems, and storage alternatives were defined, evaluated, and compared. Four different glass HLW forms, 12 individual container cases, and three storage concepts were included in this evaluation. Each case was technically developed and cost estimated. All cases were quantitatively and/or qualitatively assessed against established performance measures. These performance measures are process flowsheet/facility design impacts, operability/complexity, maintainability, maturity of technology, schedule impact, regulatory impact, safety, and cost.

All favorable options include the monolithic glass production process as the waste form. Monolithic glass waste forms are favorable primarily because the technology has considerable demonstration in the waste immobilization field and because it currently meets waste form acceptance criteria by the repository program. Monolithic glass forms are also the least difficult form to produce and least expensive glass production option investigated in this report.

Based on the most current technical and cost information presented in this report, Cases 1, 2, 3A, 3B, 10, and bore hole Cases 1, 2, and 10 appear to be the most favorable options. Relative to the assessment categories noted above, these cases had the least amount of uncertainty associated with their design concepts. Of the favorable options, Cases 2 and 10, the unshielded 4- and 7-pack overpack options respectively, have the greatest technical assurance associated with their design concepts due to their process packaging and storage methods.

Costs were determined not to be a discriminating factor in most cases. Total life-cycle costs for most options varied by less than 15 percent, well within an uncertainty allowance for these estimates. A sensitivity analysis performed on estimated canister costs indicated this cost impact to be a secondary order effect on overall life-cycle costs.

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3.0 TECHNICAL FINDINGS AND CONCLUSIONS

The technical findings presented below are based on the methods of evaluation and assessment categories established in Section 1.1 of this report. Options for HLW are summarized based on technical and cost information provided in Sections 4.0 through 10.0.

Waste form performance assessment issues, such as glass corrosion, have not been considered in this evaluation. However, in evaluations that may be impacted by performance assessment issues, comments are made in the context of the report regarding the consequences of such impacts.

Glass waste form production processes, defined as all glass process systems up to the canister fill point, include the following options: monolithic, cullet, gems, and marble production. Monolithic is the simplest and least expensive glass waste form to produce. Monolithic is also the only developed production process for this application and is currently an accepted waste form by the repository program. Technical concerns appear to make marbles and gems unfavorable. Although glass cullet production is \$33.8 million more expensive than the monolithic process, the process appears technically feasible. Selection of a favorable glass waste form production process is not independent of its canister/processing system. This factor was integrated into the evaluation before identification of favorable alternatives.

Table 3-1 lists the favorable options based on the technical findings of this study. Common to all favorable options is the monolithic glass process that is demonstrated for this application and is currently the only accepted glass waste form by the repository program. All favorable options in Table 3-1 have an uncertainty associated with the estimated rate of monolithic glass recycle. These concerns include sizing of the recycle system (facility impact) and its impact on the plant operating efficiency. However, the impact of these uncertainties are not considered discriminating since they are applicable to all options.

Case 1 (both building and bore hole storage options) has concerns associated with the capabilities of the fill and decontamination systems since they do not use overpacks. Overpacks offer a high degree of assurance that the exterior surface of a packaged configuration is not contaminated. However, alternatives and/or modifications to the reference fill and decontamination systems (i.e., more aggressive decontamination systems) are possible and the cost impact is not considered to be significant since each alternative is within 5 percent of the least expensive option. The uncertainties associated with the concrete storage pad concept of Cases 3A and 3B include weathering effects on both the pads and shielded overpacks, monitoring the storage area/soil/overpacks for leaks, and cooling capabilities/designs of the shielded casks. Short-term solutions could include construction of metal buildings over the pads. Again, the costs associated with this are not expected to be significant to either option. Finally, the bore hole concept is challenged by both cooling capacity limitations and significant land area requirements. There is no technical reason to suspect that an engineered solution could not be developed for this storage concept, and the

associated costs are not considered significant. Additionally, since land area requirements are not considered in the scope of this study, it does not influence the conclusions of this report.

Table 3-1. Favorable Container/Processing Options.

Case	Waste form container	Waste form	Storage concept	NPV ^(b) \$million
1	Unshielded small canisters	Monolith	Building	3,157
2	Unshielded 4-pack overpack canisters for unshielded small canisters	Monolith	Building	3,476
3A	Metal shielded casks for unshielded 4-pack overpack canisters	Monolith	Pad	3,458
3B	Concrete shielded casks for unshielded 4-pack overpack canisters	Monolith	Pad	3,269
10	Unshielded 7-pack overpack canisters for unshielded small canisters	Monolith	Building	3,413
1 ^a	Unshielded small canisters	Monolith	Bore hole	3,052
2 ^a	Unshielded 4-pack overpack canisters for unshielded small canisters	Monolith	Bore hole	3,418
10 ^a	Unshielded 7-pack overpack canisters for unshielded small canisters	Monolith	Bore hole	3,328

^a Bore hole options.

^b Net present value at year 0 for capital, operating, and D&D costs plus repository fees at 2.8 percent interest rate per OMB circular A-94.

Table 3-2 summarizes the technical findings of the HLW options evaluated in this report. Presented are the findings of each alternative relative to the performance measures. Due to the technical uncertainties discussed for Option 9 (Section 6.3), it is not discussed further in this section.

Costs do not differentiate between most of the options, as reported in Table 3-2. Since the total costs vary less than 15 percent between most options, it alone is not considered as a discriminating factor. However, any future optimization of waste form options should consider all cost components that contribute to the total costs, since many of these cost components may be adopted by other waste form options (e.g., interim storage methods).

Table 3-2. Glass Waste Form Technical Findings.

Case	Flowsheet/ facility impact	Operability/ complexity	Maintainability	Maturity of technology	Schedule impacts	Reg impacts	Safety	NPV ^c costs \$ million
1	-	Uncertainty in sizing glass recycle system. More complex decon systems.	-	-	-	-	-	3,157
2	-	Uncertainty in sizing glass recycle system.	-	-	-	-	-	3,476
3A	-	Uncertainty in sizing glass recycle system.	-	Pad storage concept requires demonstration.	-	-	-	3,458
3B	-	Uncertainty in sizing glass recycle system.	-	Pad storage concept requires demonstration. Heat removal of decay heat from concrete overpack requires demonstration.	-	-	-	3,269
4 ^a	Additional glass handling systems impact facility design.	More complex decon systems.	Additional maintenance requirements for glass handling systems.	Glass production process requires demonstration for this application. Pad storage concept requires demonstration.	-	-	-	3,837
5 ^a	Additional glass handling systems impact facility design.	-	Additional maintenance requirements for glass handling systems.	Glass production process requires demonstration for this application. Pad storage concept required demonstration.	-	-	-	3,203

Table 3-2. Glass Waste Form Technical Findings.

Case	Flowsheet/ facility impact	Operability/ complexity	Maintainability	Maturity of technology	Schedule impacts	Reg impacts	Safety	NPV ^c costs \$ million
6 ^a	Additional glass handling systems impact facility design.	-	Additional maintenance requirements for glass handling systems.	Glass production process requires demonstration for this application. Pad storage concept required demonstration.	-	-	-	3,064
7 ^a	Additional glass handling systems impact facility design.	-	Additional maintenance requirements for glass handling systems.	Glass production process requires demonstration for this application. Pad storage concept required demonstration.	-	-	-	3,458
8 ^a	Additional glass handling systems impact facility design.	-	Additional maintenance requirements for glass handling systems.	Glass production process requires demonstration for this application. Pad storage concept required demonstration.	-	-	-	3,319
10	-	Uncertainty in sizing glass recycle system.	-	-	-	-	-	3,413
11	-	Uncertainty in sizing glass recycle system.	-	-	-	-	-	4,391
1 ^b	Bore holes require significant land allocation.	Uncertainty in sizing glass recycle system. More complex decon systems.	-	Heat removal of decay heat from concrete bore holes require demonstration.	-	-	-	3,052

Table 3-2. Glass Waste Form Technical Findings.

Case	Flowsheet/ facility impact	Operability/ complexity	Maintainability	Maturity of technology	Schedule impacts	Reg impacts	Safety	NPV ^c costs \$ million
2 ^b	Bore holes require significant land allocation.	Uncertainty in sizing glass recycle system.	-	Heat removal of decay heat from concrete bore holes require demonstration.	-	-	-	3,418
10 ^b	Bore holes require significant land allocation.	Uncertainty in sizing glass recycle system.	-	Heat removal of decay heat from concrete bore holes require demonstration.	-	-	-	3,328
11 ^b	Bore holes require significant land allocation.	Uncertainty in sizing glass recycle system.	-	Heat removal of decay heat from concrete bore holes require demonstration.	-	-	-	4,507

^a Denote non-monolithic waste forms.

^b Denote bore hole storage options.

^c Net Present Value in 1994 dollars.

Table 3-3 presents a breakdown of the costs reported in this study and includes capital costs, annual costs, repository costs and net present value costs. Capital costs include the cost of the vitrification facility, onsite transportation equipment, and the portion of storage facilities built during initial construction. Annual costs include the cost of all containers, construction of the required interim storage facilities, operations, and equipment replacement costs (construction of storage capacity is staggered to meet production demands, thus becoming an annual operating expense). Engineering, project management, construction management and contingency costs have been included in both capital and operating costs accordingly and are detailed in Appendix A. Repository costs include transportation in a shipping cask from the Hanford Site to the repository, repackaging of the canisters at the repository, and construction and operation of the repository. Net present value costs determines the equivalent cost in year 0 (end of construction) of all capital, operating and repository costs. Future costs were brought back to year 0 using a compound interest of 2.8 percent per the Office of Management and Budget circular A-94 (OMB 1992). All costs are reported in 1994 dollars. Appendix A discusses the methods used to obtain these figures.

Table 3-3. High-Level Waste Facility Life-Cycle Costs.

Case	Case description	Total capital costs \$ million	Total annual cost \$ million	NPV ^a Repository costs \$ million	Net present value ^b \$ million
1	Unshielded, in building (M)	1,366	67	649.6	3,157
2	Unshielded, in building (M)	1,409	71	868.4	3,476
3A	Shielded on pad (M)	1,290	83	868.4	3,458
3B	Shielded on pad (M)	1,294	66	868.4	3,269
4	Shielded on pad (C)	1,333	71	1324.9	3,837
5	Shielded on pad (C)	1,340	69	707.0	3,203
6	Shielded on pad (C)	1,344	57	707.0	3,064
7	Shielded on pad (C)	1,373	79	809.9	3,458
8	Shielded on pad (C)	1,377	66	809.4	3,319
10	Unshielded in building (M)	1,409	72	799.8	3,413
11	Unshielded in building (M)	1,409	75	1743.5	4,391
1	Unshielded in bore hole (M)	1,444	49	649.6	3,052
2	Unshielded in bore hole (M)	1,474	59	868.4	3,418
10	Unshielded in bore hole (M)	1,458	59	799.8	3,328
11	Unshielded in bore hole (M)	1,581	66	1743.5	4,507

^a Present value costs.

^b Net present value costs at year 0 for capital, operating, closure and repository costs at 2.8 percent interest rate per OMB circular A-94.

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4.0 GLASS WASTE FORM PRODUCTION PROCESSES

Several glass waste forms are being considered for the vitrification of HLW. This section focuses on the production of cullet, marbles, gems, and monoliths. No particular glass chemical composition or melter types are discussed. Glass types and melters are referred to in a generic sense only. The containers for these glass waste forms and their associated processing systems are discussed in Sections 5.0 and 6.0 of this report.

This study identifies product recycle for the glass waste form alternatives as an uncertainty. Two methods exist for glass product qualification: process qualification and product qualification. Process qualification is a formidable program that involves equipment, instrumentation and controls, and process systems. The facility operator, as well as vendors that supply equipment, are equally involved in the rigorous quality assurance program. Product qualification is a statistical measurement program that tests the quality of the glass form produced. Inherent to both methods of qualification is the ability to recycle a glass product. The non-monolithic glass forms have an advantage over monolithic forms due to the simplicity of recycle systems required for the recycle function (mechanically crush glass to a frit and blend with glass formers). However, the monolithic glass forms recycle systems have yet to be demonstrated. Among the significant issues for monolith recycle are: removal of waste form from the container, reducing waste form for product recycle, and increased volume of generated wastes (includes metal container). Although no data exists to quantify glass recycle in this report, the uncertainty associated product recycle is considered greater for the monolith glass form.

This study does not address melter feed system design, the melter itself, nor performance assessment characteristics for the glass waste forms. The scope of this study starts at the melter pour spout and ends with canisters in interim storage.

4.1 CULLET PRODUCTION

Cullet is one of the glass waste forms considered for the HLW vitrification facility. The cullet production method selected for this study represents only one of the available cullet production methods. Other methods include rolling molten glass into plate glass sheets and braking the cooled sheets using cracking rollers and hammer mills. However, since these alternative methods require air exchange systems to remove the industrial heat and depend on complicated mechanical systems to process the materials, the water quenched method was selected for this study.

The paragraphs below present a cullet production system description, a listing of advantages and disadvantages, and a list of concerns and uncertainties.

4.1.1 General System Description

Figure 4-1 shows a block flow diagram of the cullet handling system. Molten glass from the melter glass separator is continuously discharged to the quench flume. In the quench flume, the molten glass makes contact with chilled water causing the glass to fracture into cullet. The cullet and water then pass through the roll crusher where large pieces of glass are broken into smaller ones. Cullet and water are collected in the cullet catch tank. The cullet slurry is pumped from the cullet catch tank to the screen to remove water and undersized cullet. The cullet is then transferred by gravity to the cullet lag storage bin. Cullet is dried in the cullet lag storage bin by blowing hot air through it. The cullet is held in the lag storage bin until after an analysis is conducted. Accepted cullet is then transferred by a pneumatic transfer system through a cyclone to the day bin. In the cyclone, the exhaust air is passed through sintered metal filters where fine particles are removed. The cullet is fed from the day bin into canisters. If necessary, out-of-specification cullet is transferred by the pneumatic system from the cullet lag storage bin to the recycle catch tank through a cyclone and a roll crusher. In the cyclone, the exhaust air is passed through sintered metal filters where fine particles are removed.

Equipment Description. The cullet handling system consists of the following equipment:

- The quench flume is an enclosed trough in which chilled water passes through at a rate of $4.73 \times 10^{-3} \text{ m}^3/\text{sec}$.

In the quench flume, molten glass is discharged from the melter glass separator and is contacted with chilled water to form cullet. The quench flume will be equipped with a chilled water inlet nozzle, a molten glass inlet, cullet slurry outlet and a vapor outlet.

- The roll crushers break large pieces of cullet into desired sizes. There are two roll crushers in the cullet handling system. One of the roll crushers, which is located after the quench flume, breaks large cullet pieces into 0.64-cm cullet. This roll crusher has a capacity of 0.236 kg/sec cullet. The second roll crusher, which is in the cullet recycle system, crushes the cullet before it enters the recycle catch tank.
- The screen removes water and undersized particles from the product cullet. The screen shall be designed to process a cullet slurry capacity of $4.73 \times 10^{-3} \text{ m}^3/\text{sec}$ with 0.236 kg/sec of cullet. The acceptable cullet is transferred to the cullet lag storage bin. The undersized cullet and water are collected in the HLW filter catch tank.

Figure 4-1. Cullet Handling Block Flow Diagram
HLW 20 Metric Tons per Day.

- The cullet lag storage bin dries cullet and provides cullet lag storage. Cullet is transferred by gravity from the screen to the lag storage bin where cullet is dried by blowing hot air through it. One HLW cullet lag storage bin will be provided. The HLW cullet storage bin will be divided into eight compartments (approximately equivalent to eight days of production). Cullet enters the cullet pneumatic transfer system through a bottom discharge in the lag storage bin.
- The pneumatic transfer system transports cullet from the cullet lag storage bin through cyclones either to the day bin or to the recycle catch tank. Cullet will be transferred at a rate of 1.32 kg/sec. The pneumatic transfer system uses plant air as a motive force for transferring the cullet.
- The cyclones receive cullet from the lag storage bin via the pneumatic transfer system. There are two cyclones in the cullet handling system. One cyclone is for processing cullet before the day bin and the other cyclone is for processing cullet to the recycle catch tank. In both cyclones, the exhaust air is passed through sintered metal filters where fine particles are removed. The cyclones will be designed for high efficiency at particle sizes of 3 to 5 μm or larger. The sintered metal filters in the cyclones will be cleaned by a compressed air pulse system. The particles from the filters will be discharged either to the day bin or to the recycle catch tank.
- The day bin will be designed to accept cullet from the cyclone via a rotary star feeder. It has one cask or canister capacity. The day bin will be equipped with a load cell to weigh the cullet before it is discharged into the canister.

4.1.2 Advantages

From a glass waste form production standpoint, cullet has no significant advantages. Cullet does have a substantial number of significant advantages in regards to canister handling though. These are discussed in Section 6.0.

4.1.3 Disadvantages

Cullet has the following disadvantages:

- Solids handling systems are required to process the cullet. These systems have not been previously used in a high-level waste facility. Adapting this equipment for remote operation may create unique material handling challenges. Since the cullet is abrasive, frequent maintenance of these systems will be required.

- Since the cullet is brittle, it may break into fine particles each time it is transported. Alternative transport systems should be investigated since pneumatic transfer systems are prone to fine particle generation, bridging, and blockage. Cullet fines must be collected and reprocessed.

4.1.4 Concerns and Uncertainties

Concerns and uncertainties for the cullet production option are as follows:

- Additional studies are required to determine the feasibility of adapting off-the-shelf hardware for this application.
- The plant's total operating efficiency (TOE) may be affected if excessive equipment replacement is required or if cullet breakage occurs.
- Cullet may violate the 10 CFR 60 requirement for a consolidated waste form and may violate the 10 CFR 71 requirement for non-dispersable fines. These issues should be investigated further if cullet is selected as the HLW form.
- The ability to meet 10 CFR 71 limitations on dispersible fines in the canister during transportation has not been verified.

4.2 MARBLE PRODUCTION

A marble form is one of the glass waste forms considered for the HLW vitrification facility. The paragraphs below present a marble production system description, a listing of advantages and disadvantages, and a list of concerns and uncertainties.

4.2.1 General System Description

Figure 4-2 shows a block flow diagram of the marble handling system for the waste marble production facility. This production method requires two melters and eight marble production machines. Molten glass is fed from the melters to the marble machines by two special feeder devices. These devices, which are attached to the melters, consist of a steel structure with a channel and several spouts with orifices. Glass flows from the melters into the channels and then into the spouts. The glass then flows in a continuous stream through the spout's orifice and into the marble machine's automatic shearing mechanism. The shears cut the glass into small molten gobs. Operators are required to maintain production operations.

Figure 4-2. Marble Handling Block Flow Diagram.
GEM Handling Block Flow Diagram
High-Level Waste 20 Metric Ton per Day

Each marble machine is equipped with two sets of rollers and one automatic shearing mechanism. This configuration is known as a double action marble machine. Gobs of glass exiting the shearing mechanism are deflected to both sets of rollers in an alternating manner. The advantage of having two sets of rollers on one machine is that production per operator can be doubled. The molten glass gobs drop onto the rollers and are rolled into spheres. The shearing mechanism can be adjusted to change the gob length and subsequently the size of the marbles. As the marbles exit the rollers on both ends of the machine, they fall on a spiral shaft where they are cooled before falling onto a belt conveyor.

Marbles that fall onto the belt conveyor are still hot, but they have cooled sufficiently such that they will not stick together. While on the belt conveyor, the marbles are brittle. Therefore, it is necessary to treat the marbles in a separate annealing furnace or "lehr" where residual stresses are removed. After the marbles have been annealed, they are transferred by a belt conveyor and bucket elevator to the lag storage bin. Marbles are held in the lag storage bin until a glass analysis has been completed. Acceptable marbles are then transferred via a circular carrier and a bucket elevator to a day bin. The marbles are then fed from the day bin into containers.

If necessary, out-of-specification marbles are transferred by a bucket elevator from the lag storage bin to a roll crusher. Crushed marbles then exit the roll crusher into a recycle catch tank.

Marble Machines. Marble machines can produce marbles ranging from 0.95 to 2.5 cm in diameter. The production rate of a marble machine varies in accordance with the type of glass being used and the size of the marble. Several machines are required to meet the glass production rate of 20 MT per day. Table 4-1 shows the number of machines required for the high-level waste plant as a function of marble size. It can be seen that as marble size goes up, the number of machines required to meet the production rate goes down drastically. For this study, it is assumed that 2.5 cm marbles will be produced. A minimum of seven machines are therefore required. So that plant symmetry can be maintained, eight machines are used for this study. A typical marble machine is approximately 2.9 m long, 1.1 m wide, and 1.5 m high. Each machine has two sets of rollers. Each set of rollers contains a 15-cm diameter roller and a 25-cm diameter roller.

4.2.2 Advantages

Marble production systems for HLW glass have the following advantages compared to cullet:

- Marbles are less abrasive than cullet.
- Fewer fines are produced. Production efficiency increases since less material is recycled.

Table 4-1. Marble Machine Production Rates as a Function of Marble Size.

Diameter of marble	Marble per minute per machine	Production rate KG per day per machine	Marble machines for HLW plant*
0.95 cm	210	358	62
1.27 cm	198	803	28
1.59 cm	174	1,603	17
1.91 cm	150	2,058	12
2.22 cm	126	2,757	9
2.54 cm	104	3,397	7

* Includes 10 percent for spares.

4.2.3 Disadvantages

Marble production systems for HLW glass have the following disadvantages:

- An offgas system is required to vent all of the marble system equipment. In addition to cleaning the overhead gases, this system must also remove the glass waste heat from the marble production system.
- The marble production system requires a high degree of maintenance.
- Since maintenance requirements are high, several spare equipment items must be provided to maintain the plant's TOE.
- The plant's HVAC system must be sized to handle the lost heat from the large quantity of equipment items in the marble production system.
- Glass marbles are brittle because of the stresses produced during the cooling process. The marbles must therefore be treated in long annealing furnaces. These furnaces and their conveyor systems occupy large areas within the vitrification facility.
- Feeder units are used to distribute molten glass from the melters to the marble machines. Each feeder unit has a channel with multiple spouts and orifices. For cases that require large quantities of marble machines, the feeder unit designs become complicated because of the long channel lengths and number of spouts required. Therefore, multiple melters and feeder units are required for these cases.

- Pneumatic transfer systems can not be used to transport marbles. These types of transfer systems would break the marbles.
- Clean up of spilled marbles may be more difficult than the clean up of cullet or gems since marbles tend to roll.

4.2.4 Concerns and Uncertainties

The following concerns and uncertainties exist for the marble production process:

- In commercial plants, operators are required to operate and maintain the marble making machines. Operators must constantly look for the occurrence of machine failures and problems with the glass. Shears and rollers require periodic maintenance. Typically, one operator is required for each three marble machines; however, the actual number of required operators per machine is dependent on plant conditions.
- Off-the-shelf commercial marble making equipment is not suitable for remote nuclear applications. Extensive modifications will be required. Little is known about the feasibility of utilizing marble making equipment in a HLW facility. Several issues such as machine design, remoteability, maintenance, and cost exist. Future efforts are required to study these attributes.
- The selection of the orifice material is important for the production of a uniform molten glass stream.
- The annealing process is very important for marble stabilization. This process must be properly controlled to produce an acceptable waste form that is not de-vitrified or brittle.
- The temperature and viscosity at the end of the feeder channel where the molten glass stream passes through the shears and falls as a gob are critical in order to produce a good waste form.
- A water cooling device and lubricator are required for the marble machine's shearing mechanism. These provisions and the maintenance of these provisions may create difficulties.
- Marble production rate is a function of marble size. If the size chosen for this study is too large, then a smaller marble size and subsequently, several more machines may be required. Large quantities of machines require more maintenance and facility space.

