CONCEPTUAL DESIGNS OF RADIOACTIVE WASTE CANISTER TRANSPORTER

Y/OWI/SUB-78/16538

Prepared for

Office of Waste Isolation
Union Carbide Corporation
Nuclear Division

by

FMC Corporation
Engineered Systems Division
328 Brokaw Road
Santa Clara, California 95052

Final Report

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February 1978

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FOREWORD

This report was prepared by FMC Corporation, Engineered Systems Division, under Union Carbide Corporation Subcontract 86Y-16538C. This contract was administered under the technical direction of the Office of Waste Isolation, Union Carbide Corporation, Nuclear Division.

This report is a summary of the work recently completed as part of this contract during the period April to December 1977.

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1.0 EXECUTIVE SUMMARY

This report covers the conceptual designs of transporters for the vertical, horizontal, and inclined installation of canisters containing spent-fuel elements, high-level waste, cladding waste, and intermediate-level waste. Low-level waste is not addressed in this report.

Three basic concepts are presented:

- A tractor-trailer unit for the vertical installation and transporting of spent fuel
- A modified forklift for the vertical installation of high-level waste (HLW), cladding waste (CW), and intermediate-level waste (ILW)
- A tractor-trailer unit for horizontal and inclined emplacement.

Shielding calculations performed for the waste forms listed above guided the development of the cask concepts so that radiation is restricted to a maximum cask surface contact dosage rate of 25 millirems per hour.

Detailed operating cycles were developed for the transporters and have been combined with travel times and transporter loading times to determine the number of transporters required for each year of repository operation. Estimates of acquisition, operating, and labor costs determined the optimum capacity of a transporter as two canisters, except for the intermediate-level waste transporter, which will carry a single large-diameter canister.

Total annual radiation dosages for the transporter operators were developed based on transporter configuration, cask shielding, and operating cycles, and are less than 5 rems for all the transporter concepts. Additionally, a survey was conducted to identify materials suitable for use as seals, hoses, lubricants, paints, and adhesives in the radiation fields which will exist inside and around the casks.

It was determined that a single transporter designed for high-level waste can also transport all of the cladding waste. A single transporter for both types of waste is a feasible concept because the cladding waste gamma shielding requirements are slightly lower than those for the HLW, and because the cladding waste requires no neutron shielding.

An 18-month program of combined design, fabrication, and testing of the first transporter vehicle is recommended. Development costs, including fabricating the first transporter, are estimated at \$2,100,000. Costs for additional units are also estimated. An alternate schedule of 37 months, in which the design and fabrication phases are completely separate, is also presented. Both schedules assume that the concepts in this report remain viable. If continuing evaluation of the repository design dictates that these concepts be extensively revised, then an additional 7 months of preliminary design will precede the 18- and 37-month schedules.

2.0 INTRODUCTION

2.1 GENERAL

The radioactive waste canister transporter is a vehicle designed to transport canisters of radioactive waste within the confines of an underground repository. Repositories, which will be used for the long-term storage and eventual disposal of radioactive waste, will utilize