- The optimal marble size must be determined so that they can be produced and handled efficiently with minimal breakage.

4.3 GEM PRODUCTION

Gem shapes is one of the glass waste forms considered for the HLW vitrification facility. The paragraphs below present a gem production system description, a listing of advantages and disadvantages, and a list of concerns and uncertainties.

4.3.1 General System Description

Figure 4-3 shows a block flow diagram of the gem handling system. The gem making process is very similar to the marble production process. Both systems utilize two melters and two feeder units. In the marble process, glass gobs are discharged from the feeder unit shearing mechanisms into marble machines. In the gem making process, the glass gobs discharge from the shearing mechanisms directly onto conveyor belts. The gobs cool on the belts to form non-spherical gems. Gems have the shape of vanilla wafer cookies. They are flat on the bottom with a rounded circular edge and a convex top. For this study, it is assumed that 2.5-cm gems will be produced. The downstream unit operations for gem annealing and handling are identical to those of the marbles.

4.3.2 Advantages

Gem productions systems offer the same advantages as the marble systems offer. These advantages are as follows:

- Gems are less abrasive than cullet.
- Fewer fines are produced. Production efficiency increases since less material is recycled.

4.3.3 Disadvantages

Gem production systems for HLW glass have the following disadvantages:

- An offgas system is required to vent all of the gem system equipment. In addition to cleaning the overhead gases, this system must also remove the glass waste heat from the gem production system.
- The gem production system requires a high degree of maintenance.
- Since maintenance requirements are high, several spare equipment items must be provided to maintain the plant's TOE.

- The plant's HVAC system must be sized to handle the lost heat from the large quantity of equipment items in the gem production system.
- Glass gems are brittle because of the stresses produced during the cooling process. The gems must therefore be treated in long annealing furnaces. These furnaces and their conveyor systems occupy large areas within the vitrification facility.
- Feeder units are used to distribute molten glass from the melters to the belt conveyors. Each feeder unit has a channel with multiple spouts and orifices. For cases that require large quantities of spouts, the feeder unit designs become complicated because of the long channel lengths and number of spouts required. Therefore, multiple melters and feeder units are required for these cases.

4.3.4 Concerns and Uncertainties

The following concerns and uncertainties exist for the gem production process:

- Operators are required to operate and maintain the gem making machines. Operators must constantly look for the occurrence of machine failures and problems with the glass. Shears require periodic maintenance. Typically, one operator is required for each three gem machines; however, the actual number of required operators per machine is dependent on plant conditions.
- Off-the-shelf commercial gem making equipment is not suitable for remote nuclear applications. Extensive modifications will be required. Little is known about the feasibility of utilizing gem making equipment in a HLW facility. Several issues such as machine design, remoteability, maintenance, and cost exist. Future efforts are required to study these attributes.
- The annealing process is very important for gem stabilization. This process must be properly controlled to produce an acceptable waste form that is not de-vitrified or brittle.
- The temperature and viscosity at the end of the feeder channel where the molten glass stream passes through the shears and falls as a gob are critical in order to produce a good waste form.
- A water cooling device and lubricator are required for the shearing mechanism. These provisions and the maintenance of these provisions may create difficulties.

Figure 4-3. Gem Handling Block Flow Diagram.
GEM Handling Block Flow Diagram
High-Level Waste 20 Metric Ton per Day

- Gem production rate is a function of gem size. If the size chosen for this study is too large, then a smaller gem size and subsequently, several more machines may be required. Large quantities of machines require more maintenance and facility space.
- The optimal gem size must be determined so that they can be produced and handled efficiently without breakage.

4.4 MONOLITHIC GLASS PRODUCTION

Monolithic glass is one of the glass waste forms considered for the high-level vitrification facility. The paragraphs below present a monolithic glass production system description, a listing of advantages and disadvantages, and a list of concerns and uncertainties.

4.4.1 General System Description

Figure 4-4 shows a block flow diagram of the monolithic handling system. Monolithic glass is formed by pouring molten glass out of the melter and directly into containers. No other glass handling equipment is necessary.

4.4.2 Advantages

Compared to the cullet, marble, and gem options, the production of monolithic glass has the following advantage:

- Once the glass stream leaves the melter pour spout and enters the waste container, no more additional glass handling systems are required.

4.4.3 Disadvantages

Monolithic glass production has the following disadvantages:

- Off-specification monolithic glass is relatively difficult to recycle.
- The discontinuous pouring operations required for monolithic production is inherently more complex than a continuous pour system. Also, the dual pour-spout (the single 20-MT per day melter requires filling capacity for two canister fill stations) is inherently more complex than a single pour-spout.
- Lag storage for monolithic canisters is more expensive than for the other waste forms considered in this report.

Figure 4-4. Monolithic Process Block Flow Diagram.
Monolith (Production) BFD
High-Level Waste 20 Metric Ton per Day

4.4.4 Concerns and Uncertainties

No major concerns exist for the production of monolithic glass. Several concerns, however, do exist for the production and handling of monolithic glass containers. These concerns are discussed in Section 6.0.

4.5 SUMMARY COMPARISON

The paragraphs below summarize and discuss glass waste form production processes in regards to process flowsheet/facility design impacts, operability/complexity, maintainability, maturity of technology, schedule impacts, regulatory impacts, safety, and costs. In some cases, no impacts have been identified and hence, the text simply states, "none."

4.5.1 Process Flowsheet/Facility Design Impacts

The process flowsheet and facility design impacts for each glass production method are summarized in Table 4-2.

Table 4-2. Glass Production Method Process Flowsheet/Facility Design Impacts.

Cullet	1. The cullet production system requires more equipment and facility space than the monolithic glass system.
Marbles	<ol style="list-style-type: none"> 1. The marble production system requires more equipment and facility space than the monolithic glass system. 2. An offgas system is required to vent all of the marble system equipment. This system must also remove glass waste heat from the marble system. 3. The marbles must be treated in long annealing furnaces. These furnaces and their conveyor systems occupy large areas within the vitrification facility. 4. Marble production rate is a function of marble size. Smaller marbles require more marble machines: large quantities of machines require more facility space.
Gems	<ol style="list-style-type: none"> 1. The gem production system requires more equipment and facility space than the monolithic glass system. 2. An offgas system is required to vent all of the gem system equipment. This system must also remove glass waste heat from the gem system. 3. The gems must be treated in long annealing furnaces. These furnaces and their conveyor systems occupy large areas within the vitrification facility. 4. Feeder units are used to distribute molten glass from the melters to the belt conveyors. Each feeder unit has a channel with multiple spouts and orifices. For cases that require large quantities of spouts, the feeder unit designs become complicated because of the long channel lengths and number of spouts required. Therefore, multiple melters and feeder units are required for these cases. 5. Gem production rate is a function of gem size. Smaller gems require more gem machines: large quantities of machines require more facility space.
Monolith	1. Monolithic glass production yields the simplest process flowsheet and facility design.

4.5.2 Operability/Complexity

The operability and complexity issues for each glass production method are summarized in Table 4-3.

4.5.3 Maintainability

The maintainability issues for each glass production method are summarized in Table 4-4.

Table 4-3. Glass Production Method Operability and Complexity.

Cullet	<ol style="list-style-type: none"> 1. Since the cullet is brittle, it may break into fine particles each time it is transported. These fines must be collected and processed. The plant's (TOE) may be severely affected if excessive cullet breakage occurs.
Marbles	<ol style="list-style-type: none"> 1. Marble production produces fewer fines than cullet production. Production efficiency increases since less fine material is recycle. 2. Since maintenance requirements are high, several spare equipment items must be provided to maintain the plant's TOE. 3. Feeder units are used to distribute molten glass from the melters to the marble machines. Each feeder unit has a channel with multiple spouts and orifices. For cases that require large quantities of marble machines, the feeder unit designs become complicated because of the long channel lengths and number of spouts required. Therefore, multiple melters and feeder units are required for these cases. 4. In commercial plants, operators are required to operate and maintain the marble making machines. Operators must constantly look for the occurrence of machine failures and problems with the glass. Shears and rollers require periodic maintenance. Typically, one operator is required for each three marble machines; however, the actual number of required operators per machine is dependent on plant conditions. 5. The annealing process is very important for marble stabilization. This process must be properly controlled to produce an acceptable waste form that is not de-vitrified or brittle. 6. The temperature and viscosity at the end of the feeder channel where the molten glass stream passes through the shears and falls as a gob are critical in order to produce a good waste form. 7. The optimal marble size must be determined so that they can be produced and handled efficiently without breakage.

Table 4-3. Glass Production Method Operability and Complexity.

Gems	<ol style="list-style-type: none"> 1. Gem production produces fewer fines than cullet production. Production efficiency increases since less fine material is recycle. 2. Since maintenance requirements are high, several spare equipment items must be provided to maintain the plant's TOE. 4. In commercial plants, operators are required to operate and maintain the gem making machines. Operators must constantly look for the occurrence of machine failures and problems with the glass. Shears require periodic maintenance. Typically, one operator is required for each three gem machines; however, the actual number of required operators per machine is dependent on plant conditions. 5. The annealing process is very important for gem stabilization. This process must be properly controlled to produce an acceptable waste form that is not de-vitrified or brittle. 6. The temperature and viscosity at the end of the feeder channel where the molten glass stream passes through the shears and falls as a gob are critical in order to produce a good waste form. 7. The optimal gem size must be determined so that they can be produced and handled efficiently without breakage.
Monolith	<ol style="list-style-type: none"> 1. Once the glass stream leaves the melter pour spout and enters the waste container, no more additional glass handling systems are required. 2. The control features required to support discontinuous pour operations for monolithic forms are more complex than continuous pour operations.

Table 4-4. Glass Production Method Maintainability.

Cullet	1. Cullet is abrasive and equipment is highly mechanically configured. Hence, equipment may require frequent maintenance.
Marbles	<ol style="list-style-type: none">1. Marbles are less abrasive than cullet. Downstream handling equipment may therefore require less maintenance than do the downstream cullet handling equipment.2. Marble production rate is a function of marble size. Smaller marbles require more marble machines: large quantities of machines require more maintenance of production systems.3. A water cooling device and lubricator are required for the marble machine's shearing mechanism. These provisions and the maintenance of these provisions may create difficulties.
Gems	<ol style="list-style-type: none">1. Gems are less abrasive than cullet. Downstream handling equipment may therefore require less maintenance than do the downstream cullet handling equipment.2. Gem production rate is a function of gem size. Smaller gems require more gem machines: large quantities of machines require more maintenance of production systems.3. A water cooling device and lubricator are required for the gem machine's shearing mechanism. These provisions and the maintenance of these provisions may create difficulties.
Monolith	1. Monolithic pour system maintenance is relatively simple compared to the other options.

4.5.4 Maturity of Technology

The technology maturity issues for each glass production method are summarized in Table 4-5.

Table 4-5. Glass Production Method Technology Maturity.

Cullet	1. Cullet systems have not been previously used in a HLW facility. Adapting this equipment for remote operation may create unique challenges. Additional studies are required to determine the feasibility of adapting off-the-shelf hardware for this application.
Marbles	1. Off-the-shelf commercial marble making equipment is not suitable for remote nuclear applications. Extensive modifications will be required. Little is known about the feasibility of utilizing marble making equipment in a high-level facility. Several issues such as machine design, remoteability, maintenance, and cost exist. Future efforts are required to study these attributes.
Gems	1. Off-the-shelf commercial gem making equipment is not suitable for remote nuclear applications. Extensive modifications will be required. Little is known about the feasibility of utilizing gem making equipment in a high-level facility. Several issues such as machine design, remoteability, maintenance, and cost exist. Future efforts are required to study these attributes.
Monolith	1. Monolithic pour technology is developed for this application.

4.5.5 Schedule Impacts

None.

4.5.6 Regulatory Impacts

None.

4.5.7 Safety

There are no significant safety concerns regarding the various glass waste form production processes. Although there are potentially more glass fines for the cullet process, the production equipment is inside the vitrification building and any releases are mitigated by the Zone I confinement systems.

4.5.8 Costs

This section presents a cost comparison of cullet, marble, gem, and monolithic glass production processes and their associated facility requirements. This method selects as the reference case the 20-MT per day monolithic glass production process. Using the equipment and facility definitions of the reference case, equipment deletions, equipment additions, and facility adjustments have been quantified for each of the other glass form processes. Associated cost additions and deletions for these adjustments have been estimated and the results are reported in Table 4-6. All costs are reported in 1994 direct costs. No other costs such as escalation, contingency, project management, construction management or engineering are included. Appendix B presents the basis for these estimates.

Table 4-6. Relative Cost Differences in Glass Waste Form Production Processes.

Production Process	Relative cost difference \$ million
Cullet	33.8
Marble	31.3
Gem	28.8
Monolithic (Reference Case)	0.0

The cullet production equipment and its associated facility requirements are \$33.8 million more expensive than the reference case; the marble production equipment and its associated facility requirements are \$31.3 million more expensive than the reference case; and the gem production equipment and its associated facility requirements are \$28.8 million more expensive than the reference case.

5.0 WASTE FORM CONTAINERS

This section addresses several HLW form container sizes and configurations. Six small container configurations with monolithic glass and six large container configurations with cullet, gem, marble, or monolithic glass waste forms are discussed in the paragraphs below. A summary of container sizes, weights, production rates and quantities is presented in Table 5-1. Glass weights for the cases with cullet, marbles, or gems are listed in the table as cullet weights. The glass weights with marbles or gems vary slightly depending on final packing densities.

The outer dimensions of all large containers are based on the dimensions of the overpack defined in Case 2. It should be noted that none of the container configurations discussed in this report have been optimized. The final designs of the canisters and casks are interrelated with the following:

- Interim and Final Storage
- Offsite Transportation
- Canister and Cask Constructability and Cost
- Canister and Cask Process Equipment Design
- Canister and Cask Handling Facility Design
- Decay Heat, Glass Centerline Temperatures, and Neutron Activation.

Future engineering studies should be performed to investigate the mechanical design details of the canisters and casks before, and in conjunction with, the definition of the systems related to the items listed above.

In container configurations that contain overpack shielded casks, the shielded casks are intended for onsite transportation and interim storage only. Therefore, these casks provide shielding but not a hermetic seal.

5.1 UNSHIELDED SMALL CANISTERS (MONOLITH), CASE 1

Figure 5-1 shows a conceptual sketch of a small unshielded canister filled with monolithic glass. It is assumed that the configuration of the canister is similar to the Hanford Waste Vittrification Plant (HWVP) canister. The canister shall be 4.57 m tall and 0.68 m in diameter. The canister is made of stainless steel. It is assumed that the canister is 0.95 cm thick on all surfaces. The calculated empty weight of the canister is 0.785 MT.

The following assumptions are made for the monolithic glass in the canister:

- The canister is filled with glass to approximately 89 cm from the top of the canister.

Table 5-1. High-Level Waste Form Container Summary.

Case	Waste form container	Glass wt. metric tons	Canister wt. metric tons	Overpack wt. metric tons	Cask wt. metric tons	Total wt. metric tons	Product'n rate hours per container	Total no. of containers required	Outer dimensions m (O.D.) x m (Height)
1	Unshielded small canisters (monolith)	3.33	0.785	--	--	4.12	4.0	6,817	0.68 x 4.57
2	Unshielded 4-pack overpack canisters for unshielded small canisters (monolith)	13.32	3.14	6.5	--	22.96	16.0	1,705	1.75 x 4.65
3A	Metal shielded casks for unshielded 4-pack overpack canisters (monolith)	13.32	3.14	6.5	65.9	88.86	16.0	1,705	2.24 x 5.07
3B	Concrete shielded casks for unshielded 4-pack overpack canisters (monolith)	13.32	3.14	6.5	90.0	112.96	16.0	1,705	3.20 x 6.03
4	Large shielded casks (cullet, marbles, or gems)	8.7	--	--	46.3	55.0	10.42	2,610	1.75 x 4.65
5	Large unshielded canisters and metal overpack shielded casks (cullet, marbles, or gems)	16.4	5.6	--	63.0	85.0	19.68	1,385	2.22 x 5.1
6	Large unshielded canisters and concrete overpack shielded casks (cullet, marbles, or gems)	16.4	5.6	--	90.7	112.7	19.68	1,385	3.2 x 6.08
7	Large unshielded canisters, unshielded overpack canisters, and metal overpack shielded casks (cullet, marbles, or gems)	14.3	5.5	6.5	53.0	79.3	17.15	1,588	2.16 x 5.04

Table 5-1. High-Level Waste Form Container Summary.

Case	Waste form container	Glass wt. metric tons	Canister wt. metric tons	Overpack wt. metric tons	Cask wt. metric tons	Total wt. metric tons	Product'n rate hours per container	Total no. of containers required	Outer dimensions m (O.D.) x m (Height)
8	Large unshielded canisters, unshielded overpack canisters, and concrete overpack shielded casks (cullet, marbles, and gems)	14.3	5.5	6.5	73.8	100.1	17.15	1,588	3.01 x 5.89
9	Large containers (monolith)	24.8	6.5	--	--	31.3	29.76	916	1.75 x 4.65
10	Unshielded 7-pack overpack canisters for unshielded small canisters (monolith)	14.47	4.35	6.5	--	25.3	17.37	1,569	1.75 x 4.65
11	Unshielded 4-pack overpack canisters for unshielded HWVP-type canisters (monolith)	6.6	1.8	4.2	--	12.6	7.92	3,440	1.58 x 3.08

Figure 5-1. Unshielded Small Canisters (Monolith).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glass Per Day

- The specific density of the waste glass is 2,643 Kg/m³ irrespective of waste oxide loading.

Based on these assumptions, the total quantity of glass per canister is 1.26 m³ with a weight of 3.33 MT. For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. This plant uses the "enhanced sludge wash" pretreatment scheme and produces 46.7 wt% waste oxide glass. Based on these numbers, a canister is produced every 4.0 hours. The total number of canisters produced over the life of the plant is 6,817.

The dose rate on the outer surface of a canister is estimated to be 22,730 Msv/h.

5.2 UNSHIELDED 4-PACK OVERPACK CANISTERS FOR UNSHIELDED SMALL CANISTERS (MONOLITH), CASE 2

Figure 5-2 shows a conceptual sketch of small unshielded canisters filled with monolithic glass in an unshielded 4-pack overpack canister. The small canisters are identical to those described in Section 5.1. It is assumed that the overpack is a thin-walled cylinder with a flat bottom and a flat bolt-on top. The overpack's inner diameter is 1.70 m. It is assumed that the overpack fits into the HLW repository storage and shipping containers that the repository HLW multipurpose canisters fit into.

The calculated empty weight of the overpack canister is 6.5 MT. The weight of an overpack loaded with four canisters filled with monolithic glass is 22.96 MT. For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, an overpack is produced every 16 hours. The total number of overpacks produced over the life of the plant is 1,705.

The dose rate on the outer surface of an overpack canister is estimated to be 4,450 mSv/h.

5.3 SHIELDED CASKS FOR UNSHIELDED 4-PACK OVERPACK CANISTERS (MONOLITH)

Two shielded casks exist for the 4-pack overpack canisters. One of the casks is fabricated from metal and the other from concrete. Descriptions of the two shielded casks are presented below.

Figure 5-2. Unshielded 4-Pack Overpack Canisters for
Unshielded Small Canisters (Monolith).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glass Per Day

5.3.1 Metal, Case 3A

Figure 5-3 shows a conceptual sketch of a metal shielded cask for an unshielded 4-pack overpack canister that contains four canisters filled with glass. The 4-pack canister is described in Section 5.2. It is assumed that the cask is a cylinder with a flat bottom and flat bolt-on top. The cask's 25-cm thick wall yields a radiation dose rate of 0.1 mSv/h at the outer surface of the cask. The calculated empty weight of the cask is 65.9 MT. The weight of a cask that contains an overpack loaded with four canisters filled with monolithic glass is 88.86 MT. For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, a full cask is produced every 16 hours. The total number of overpacks produced over the life of the plant is 1,705.

5.3.2 Concrete, Case 3B

Figure 5-4 shows a conceptual sketch of a concrete shielded cask for an unshielded 4-pack overpack canister that contains four canisters filled with glass. The 4-pack canister is described in Section 5.2. It is assumed that the cask is a cylinder with a flat bottom and flat bolt-on top. The cask's 70-cm thick wall yields a radiation dose rate of 0.1 mSv/h at the outer surface of the cask. The calculated empty weight of the cask is 90 MT. The weight of a cask that contains an overpack loaded with four canisters filled with monolithic glass is 112.96 MT. For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, a full cask is produced every 16 hours. The total number of overpacks produced over the life of the plant is 1,705.

5.4 LARGE SHIELDED CASKS (CULLET, MARBLES, OR GEMS), CASE 4

Figure 5-5 shows a conceptual sketch of a large self-shielded cask filled with cullet. Alternatively, the cask could contain marbles or gems. Cask weights, production rates, and quantities may vary slightly with marbles or gems depending on their obtained packing densities. It is assumed that the cask is a carbon steel cylinder with a flat bottom and a flat top. The cask functions as a hermetically sealed waste form container and a radiation shield. It is assumed that the total shield thickness of the cask is 23 cm of steel on all surfaces and that this shielding thickness yields a radiation dose rate of 0.1 mSv/h at the outer surface of the cask. It is assumed that the cask contains trunnions and/or lifting lugs for turning and lifting. The calculated empty weight of the cask is 46.3 MT based on carbon steel as the material of construction.

The following assumptions are made for the glass cullet in the cask:

- The cask is filled with glass to approximately 0.3 m from the bottom of the cask's fill port.

Figure 5-3. Metal Shielded casks for Unshielded
4-Pack Overpack Canisters (Monolith).

Figure 5-4. Concrete Shielded Casks for Unshielded
4-pack Overpack Canisters (Monolith).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glass Per Day

Figure 5-5. Large Shielded Casks (Cullet, Marbles, or Gems).

High-Level Waste Vitrification Plant Production
Rate of 20 Metric Tons of Glass Per Day

- The specific density of the waste glass is $2,643 \text{ kg/m}^3$ irrespective of waste oxide loading. The packing density of the glass cullet is 0.70. This yields a bulk density of $1,850 \text{ kg/m}^3$.
- The shape of the cullet is cubic with a side dimension of 0.64 cm.
- The angle of repose for dry glass cullet is 35° .

These glass cullet assumptions are made for all of the cullet container options discussed in this report.

Based on these assumptions, the total quantity of glass cullet per cask is 4.70 m^3 with a weight of 8.7 MT. The total weight of a cask that is filled with glass is 55 MT. This heavy of a container may not be compatible with the design of the "in-shaft" handling equipment at the repository. This alternative could therefore be not acceptable to the repository program.

For the detached 20-MT per day HLW plant, the mass balance shows $2.27 \times 10^4 \text{ MT}$ of glass being produced over the life of the plant. This plant uses the "enhanced sludge wash" pretreatment scheme and produces 46.7 wt% waste oxide glass. Based on these numbers, a full cask is produced every 10.42 hours. The total number of casks produced over the life of the plant is 2,610.

5.5 LARGE UNSHIELDED CANISTERS AND METAL OVERPACK SHIELDED CASKS (CULLET, MARBLES, OR GEMS) (CASE 5)

Figure 5-6 shows a conceptual sketch of a large canister filled with cullet in a metal overpack cask. It is assumed that the cask is a cylinder with a flat bottom and a flat bolt-on top. The cask functions as a radiation shield for the canister. It is assumed that the total shield thickness of the canister plus the cask is 23 cm of steel and that this shielding thickness yields a radiation dose rate of 0.1 mSv/h at the outer surface of the cask. Assuming a canister thickness of 2.5 cm, the cask thickness is defined as approximately 21 cm. It is assumed that the cask contains trunnions and/or lifting lugs for turning and lifting. The calculated empty weight of the cask is 63 MT based on carbon steel as the material of construction.

It is assumed that the canister is a cylinder with a flat bottom and a dished head. The canister is made of stainless steel and is 2.5 cm thick on all surfaces. It is assumed that the canister contains provisions on its top for lifting. The calculated empty weight of the canister is 5.6 MT.

Based on glass cullet assumptions previously stated in Section 5.4, the total quantity of glass cullet per canister is 8.85 m^3 with a weight of 16.4 MT. The total weight of a cask that contains a canister filled with glass is 85 MT.

Figure 5-6. Large Unshielded Canisters and Metal Overpack
Shielded Casks (Cullet, Marbles, or Gems).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glas Per Day

For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, a full canister is produced every 19.68 hours. The total number of canisters produced over the life of the plant is 1,385.

5.6 LARGE UNSHIELDED CANISTERS AND CONCRETE OVERPACK SHIELDED CASKS (CULLET, MARBLES, OR GEMS) (CASE 6)

Figure 5-7 shows a conceptual sketch of a large canister filled with cullet in a concrete overpack cask. It is assumed that the cask is a cylinder with a flat bottom and a flat bolt-on top. The cask functions as a radiation shield for the canister. It is assumed that with a stainless steel canister thickness of 2.5 cm and a concrete cask thickness of 70 cm, the radiation dose rate at the outer surface of the cask is 0.1 mSv/h. It is assumed that the cask contains trunnions and/or lifting lugs for turning and lifting. The calculated empty weight of the concrete cask is 90.7 MT.

The canister is identical to the Case 5 canister described in Section 5.5. Recall that this canister is a cylinder with a flat bottom and a dished head. The canister is made of stainless steel and is 2.5 cm thick on all surfaces. It is assumed that the canister contains provisions on its top for lifting. The calculated empty weight of the canister is 5.6 MT.

Based on glass cullet assumptions previously stated in Section 5.4, the total quantity of glass cullet per canister is 8.85 m^3 with a weight of 16.4 MT. The total weight of a cask that contains a canister filled with glass is 112.7 MT.

For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, a canister is produced every 19.68 hours. The total number of canisters produced over the life of the plant is 1,385.

5.7 LARGE UNSHIELDED CANISTERS, UNSHIELDED OVERPACK CANISTERS, AND METAL OVERPACK SHIELDED CASKS (CULLET, MARBLES, OR GEMS) (CASE 7)

Figure 5-8 shows a conceptual sketch of a large canister filled with cullet in an unshielded overpack canister in a metal overpack cask. It is assumed that the cask is a cylinder with a flat bottom and a flat bolt-on top. The cask functions as a radiation shield for the two canisters. To achieve a radiation dose rate of 0.1 mSv/h at the outer surface of the cask, 23 cm of steel shielding is required. Therefore, if the canisters are both 2.5 cm thick, then the metal cask must be 18 cm thick. It is assumed that the cask contains trunnions and/or lifting lugs for turning and lifting. The calculated empty weight of the metal cask is 53 MT.

Figure 5-7. Large Unshielded Canisters and Concrete Overpack Shielded Casks (Cullet, Marbles, or Gems).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glas Per Day

Figure 5-8. Large Unshielded Canisters, Unshielded Overpack Canisters, and Metal Overpack Shielded Casks (Cullet, Marbles, or Gems).

It is assumed that the overpack canister is a cylinder with a flat bottom and a flat bolt-on top. This overpack canister serves as a containment barrier for contamination that was potentially not removed during the decontamination of the primary canister. This option was added to this study since the effectiveness of a cullet filling system and a non-abrasive decontamination system are unknown. This subject is addressed further in Section 6.2.

The overpack canister is made of stainless steel and is 2.5 cm thick on all surfaces. It has an outer diameter of 1.75 m. A 2.5-cm annular space is present between the overpack canister and the primary canister and also between the overpack canister and the metal overpack shield cask. It is assumed that the overpack canister contains provisions on its top for lifting. The calculated empty weight of the overpack canister is 6.5 MT.

It is assumed that the canister is a cylinder with a flat bottom and a dished head. The canister is made of stainless steel and is 2.5 cm thick on all surfaces. It is assumed that the canister contains provisions on its top for lifting. The calculated empty weight of the canister is 5.5 MT.

Based on glass cullet assumptions previously stated in Section 5.4, the total quantity of glass cullet per canister is 7.73 m³ with a weight of 14.3 MT. The total weight of a cask that contains an overpack canister and a primary canister filled with glass is 79.3 MT.

For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, a canister is produced every 17.15 hours. The total number of canisters produced over the life of the plant is 1,588.

5.8 LARGE UNSHIELDED CANISTERS, UNSHIELDED OVERPACK CANISTERS, AND CONCRETE OVERPACK SHIELDED CASKS (CULLET, MARBLES, OR GEMS) (CASE 8)

Figure 5-9 shows a conceptual sketch of a large canister filled with cullet in an unshielded overpack canister in a concrete overpack cask. It is assumed that the cask is a cylinder with a flat bottom and a flat bolt-on top. The cask functions as a radiation shield for the two canisters. To achieve a radiation dose rate of 0.1 mSv/h at the outer surface of the concrete cask, the cask must be 60.5 cm thick if both canisters are 2.5 cm thick. It is assumed that the cask contains trunnions and/or lifting lugs for turning and lifting. The calculated empty weight of the concrete cask is 73.8 MT.

Both canisters are identical to the Case 7 canisters described in Section 5.7. Recall that the overpack canister is a cylinder with a flat bottom and a flat bolt-on top. This overpack canister serves as a containment barrier for contamination that was potentially not removed during the decontamination of the primary canister.

Figure 5-9. Large Unshielded Canisters, Unshielded Overpack Canisters, and Concrete Overpack Shielded Casks (Cullet, Marbles, or Gems).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glass Per Day

The overpack canister is made of stainless steel and is 2.5 cm thick on all surfaces. It has an outer diameter of 1.75 m. A 2.5-cm annular space is present between the overpack canister and the primary canister and also between the overpack canister and the concrete overpack shield cask. It is assumed that the overpack canister contains provisions on its top for lifting. The calculated empty weight of the overpack canister is 6.5 MT.

It is assumed that the canister is a cylinder with a flat bottom and a dished head. The canister is made of stainless steel and is 2.5 cm thick on all surfaces. It is assumed that the canister contains provisions on its top for lifting. The calculated empty weight of the canister is 5.5 MT.

Based on glass cullet assumptions previously stated in Section 5.4, the total quantity of glass cullet per canister is 7.73 m³ with a weight of 14.3 MT. The total weight of a cask that contains an overpack canister and a primary canister filled with glass is 100.1 MT.

For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, a canister is produced every 17.15 hours. The total number of canisters produced over the life of the plant is 1,588.

5.9 LARGE CONTAINERS (MONOLITH) (CASE 9)

In this section, large container configurations for monolithic glass are discussed generically for cullet configuration comparison purposes only. All large container configurations for cullet can be applied to the monolithic configurations; however, since the technical feasibility of the monolithic configurations has not been verified, only one monolithic configuration is presented in this study. The technical feasibility of processing monolithic large containers is discussed in Section 6.3.

Figure 5-10 shows a conceptual sketch of a large un-shielded canister filled with monolithic glass. It is assumed that the canister is a stainless steel cylinder with a flat bottom and a flat top. The canister's 2.5-cm thickness yields an approximate radiation dose rate of 9,160 mSv/h at the outer surface of the canister. It is assumed that the canister contains trunnions and/or lifting lugs for turning and lifting. The calculated empty weight of the canister is 6.5 MT based on stainless steel as the material of construction.

The following assumptions are made for the glass in the canister:

- Ninety percent of the canister's internal volume is filled with glass.
- The specific density of the waste glass is 2,643 kg/m³ irrespective of waste oxide loading.

Based on these assumptions, the total quantity of glass per canister is 9.4 m³ with a weight of 24.8 MT. The total weight of a canister that is filled with glass is 31.3 MT.

Figure 5-10. Large Container (Monolith).

High-Level Waste Vittrification Plant
Production Rate of 20 Metric Tons of Glass Per Day

For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. Based on these numbers, a full canister is produced every 29.76 hours. The total number of canisters produced over the life of the plant is 916.

5.10 UNSHIELDED 7-PACK OVERPACK CANISTERS FOR UNSHIELDED SMALL CANISTERS (MONOLITH) (CASE 10)

Figure 5-11 shows a conceptual sketch of small unshielded canisters filled with monolithic glass in an unshielded 7-pack overpack canister. The small canister shall be 4.57 m tall and 0.54 m in diameter. The canister is made of stainless steel. It is assumed that the canister is 0.95 cm thick on all surfaces. The calculated empty weight of the canister is 0.621 MT.

The following assumptions are made for the monolithic glass in the canister:

- ~ The canister is filled with glass to approximately 89 cm from the top of the canister.
- ~ The specific density of the waste glass is $2,643 \text{ Kg/m}^3$ irrespective of waste oxide loading.

Based on these assumptions, the total quantity of glass per canister is 0.782 m^3 with a weight of 2.07 MT. For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. This plant uses the "enhanced sludge wash" pretreatment scheme and produces 46.7 wt% waste oxide glass. Based on these numbers, a canister is produced every 2.48 hours. The total number of canisters produced over the life of the plant is 10,983.

It is assumed that the overpack canister is identical to the overpack described in Section 5.2. The calculated empty weight of the overpack canister is 6.5 MT. The weight of an overpack loaded with seven canisters filled with monolithic glass is 25.3 MT. An overpack is produced every 17.37 hours. The total number of overpacks produced over the life of the plant is 1,569.

The dose rate on the outer surface of an overpack canister is estimated to be 4,500 mSv/h.

Figure 5-11. Unshielded 7-Pack Overpack Canisters for Unshielded Small Canisters (Monolith).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glass Per Day

5.11 UNSHIELDED 4-PACK OVERPACK CANISTERS FOR UNSHIELDED HWVP CANISTERS (MONOLITH) (CASE 11)

Figure 5-12 shows a conceptual sketch of HWVP-type unshielded canisters filled with monolithic glass in an unshielded 4-pack overpack canister. The HWVP canister is 3.0 m tall and 0.61 m in diameter. The canister is made of stainless steel. It is assumed that the canister is 0.95 cm thick on all surfaces. The calculated empty weight of the canister is 0.454 MT.

The following assumptions are made for the monolithic glass in the canister:

- The canister is filled with glass to approximately 70 cm from the top of the canister.
- The specific density of the waste glass is 2,643 Kg/m³ irrespective of waste oxide loading.

Based on these assumptions, the total quantity of glass per canister is 0.62 m³ with a weight of 1.65 MT. For the detached 20-MT per day HLW plant, the mass balance shows 2.27×10^4 MT of glass being produced over the life of the plant. This plant uses the "enhanced sludge wash" pretreatment scheme and produces 46.7 wt% waste oxide glass. Based on these numbers, a canister is produced every 1.98 hours. The total number of canisters produced over the life of the plant is 13,758.

It is assumed that the overpack is a thin-walled cylinder with a flat bottom and a flat bolt-on top. The overpack's inner diameter is 1.53 m. The calculated empty weight of the overpack canister is 4.2 MT. The weight of an overpack loaded with four canisters filled with monolithic glass is 12.6 MT. An overpack is produced every 7.92 hours. The total number of overpacks produced over the life of the plant is 3,440.

The dose rate on the outer surface of an overpack canister is estimated to be 4,500 mSv/hr.

5.12 SUMMARY COMPARISON

The paragraphs below summarize and discuss waste form containers in regards to process flowsheet/facility design impacts, operability/complexity, maintainability, maturity of technology, schedule impacts, regulatory impacts, safety, and costs. In some cases, no impacts have been identified and, hence, the text simply states "none." In other cases, topics are not applicable as alternative discriminators and are so stated.

Figure 5-12. Unshielded 4-Pack Overpack Canisters for Unshielded
HWVP Canisters (Monolith).

High-Level Waste Vitrification Plant
Production Rate of 20 Metric Tons of Glass Per Day

5.12.1 Process Flowsheet/Facility Design Impacts

Container sizes and shapes affect the designs of container processing equipment and the facilities that house these equipment. Facility and equipment designs for all small container cases (Cases 1, 2, 3A, 3B, 10, and 11) are similar. Likewise, facility and equipment designs for all large container cases are similar to each other. See Section 6.4.1 for a full discussion on container processing equipment impacts to facilities.

5.12.2 Operability/Complexity

Operability and complexity issues are more pertinent to container processing equipment than containers. See Section 6.4.2 for a discussion of container processing equipment operability and complexity issues.

5.12.3 Maintainability

Not applicable.

5.12.4 Maturity of Technology

High-level waste form container design is a well developed subject. However, specific container designs for each container option will have to undergo testing to meet handling and waste form criteria. One particular test would be a drop test.

5.12.5 Schedule Impacts

None.

5.12.6 Regulatory Impacts

Not applicable as discriminators between canister alternatives.

5.12.7 Safety

This section assumes that all primary canisters will be constructed such that all credible canister impact events will result without dispersion of radionuclides (e.g., canister drop accident). The producer of the primary canisters will institute the appropriate controls to ensure the quality of this program.

5.12.8 Costs

Canister and cask costs are summarized in Table 5-2. Cases 1, 2, 10 and 11 canister costs are the same for both building and bore hole storage options. All containers are estimated on a fabricated per mass basis in 1994 dollars and are reported as an annual cost. Stainless steel containers are estimated at \$10.45 per kilogram; carbon steel containers are estimated at \$3.48 per kilogram; and concrete containers are estimated at \$1.10 per kilogram. No other costs such as escalation, contingency, project management, construction management, or engineering are included in the table.

Other costs, such as administrative control features to ensure product quality, are not considered in these estimates. However, since these costs are common to all options, they are not expected to differentiate between canister options. The most significant element of the cost basis is the bulk materials required to fabricate each canister option. If detailed estimates are required, it is suggested that the estimate include, as a minimum, costs associated with capitalization, start-up, material, fabrication, quality control, operation, delivery, and overhead.

Shielded overpack options represent the most significant set of annual costs, ranging from \$23.4 to \$40.2 million. The unshielded overpack options range from \$12.3 to \$15.5 million annually, while the least expensive options are the monolithic canisters ranging from \$4.0 to \$4.4 million annually.

Section 3.0 presents a summary of total costs for all options considered in this study. In order to understand the impact of uncertainty on the canister costs presented in Table 5-2, a sensitivity analysis on the annual costs of canisters over the lifetime of the plant was performed. The estimated unit cost for each canister option reported in this section was varied and its effect on life-cycle costs was measured against the costs (base cases) reported in Table 3-3. Results indicate that life-cycle costs, reported as net present values, vary from 2 to 15 percent above the base cases when canisters unit costs are doubled. When canister unit costs are decreased by a factor of 2, net present values vary from 1 to 7 percent below the base cases. The results of this exercise indicate the following:

- Based on the information presented in this section, the impact of estimated canister cost to life-cycle cost is a second order effect.
- Canister estimates based on bulk material weight are an adequate cost basis for this study. Detailed canister cost estimates would not discriminate between reported life-cycle costs.

Life-cycle costs are developed for all of the alternatives in this study and are discussed in Appendix A of this report.

Table 5-2. High-Level Waste Form Container Costs.

Case	Waste form container	SS. WT. MT	CS. WT. MT	Concrete WT. MT	Unit price*\$	Total No. of containers required	Annual No. of containers required	Annual cost of containers \$ million
1	Unshielded small canisters (monolith)	0.785	N/A	N/A	8,843	6,817	487	4.3
2	Unshielded 4-pack overpack canisters for unshielded small canisters (monolith)	9.64	N/A	N/A	108,596	1,705	122	13.2
3A	metal shielded casks for unshielded 4-pack overpack canisters (monolith)	9.64	65.9	N/A	355,815	1,705	122	43.3
3B	Concrete shielded casks for unshielded 4-pack overpack canisters (monolith)	9.64	N/A	90.0	215,318	1,705	122	26.2
4	Large shielded casks (cullet, marbles, or gems)	N/A	46.3	N/A	173,692	2,610	186	32.4
5	Large unshielded canisters and metal overpack shielded casks (cullet, marbles, or gems)	5.6	63.0	N/A	299,425	1,385	99	29.6
6	Large unshielded canisters and concrete overpack shielded casks (cullet, marbles, or gems)	5.6	N/A	90.7	170,637	1,385	99	16.9
7	Large unshielded canisters, unshielded overpack canisters, and metal overpack shielded casks (cullet, marbles, or gems)	12.0	53.0	N/A	334,008	1,588	113	37.9
8	Large unshielded canisters, unshielded overpack canisters, and concrete overpack shielded casks (cullet, marbles, and gems)	12.0	N/A	73.8	222,693	1,588	113	25.3
9	Large containers (monolith)	6.5	N/A	N/A	73,223	916	65	4.8
10	Unshielded 7-pack overpack canisters for unshielded small canisters	10.85	N/A	N/A	122,192	1,569	112	13.7
11	Unshielded 4-pack overpack canisters for unshielded HWVP-type canisters	6.0	N/A	N/A	67,771	3,440	246	16.7

* Unit costs include 7.8 percent sales tax.

6.0 WASTE FORM CONTAINER PROCESSING SYSTEMS

Descriptions of container processing systems for the HLW form containers described in Section 5.0 are presented below. The following three basic systems are discussed: small container processing systems (monolith), large container processing systems (cullet, marbles, gems), and large container processing systems (monolith).

6.1 SMALL CONTAINER PROCESSING SYSTEMS (MONOLITH)

Small canisters may exit the vitrification facility as single containers or in sets of four or seven in overpack containers. The overpack containers act as secondary containment barriers for contamination. The overpacks also reduce the number of containers to be transported and stored on and offsite. Container Case 1 is the only case that utilizes a single container concept. In Case 2, four small canisters are processed in an overpack canister without any shielding provisions. In Cases 3A and 3B, the overpack canisters from Case 2 are placed into a third container which functions as a shielding container. The shielding containers are intended for onsite transportation and storage only. Cases 10 and 11 also utilize canisters that are placed into an overpack canister without any shielding provisions. Case 10 has seven canisters and Case 11 has four HWVP canisters.

6.1.1 With Overpacks

This section discusses the processing of container configurations that utilize canisters that are placed into overpacks. These configurations include container Cases 2, 3A, 3B, 10, and 11. A general system description that applies to all three cases is provided below. For Cases 3A and 3B, additional process steps are required to place the overpacks into the shielding containers.

6.1.1.1 General System Description

Overview. Figure 6-1 depicts a block flow diagram of the canister and overpack handling systems. All handling operations are automated as much as possible. Rail cars or trucks transport the canisters and overpacks to the vitrification plant site. A modified fork lift unloads the canisters from the rail cars and transports them to a staging area. A different modified fork lift or gantry crane unloads the overpacks and moves them to a separate staging area. In their respective staging areas, canisters and overpacks are cleaned, inspected, and stored until the vitrification plant is ready to process them.

Figure 6-1. High-Level Waste Vitrification Plant Production Rate of 20 Metric Tons of Glass per Day.

The diagram illustrates the glass manufacturing process, starting with raw materials entering a melter. The molten glass then passes through a glass separator and into a series of forming stations, including a crown sheet, a float bath, and a fire. The process continues through various annealing and finishing stages, such as a lehr, a fire, and a fire, before the final products are loaded onto a truck. A graphic scale at the bottom indicates distances from 0 to 40 feet.

GRAPHIC SCALE

0 10 20 40

A crane or monorail hoist lowers the canisters onto carts that are in a tunnel within the vitrification facility. Figure 6-2 shows a pictorial representation of the canister and overpack movement within this facility. Note that this figure shows relative elevations only and does not represent a section cut of a facility plan view. The cart system, which is considered to be a "dirty system," contains several carts on two independent concentric looping tracks. The carts transport the canisters to the canister fill cell where the canisters are filled with glass. The carts then transport the filled canisters to positions that are below a hatch in the fill cell. A canister handling robot lifts the canisters off of the carts and through the hatch into the canister cooling cell. In the cooling cell, canisters are allowed to cool in water-jacketed racks for approximately 50 hours. The empty cart then moves through a door and into the canister weld cell. A cooled canister is lowered with the canister handling robot through a hatch and onto the empty cart in the weld cell. In this cell, canisters are welded and inspected. Upon passing a successful inspection, the carts transport the canisters to the canister decontamination cell. A canister handling robot removes the canisters from the carts and places them into ultrasonic decontamination tanks. After the decontamination process is completed, the handling robot moves the canisters into rinse chambers. Nozzles within the rinse chambers spray water onto the canisters. When the canisters are dry, a canister handling robot lifts the canisters up through a hatch and into the smear test cell. The empty carts are then decontaminated and returned to receive more canisters via the looping tracks in the tunnel.

After successful smear tests and inspections are completed, the canister handling robot picks up the canisters and places them into overpacks. Each overpack is filled with four or seven canisters. The overpacks are brought into the overpack area on carts. This cart system, which is considered to be a "clean system," contains several carts on a single looping track. After the last canister is placed into an overpack, a cart transports the overpack to a weld and inspection area. After a successful inspection is performed, the cart moves the overpack into a smear test area. An overpack handling robot then picks up the overpack from the cart and places it on the smear test turntable. The empty cart then returns via its looping track to receive another overpack.

Upon completing a smear test, the handling robot transports the overpack into a decontamination area. The overpack is then decontaminated only if the smear test shows unacceptable contamination levels. If an overpack requires decontamination, it is transported back to the smear test station for a final smear test after the decontamination process is completed. The overpack leaves the decontamination area via the handling robot. The robot places the overpack on a stand that is located beneath a hatch. A crane lifts the overpack off of the stand and into the full-overpack staging building.

A transporter then moves the overpacks from the staging area to an onsite interim storage facility. Overpacks are stored until the repository is ready to accept them.

Canister Staging Area. The fork truck delivers the canisters to a cleaning area within the canister staging building. Canisters are cleaned and then transported via a crane or monorail system to an inspection area. Surface finish, dimensional tolerances, and basic canister integrity are checked. The crane then moves the canisters directly to the hatch

above the load-in tunnel. Canisters are then lowered through the hatch onto a cart within the tunnel. If the vitrification process is not ready to accept a canister, the monorail sets the canister down and the fork truck transports it to a storage area.

Canister Fill Cell Operations. Each cart train in the canister fill cell contains two positions for canisters. Position #1 is for plug removal and insertion. Position #2 is for canister filling.

The transfer cart moves a canister into position #1. Canisters enter the cell with their fill-port plugs in place. In position #1, the plug removal/insertion device removes the plug and temporarily stores it. The cart then moves the canister to position #2 which is beneath the melter pour spout. A retractable pour spout with a bellows is lowered to mate tightly with the canister. An alternative to the retractable bellows is to have a lift on the cart that raises the canister up to the pour spout. The pour spout assembly is vented to an offgas system. It is assumed that the canister is filled, vented, and moved within the allotted 4- to 8-hour cycle time.

The canister filling process is a key step within the canister handling system. Clean filling is essential for good plant operability. The mechanical design of the fill system significantly affects the design and operating philosophy of the facility. Therefore, this subject requires further study.

After canister filling is completed, the transfer cart moves the filled canister back to position #1 where the plug removal/insertion device installs the fill-port plug. The cart then moves the canister to a position below a hatch. The canister is lifted through the hatch with the canister handling robot that is housed in the above canister cooling cell. The empty cart then moves through a door and into the canister weld cell.

Canister fill cell operations are monitored through a shield window or via closed circuit television (CCTV).

Canister Cooling Cell Operations. Canisters are cooled in a separate, insulated, canister cooling cell. Canisters are brought into the cell with the cell's canister handling robot. The robot places the canisters into a water-cooled 30-position rack. The robot's operation is completely automated. Sixteen of the rack's 30 positions are for cooling and 14 positions are for lag storage. After each canister is cooled for approximately 50 hours, the handling robot moves it through a hatch and onto an empty cart in the weld cell.

Canister Weld Cell Operations. The canister weld cell contains two positions for canisters. Position #1 is used for canister welding and position #2 is used for canister inspection. Canisters are moved through a hatch and into the weld cell with the cooling cell's handling robot. Canisters are moved through and out of the canister weld cell with the canister transfer carts. Canister weld cell operations can be monitored through shield windows or via a CCTV.

Canister welding is accomplished with a tungsten-inert-gas (TIG) type welder. Two welders are normally kept within the cell for each cart train. One serves as a spare to the other. The welder is designed to work with or without filler material. Jib cranes that service positions #1 and #2 within the cell move the weld heads onto the canisters. To locate a welder on a canister, a pintle or locating provision on the canister's fill-port plug is required. It is assumed that the canister is welded within one hour.

Selection of the weld inspection technique depends on the canister's leak tightness criteria. At a leakage rate of 1×10^{-7} std cc He/sec, a helium mass spectrometer is required. At less stringent leakage rates, other methods are employed. For the purposes of this study, it is assumed that the mass spectrometer arrangement is used. It is also assumed that the canister is inspected within one hour.

Canister Decontamination Cell Operations. A transfer cart moves a canister into the decontamination cell from the weld cell. The decontamination cell's canister handling robot lifts the canister from the cart and places it into an ultrasonic decontamination chamber. The robot then moves the canister into an adjacent rinse chamber. After the canister is dried, the smear test cell's canister handling robot picks up the canister and lifts it up directly into the smear test cell. The canister transfer cart is then decontaminated, dried, and returned to the load-in area to pick up another canister. The canister decontamination cell operations are monitored through a shield window or via CCTVs.

Smear Test Cell and Overpack Operations. Several canister inspection operations occur in the smear test cell. Canisters are smear tested, visually inspected, temperature surveyed, gamma surveyed, and neutron surveyed. The cell's canister handling robot lifts a canister into the cell from the decontamination cell and hangs the canister over the smear test station turntable. The robot's hook rotates the canister while smear tests are performed on the canister's bottom portion. After the smear clothes are analyzed and if the radiation counts are below the allowed levels, the robot lowers the canister onto the turntable. The canister's sides and top portion are smear tested. The canister is temperature surveyed and a video recording is then made of the entire canister while the canister rotates on the turntable. The CCTV that provides the video signals to the recorder is mounted on a lift platform. This platform enables the CCTV to view the entire length of the canister.

After a successful smear test is completed, the robot lifts and transports the canister to the overpack area near the opposite end of the smear test cell. Before the overpacking operation occurs, canisters are surveyed for gamma and neutron levels in a shielded area adjacent to the overpack position. The robot then places the canister into an overpack that is on a transfer cart. The overpack is brought into the cell via the cart with its lid on. The robot removes the lid and places it in the cell. After the maximum number of canisters is placed into the overpack, the robot picks up the lid and places it back on the overpack. The transfer cart then moves the filled overpack into the overpack weld cell.

Overpack Weld Cell Operations. Filled overpacks are transported into the weld cell with transfer carts. The carts travel on a single looping track. Before welding, the overpacks' lids are bolted on. The lids are then seal welded with a TIG-type welder. The carts then move the overpacks to an inspection area. Following a successful inspection, the carts transport the overpacks to the overpack smear test cell.

Overpack Smear Test, Decontamination, and Load Out Operations. An overpack enters the overpack smear test cell on a cart. The cell's overpack handling robot lifts the overpack from the cart and hangs it over the smear test station turntable. The robot's hook rotates the overpack while smear tests are performed on the overpack's bottom portion. After the smear clothes are analyzed and if the radiation counts are below the allowed levels, the robot lowers the overpack onto the turntable. The overpack's sides and top portion are smear tested. The overpack is temperature surveyed and a video recording is then made of the entire overpack while the overpack rotates on the turntable. The CCTV that provides the video signals to the recorder is mounted on a lift platform. This platform enables the CCTV to view the entire length of the overpack.

After a successful smear test is completed, the robot lifts and transports the overpack to a decontamination cell. The overpack is decontaminated only if the smear test shows unacceptable contamination levels. If an overpack requires decontamination, it is transported back to the smear test station for a final smear test after the decontamination process is completed. The overpack leaves the decontamination area via the handling robot. The robot places the overpack on a stand that is located beneath a hatch. A crane then lifts the overpack off of the stand and into the full-overpack staging building.

Canister Transfer Cart System. As mentioned in the preceding paragraphs, canister transfer carts move canisters through the canister load-in, fill, weld, and decontamination cells. This section describes the cart system configuration that is assumed for this study. Six carts on each canister train are required to achieve plant operability. Cart locations are as follows:

Location	No. of Carts per Train
Load-in Area	1
Fill Cell	1
Weld Cell	2
Decon Cell	1
Spare	<u>1</u>
Total	6

The carts and cart rail system must have the following features:

- Carts must have a load capacity equal to the weight of a full canister.
- Carts must have a reversible multi-speed drive system.
- Carts must have redundant drives and brakes.

- The cart rail system must have a cart retrieval system.
- The cart rail system must have a control system that allows independent operation of each individual cart.

Overpack Staging Building Operations. The gantry crane delivers empty overpacks to a cleaning area within the overpack staging building. Overpacks are cleaned and then transported via the gantry crane to an inspection area. Surface finish, dimensional tolerances, and basic overpack integrity are checked. The gantry crane then moves the overpacks to an area near the hatch above the load-out well. The overpack staging building crane then picks up the empty overpack and lowers it onto a cart in the overpack entry tunnel. If the vitrification process is not ready to accept an overpack, the gantry crane transports the overpack to a storage area.

Overpack Transfer Cart System. As mentioned in the preceding paragraphs, overpack transfer carts move overpacks through the overpack load-in, fill, weld, and smear test cells. This section describes the cart system configuration that is assumed for this study. Six carts are required to achieve plant operability. Cart locations are as follows:

Location	No. of Carts
Load-in Area	1
Overpack Area	1
Weld Cell	1
Smear Test Cell	1
Load-out Area	1
Spare	<u>1</u>
Total	6

The carts and cart rail system must have the following features:

- Carts must have a load capacity equal to the weight of a full overpack.
- Carts must have a reversible multi-speed drive system.
- Carts must have redundant drives and brakes.
- The cart rail system must have a cart retrieval system.
- The cart rail system must have a control system that allows independent operation of each individual cart.

Recycle of Monolithic Glass. Two basic methods have been identified to recycle monolithic glass that is contained in canisters. The first method involves remelting the glass and pouring it out of the canister. The glass is poured into a water bath and the resulting cullet is then crushed and recycled back to the melter. Glass heating could be achieved with a heater assembly that attaches to the canister. An offgas system connection would be required to collect the fumes and steam that offgases from the glass and water bath.

Figure 6-3. Recycled Glass Melter (Static).

The second method involves cutting the metal canister away from the glass and mechanically breaking the glass into processable chunks. The chunks are then crushed and recycled back to the melter. A process would also need to be developed to separate the metal chips from the glass chips. Separating the glass from the canister's stainless steel may be a difficult task since hot glass tends to bond to hot metal.

For the purposes of this study, the glass heating method was chosen as the method for monolithic glass recycle. A sketch of the recycle device is shown in Figure 6-3. The canister with a hole drilled in its bottom is lowered into the device. High temperature heaters are turned on and the glass melts. The melted glass pours into a water bath where cullet is formed. The offgas system connection vents steam and other fumes from the recycle device. The cullet then falls into a set of roll crushers that smash the cullet into fine pieces. The resulting slurry is then eventually pumped to the melter feed system. The recycle equipment costs are included in the vitrification building cost estimates for all small monolithic container cases.

Overpacks in Shield Containers. For container Cases 3A and 3B, additional equipment and facilities are required to place the overpack canisters into shield containers. This additional equipment essentially consists of a third set of equipment items such as handling, inspection, bolting/welding, smear test, and decontamination equipment. Additional facility space for this equipment and a staging area for empty and full shield containers must also be provided.

6.1.1.2 Advantages. Compared to the large container systems, advantages of the monolithic pour canister system include the following:

- The solids handling systems associated with the cullet, gem, and marble machines are not required.
- The facility space for the cullet, marble, and gem handling systems is not required.

Compared to the systems for monolithic canisters without overpacks, the process systems for monolithic canisters with overpacks have the following advantages:

- The overpacking operation eliminates concerns about the effectiveness of the canister fill and decontamination processes since the overpack containers never enter contaminated cells.
- Fewer containers would be transported and stored onsite and at the repository.

6.1.1.3 Disadvantages. Compared to the large containers systems, disadvantages of the monolithic pour system include the following:

- More waste form containers are required for the monolithic cases. For the large container cases, 1,385 to 2,610 container sets are required. For the

monolithic cases, 6,817 to 13,758 canisters and 1,705 to 3,440 overpacks are required.

In regards to the relative number of containers required for each case, a brief discussion on container void space is appropriate. The void fractions of the two final waste forms are approximately the same. Although monolithic glass has a very small amount of void space within it, the upper portion of the canister has a relatively large void space. This void space exists since pouring molten glass to the rim of the canister is risky. This canister void space coupled with the void space between the four canisters in the overpack yields a total void space of approximately 40 percent. The void space within loose cullet is approximately 30 percent. This void space combined with the void space within the top portion of the canister yields a total void space of approximately 35 to 40 percent. The void space of the two cases are therefore about the same. Note that the void space with the 7-pack case will be slightly greater.

- For Cases 2, 3A, and 3B, two canister process trains are required to meet the canister production rates of one canister per 4.0 h and one overpack container per 16.0 h. Each canister train must therefore produce a canister every 8.0 h. Not much time is allowed for maintenance operations to be performed before canisters start to back up into lag storage. Catch-up capability of canisters in lag storage is also marginal since some individual process steps may require 2 to 4 h. This could lower the plant's TOE. In Cases 10 and 11, this disadvantage is magnified since canister production rates are higher.
- The glass product must be cooled while in the canister. Several major disadvantages are associated with this cooling method. A large canister cooling cell and canister cooling system are required. De-vitrification may become an issue if cooling times are too long. Excessive cracking may occur in the monolith if cooling times are too short. The amount of radiation shielding is significant since large quantities of glass will be in cooling or lag storage positions in the cell. The facility's HVAC system must be sized for larger heat loads. During loss of electrical power scenarios, a mitigating cooling system is required to cool the canisters and maintain cell concrete temperatures below critical temperatures. Heat shielding may be required for the cell concrete and canister handling equipment during normal operations.
- Lag storage capabilities are more difficult to obtain. During failures of downstream canister and overpack handling equipment, canisters must be accumulated in cell storage racks.
- Since hot glass enters the canisters, oxidation of the canister's surface will occur. Furthermore, cesium may exit the canister when the seal between the pour spout and canister is broken. The canister decontamination system may therefore be more complex; although, the use of an overpack may eliminate

this concern completely. Contamination levels within the fill cell may also be greater for the monolithic pour system.

- Recycle of off-spec monolithic glass is cumbersome.
- Glass sampling techniques may be more difficult requiring samples taken from the molten glass rather than glass chips within a cooled canister.
- The melter pour system is more complex since overfilling a canister with hot glass becomes an issue.
- If a canister were to be over filled, excess glass clean-up would be a relatively difficult operation.
- The canister handling cells must be maintained remotely.

Compared to the systems for monolithic canisters without overpacks, the process systems for monolithic canisters with overpacks have the following disadvantages:

- Two containers are required to process the waste form. This adds complexity and cost to the overall project.
- Essentially two sets of container process equipment (cranes, welders, smear test stations, decontamination units, etc.) are required. One set is required to process the canisters and another set is required for the overpacks.
- The additional equipment set requires additional facility space.

6.1.1.4 Concerns and Uncertainties. If off-spec conditions occur frequently, recycle of off-spec monolithic glass in containers may be difficult to accomplish.

6.1.2 Without Overpacks

This section discusses the processing of container Case 1. This case is the only small container configuration that utilizes a single container concept.

6.1.2.1 General System Description. The basic steps for processing a single container are identical to those of the overpack cases except for the absence of the overpack containers and their associated equipment and facility requirements. These process steps are described in Section 6.1.1.1.

It should be noted that the process described in Section 6.1.1.1 is feasible only if the proposed canister decontamination step works well enough so that canisters can be removed

from the vitrification building. If smear test levels are not acceptable, then a decontamination system similar to that of the HWVP may be necessary.

The HWVP decontamination system uses a frit-blast process. In addition to canister handling facility modifications, the incorporation of this system would also require changes to the main process streams since spent frit must be recycled back to the melter feed system. For this study, it is assumed that the ultrasonic decontamination chamber will perform adequately.

6.1.2.2 Advantages. Compared to the large container systems, advantages of the monolithic pour canister system without overpacks include the following:

- The solids handling systems associated with the cullet, gem, and marble machines are not required.
- The facility space for the cullet, marble, and gem handling systems is not required.

Compared to the systems for monolithic canisters with overpacks, the process systems for monolithic canisters without overpacks have the following advantages:

- Only one container is required to process the waste form. This reduces the plant's complexity and cost.
- Only one set of container process equipment (cranes, welders, smear test stations, decontamination units, etc.) is required.
- Less facility space is required since only one set of container processing equipment is utilized.

6.1.2.3 Disadvantages. Compared to the systems for monolithic canisters with overpacks, the process systems for monolithic canisters without overpacks have the following disadvantages:

- The use of a single container creates concerns about the effectiveness of the canister fill and decontamination processes since no overpack containers are used. A decontamination system similar to the HWVP system may need to be used. This substantially impacts the overall vitrification process.
- More containers would be transported and stored onsite and at the repository.

Compared to the large containers systems, disadvantages of the monolithic pour system without overpacks include the following:

- More waste form containers are required for the monolithic case. For the large container cases, 1,385 to 2,610 container sets are required. For the monolithic case, 6,817 canisters are required.
- Two canister process trains are required to meet the canister production rate of one canister per 4.0 hours. Each canister train must therefore produce a canister every 8.0 hours. Not much time is allowed for maintenance operations to be performed before canisters start to back up into lag storage. Catch-up capability of canisters in lag storage is also marginal since some individual process steps may require 2 to 4 hours. This could lower the plant's TOE.
- The glass product must be cooled while in the canister. Several major disadvantages are associated with this cooling method. A large canister cooling cell and canister cooling system are required. De-vitrification may become an issue if cooling times are too long. Excessive cracking may occur in the monolith if cooling times are too short. The amount of radiation shielding is significant since large quantities of glass will be in cooling or lag storage positions in the cell. The facility's HVAC system must be sized for larger heat loads. During loss of electrical power scenarios, a mitigating cooling system is required to cool the canisters and maintain cell concrete temperatures below critical temperatures. Heat shielding may be required for the cell concrete and canister handling equipment during normal operations.
- Lag storage capabilities are more difficult to obtain. During failures of downstream canister handling equipment, canisters must be accumulated in cell storage racks.
- Since hot glass enters the canisters, oxidation of the canister's surface will occur. Furthermore, cesium may exit the canister when the seal between the pour spout and canister is broken. The canister decontamination system may therefore be more complex. Contamination levels within the fill cell may also be greater for the monolithic pour system.
- Recycle of off-spec monolithic glass is cumbersome.
- Glass sampling will be more difficult since hot glass sampling may be required if glass chips can not be removed from within the canister.
- The melter pour system is more complex since overfilling a canister with hot glass becomes an issue.

- If a canister were to be over filled, excess glass clean-up would be a relatively difficult operation.
- The canister handling cells must be maintained remotely.

6.1.2.4 Concerns and Uncertainties. The monolithic canister option without overpacks contains the following concerns and uncertainties:

- If off-spec conditions occur frequently, recycle of off-spec monolithic glass in containers may be difficult to accomplish.
- The use of a single container creates concerns about the effectiveness of the canister fill and decontamination processes since no overpack containers are used. A decontamination system similar to the HWVP system may need to be used. This substantially impacts the overall vitrification process.

6.2 LARGE CONTAINER PROCESSING SYSTEMS (CULLET, MARBLES, GEMS)

Large containers filled with cullet, marbles, or gems may exit the vitrification facility as a single container or as a container that is placed into a secondary container or secondary container set. The secondary containers may act as shielding devices and/or secondary containment barriers for contamination. Container Case 4 is the only case that utilizes a single container concept. This single container must function as a shielding and containment device. In Cases 5 and 6, a single container must function as the containment device, however, a secondary container is utilized as a shielding device. In Cases 7 and 8, two containers are used for containment. These containers are then placed into a third container which acts as the shielding container.

In container configurations that contain overpack shielded casks (Cases 5, 6, 7, and 8), the shielded casks are intended for onsite transportation and interim storage only. Therefore, these casks provide shielding but not a hermetic seal.

All container processing systems discussed in this section are presented with cullet as the glass waste form. Alternatively, the containers could contain marbles or gems. The basic processes remain the same for all waste forms; however, container weights, production rates, and quantities may vary slightly depending on waste form packing densities.

During the initial stages of this study, it was proposed that self-shielded casks be filled directly with cullet. The casks would be filled, sealed, decontaminated, inspected, and removed from the vitrification facility without an overpacking procedure. This concept seemed reasonable since the plant under study utilizes a cullet-fill method. Since the canister does not contact hot glass at temperatures near 1,150 °C, the potential for molten glass, oxidation, and cesium sublimate to contact the outside surfaces of the canister does not exist. It was postulated that a spray wash system could be used to decontaminate the self-shielded

casks rather than a harsh, frit-blast process as was used in the Hanford Waste Vitrification Plant (HWVP).

Even though the decontamination of casks could be made even easier by polishing the cask's outer surfaces, there still exists the potential for relatively large quantities of small particles to rest on all surfaces of the casks. The effectiveness of a spray wash system was questioned since transportation requirements are stringent. It is assumed that alpha levels must be less than 220 dpm/100 cm² and beta/gamma levels must be less than 2,200 dpm/100 cm² (reference: HWVP Technical Data Package, SD-HWV-DP-001, Revision 6P, Section 18, Item 180, page 1). To eliminate the uncertainty of the problem, the overpack method was added to the work scope as an additional option. This method insures that contamination problems are minimized since the cask never enters the contaminated process cells. A complete discussion of both systems is described below.

6.2.1 With Overpacks

This section discusses the processing of container configurations that utilize a canister that is overpacked into a secondary container or secondary container set. The secondary containers may act as shielding or contamination confinement containers. Container Cases 5 and 6 utilize an overpack that is for shielding only. Cases 7 and 8 utilize two overpacks, one for containment and the second one for shielding. One generic canister and overpacking process is discussed below for Cases 5, 6, 7, and 8, even though each container option is processed in a slightly different manner.

6.2.1.1 General System Description

Overview. Cullet is formed by pouring molten glass into a water quench flume. As the glass enters the flume, the resulting thermal shock causes the glass to fracture into small pieces. The glass can then be homogenized, dried, and poured into canisters. The filled canisters are then placed into overpack casks. Figure 6-4 depicts a block flow diagram of the canister and cask handling systems.

Rail cars transport the empty canisters and casks to the vitrification plant site. A modified fork lift unloads the canisters from the rail cars and transports them to a staging area. A gantry crane unloads the casks and moves them to a separate staging area. In their respective staging areas, canisters and casks are washed, inspected, and stored until the vitrification plant is ready to process them.

A monorail hoist lowers the canisters onto carts that are in a tunnel within the vitrification facility. Figure 6-5 shows a pictorial representation of the canister and cask movement within this facility. The cart system, which is considered to be a "dirty system," contains several carts. The carts transport the canisters to the canister fill cell where they are filled with cullet. The carts then transport the canisters to the canister weld cell where canister welding and inspection occurs. Upon passing a successful inspection, the carts transport the canisters to the canister decontamination cell. An overhead crane removes the

canisters from the carts and places them on a stand. Nozzles within the cell spray decontamination solution and water onto the canisters. When the canisters are dry, the overhead crane picks up and transports the canisters to the smear test cell. The carts are then decontaminated and returned to receive more canisters via a looping track in the tunnel.

After successful smear tests and inspections have been completed, the overhead crane picks up the canisters and places them onto a "clean" cart. The cart transports the canisters into the load-out tunnel. The tunnel contains its own overhead crane. This crane removes the canisters from the canister cart and places them into casks that are on a cask cart. The cask cart transports the filled casks into the load-out well. An overhead crane within the cask staging area removes the casks from the load-out well. Empty casks enter the facility in the reverse order as described above.

Casks are bolted, welded, smear tested, and inspected in the cask staging area. A transporter then transports the casks from the staging area to an onsite interim storage facility. Casks are stored until the repository is ready to accept them. After final inspections are completed, the gantry crane or transporter loads the casks onto rail cars for shipment to the repository.

Canister and Cask Transportation. Rail cars transport empty canisters and casks from the vendor's fabrication shop to the waste facility and then to the repository. Additional trade studies are required to optimize the relationships between the final container design sizes and weights and the transportation arrangements. For example: The maximum shipping weights and shielding requirements may determine the container size and thickness which, in turn, determines the amount of waste glass per container. This waste glass per container results in specifying the number and production rate of containers which, ultimately, determines the facility designs and costs. These additional trade studies apply to all of the large container options. Offsite transportation methods are discussed further in Section 9.0 of this report.

Canisters and casks arrive at the waste facility on their sides in rail-car shipping saddles. A fork truck unloads and transports the canisters to the canister staging area. The fork truck is fitted with a special barrel handler that lifts, uprights, and carries the canisters. A gantry crane unloads and transports the casks to the cask staging area. The gantry crane's lifting yoke used in conjunction with the casks' trunnions is used to lift, upright, and transport the casks.

Canister Staging Area. The fork truck delivers the canisters to a wash area within the canister staging building. Canisters are washed with cleaning solution; rinsed with water; dried; and transported via a monorail system to an inspection area. Surface finish, dimensional tolerances, and basic canister integrity are checked. The monorail then moves the canister directly to the hatch above the load-in tunnel. Canisters are then lowered through the hatch onto a cart within the tunnel. If the vitrification process is not ready to accept a canister, the monorail sets the canister down and the fork truck transports it to a storage area. The storage area is sized to hold about 30 canisters. This quantity is approximately equal to one month of plant production.

Figure 6-4. Canister and Cask Handling System Block Flow Diagram.

Figure 6-5. Cask and Canister Handling System.

Canister Fill Cell Operations. The canister fill cell contains two positions for canisters. Position #1 is for plug removal and insertion and position #2 is for canister filling. The transfer cart moves a canister into position #1. Canisters enter the cell with their fill-port plugs in place. In position #1, the plug removal/insertion device removes the plug and temporarily stores it. The cart then moves the canister to position #2 which is beneath the cullet fill tube. The retractable fill tube is lowered to mate tightly with the canister. The fill tube contains a passage for cullet to flow into the canister and a separate passage for air to vent out of the canister. It is assumed that the canister can be filled within 2 hours.

The canister filling process is a key step within the canister handling system. Clean filling is essential for good plant operability. The mechanical design of the fill system significantly affects the design and operating philosophy of the facility. Therefore, this subject requires further study.

After canister filling has been completed, the transfer cart moves the filled canister back to position #1 where the plug removal/insertion device installs the fill-port plug. The cart then moves the canister to the canister weld cell.

Canister fill cell operations can be monitored through shielded windows or via a CCTV. If spillage occurs during canister filling, portions of the cell and canister can be cleaned with a manipulator-controlled vacuum hose assembly.

Canister Weld Cell Operations. The canister weld cell contains three positions for canisters. Position #1 is used for canister lag storage within the canister handling system. Position #2 is used for canister welding and position #3 is used for canister inspection. Canisters are moved into, through, and out of the canister weld cell with the canister transfer carts. Canister weld cell operations can be monitored through shielded windows or via a CCTV.

Canister welding is accomplished with a TIG type welder. Two welders are normally kept within the cell. One serves as a spare to the other. The welder can be designed to work with or without filler material. A jib crane that services positions #2 and #3 within the cell moves the weld head onto the canister. To locate the welder on the canister, a pintle or locating provision on the canister's fill-port plug is required. It is assumed that the canister can be welded within one hour.

Selection of the weld inspection technique will depend on the canister's leak tightness criteria. At a leakage rate of 1×10^{-7} std cc He/sec, a helium mass spectrometer would be required. At less stringent leakage rates, other methods could be employed. For the purposes of this study, it is assumed that the mass spectrometer arrangement is used. It is also assumed that the canister can be inspected within one hour.

Canister Decontamination Cell Operations. A transfer cart moves a canister into the decontamination cell from the weld cell. The decontamination cell contains the CDC-STC crane. This crane, which has a rotatable hook, operates within the entire cell and the adjacent smear test cell. The crane lifts the canister from the cart and moves it to a

decontamination area. Decon solution is sprayed onto the bottom portion of the canister while the canister is rotated with the crane's hook. The crane lowers the canister onto a stand. The crane's lifting provisions and the top and side portions of the canister are then sprayed with decontamination solution. The crane then lifts the canister. The canister's bottom portion is sprayed once again along with the canister stand. Each decon spray step is followed by a water rinse. After the canister is dried, the crane transports it to the smear test cell. The canister transfer cart is then decontaminated, dried, and returned to the load-in area to pick up another canister. The canister decontamination cell operations can be monitored through shielded windows or via CCTVs. It has been estimated that the entire canister decontamination process takes about 3 hours.

It is estimated that the canister decon process consumes about 12.5 m³ of water for each canister. It is assumed for this study that plain water is used as the decon solution. Other solutions such as trisodiumphosphate, acid, or caustic could also be used if necessary.

Smear Test Cell Operations. Several canister inspection operations occur in the smear test cell. Canisters are smear tested, visually inspected, temperature surveyed, gamma surveyed, and neutron surveyed. The CDC-STC crane transfers a canister into the smear test cell from the decontamination cell. The crane operates within the entire cell and the adjacent decontamination cell. The crane hangs the canister over the canister turntable. The crane's hook rotates the canister while smear tests are performed on the canister's bottom portion. After the smear cloths have been analyzed and if the radiation counts are below the allowed levels, the crane lowers the canister onto the turntable. The canister's sides and top portion are smear tested. A video recording is then made of the entire canister while the canister rotates on the turntable. The CCTV that provides the video signals to the recorder is mounted on a lift platform. This platform enables the CCTV to view the entire length of the canister. It is assumed that 5.5 hours are required to complete the smear tests and video inspections.

After a successful smear test and video recording have been completed, the crane lifts and transports the canister to a transfer cart on the opposite end of the smear test cell and then returns to the canister decontamination cell. While on the cart, the canister is temperature, gamma, and neutron surveyed. The cart then transports the canister out of the smear test cell and into the load-out cell. It is assumed that 50 minutes are required to perform the three surveys.

It is assumed that alpha levels greater than 220 dpm/100 cm² and beta/gamma levels greater than 2,200 dpm/100 cm² may be allowed since the canisters are overpacked into shielded casks. Radiation levels must be kept as low as possible though so that contact maintenance operations can be performed in the canister process cells.

Load-Out Tunnel Operations. Canisters enter the load-out tunnel on a transfer cart. The tunnel has a crane that removes the canister from the cart and places it into a cask that is on a cask transfer cart. The cask is brought into the cell via the cart with its lid on. The crane removes the lid and places it in the cell. After the crane places the canister in the

cask, it picks up the lid and places it back on the cask. The lid is bolted on and the transfer cart moves the filled cask into the load-out well.

Load-Out Well Operations. Empty casks enter the load-out well from above via an overhead crane in the cask staging area. The casks are placed onto a transfer cart that transports the casks to the load-out tunnel. The cart then returns to the well with a filled cask. The filled casks are removed from the well with the staging area crane.

Cask Staging Building Operations. The gantry crane delivers empty casks to a wash area within the cask staging building. Casks are washed with cleaning solution, rinsed with water, dried, and transported via the gantry crane to an inspection area. Surface finish, dimensional tolerances, and basic cask integrity are checked. The gantry crane then moves the casks to an area near the hatch above the load-out well. The cask staging building crane then picks up the empty cask and lowers it onto a cart in the load-out well. If the vitrification process is not ready to accept a cask, the gantry crane transports the cask to a storage area. The storage area is sized to hold about 30 casks. This quantity is approximately equal to one month of plant production.

Full casks are removed from the load-out well with the cask staging building crane. The casks' bolt-on lids are then welded if necessary. The casks are smear tested, inspected, and then transferred out of the building with the transporter.

Depending on the cask's design configuration, additional operations and associated equipment may be required in the cask staging building. For example, if casks are painted with an epoxy paint rather than plated with stainless steel, paint booths, drying areas, etc. may be required to paint welded or damaged casks.

Canister Transfer Cart System. As mentioned in the preceding paragraphs, canister transfer carts move canisters through the canister load-in, fill, weld, and decontamination cells. This section describes the cart system configuration that is assumed for this study.

Eight carts are required to achieve plant operability. Cart locations are as follows:

Location	No. of Carts
Load-in Area	1
Canister Fill Cell	1
Canister Weld Cell	3
Canister Decon Cell	1
Return Area	1
Spare	1
Total	8

The carts and cart rail system must have the following features:

- Carts must have a load capacity equal to the weight of a full canister.
- Carts must have a reversible multi-speed drive system.
- Carts must have redundant drives and brakes.
- The cart rail system must have a cart retrieval system.
- The cart rail system must have a control system that allows independent remote operation of each individual cart.

Other systems were considered for transporting canisters. The initial process flow sheet showed air pallets moving canisters. Air pallets would be difficult to use for the following reasons:

- Air pallets need to be connected with air sources. Management of air-source lines through shielded doors between cells would be challenging. Air flows within the cells would also tend to spread contamination.
- Air pallets require very flat surfaces. They also cannot travel over cracks larger than 0.16 centimeters in width.
- The air pallets would only lift the canisters. A propulsion and directional control system would need to be added.
- Recovery of a failed air pallet that contains a filled canister would be difficult if not impossible.

Systems other than motor-driven carts should be investigated in future engineering studies. Other systems could include cable-driven cart systems.

6.2.1.2 Advantages. Compared to the monolithic small container processing systems, the process systems for overpacked large containers filled with cullet, marbles, or gems have the following advantages:

- Fewer waste form containers are required for the cullet cases. For the cullet cases, 1,385 to 2,610 container sets are required. For the monolithic cases, 6,817 to 13,758 canisters and 1,705 to 3,440 overpacks are required.
- Only one process train is required to meet the production rate of one final waste form container per 10.4 to 19.68 hours. Canisters and overpack casks are both processed at this rate. This allows a significant amount of time for maintenance operations to be performed. Catch-up capability of cullet that is in lag storage due to equipment break-downs is also enhanced since no individual process step requires more than 8 hours. This enhances the plant's TOE.

- In the case of cullet, the glass product is cooled quickly and efficiently in a water stream. Several major advantages are gained with this cooling method. A large canister cooling cell and canister cooling system are not required. The amount of radiation shielding is minimized since large numbers of canisters are not in cooling or lag storage positions in the cell. The facility's HVAC system can be sized for lower heat loads. During loss of electrical power scenarios, a mitigating cooling system is not required to cool the canisters and maintain cell concrete temperatures below critical temperatures. No heat shielding is required for the cell concrete and canister handling equipment during normal operations. The offgas system for venting the water quench flume for the glass is relatively simple and inexpensive. The offgas system does not have to absorb the sensible heat of the glass during cooling.

Even though marbles and gems are not cooled in a water system, their container processing systems have the same advantages as the cullet container systems.

- Cells that process cullet-filled canisters can be contact maintained. This is accomplished by several methods. One method is to provide shielded lag storage areas for the unshielded canisters in process. Before a maintenance activity, process activities stop (e.g., canister fill) while all canisters are moved to shielded lag storage (applicable to Cases 5 through 8). Another method that permits contact maintenance requires that all process activities stop, except those processes that overpack canisters. Once all canisters are overpacked (shielded), maintenance activities can begin. Finally, Case 4 permits contact maintenance during most operational activities (provided all casks are closed) since the waste form container is a shielded cask.
- Lag storage capabilities are relatively easy to design. During failures of downstream canister and cask handling equipment, cullet can be stored in large bins instead of canisters in storage racks in cells. This feature is important since the canister process cells are contact maintained and canisters must be removed from the cells before performing maintenance activities.
- Since cold glass enters the canisters, no oxidation of the canister's surface will occur. The canister decontamination system can therefore be simplified.
- Off-spec cullet is relatively easy to retrieve and recycle.
- Glass sampling should be relatively easy since hot glass sampling does not have to be performed.
- The melter pour system can be simplified since overfilling a canister with hot glass is not an issue.

- If a canister were to be over filled, excess glass clean-up would be a relatively easy operation.

Compared to the systems for large containers without overpacks, the process systems for overpacked large containers have the following advantages:

- The overpacking operation eliminates concerns about the effectiveness of the canister fill and decontamination processes since the overpack containers never enter contaminated cells.
- The canister's thickness is 2.5 cm and the direct-fill cask's thickness is 23 cm. Therefore, the canister's lid design, upper section design, and weld method may be less complicated than the direct-fill cask's.
- The shipping weight of the final waste form is lighter since the shielding is not part of the final waste form.

6.2.1.3 Disadvantages. Compared to the systems for large containers without overpacks, the process systems for overpacked large containers have the following disadvantages:

- Two containers are required to process the waste form. This adds complexity and cost to the overall project.
- All cells that process the canisters have thick shielded walls since a canister provides very little shielding of the glass waste form.
- It is postulated that all cells that process containers are contact maintained. Since the primary canisters in the overpack cases do not provide adequate shielding, they have to be moved out of the subject cell before performing maintenance operations. This additional operation reduces plant efficiency. Large shielded doors between cells and personnel shielded doors are also required to perform contact maintenance.
- Essentially two sets of container process equipment (cranes, welders, smear test stations, decontamination units, etc.) are required. One set is required to process the canisters and another set is required for the casks.
- The additional equipment set requires additional facility space.

6.2.1.4 Concerns and Uncertainties. No major concerns or uncertainties exist for the overpacked large container options.

6.2.2 Without Overpacks

This section discusses the processing of container Case 4. This case is the only large configuration that utilizes a single shielded container/cask concept. In this case, glass waste is directly filled into the waste form container. This single container functions as both a shielding and containment device.

6.2.2.1 General System Description. The basic process steps for the direct fill option are identical to those of the overpack cases with the following exception. Rather than fill thin-walled canisters with cullet, thick shielded casks are filled directly with cullet, marbles, or gems. No overpacking operation is performed. Significant amounts of equipment and facility space are therefore eliminated.

6.2.2.2 Advantages. Compared to the monolithic small container processing systems, the process systems for direct-fill large containers have the same basic advantages as the large containers with overpacks.

Compared to the systems for large containers with overpacks, the process systems for directly-filled large containers have the following advantages:

- Only a single container/cask is required to process the waste form.
- Cells that process the casks do not require thick shielded walls since casks provide shielding of the glass waste form.
- Casks may not have to be removed from the process cells when maintenance operations need to be performed. Less material movement increases plant efficiency. Large shielded doors between cells and personnel shielded doors are also not required to perform contact maintenance.
- Only one set of process equipment (cranes, welders, smear test stations, decontamination units, etc.) is required for the shielded cask.

6.2.2.3 Disadvantages. A major disadvantage of the direct-fill option is that concerns about the effectiveness of the cask fill and decontamination processes exist.

6.2.2.4 Concerns and Uncertainties. Concerns and uncertainties for the processing of large containers/casks without overpacks are as follows:

- The cask filling process is a key step within the cask handling system. Clean filling is essential for good plant operability. The mechanical design of the fill system significantly affects the design and operating philosophy of the facility. Therefore, this subject requires further study.

- This option proposes that shielded casks be filled directly with cullet. On the surface, this concept seems reasonable. Since the cask does not contact hot glass at temperatures near 1,150 °C, the potential for molten glass, oxidation, and cesium sublimate to contact the outside surfaces of the cask does not exist. It is postulated that a spray wash system could be used to decontaminate the casks rather than a harsh, complex, frit-blast process as was used in the Hanford Waste Vitrification Plant (HWVP).

Even though the decontamination of casks could be made even easier by polishing the cask's outer surfaces, there still exists the potential for relatively large quantities of small particles to rest on all surfaces of the casks. The effectiveness of a spray wash system is questionable since transportation requirements are stringent. It is assumed that alpha levels must be less than 220 dpm/100 cm² and beta/gamma levels must be less than 2,200 dpm/100 cm². Knowing the effectiveness of the decontamination system is crucial for evaluating the feasibility of using the direct-fill method. Since little is known about the effectiveness of the spray wash decontamination process, this subject requires further study. Future studies may show that the direct-fill method can only be used if a more aggressive and complex decontamination system is used.

6.3 LARGE CONTAINER PROCESSING SYSTEMS (MONOLITH)

This section discusses the process systems required to pour monolithic glass into large containers. Canisters for this option are described in Section 5.9 (container Case 9).

6.3.1 General System Description

The basic process for the monolithic pour large container option is similar to that of the large container cullet, marbles, and gems cases. The major functional difference for the monolithic canister is that a cooling step must be added to the process after the canister is filled with hot glass.

Even though the functional steps are similar for all large container cases, the basic canister design, process equipment designs, and facility designs are significantly different. Major differences for the monolithic case include the following:

- The canister's internal design may be significantly different. Internal cooling fins, passages, and compartments may be required to increase the heat transfer rate. If several internal compartments are required, multiple canister fill port nozzles and a canister turning device may be required.
- The monolithic case does not require a cullet handling system.

- Canister handling cells would require remote maintenance. The remotely maintained cells do not require shielded doors like the contact maintained cullet-canister cells do.
- The pour system becomes more complicated. A heat shield is required to protect the cell walls and adjacent equipment items.
- A cooling cell is required. This cell requires a large amount of radiation shielding. The cell also requires a mitigating cooling system for loss of power scenarios. A larger HVAC system is also required.
- Canister lag storage positions are required.
- A more aggressive decontamination method may be required.
- A hot glass sample system is required.
- An off-spec monolithic glass recovery and recycle system is required.
- A spilled glass clean-up system is required.

6.3.2 Advantages

Advantages of the monolithic pour system include the following:

- Assuming that no "roping," "bird-nesting," or "coning" occurs, void space in the canister is minimized. The result is that fewer canisters are required to process the total volume of waste.
- The solids handling systems associated with cullet, marbles, and gems, are not required. Facility space is also not required for these items.

6.3.3 Disadvantages

Disadvantages of the monolithic pour system include the following:

- The glass product must be cooled while in the canister. Several major disadvantages are associated with this cooling method. A large canister cooling cell and canister cooling system are required. Canisters with hot glass are difficult to cool due to the large diameter of the glass monolith. Cooling times are long. The amount of radiation shielding is significant since large quantities of glass are in cooling or lag storage positions in the cell. The facility's HVAC system must be sized for larger heat loads. During loss of electrical power scenarios, a mitigating cooling system is required to cool the

canisters and maintain cell concrete temperatures below critical temperatures. Heat shielding is required for the cell concrete and canister handling equipment during normal operations.

- Lag storage capabilities are more difficult to obtain. During failures of downstream canister and cask handling equipment, canisters must be accumulated in cell storage racks.
- Since hot glass enters the canisters, oxidation of the canister's surface occurs. Furthermore, cesium may exit the canister when the seal between the melter's pour spout and canister is broken. The canister decontamination system may therefore be more complex.
- Off-spec monolithic glass in large containers is relatively difficult to retrieve and recycle.
- Glass sampling is more difficult since hot glass sampling must be performed.
- The melter pour system is more complex since overfilling a canister with hot glass becomes an issue.
- If a canister were to be over filled, excess glass clean-up would be a relatively difficult operation.
- The canister handling cells would need to be maintained remotely.

6.3.4 Concerns and Uncertainties

Several major concerns exist for the monolithic pour large container option:

- Canister cooling may be difficult to accomplish. For example, a 0.6-m diameter monolithic canister's surface requires approximately 44 hours to cool from 1,150 °C to 100 °C. Canister cooling studies generated during the HWVP Increased Capacity Study showed that the primary resistance to heat transfer is the glass form. With a canister that contains a 1.7-m diameter monolithic glass form, the surface area to volume ratio significantly changes. Basic, order of magnitude calculations have shown cooling times to exceed hundreds of hours for the same temperature difference. The maximum temperature of the glass exiting a high-temperature melter may be close to 1,300 °C. This increased temperature difference would increase the duration of cooling time. This concern is significant since the glass may reside for an extended period of time in a critical temperature range where de-vitrification can occur. A very large cooling space would also be required to store canisters for long time periods.

Due to the large diameter of the canister, poor heat conduction of the glass, and decay heat in the canister, the glass centerline temperature may never drop below the glass transition temperature. Additional studies are required to determine if the monolithic canister is feasible in regards to this subject. This concern is true for all large container fill methods; however, the monolithic pour option produces the greatest concern.

Recycle of a large glass monolith by the methods discussed in Section 6.1.1 may not be feasible due to the significant increase in glass volume and the additional heat required to melt the large monolith. An alternative to this method would be to cut up the monolith and separate the metal from the glass. The glass would then have to be broken up and sent back to the melter.

6.4 SUMMARY COMPARISON

The paragraphs below summarize and discuss waste form container processing in regards to process flowsheet/facility design impacts, operability/complexity, maintainability, maturity of technology, schedule impacts, regulatory impacts, safety, and costs. In some cases, no impacts have been identified and hence, the text simply states, "none".

6.4.1 Process Flowsheet/Facility Design Impacts

The process flowsheet and facility design impacts for each container processing method are summarized in Table 6-1.

6.4.2 Operability/Complexity

The operability and complexity impacts for each container processing method are summarized in Table 6-2.

6.4.3 Maintainability

The maintenance of all container processing systems is relatively a simple process.

6.4.4 Maturity of Technology

All container processing system technologies are well developed. However, certain unit operations such as decontamination and welding may require qualification programs.

Table 6-1. Container Processing Flowsheet/Facility Design Impacts.

Small Containers with Overpacks	<ol style="list-style-type: none"> 1. Relatively few containers would be transported and stored onsite and at the repository. 2. The glass product must be cooled while in the canister. Several major disadvantages are associated with this cooling method. A large canister cooling cell and canister cooling system are required. The amount of radiation shielding is significant since large quantities of glass will be in cooling or lag storage positions in the cell. The facility's HVAC system must be sized for larger heat loads. During loss of electrical power scenarios, a mitigating cooling system is required to cool the canisters and maintain cell concrete temperatures below critical temperatures. Heat shielding may be required for the cell concrete and canister handling equipment during normal operations. 3. Essentially two sets of container process equipment are required. The additional set requires additional facility space.
Small Containers without Overpacks	<ol style="list-style-type: none"> 1. Only one set of container process equipment is required. Less facility space is therefore required. 2. More containers would be transported and stored onsite and at the repository. 3. The same disadvantages that the small container cases with overpacks have with canister cooling apply to small containers without overpacks. See above.
Large Containers with Overpacks (Cullet)	<ol style="list-style-type: none"> 1. Relatively few containers would be transported and stored onsite and at the repository. 2. No canister cooling concerns exist for these container processing options. 3. Essentially two sets of container process equipment are required. The additional set requires additional facility space.
Large Containers without Overpacks (Cullet)	<ol style="list-style-type: none"> 1. Relatively few containers would be transported and stored onsite and at the repository. 2. No canister cooling concerns exist for this container processing option. 3. Only one set of container process equipment is required. Less facility space is therefore required.
Large Containers (Monolith)	<ol style="list-style-type: none"> 1. Due to the container cooling concerns, the technical feasibility of this option is rather poor.

Table 6-2. Container Processing System Operability and Complexity.

Small Containers with Overpacks	<ol style="list-style-type: none"> 1. The overpacking operation eliminates concerns about the effectiveness of the canister decontamination processes since the overpack containers never enter contaminated cells. 2. Not much time is allowed for maintenance operations to be performed before canisters start to back up in lag storage. 3. Lag storage capabilities are more difficult to obtain. 4. Recycle of off-spec monolithic glass is cumbersome. 5. Two containers are required to process the waste form. This adds complexity and cost to the overall project.
Small Containers without Overpacks	<ol style="list-style-type: none"> 1. Only one container is required to process the waste form. 2. Not much time is allowed for maintenance operations to be performed before canisters start to back up in lag storage. 3. Lag storage capabilities are more difficult to obtain. 4. The canister decontamination system may be more complex than those of other systems. 5. Recycle of off-spec monolithic glass is cumbersome.
Large Containers with Overpacks (Cullet)	<ol style="list-style-type: none"> 1. Adequate time is allowed for maintenance operations to be performed before waste begins to back up in lag storage. 2. Lag storage capabilities are relatively easy to obtain. 3. The overpacking operation eliminates concerns about the effectiveness of the canister decontamination processes since the overpack containers never enter contaminated cells. 4. Recycle of off-spec glass cullet, marbles, or gems is easier to perform. 5. Two containers are required to process the waste form. This adds complexity and cost to the overall project.
Large Containers without Overpacks (Cullet)	<ol style="list-style-type: none"> 1. Adequate time is allowed for maintenance operations to be performed before waste begins to back up in lag storage. 2. Lag storage capabilities are relatively easy to obtain. 3. The use of a single container creates concerns about the effectiveness of the canister decontamination processes since no overpack containers are used. 4. Recycle of off-spec glass cullet, marbles, or gems is easier to perform. 5. Only one container set is required to process the waste form. 6. More weight must be shipped to the repository if the single container provides shielding such as the container in container Case 4 does. 7. The canister decontamination system may be more complex than those of other systems.
Large Containers (Monolith)	<ol style="list-style-type: none"> 1. Due to the container cooling concerns, the technical feasibility of this option is rather poor.

6.4.5 Schedule Impacts

None.

6.4.6 Regulatory Impacts

The HLW stream meets the criteria of a dangerous waste, and the processing of these dangerous wastes is regulated in the state of Washington by WAC 173-303, Dangerous Waste Regulations. These regulations are the state equivalent of the federal RCRA hazardous waste regulations in 40 CFR 260-270. The processing described in Section 6 of this report will require a permit in accordance with WAC 173-303. This permit must be in existence before the start of operations, and the permit covers a Treatment, Storage, and Disposal (TSD) facility. Thus, the permit can be prepared to cover all treatment and storage activities. All container options within this study must conform to the same applicable requirements.

6.4.7 Safety

There are no safety concerns regarding the container processing systems. Any accidents associated with these processing systems are enveloped by the container drop accidents discussed in Section 5.12.7. Although there are potentially more glass fines for the cullet process, any spill that would occur during filling the cullet containers occurs inside the vitrification building and the releases are easily mitigated by the Zone I confinement systems.

6.4.8 Costs

Vitrification building costs for each container option are shown in Table 6-3. Included is the direct cost for the vitrification facility, annual equipment replacement costs, operations and maintenance costs. All costs are expressed in 1994 dollars. No other costs such as escalation, contingency, project management, construction management, or engineering are included in the direct costs of the vitrification building.

Section 3.0 presents a summary of total costs for all options considered in this study. Life-cycle costs were developed for all of the alternatives in this study and are discussed in Appendix A of this report.

6.4.8.1 Small Container Processing Systems with Overpacks (Monolith). For container Cases 2, 3A, and 3B, vitrification building costs are \$548.5 million, \$552.2 million, and \$552.2 million respectively. It is assumed that building costs for container Cases 10 and 11 are identical to those of Case 2. The cost difference between Cases 2 and 3 is due to the additional equipment and facility provisions required to process the overpack shielding containers in Case 3.

Table 6-3. High-Level Waste Vitrification Building Costs.

Case	Waste form container	Equipment cost ^a \$ million	Vitrification Bldg. cost \$ million	Annual equipment cost ^b \$ million	Annual O&M cost ^c \$ million	Annual cost ^d \$ million
1	Unshielded small canisters (monolith)	150.7	537.7	22.6	16.6	39.2
2	Unshielded 4-pack overpack canisters for unshielded small canisters (monolith)	154.7	548.5	23.2	16.9	40.1
3A	Metal shielded casks for unshielded 4-pack overpack canisters (monolith)	150.6	552.2	22.6	16.6	39.2
3B	Concrete shielded casks for unshielded 4-pack overpack canisters (monolith)	150.6	552.2	22.6	16.6	39.2
4	Large shielded casks (cullet, marbles, or gems)	153.8	570.6	23.1	15.5	38.6
5	Large unshielded canisters and metal overpack shielded casks (cullet, marbles, or gems)	155.6	574.2	23.3	15.8	39.1
6	Large unshielded canisters and concrete overpack shielded casks (cullet, marbles, or gems)	155.6	574.2	23.3	15.8	39.1
7	Large unshielded canisters, unshielded overpack canisters, and metal overpack shielded casks (cullet, marbles, or gems)	161.9	588.4	24.3	16.2	40.5
8	Large unshielded canisters, unshielded overpack canisters, and concrete overpack shielded casks (cullet, marbles, and gems)	161.9	588.4	24.3	16.2	40.5
9	Large containers (monolith)	N/A	N/A	N/A	N/A	N/A
10	Unshielded 7-pack overpack canisters for unshielded small canisters	154.7	548.5	23.2	16.9	40.1
11	Unshielded 4-pack overpack canisters for unshielded HWVP-type canisters	154.7	548.5	23.2	16.9	40.1

^a Equipment costs included in Vitrification Building cost.

^b Computed at 15 percent of total equipment cost annually.

^c Computed at \$90,000 per man-year. See Appendix A for labor structure.

^d Annual costs do not include annual storage costs. See Section 3.0.

6.4.8.2 Small Container Processing Systems without Overpacks (Monolith). For container Case 1, building costs are \$537.7 million. Note that building costs for container Case 2 are \$548.5 million. The \$11 million cost difference between Cases 1 and 2 is due to the additional equipment and facility provisions required to process the overpack containers in Case 2.

6.4.8.3 Large Container Processing Systems with Overpacks (Cullet, Marbles, Gems). For container Cases 5 and 6, building costs are \$574.2 million. For container Cases 7 and 8, building costs are \$588.4. The \$14 million cost difference between the two sets of cases is due to the additional equipment and facility provisions required to process the additional overpack containers in Cases 7 and 8.

6.4.8.4 Large Container Processing Systems without Overpacks (Cullet, Marbles, Gems). For container Case 4, building costs are \$570.6 million. Note that building costs for container Case 5 are \$574.2 million. The \$4 million cost difference between Cases 4 and 5 is due to the additional equipment and facility provisions required to process the overpack containers in Case 5.

6.4.8.5 Large Container Processing Systems (Monolith). Due to the poor technical feasibility of this option, a facility layout concept, a facility cost estimate, and an equipment cost estimate was not prepared. However, compared to the other large container cases, facility costs for the monolithic pour option are most likely higher since the canister processing cells are remotely operated and maintained. The addition of a canister cooling cell increases costs, but this increase most likely is offset by the removal of the cullet system facility space. Additional building space is required to house all of the additional systems that are mentioned in Section 6.3.1. Equipment costs for these additional systems are probably more than the cost credit for the removal of the cullet handling system equipment. Canister costs are probably increased by 20 to 30 percent if internal cooling provisions are required.

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7.0 ONSITE TRANSPORTATION

Based upon the configuration of the waste form container, a shielded transporter or an unshielded transporter is used to transport waste form containers from the vitrification building to the storage facilities discussed in Section 8. A general discussion on each type of transporter is provided below.

7.1 SHIELDED TRANSPORTATION

Shielded transporters are provided for container configurations that are unshielded. These container cases are Cases 1, 2, 10, and 11 described in Section 5.0. Case 1 utilizes a small canister that weighs 4.12 MT. Case 2 utilizes a 4-pack overpack canister that weighs 22.96 MT full. Case 10 uses a 7-pack overpack canister that weighs 25.3 MT full. Case 11 uses a 4-pack overpack canister that weighs 12.6 MT full. Each case requires one transporter to meet its specified production rate. Shielded transporters that are assumed for this study are similar to the HWVP Shielded Canister Transporter. However, the transporters in this study must carry larger and heavier waste form containers. Figure 7-1 shows a sketch of a shielded transporter.

Shielded transporters are four-wheel drive vehicles controlled by a single operator. The width of a shielded transporter is approximately 7.6 m and the wheel base is approximately 6.1 m. The height of a transporter shall be less than 7.6 m. The gross weight of a transporter including the weight of the waste form containers and floor plug, is in excess of 200 MT.

The shielded transporters provide shielding protection from the containers during handling and transportation. The transporter's shielding provisions will yield dose rates as follows: 0.001 mSv/h in the transporter cab, 0.5 mSv/h on the accessible surface of the transporter's shield cask, and less than 0.1 mSv/h on the transporter's exterior perimeter. These dose rates include the combined dose from gamma and neutron radiation.

7.2 UNSHIELDED TRANSPORTATION

Unshielded transporters are provided for container configurations that are shielded. These container cases are Cases 3A, 3B, 4, 5, 6, 7, and 8 described in Section 5. Each container case requires one transporter to meet its specified production rate. Figure 7-2 shows a conceptual sketch of an unshielded transporter.

Figure 7-1. Shielded Canister Transporter.

Figure 7-2. Shielded Canister Transporter Side View.

An unshielded transporter is essentially a mobile crane with a short boom. This transporter is a single-axle drive vehicle with a dual-direction cab controlled by a single operator. The width of an unshielded transporter is approximately 5.5 to 7.3 m and the wheel base is approximately 4.6 to 6.1 m. The height of a transporter shall be 7.6 to 9.1 m. The gross weight of a transporter excluding the weight of the waste form containers is in the range of 40 to 74 MT.

The unshielded transporters provide shielding protection for the operator during waste form container handling and transportation. The radiation dose rate within the cab shall not exceed 0.001 mSv/h. This dose rate includes the combined dose from gamma and neutron radiation.

7.3 SUMMARY COMPARISON

The paragraphs below summarize and discuss waste form container onsite transportation in regards to process flowsheet/facility design impacts, operability/complexity, maintainability, maturity of technology, schedule impacts, regulatory impacts, safety, and costs. In some cases, no impacts have been identified and hence, the text simply states, "none."

7.3.1 Process Flowsheet/Facility Design Impacts

None.

7.3.2 Operability/Complexity

None.

7.3.3 Maintainability

The maintenance of all transporters can be done in a contact manner.

7.3.4 Maturity of Technology

Although no major difficulties are foreseen for developing onsite transporters for HLW containers, design tasks may be challenging particularly if safety class restrictions are applied.

7.3.5 Schedule Impacts

None.

7.3.6 Regulatory Impacts

Neither the federal regulations in 40 CFR 263.10(b) nor the state regulations in WAC-173-303-240(4) require onsite regulation for the transportation of hazardous wastes. However, WHC-CM-7-5, Environmental Compliance Manual, Chapter 7, Solid Waste Management, Section 7.9.2(5), establishes a requirement for a "uniform hazardous waste manifest" for all onsite (as well as offsite) transportation of hazardous materials. Two exceptions include: (1) Hanford bulk shipments that are destined for tank farm storage, and (2) onsite waste transfers where control of the waste remains with the same RCRA unit manager. All container options within this study must conform to the same applicable requirements.

7.3.7 Safety

The accidents associated with the unshielded transporter are the same as the container drop accidents discussed in Section 5.12.7. However, in addition to the container drop accidents, the shielded transporter may also be vulnerable to the "container sheer" accident, when employed in conjunction with bore hole storage and building storage concepts. Further discussions are provided in Section 8.4.7 of this report.

7.3.8 Costs

The direct costs of the transporters for all options are presented in Table 7-1. All costs are expressed in 1994 dollars. No other costs such as escalation, contingency, project management, construction management, or engineering are included in the table.

Section 3 presents a summary of total costs for all options considered in this study. Life-cycle costs were developed for all of the alternatives in this study and are discussed in Appendix A of this report.

For container Case 1, the transporter is estimated to cost \$4.5 million. For container Cases 2, 10, and 11, the transporter is estimated to cost \$12.4 million. These costs were obtained based on factored estimates of the HWVP transporter. The costs of the shielded transporters are significantly higher than the costs of the unshielded transporters. Unshielded transporters for all shielded container cases cost approximately \$1 million.

Due to the poor technical feasibility of container Case 9, no transporter cost estimate was prepared for this option.

Table 7-1. High-Level Waste Onsite Transporter Costs.

Case	Waste form container	Transporter costs \$ million
1	Unshielded Small Canisters (Monolith)	4.5
2	Unshielded 4-Pack Overpack Canisters for Unshielded Small Canisters (Monolith)	12.4
3A	Metal Shielded Casks for Unshielded 4-Pack Overpack Canisters (Monolith)	0.7
3B	Concrete Shielded Casks for Unshielded 4-Pack Overpack Canisters (Monolith)	0.8
4	Large Shielded Casks (Cullet, Marbles, or Gems)	0.8
5	Large Unshielded Canisters and Metal Overpack Shielded Casks (Cullet, Marbles, or Gems)	0.9
6	Large Unshielded Canisters and Concrete Overpack Shielded Casks (Cullet, Marbles, or Gems)	1.1
7	Large Unshielded Canisters, Unshielded Overpack Canisters, and Metal Overpack Shielded Casks (Cullet, Marbles, or Gems)	0.9
8	Large Unshielded Canisters, Unshielded Overpack Canisters, and Concrete Overpack Shielded Casks (Cullet, Marbles, and Gems)	1.0
9	Large Containers (Monolith)	N/A
10	Unshielded 7-Pack Overpack Canisters for Unshielded Small Canisters	12.4
11	Unshielded 4-Pack Overpack Canisters for Unshielded HWVP-Type Canisters	12.4

8.0 ONSITE INTERIM STORAGE

Three onsite interim storage methods for HLW containers are discussed in this report. These methods include storage pads, bore holes, and storage buildings. Bore holes and storage buildings are being considered for unshielded containers (container Cases 1, 2, 9, 10, and 11). Storage pads are being considered for shielded containers (container Cases 3, 4, 5, 6, 7, and 8). General system descriptions, advantages, disadvantages, and concerns and uncertainties for each storage method are provided below.

8.1 PAD STORAGE

Storage pads are being considered for the interim storage of HLW containers. These containers include container Cases 3, 4, 5, 6, 7, and 8. All of these container configurations provide self shielding for their radionuclides.

8.1.1 General Description

The pad facility could be one large pad or several smaller ones depending on site layout considerations. The pad is designed and estimated with concrete as the material of construction. To support the loads of the containers and their transporters, the concrete must be 30.48 cm thick. Figure 8-1 shows a conceptual layout for containers on the storage pad. In this layout, the containers are positioned in a hexagonal packing arrangement, which is the optimal packing configuration for vertical cylinders. Site layout restrictions may require that containers be stored in a rectangular pattern. In general, rectangular layouts require more area than hexagonal layouts. Table 8-1 shows the amount of hexagonal and rectangular area required for each container option. The area for each option was calculated based on 60.96 cm of spacing between each container. It is assumed that this spacing will allow adequate heat transfer of decay heat to occur. With this spacing, container handling should also be relatively easy.

For this study, it is assumed that no building is required for weather protection, confinement, or shielding. Since the containers to be stored are self-shielded, no other large shielding provisions are required at the pad. A security fence or thin shield wall around the pad's perimeter would be provided to keep personnel from entering the area. It is also assumed that no monitoring provisions for particulates are required.

Figure 8-1. High-Level Waste Onsite Storage Pad.

Table 8-1. High-Level Waste Containers Storage Pad Summary.

Case	Waste form container	Cask Diameter meters	No. of casks	Hexagon pad area square meters	Rectangle pad area square meters
3A	Metal shielded cask for unshielded 4-pack overpack canister (monolith)	2.24	1,705	12,658	13,873
3B	Concrete shielded casks for unshielded 4-pack overpack canisters (monolith)	3.20	1,705	22,664	24,837
4	Large shielded casks (cullet, marbles, or gems)	1.75	2,610	13,416	14,635
5	Large unshielded canisters and metal overpack shielded casks (cullet, marbles, or gems)	2.22	1,385	10,542	11,133
6	Large unshielded canisters and concrete overpack shielded casks (cullet, marbles, or gems)	3.2	1,385	19,126	20,216
7	Large unshielded canisters, unshielded overpack canisters, and metal overpack shielded casks (cullet, marbles, or gems)	2.16	1,588	11,010	12,188
8	Large unshielded canisters, unshielded overpack canisters, and concrete overpack shielded casks (cullet, marbles, or gems)	3.01	1,588	18,821	20,851

8.1.2 Advantages

Pad storage has the following advantages:

- Pads are relatively simple and inexpensive.
- No major shielding provisions are required since the containers are self-shielding.
- Pads require little or no maintenance and are very durable. Operators are also not required.

8.1.3 Disadvantages

Pad storage has the following disadvantages:

- Pads do not offer any protection for containers against the outside weather elements. Additionally, if a container were to leak, then rain run-off water could contaminate the surrounding area.

- Pads without shielding provisions require the canisters to be self-shielding. The cost of shield containers is most likely more than the capital cost of a building for unshielded containers.
- Monitoring the pads for leaking containers is difficult since the pads do not have an enclosure over them.

8.1.4 Concerns and Uncertainties

The pad storage concept assumed for this study has the following concerns and uncertainties:

- No building has been provided over the storage pad. Over time, the outside weather elements may damage the containers. Thus, buildings may be required. The addition of buildings would significantly increase the facility's capital, operating, and maintenance costs. If buildings were to be added, then pad area may also need to be increased; thus, pad capital costs would also increase. This concern needs additional evaluation.
- No monitoring for leached/leaking radioactive material is provided. Its need and usefulness is questionable though. If an area monitor were to signal a leak, then detection of the individual container that is leaking may be difficult. If individual containers were provided leak detection devices, identifying the leaking container could still be difficult without a complex integrated system. A better approach may be to provide a container designed not to leak. This entire subject requires further investigation.

8.2 BORE HOLE STORAGE

Bore holes are being considered for the interim storage of HLW containers. These containers include container Cases 1, 2, 10, and 11. All of these container configurations are unshielded.

8.2.1 General Description

Bore holes are essentially tubes that are embedded in the ground. The tubes are constructed of concrete with a metal interior liner. Each bore hole contains a shield plug and a cover plate. Figures 8-2, 8-3, 8-4, and 8-5 show sketches of containers in bore holes for container Cases 1, 2, 10, and 11 respectively. A small canister bore hole contains two containers. Four-pack and 7-pack bore holes contain one container.

Figure 8-2. High-Level Waste Bore Hole Storage for Small Unshielded Canisters.

Figure 8-3. High-Level Waste Bore Hole Storage for
Unshielded 4-Pack Overpacks with
Unshielded HWVP-Type Canisters.

Figure 8-4. High-Level Waste Bore Hole Storage for Unshielded 7-Pack Overpacks with Unshielded Small Canisters.

Figure 8-5. High-Level Waste Bore Hole Storage for
Unshielded 4-Pack Overpacks with
Unshielded Small Canisters.

Figures 8-6, 8-7, 8-8, and 8-9 show layout arrangements of bore holes for the same four container cases. Each of the layout figures includes a table that gives the required area as a function of the number of rows and columns chosen.

Fewer bore holes and less real estate would be required if more containers were configured in each bore hole. However, it is suspected that overall costs of bore hole storage may increase due to additional structural requirements and construction constraints as the container configuration is modified. Deeper bore hole tubes will require thicker walls. Therefore, the total cost of the deeper holes would probably be more. The feasibility of digging or drilling large diameter holes deep within the Hanford soil has not been investigated.

Bore hole spacing is a function of heat transfer requirements and container transporter size and weight. The spacing is set such that the wheels of the transporter are not traveling over any of the bore hole cover plates. The weight of the transporter with a full waste form container is approaching 200 MTs. Cover plates can be designed to withstand these forces. However, the base of the bore hole tubes are not supported by solid foundations. Hence, repetitive loading due to a transporter traveling over a bore hole cover would tend to push the entire bore hole into the ground.

Adequate spacing is also required to allow heat transfer of decay heat from within the stored containers. No heat transfer analyses have been performed on bore holes during the course of this study. Further efforts are required for this subject.

It is assumed that no monitoring provisions have been provided.

8.2.2 Advantages

Bore holes have the following advantages:

- Bore holes provide protection for the waste form containers against most of the weather elements. Normal run-off water could be protected against, but flooding protection would be difficult to provide without great expense.
- Bore holes require little or no maintenance. Operators are not required. Life-cycle costs, therefore, are predominantly capital costs.

Figure 8-6. Bore Hole Storage Arrangement for High-Level Waste Unshielded Small Canisters (Monolith).

No. of Columns	No. of Rows	Width Meters	Length Meters	Area Sq. Meters (Acres)
100	35	764.4	137.8	105,344 (26.0)
60	57	460.4	219.2	100,920 (24.94)
40	86	308.4	236.5	100,693 (24.88)
30	114	232.4	430.1	99,955 (24.70)
20	171	156.4	641.0	100,252 (24.77)

Figure 8-7. Bore Hole Storage Arrangement for High-Level Waste Unshielded 4-Pack Overpack Canisters with Unshielded Small Canisters.

No. of Columns	No. of Rows	Width Meters	Length Meters	Area Sq. Meters (Acres)
60	29	460.4	180	82,872 (20.48)
40	43	308.4	264	81,418 (20.12)
30	57	232.4	348	80,875 (20.0)
20	86	156.4	522	81,641 (20.17)

Figure 8-8. Bore Hole Storage Arrangement for High-Level Waste Unshielded 7-Pack Overpack Canisters with Unshielded Small Canisters.

No. of Columns	No. of Rows	Width Meters	Length Meters	Area Sq. Meters (Acres)
60	27	460.4	168	77,347 (19.11)
40	40	308.4	246	75,867 (18.75)
30	53	232.4	324	75,298 (18.61)
20	79	156.4	480	75,072 (18.55)

Figure 8-9. Bore Hole Storage Arrangement for High-Level Waste Unshielded 7-Pack Overpack Canisters with Unshielded Small Canisters.

No. of Columns	No. of Rows	Width Meters	Length Meters	Area Sq. Meters (Acres)
80	43	612.4	264	161,674 (34.95)
60	58	460.4	354	162,982 (40.27)
50	69	384.4	420	161,448 (39.89)
40	86	308.4	522	160,985 (39.78)

8.2.3 Disadvantages

Bore holes have the following disadvantages:

- Capital costs are relatively high.
- Large areas of real estate are required.
- Cooling of the waste forms is not actively controlled. Several uncertainties exist with this subject.

8.2.4 Concerns and Uncertainties

Bore holes have the following concerns and uncertainties:

- The heat transfer characteristics of the container and bore hole combination are not known. Heat transfer can affect the long term quality of the bore hole structure and the waste form. Further studies are required in this area.
- The feasibility of digging or drilling large diameter holes on the Hanford site requires further investigation.
- Protecting the bore holes against flooding would require additional design features.

8.3 BUILDING STORAGE

Storage buildings are being considered for the interim storage of HLW containers. These containers include container Cases 1, 2, 9, 10, and 11. All of these container configurations are unshielded.

8.3.1 General Description

The storage building proposed in this study is similar to the HWVP Canister Storage Building. Decay heat from waste in the containers is removed by convection cooling air. Containers are stored in a shielded vault in steel storage tubes. Each tube location has an associated cover plug and holds multiple canisters, one above the other.

8.3.2 Advantages

Advantages of storage buildings include the following:

- Storage buildings provide protection for the waste form containers against all outside weather elements.
- No shield containers are required for waste form containers.
- Waste form cooling can be actively controlled.
- Monitoring can be provided.

8.3.3 Disadvantages

Disadvantages of storage buildings include the following:

- Storage buildings are relatively expensive and complex.
- Operator shielding provisions are required since the containers are not self-shielding.
- Storage buildings require maintenance. Operators are required.

8.3.4 Concerns and Uncertainties

No technical concerns or uncertainties exist for the storage building alternative.

8.4 SUMMARY COMPARISON

The paragraphs below summarize and discuss waste form container onsite interim storage in regards to process flowsheet/facility design impacts, operability/complexity, maintainability, maturity of technology, schedule impacts, regulatory impacts, safety, and costs. In some cases, no impacts have been identified and, hence, the text simply states "none."

8.4.1 Process Flowsheet/Facility Design Impacts

Relatively large areas of real estate are required for bore holes. Pads and buildings require relatively small areas of real estate.

8.4.2 Operability/Complexity

The following operability and complexity issues have been identified for pads, bore holes, and storage buildings:

Pads. Pads do not offer any protection for containers against the outside weather elements, where as buildings and bore holes do. Monitoring the pads for leaking containers is difficult since the pads do not have an enclosure over them. Pad designs are rather simple.

Bore Holes. With bore hole storage, container cooling is a concern. Protecting bore holes against flooding is also a concern.

Storage Buildings. Buildings offer provisions for container cooling and monitoring. However, storage building designs are rather complex.

8.4.3 Maintainability

Pads and bore holes require little or no maintenance. Buildings do require maintenance.

8.4.4 Maturity of Technology

None.

8.4.5 Schedule Impacts

None.

8.4.6 Regulatory Impacts

As noted previously in Section 6.4.6, a dangerous waste permit issued in accordance with WAC 173-303, Dangerous Waste Regulations, will be required to process the HLW stream. Since this permit covers storage activities as well, the storage regulatory requirements will be included in this Dangerous Waste Permit.

8.4.7 Safety

Based on past calculations by WHC and Fluor Daniel regarding heat removal from glass containers, it is questionable if a concrete shield cask is able to transfer sufficient heat to maintain glass temperatures adequately. The same concern also applies to the decay heat removal associated with the bore hole storage design.

The heat load of a glass container which was previously 1 kw for the HWVP design, has been increased to 2 kw for this study. Such an increase would pose an extreme difficulty for the HWVP canister storage building (CSB) due to the elevated temperature of the concrete floor of the CSB. The concrete strength would be reduced by such elevated temperature. The potential weakening of the concrete floor is a major safety concern.

The shielded transporter, is also vulnerable to a "container sheer" accident. In this accident scenario, the shielded transporter is assumed to move (due to a design basis earthquake) during insertion of a container. As a result, the container may be sheered in half and drop to the bottom of the storage hole/tube. Based upon HWVP results, many more glass fines are produced by this sheering and dropping scenario, as compared to a container drop scenario. Therefore, the consequences are much higher than those discussed in Section 5.12.7 of this report. The results may place some SC-1 design requirements on the shielded transporter. Further detailed analysis needs to be performed to address these safety concerns.

8.4.8 Costs

Costs of pads, bore holes, and buildings for container storage are presented in Table 8-2. These costs are summarized in the paragraphs below. All costs are expressed in 1994 dollars and are defined in terms of direct and annual costs. Direct costs are defined as a capital expense that provides 40 percent of the total storage capacity for a storage option. The remaining 60 percent of the storage capacity is averaged over the lifetime of the plant as an annual storage cost. Costs such as escalation, contingency, project management, construction management, or engineering are not included in the table. Due to the poor technical feasibility of container Case 9, no container storage cost estimates were prepared for this option.

Section 3 presents a summary of total costs for all options considered in this study. Life-cycle costs were developed for all of the alternatives in this study and are discussed in Appendix A of this report.

8.4.8.1 Pad Storage

Storage pad direct costs for the appropriate container options range from \$5.0 million to \$7.3 million. These costs are based on the rectangular pad layouts. Annual costs for all options remain under \$1 million. Note that these costs are significantly less than those of bore hole and storage building options.

8.4.8.2 Bore Hole Storage

Bore hole direct costs for the appropriate container options range from \$70.2 to \$123.6 million. Annual costs range from \$7.5 to \$13.3 million. Note that these costs are significantly higher than those of the storage buildings and storage pads. Since the bore hole estimates do not include an allowance for impact limiters, it is expected that the reported costs will increase.

8.4.8.3 Building Storage

The cost of a single building for each option is approximately \$49.2 million. These costs were determined based on the cost of the HWVP Canister Storage Building. Annual costs vary between \$10.5 and \$14.1 million and represent the balance of storage buildings required to be constructed averaged over the lifetime of the plant.

Table 8-2. High-Level Waste Onsite Storage Costs.

Case	Waste form container	Storage Form	Direct storage costs \$ million	Annual storage cost \$ million
1	Unshielded small canisters (monolith)	Building	49.2	14.1
2	Unshielded 4-pack overpack canisters for unshielded small canisters (monolith)	Building	49.2	10.5
3A	Metal shielded casks for unshielded 4-pack overpack canisters (monolith)	Pad	5.4	0.2
3B	Concrete shielded casks for unshielded 4-pack overpack canisters (monolith)	Pad	7.3	0.3
4	Large shielded casks (cullet, marbles, or gems)	Pad	5.6	0.2
5	Large unshielded canisters and metal overpack shielded casks (cullet, marbles, or gems)	Pad	5.0	0.2
6	Large unshielded canisters and concrete overpack shielded casks (cullet, marbles, or gems)	Pad	6.5	0.3
7	Large unshielded canisters, unshielded overpack canisters, and metal overpack shielded casks (cullet, marbles, or gems)	Pad	5.1	0.2
8	Large unshielded canisters, unshielded overpack canisters, and concrete overpack shielded casks (cullet, marbles, and gems)	Pad	6.6	0.3
9	Large containers (monolith)	N/A	N/A	N/A
10	Unshielded 7-pack overpack canisters for unshielded small canisters	Building	49.2	10.5
11	Unshielded 4-pack overpack canisters for unshielded HWVP-type canisters	Building	49.2	10.5
1	Unshielded small canisters (monolith)	Bore hole	82.8	3.6
2	Unshielded 4-pack overpack canisters for unshielded small canisters (monolith)	Bore hole	77.1	3.3
10	Unshielded 7-pack overpack canisters for unshielded small canisters	Bore hole	70.2	3.0
11	Unshielded 4-pack overpack canisters for unshielded HWVP-type canisters	Bore hole	123.6	5.3

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9.0 OFFSITE TRANSPORTATION

The waste form container process system descriptions in Section 6.0 describe the assumed offsite transportation methods for each cask option. This section describes offsite transportation from a generic point of view. Waste form container sizes and shapes may ultimately be determined by some of the findings stated in this section.

9.1 INTRODUCTION

Transportation of containers of vitrified radioactive waste from the Hanford site to a repository can be accomplished in several ways. Each of these has various limiting parameters which can be used to envelope the size and weight of the containers and affect the cost of shipping. Transportation by rail, truck, or barge, or a combination of the three could be used. A brief discussion of these different transportation methods and their limits follow. This discussion was developed from the standpoint of transporting generic, non-toxic material and does not address regulatory requirements associated with transporting hazardous or radioactive materials.

9.2 DISCUSSION

9.2.1 Rail

There are several types of rail cars which can be used. These include open flatcars and partially or totally enclosed rail cars or boxcars. There are standard rail cars and there are those which can be custom designed to accommodate special needs. A flatcar has a 3 m wide flat surface about 1 m above the top of the rails. There is no side or roof confinement and any hauled material would need to be self shielded and secured to the car. The maximum size of the hauled material is constrained by bridge and tunnel clearances and the load capacity of the flatcar. The standard flatcar is limited to a load size of about 4 m wide and 3.7 m high and has a maximum haul capacity of 68 MT.

Flatcars can be custom designed to accommodate larger and heavier loads. Adding reinforcing or more axles would provide additional capacity. The maximum gross weight (flatcar with load) allowed on eastern Washington rail systems is 119 MT. This limit can be exceeded, but special approval from the rail operators and an evaluation of the bridge load capacities along the route would be required. Tunnel and bridge clearances vary along different sections of the rail system, therefore, larger loads could be accommodated with a study of specific routes.

Non-standard loads and sizes would need approval from rail lines operating the sections of track over which the material is hauled. Extra cost and time would be required for use of non-standard flatcars but they could handle larger loads and sizes than the standard flatcar.

Gondolas and enclosed boxcars can be used to transport this material. These are more restrictive in size but will provide enclosure on both the sides and over the top. With a gondola or open top boxcar the material is more confined than it would be on a flatcar however, the width of the load is limited to under 3 m. Height limits would be the same as for the flatcar. A fully enclosed box car would have the same width restrictions but has an inside height limit of about 2.7 m. The standard gondola and standard box car have a maximum haul capacity of 91 MT. These rail cars provide some environmental protection but do not offer any significant shielding benefits. If shielding is a requirement then a specially designed car would be required.

As with the flatcars, custom designed gondola and box cars can be developed to accommodate larger and heavier loads. The transporting of these larger, heavier loads could be accomplished only after obtaining special permits from the rail operators and evaluating the specific routes for clearances and bridge capacities.

9.2.2 Truck

Weights and sizes of trucks hauling materials are regulated by the state through which the material is being transported. In the State of Washington, as in most other states, the standard highway and bridge design is based on an American Association of State Highway and Transportation Officials HS 20 load. A HS 20 load is a standard tractor/trailer truck with a gross vehicle weight of around 33 MT. In the State of Washington the actual allowable gross vehicle weight allowed on the highways without obtaining a special permit is between 41 MT and 45 MT. Gross loads of 45 MT to 91 MT require a special permit but usually do not entail much effort in the way of state overview and evaluation of actual bridge and road capacities. Gross weights over 91 MT require more overview and an evaluation of bridge and road capacities. Gross weights of up to 454 MT have been approved for transport, but there are extreme restrictions in terms of route and frequency of shipments.

The allowable physical size of a vehicle and its hauled load is governed by lane width and bridge height clearances. The standard lane width and bridge clearances will accommodate a load with a maximum width of 3 m and overall height of 4.6 m. Widths of 3 to 4.3 m can be handled with an oversize load permit. Widths over 4.3 m require a police escort and could only occur at certain times and with limited frequency. The maximum width that can be handled on an interstate highway is 7.3 m. The maximum height that could be transported is dependent on the actual bridge clearances along a specific route.

A typical tractor/trailer rig weighs about 14 to 18 MT and can haul a load of up to 18 MT. This configuration could provide environmental protection but not any shielding. The standard low-boy trailer has a tractor with a flat trailer behind. This configuration

weighs about 27 MT and has a haul capacity of 45 MT. Larger 9 and 13 axle low boy trailers weighing 34 to 45 MT can be used to handle loads up to 68 MT. Custom designed truck/trailers can be developed to handle higher loads and meet special requirements. Specially designed low boys have been used to haul loads with a gross weight of up to 454 MT.

The top surface of these type of trailers is usually about 2.4 m wide and 1 m above the surface of the road. They provide no environmental protection or shielding. Environmental protection or even shielding could be provided, but would add to the overall gross weight.

9.2.3 Barge

Transportation over water by barge is another option for conveying materials offsite. The load size and weight are unrestricted as a barges can usually handle very large and heavy loads. The barge can be loaded directly from the Hanford Site at the Columbia River. The load can then be transported to an off loading facility in the proximity of its final destination. It must be remembered that this transportation scheme could only be used in conjunction with rail and/or truck transport to move the containers to and from the barge. Off loading and environmental concerns must be addressed before this option can be adopted.

9.2.4 Transportation Methods Applied to High-Level Waste Containers

The total weights of filled containers with shielding listed in Table 5-1 range from 55 to 113 MT. These weights include the weight of the onsite storage shielded containers. When waste form containers are shipped to the repository, they are removed from the onsite shielding containers and are placed into transportation casks. Based on shielding requirements, the weights of the transportation casks will be similar to the weights of the storage containers. Therefore, the total weights in Table 5-1 may closely approximate the weights of the shipments to the repository. If this is the case, then several of the container configurations approach or exceed the standard transportation limits and thus special transportation considerations are required for those cases. Additional trade studies are therefore required to optimize the relationships between the final container design sizes and weights and the transportation arrangements.

9.3 SYNOPSIS

There are several means of transporting vitrified radioactive wastes from the Hanford Reservation. Scenarios using rail, trucking, barges or a combination of these could be developed. Regardless of the selected transportation mode, the size and weight of the package being transported will affect the cost and the number of obstacles which must be overcome. Generally, the larger and heavier the load, the more cumbersome and costly it becomes to transport it. The availability of transporters decreases and the cost increases as

the weight goes up. The level of regulatory overview also increases with increasing weight. Proper route selection becomes more important as size and weight increases. And finally, regulatory overview for the transportation of radioactive hazardous wastes must be researched and incorporated into the transportation scheme. Regulatory aspects of transporting HLW are discussed further in Section 9.4.6.

9.4 SUMMARY COMPARISON

The paragraphs below summarize and discuss offsite transportation in regards to process flowsheet/facility design impacts, operability/complexity, maintainability, maturity of technology, schedule impacts, regulatory impacts, safety, and costs. In some cases, no impacts have been identified and, hence, the text simply states "none."

9.4.1 Process Flowsheet/Facility Design Impacts

None.

9.4.2 Operability/Complexity

None.

9.4.3 Maintainability

None.

9.4.4 Maturity of Technology

None.

9.4.5 Schedule Impacts

None.

9.4.6 Regulatory Impacts

The offsite transportation of HLW containers (e.g., related to transportation to a Federal Repository) will become subject to federal and state regulations for transportation of radioactive wastes/materials. In addition, the container may also be subject to federal and state regulations for the transportation of RCRA-type hazardous wastes, depending upon several administrative and regulatory decisions.

In this section, the regulations covering the offsite transportation of HLW will be reviewed. The regulations apply to all container cases that are included in this study. Since the eventual off-site transportation container may not be the filled canister *per se*, the goal of this section is to review regulatory requirements by code rather than attempt a compliance review of a container that has not yet been established. Regulatory requirements for both radioactive and hazardous materials are included.

Transportation of Radioactive Wastes/Materials. The transportation of radioactive materials is subject to 10 CFR 71, Packaging and Transportation of Radioactive Materials. These regulations include requirements for both packaging standards and package tests. The standards include general design requirements including the maximum weight and curie content for each type of container, external surface radiation standards, and special criticality requirements for packages (containers) that contain fissile material such as ^{235}U and ^{239}Pu . The package tests include several environmental (temperature, pressure, vibration, water spray, immersion and leachability) and structural (free drop, compression, bending, and penetration/percussion) evaluations. Note that the shipping container/package subject to the above requirements need not be the containers discussed in the HLW form study; any of the HLW form canisters could be placed inside a shipping container where the shipping container must meet the requirements of 10 CFR 71.

In addition to the above, 49 CFR 173, Shippers - General Requirements for Shipments and Packages, Subpart I (Radioactive Materials), contains additional design and performance criteria for the transportation of packages containing radioactive materials. These include impact, percussion, bending and heat tests. See 173.469(b).

Transportation of Hazardous Wastes. The offsite transportation of hazardous wastes is regulated by Federal Code 40 CFR 263 and by State Codes WAC 173-303-240 through WAC 173-303-270. These regulations are operational in nature and include such items as requiring an EPA identification number, the manifest system, and record keeping.

WAC 173-303-190 requires that dangerous waste generators package all dangerous waste for transport in accordance with DOT regulations on packaging, 49 CFR Parts 173 (General Requirements for Shipments and Packages), 178 (Specifications for Packagings) and 179 (Specification for Tank Cars). Subpart B of 49 CFR 173 describes the requirements for preparation of hazardous materials for transportation. WAC 173-303-190 also contains various marking and placarding requirements for transportation containers.

9.4.7 Safety

There are no significant safety concerns for offsite transportation systems that meet 10 CFR 71 and applicable DOT requirements.

9.4.8 Costs

The costs of offsite transportation are included in repository costs discussed in Appendix A.

10.0 FINAL STORAGE

At some point, HLW containers will be transported from their onsite interim storage locations to a repository. Container sizes, weights, and quantities will influence the final container disposal costs. Cost data based on container quantities and waste volumes are discussed in Appendix A.

11.0 REFERENCES

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- 40 CFR 270, 1990, "EPA Administered Permit Programs: The Hazardous Waste Permit Program," *Code of Federal Regulations*, as amended.
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APPENDIX A

**HIGH-LEVEL WASTE FORM STUDY
LIFE-CYCLE COST ANALYSIS**

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APPENDIX A

**HIGH-LEVEL WASTE FORM STUDY
LIFE-CYCLE COST ANALYSIS****A1.0 Introduction**

This appendix describes the methodology for preparing the life-cycle cost analysis for the high-level waste (HLW) form study. This analysis was performed in order to provide a common basis upon which to compare costs of the 16 different HLW form options. This analysis uses the net present value method for comparing costs that occur at different times. This method "discounts" future costs back to the present value, defined as time 0. The present value of a future cash flow can be thought of as the amount of money that must be deposited in a bank today, at the given compound interest rate, that will result in the required amount at the given time in the future. The discount, or interest rate is defined by the Office of Management and Budget in Appendix C of their circular A-94. Two discount rates are defined in this circular, nominal and real. The real discount rate is defined as the difference between the inflation rate and the nominal rate and is intended to be used for evaluations where all costs are in constant dollars. Since all costs for this study are in constant 1994 dollars, the real discount rate is used. The real discount rate for projects with a 30-year time span is 2.8 percent.

The net present value of each option consists of four components: initial capital cost, annual operating and maintenance costs, decontamination and decommissioning costs, and repository costs. Each of these components are derived below. Table A-1 summarizes the results of this analysis.

A2.0 Capital Costs

Direct capital costs consist of three basic components: vitrification building and associated equipment cost, a portion of the interim storage facility cost, and the onsite transporter cost. Total capital costs for each alternative are shown in Table A-2. Direct costs are adjusted by the following factors to arrive at total capital costs:

Engineering	-	40 percent of direct cost
Construction Mgmt	-	10 percent of direct cost
Project Management	-	10 percent of direct, engineering, and const. mgmt costs
Contingency	-	40 percent of direct, engr., const. mgmt, and proj. mgmt costs

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Table A-1. High-Level Waste Facility Life-Cycle Costs (\$ Millions)

Case no.	Description	Total capital costs	Total annual costs	Net present value ⁽¹⁾
1	Unshielded, in building (M)	\$1,366	\$67	\$3,157
2	Unshielded, in building (M)	\$1,409	\$71	\$3,476
3A	Shielded, on pad (M)	\$1,290	\$83	\$3,458
3B	Shielded, on pad (M)	\$1,294	\$66	\$3,269
4	Shielded, on pad (C)	\$1,333	\$71	\$3,837
5	Shielded on pad (C)	\$1,340	\$69	\$3,203
6	Shielded, on pad (C)	\$1,344	\$57	\$3,064
7	Shielded, on pad (C)	\$1,373	\$79	\$3,458
8	Shielded, on pad (C)	\$1,377	\$66	\$3,319
9	Unshielded, in building (M)	NA	NA	NA
10	Unshielded, in building (M)	\$1,409	\$72	\$3,413
11	Unshielded, in building (M)	\$1,409	\$75	\$4,391
1	Unshielded, in bore hole (M)	\$1,444	\$49	\$3,052
2	Unshielded, in bore hole (M)	\$1,474	\$59	\$3,418
10	Unshielded, in bore hole (M)	\$1,458	\$59	\$3,328
11	Unshielded, in bore hole (M)	\$1,581	\$66	\$4,507

⁽¹⁾ Net present value of year 0 for capital, operating, and D&D costs at 2.8 percent interest rate per OMB Circular A-94.

Table A-2. High-Level Waste Facility Capital Costs (\$ millions).

Case no.	Description ^c	Vit. bldg costs	Equip. costs ^a	Interim storage costs ^b	Onsite transport costs	Total direct costs ^b	Eng.	Construct mgmt	Project mgmt	Conting.	Total capital costs
1	Unshielded, in bldg. (M)	537.7	150.653	49.2	4.5	\$591	237	59	89	390	\$1,366
2	Unshielded, in bldg. (M)	548.5	154.691	49.2	12.4	\$610	244	61	92	403	\$1,409
3A	Shielded, on pad (M)	552.2	150.572	5.4	0.7	\$558	223	56	84	369	\$1,290
3B	Shielded, on pad (M)	552.2	150.576	7.3	0.8	\$560	224	56	84	370	\$1,294
4	Shielded, on pad (C)	570.6	153.750	5.6	0.8	\$577	231	58	87	381	\$1,333
5	Shielded, on pad (C)	574.2	155.616	5.0	0.9	\$580	232	58	87	383	\$1,340
6	Shielded, on pad (C)	574.2	155.620	6.5	1.1	\$582	233	58	87	384	\$1,344
7	Shielded, on pad (C)	588.4	161.920	5.1	0.9	\$594	238	59	89	392	\$1,373
8	Shielded, on pad (C)	588.4	161.925	6.6	1.0	\$596	238	60	89	393	\$1,377
9	Unshielded, in bldg. (M)	NA	NA	49.2	NA	NA	NA	NA	NA	NA	NA
10	unshielded, in bldg. (M)	548.5	154.691	49.2	12.4	\$610	244	61	92	403	\$1,409
11	Unshielded, in bldg. (M)	548.5	154.691	49.2	12.4	\$610	244	61	92	403	\$1,409
1	Unshielded, in bore hole (M)	537.7	150.653	82.8	4.5	\$625	250	63	94	413	\$1,444
2	Unshielded, in bore hole (M)	548.5	154.691	77.1	12.4	\$638	255	64	96	421	\$1,474
10	Unshielded, in bore hole (M)	548.5	154.691	70.2	12.4	\$631	252	63	95	417	\$1,458
11	Unshielded, in bore hole (M)	548.5	154.691	123.6	12.4	\$685	274	68	103	452	\$1,581

^a Equipment costs are included in vit bldg costs.

^b Only the portion of interim storage costs incurred during initial construction are shown.

^c M = monolith C = culet.

The interim storage facility will be partially built during initial construction and completed in stages during the life of the facility (14 years). Seven options utilize storage pads and for utilize bore holes. The first 40 percent of the storage pads and bore holes must be built initially. At first glance this appears to be an excessive amount, however, sufficient distance must be provided between the area where storage operations are ongoing and the construction area. This distance serves two functions, first to provide sufficient separation between the operating crews and the construction crews so as not to create interference between the two, and second to provide sufficient shielding of the construction crew. The present design of the canister shielding is 10 mrem/h at the surface. The required uncontrolled area radiation field for construction work is 0.05 mrem/h. Approximately 100 m is required to provide this shielding.

A3.0 OPERATING COSTS

Operating costs have many components as discussed below. Total annual operating costs are shown in Table A-3.

A3.1 CONTAINERS

The largest and most variable of the operating costs is container costs. Containers consist of one or more of the following:

- canisters
- overpacks
- steel casks
- concrete casks.

Options 1, 4, and 9 use only one container. Options 2, 5, 6, 10, and 11 use two containers. Options 3, 7, and 8 use three containers. The total number of containers to be produced during the life of the facility has been calculated based on the total quantity of glass that will be produced and the volume of glass that can be stored in each container. The annual number of containers produced is the total number divided by 14.

A3.2 INTERIM STORAGE

A portion of the interim storage facilities will be built during initial construction and the remainder will be built over the life of the facility as required.

Container Options 1, 2, 9, 10, and 11 may use canister storage buildings. The canister storage building designed and partially constructed for the Hanford Waste Vitrification Plant project is used as the basis. For all options using canister storage buildings, one building will be constructed initially and the remainder constructed over time. Option 1, because of the large number of individual will require 5 separate buildings. Options 2, 9, 10, and 11, because of the grouping of individual canisters into an overpack, will require 4 separate buildings.

Table A-3. High-Level Waste Facility Operating Costs (\$ millions).

Case	Description	Total no. containers	Annual no. containers	Unit cost of containers ⁽¹⁾	Annual cost of containers	Annual cost of storage ⁽²⁾	Annual storage cost CM	Annual storage cost PM	Annual storage cost operating staff	No. of O&M costs ⁽³⁾	Annual O&M costs ⁽⁴⁾	Total annual costs
1	Unshielded, in bldg (M)	6,817	487	\$8,843	\$4,31	\$14.06	\$1.41	\$1.55	\$6.80	184	\$16.56	\$22.60
2	Unshielded, in bldg (M)	1,705	122	\$108,596	\$13.23	\$10.54	\$1.05	\$1.16	\$5.10	188	\$16.92	\$23.20
3A	shielded, on pad (M)	1,705	122	\$355,815	\$43.33	\$0.23	\$0.03	\$0.15	\$0.11	184	\$16.56	\$22.59
3B	Shielded, on pad (M)	1,705	122	\$215,318	\$26.22	\$0.31	\$0.03	\$0.15	\$0.11	184	\$16.56	\$22.59
4	Shielded, on pad (C)	2,610	186	\$173,692	\$32.38	\$0.24	\$0.02	\$0.03	\$0.12	172	\$15.48	\$23.06
5	Shielded, on pad (C)	1,385	99	\$299,425	\$29.62	\$0.21	\$0.02	\$0.10	\$0.10	176	\$15.84	\$23.34
6	Shielded, on pad (C)	1,385	99	\$170,637	\$16.88	\$0.28	\$0.03	\$0.14	\$0.14	176	\$15.84	\$23.34
7	Shielded, on pad (C)	1,588	113	\$334,008	\$37.89	\$0.22	\$0.02	\$0.11	\$0.11	180	\$16.20	\$24.29
8	Shielded, on pad (C)	1,588	113	\$222,693	\$25.26	\$0.28	\$0.03	\$0.14	\$0.14	180	\$16.20	\$24.29
9	Unshielded, in bldg (M)	916	65	\$73,223	\$4.79	\$10.54	NA	NA	NA	184	\$16.56	NA
10	Unshielded, in bldg (M)	1,569	112	\$122,192	\$13.69	\$10.54	\$1.05	\$1.16	\$5.10	188	\$16.92	\$23.20
11	Unshielded, in bldg (M)	3,440	246	\$67,771	\$16.65	\$10.54	\$1.05	\$1.16	\$5.10	188	\$16.92	\$23.20
1	Unshielded, in bore hole (M)	6,817	487	\$8,843	\$4.31	\$3.55	\$0.36	\$0.39	\$1.72	184	\$16.56	\$22.60
2	Unshielded, in bore hole (M)	1,705	122	\$108,596	\$13.23	\$3.30	\$0.33	\$0.36	\$1.60	188	\$16.92	\$23.20
10	Unshielded, in bore hole (M)	1,569	112	\$122,192	\$13.69	\$3.01	\$0.30	\$0.33	\$1.46	188	\$16.92	\$23.2
11	Unshielded, in bore hole (M)	3,440	246	\$67,771	\$16.65	\$3.30	\$0.53	\$0.58	\$2.56	188	\$16.92	\$23.20
												\$65.75

(1) Actual dollars per container.

(2) Remainder of the interim storage costs prorated over 14 years.

(3) Computed at \$90,000 per man-year.

(4) Computed at 15 percent of direct equipment costs.

For the storage pad and bore hole options, 40 percent of the storage area is assumed to be constructed initially and the remaining 60 percent is prorated over the 14-year operating life. These interim storage costs have construction management, project management, and contingency added to them like capital costs, but no engineering costs are added.

A3.3 OPERATIONS AND MAINTENANCE

The next component of operating costs is Operations and Maintenance (O&M). This consists of salaries paid to the operations and maintenance personnel. An average annual rate of \$90,000 per man-year is used here. Staffing levels for the entire facility (HLW, LLW, Separations, and common facilities) were estimated to be 708 as shown on Table A-4. Table A-5 breaks down the total staffing into the four facilities mentioned above. The base case, which is a four-pack overpack in a concrete shielding cask on a storage pad, has a staff of 184 people. Staffing levels for the alternative waste form options were estimated using the following criteria. Estimates are for round-the-clock operation:

- 4 people are required for each canister, overpack, or cask loading step in the process.
- 8 more people are required to operate either the canister storage buildings or bore holes than the storage pads.
- 4 more people are required to produce monolithic canisters than cullet.

The application of these estimates is shown below and incorporated into the operating staff numbers of Table A-3.

CASE	DELTA STAFF
1 Bldg	0
2 Bldg	+ 4
3A	0
3B	BASE
4	-12
5	- 8
6	- 8
7	- 4
8	- 4
9	0
10 Bldg	+ 4
11 Bldg	+ 4
1 Bore Hole	0
2 Bore Hole	+ 4
10 Bore Hole	+ 4
11 Bore Hole	+ 4

A3.4 Equipment Replacement

Annual equipment replacement costs are estimated at 15 percent of the initial equipment capital costs. This cost includes an allowance for normal equipment failures as well as melter replacement. Equipment replacement costs are incorporated into Table A-3.

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Table A-4. Staffing for TWRS Treatment Complex. (Sheet 1 of 3)

POSITION	SHIFT STAFFING														Total							
	Day Shift			A Shift			B Shift			C Shift			D Shift			Training Shift			Sub Total			
	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE		BU	E	NE	BU	E	NE	BU
Building Support																						
PLANT MANAGEMENT																						
Plant Manager	1																		1	0	0	1
Administrative Assistant	1																		1	0	0	1
Technical/Budget Analysts	2																		2	0	0	2
Clerical	1	2																	1	2	0	3
JOB CONTROL																						
Managers	2																		2	0	0	2
Clerical		4																	0	4	0	4
Facility Administrator	3																		3	0	0	3
Job Control Specialists	4																		4	0	0	4
Material Specialists	2																		2	0	0	2
Schedulers	10																		10	0	0	10
Planners	10																		10	0	0	10
Crane Planners	2																		2	0	0	2
PLANT ENGINEERING																						
Managers	1																		1	0	0	1
Clerical		2																	0	2	0	2
Designers/Drafters		2																	0	2	0	2
Plant Engineers	14																		14	0	0	14
ANALYTICAL LABORATORY																						
Managers/Supervisors	1			1			1			1			1			1			6	0	0	6
Clerical		2																	0	2	0	2
Chemists	3			3			3			3			3			3			18	0	0	18
Chemical Technicians		4			11			11			11			11			11		0	0	59	59
STANDARDS LABORATORY																						
Managers	1																		1	0	0	1
Clerical		1																	0	1	0	1
Chemists	2																		2	0	0	2
Chemical Technicians		2																	0	0	2	2
RADIATION PROTECTION																						
Managers	1																		1	0	0	1
Clerical		1																	0	1	0	1
Health Physics Technologists		18																	0	0	18	18
FACILITY SERVICES																						
Managers/Supervisors	1																		1	0	0	1
Clerical		1																	0	1	0	1
Process Operators		18			2			2			2			2			2		0	0	28	28
Crane Operators		3			2			2			2			2			2		0	0	13	13
Power Operators		4			3			3			3			3			3		0	0	19	19
Driver		2																	0	0	2	2
COMPUTER SUPPORT																						
Managers	1																		1	0	0	1
Clerical		1																	0	1	0	1
System Admin./Analyst	3																		3	0	0	3
DOCUMENT CONTROL																						
Managers	1																		1	0	0	1
Clerical		2																	0	2	0	2
Document Control Specialist	4																		4	0	0	4
Technical Editor	2																		2	0	0	2
PROGRAM OFFICE																						
Program Managers	1																		1	0	0	1
Clerical		1																	0	1	0	1
Program Scheduler	1																		1	0	0	1
Activity Engineer	3																		3	0	0	3
Subtotal	78	19	51	4		18	4		18	4		18	4		18	4		18	98	19	141	258

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Table A-4. Staffing for TWRS Treatment Complex. (Sheet 2 of 3)

POSITION	SHIFT STAFFING															Total						
	Day Shift			A Shift			B Shift			C Shift			D Shift				Training Shift			Sub Total		
	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU		E	NE	BU	E	NE	BU
ENGINEERING & SUPPORT																						
PROCESS & TECHNOLOGY																						
Managers	3																		3	0	0	3
Clerical		4																	0	4	0	4
Shift Engineers	3			1			1			1			1			1			7	0	0	7
Process Engineers	20																		20	0	0	20
Technicians		2																	0	2	0	2
SURVEILLANCE & TESTING																			0	0	0	0
Manager	1																		1	0	0	1
Clerical		1																	0	1	0	1
Surveillance & Testing Engrs.	10																		10	0	0	10
QUALITY ASSURANCE &																			0	0	0	0
Manager	1																		1	0	0	1
Clerical		1																	0	1	0	1
Quality Control Inspectors	5																		5	0	0	5
Quality Assurance Engineer	3																		3	0	0	3
SAFETY ENGINEERING																			0	0	0	0
Managers	1																		1	0	0	1
Clerical		1																	0	1	0	1
Emergency Preparedness	1																		1	0	0	1
Radiation Engineers	5																		5	0	0	5
Nuclear Engineers	5																		5	0	0	5
Industrial Safety Engineers	2																		2	0	0	2
NUCLEAR MATERIALS																			0	0	0	0
Managers	1																		1	0	0	1
Clerical		2																	0	2	0	2
Specialists	3																		3	0	0	3
TRAINING																			0	0	0	0
Managers	1																		1	0	0	1
Clerical		2																	0	2	0	2
Trainers	8																		8	0	0	8
Subtotal	73	13		1			1			1			1			1			78	13	0	91
PROCESS STAFF																						
OPERATIONS MANAGEMENT																						
Operations Manager	1																		1	0	0	1
Shift Manager	2			1			1			1			1			1			7	0	0	7
Shift Support Manager	2			2			2			2			2			2			12	0	0	12
Operations Plant Engineers	8																		8	0	0	8
Clerical		2		1			1			1			1			1			0	7	0	7
OPERATORS																						
Receipt			1			2			2			2			2			2	0	0	11	11
Cesium Ion Exchange			1			2			2			2			2			2	0	0	11	11
Effluents			1			2			2			2			2			2	0	0	11	11
Evaporators			1			2			2			2			2			2	0	0	11	11
LLW Melter			2			3			3			3			3			3	0	0	17	17
HLW Melter			2			2			2			2			2			2	0	0	12	12
Product Handling			2			2			2			2			2			2	0	0	12	12
HAZARDOUS MATERIAL																						
Manager	1																		1	0	0	1
Clerical		2																	0	2	0	2
Technicians		3																	0	3	0	3
Engineers	8																		8	0	0	8
ENVIRONMENTAL CONTROL																						
Manager	1																		1	0	0	1
Clerical		1																	0	1	0	1
Technicians		2																	0	2	0	2
Engineers	5																		5	0	0	5
RADIATION PROTECTION																						
Managers/Supervisors	3			1			1			1			1			1			8	0	0	8
Clerical		1																	0	1	0	1
Health Physics Technologists																			0	0	40	40
Subtotal	31	11	10	4	1	23	4	1	23	4	1	23	4	1	23	4	1	23	51	16	125	192

Table A-4. Staffing for TWRS Treatment Complex. (Sheet 3 of 3)

POSITION	SHIFT STAFFING													Total								
	Day Shift			A Shift			B Shift			C Shift			D Shift			Training Shift			Sub Total			
	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E		NE	BU	E	NE	BU	E	NE	BU
MAINTENANCE																						
Manager	1																		1	0	0	1
Clerical		1																	0	1	0	1
Maintenance Engr.	3																		3	0	0	3
Training Coordinator	1																		1	0	0	1
MECHANICAL MAINTENANCE																			0	0	0	0
Managers/Supervisors	1			1			1			1			1			1			6	0	0	6
Clerical		1																	0	1	0	1
Person in Charge	1																		1	0	0	1
Mill Wrights			6			2			2			2			2			2	0	0	16	16
Pipe Fitters			8			2			2			2			2			2	0	0	18	18
Insulators			2																0	0	2	2
Riggers			2			2			2			2			2			2	0	0	12	12
Drivers			1			2			2			2			2			2	0	0	11	11
Welders			2																0	0	2	2
Carpenters			2																0	0	2	2
Painters			2																0	0	2	2
Sign Writer			1																0	0	1	1
I & E MAINTENANCE																			0	0	0	0
Managers/Supervisors	1																		1	0	0	1
Clerical		2																	0	2	0	2
Person in Charge	1			1			1			1			1			1			6	0	0	6
I&E Technicians			8			2			2			2			2			2	0	0	18	18
Electricians			6			2			2			2			2			2	0	0	16	16
MANIPULATOR																			0	0	0	0
Managers/Supervisors	1																		1	0	0	1
Clerical		1																	0	1	0	1
Person in Charge	1			1			1			1			1			1			6	0	0	6
Mill Wrights			2			2			2			2			2			2	0	0	12	12
Electricians			2			2			2			2			2			2	0	0	12	12
I & E Technicians			2			2			2			2			2			2	0	0	12	12
Subtotal	11	5	46	3		18	3		18	3		18	3		18	3		18	26	5	136	167
TOTAL	190	48	110	12	1	59	12	1	59	12	1	59	12	1	59	12	1	59	250	53	402	708

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Table A-5. Staffing Breakdown by Plant.

POSITION	LLW PLANT	HLW PLANT	PRETREAT FACILITY	COMMON AREAS	TOTAL
BUILDING SUPPORT					
Plant Management				7	7
Job Control	14	8	8	7	37
Plant Engineering	6	5	3	5	19
Analytical Laboratory	34	25	21	5	85
Standards Laboratory				6	6
Radiation Protection	6	5	4	5	20
Facility Services	23	17	14	10	64
Computer Support				5	5
Document Control				9	9
Program Office				6	6
Subtotal Building Support	83	60	50	65	258
ENGINEERING & SUPPORT					
Process & Technology	13	9	7	6	37
Surveillance & Testing	4	3	2	3	12
Quality Assurance & Control	3	2	2	3	10
Safety Engineering	5	4	3	3	15
Nuclear Materials				6	6
Training	3	2	2	4	11
Subtotal Engineering & Support	28	20	16	25	91
PROCESS STAFF					
Operations Management	12	9	7	7	35
Operators	29	24	31	1	85
Hazardous Material Control	5	4	3	2	14
Environmental Control	3	2	2	2	9
Radiation Protection	19	14	12	4	49
Subtotal Process Staff	68	53	55	16	192
MAINTENANCE					
Management	1	1	1	3	6
Mechanical Maintenance	28	20	17	9	74
I&E Maintenance	16	12	10	5	43
Manipulator Maintenance	25	18	1	0	44
Subtotal Maintenance	70	51	29	17	167
GRAND TOTAL	249	184	150	123	708
PERCENT OF TOTAL	0.35	0.26	0.21	0.17	
BASE CASE	9	3B	NA	NA	

A4.0 DECONTAMINATION AND DECOMMISSIONING COSTS

Decontaminating and Decommissioning (D&D) costs were estimated as 40 percent of the initial capital costs. Table A-6 presents D&D costs for each option.

A5.0 REPOSITORY COSTS

Repository costs were estimated by the Office of Civilian Radioactive Waste Management¹, the DOE office responsible for design and operation of the repository. These costs were estimated for various quantities of waste and sizes of canisters on a per canister basis. Canister sizes used in the estimate are the same as used in this study, but the quantities were not. Per canister repository costs were prorated based on the total number of canisters produced.

Waste shipments to the repository will be limited to 400 MTs of heavy metal equivalent per year. The total amount of waste in the Hanford tank farms is equivalent to 2,600 MTs of heavy metal, therefore, 15.385 percent of the canisters will be sent to the repository per year, regardless of the quantity of canisters. Shipments are scheduled to begin in 2035. Table A-6 presents the repository costs for each option.

A6.0 NET PRESENT VALUE

Net present value costs were calculated based on a real interest rate of 2.8 percent per the Office of Management and Budget circular A-94. Net present value determines the equivalent cost in year 0 (end of construction) of all capital, operating, D&D, and repository costs. All costs are expressed in 1994 dollars. Net present value costs are shown on Table A-6.

¹Memorandum from Harold H. Brandt, USDOE RW-133 to Acting Director, Tank Waste Remediation System Division, EM-361. Dated July 13, 1993.

Table A-6. High-Level Waste Facility Life-Cycle Costs (\$ millions).

Case	Description	Total capital costs	Total annual costs	D&D costs ^a	Repository shipments per year ^b	Repository costs per container	NPV of repository costs ^c	Net present value ^d
1	Unshielded, in bldg (M)	\$1,366	\$67.28	\$546	1,049	\$0.217	649.6	\$3,157
2	Unshielded, in bldg (M)	\$1,409	\$71.21	\$564	262	\$1.157	868.4	\$3,476
3A	Shielded, on pad (M)	\$1,290	\$82.87	\$516	262	\$1.157	868.4	\$3,458
3B	Shielded, on pad (M)	\$1,294	\$65.90	\$518	262	\$1.157	868.4	\$3,269
4	Shielded, on pad (C)	\$1,333	\$71.33	\$533	402	\$1.153	1,324.9	\$3,837
5	Shielded, on pad (C)	\$1,340	\$69.16	\$536	213	\$1.160	707.0	\$3,203
6	Shielded, on pad (C)	\$1,344	\$56.54	\$538	213	\$1.160	707.0	\$3,064
7	Shielded, on pad (C)	\$1,373	\$78.75	\$549	244	\$1.159	809.9	\$3,458
8	Shielded, on pad (C)	\$1,377	\$66.23	\$551	244	\$1.158	809.4	\$3,319
9	Unshielded, in bldg (M)	NA	NA	NA	141	\$1.502	605.3	NA
10	Unshielded, in bldg (M)	\$1,409	\$71.68	\$564	241	\$1.158	799.8	\$3,413
11	Unshielded, in bldg (M)	\$1,409	\$74.64	\$564	529	\$1.152	1,743.5	\$4,391
1	Unshielded, in bore hole (M)	\$1,444	\$49.48	\$578	1,049	\$0.217	649.6	\$3,052
2	Unshielded, in bore hole (M)	\$1,474	\$58.95	\$589	262	\$1.157	868.4	\$3,418
10	Unshielded, in bore hole (M)	\$1,458	\$58.91	\$583	241	\$1.158	799.8	\$3,328
11	Unshielded, in bore hole (M)	\$1,581	\$65.75	\$633	529	\$1.152	1,743.5	\$4,507

^a 40 percent of total capital cost.

^b Based on 400 metric tons of heavy metal per year beginning in 2035.

^c Present value cost.

^d Net present value at year 0 for capital, operating, D&D, and repository costs at 2.8 percent interest rate per OMB Circular A-94.

APPENDIX B

ESTIMATING BASIS

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APPENDIX B

ESTIMATING BASIS

B1.0 INTRODUCTION

Sixteen cost estimates were prepared in support of the HLW Form Study:

- Five unshielded canisters in building
- Seven shielded canisters on pad
- Four unshielded canisters in bore hole

The estimates compared shielding & types of canisters. The estimates included the quantity and type of canister, facility, onsite transportation, storage costs, and the engineering, construction & project management costs.

The estimates were prepared as very rough order of magnitude utilizing quantity take-off and factoring techniques.

B2.0 DOCUMENTS AND DRAWINGS

Documents. Hanford Waste Vitrification Plant (HWVP) baselined Preliminary Design Estimate, rev. "F" dated July 1991.

Drawings. Various drawings and concept sketches prepared by engineering as basis for the estimate.

B3.0 QUANTITIES

The following quantity abbreviations are used throughout the estimate or estimate backup line items:

DESCRIPTION	UNIT ABBREVIATIONS
Excavation and Backfill	M3 = Cubic Meters
Concrete	M3
Structural Steel	MT = Metric Tons
Liner Plate, Architectural Finishes	M2 = Square Meters
Machinery and Equipment	EA = Each
Power Cable	M = Meters
Miscellaneous Individual Items	Ea
Miscellaneous Allowances and Composites	Lot
Manhour Allowances	MH = Manhours

B4.0 LABOR RATES

An estimated average craft wage rate of \$31.50/h is applied to the direct construction manhours. The average rate is based on the current Hanford site stabilization agreement, and current Hanford site prevailing wages. The rate covers the craft's base wage, plus benefits and state legislated burdens.

B5.0 GENERAL REQUIREMENTS

On February 15, 1994, an estimate kick-off and alignment meeting among Fluor Daniel, Ebasco/BNFL and Westinghouse Hanford Company, was held in Richland, Washington. The purpose of the meeting was to establish the basis for pricing and to review estimating methodologies used in the preparation of the trade studies estimates. The following general estimating allowances were established at the meeting to ensure estimating continuity among the participants estimates:

- Title I, II & III engineering costs are calculated at 40 percent of direct construction costs.

- Construction management is calculated at 10 percent of direct construction costs.
- Project management costs are calculated at 10 percent of the sum of direct construction, engineering and construction management costs.
- Field construction is fixed price. An allowance of 53 percent is applied to direct field labor dollars to provide for the indirect field labor, temporary facilities, personnel protection, weather protection, area maintenance, small tools and consumables, field and home office staff, QA/QC staff, construction equipment usage, bond and insurance, and Washington State Business and Occupation (B&O) tax.
- 5 percent is applied to material and equipment costs to cover overhead and profit.
- 10 percent is applied to subcontract costs to cover overhead and profit.

B6.0 ESCALATION

All costs are expressed in 1994 U.S. dollars. Allowance for escalation cost beyond 1994 is excluded from the estimate.

B7.0 CONTINGENCY

A contingency of 40 percent has been applied to direct field costs, engineering, construction management and project management per agreement among Fluor Daniel, Ebasco/BNFL and Westinghouse Hanford Company, at the estimate kick-off meeting held in Richland, Washington on February 15, 1994.

B8.0 ROUNDING

U.S. Department of Energy - DOE Order 5100.4, Page J-2, Subparagraph (M) requires rounding of a cost estimate to \$1000 for item cost, and \$10,000 for total cost. Reference: DOE 5100.4, Figure I-11, Dated 10-31-84.

B9.0 REMARKS

The following assumptions are made in the preparation of the estimate:

- The site arrangement capital cost estimate is expressed in present day (1994) dollars plus contingency. Escalation to the centroid dates of engineering, procurement, construction, & construction management is excluded by project direction.
- Sufficient skilled labor is available on site during the period of construction.
- No radioactive or otherwise contaminated soil or underground obstructions will be encountered during the excavation of the facility.
- No project mission change or major rework will occur during the engineering and construction of the facility.

The following cost impacts are excluded from the scope of the estimate:

- All capital, start-up and operating spare parts
- Allowance for special work procedure (SWP) construction
- Pre-conceptual and conceptual design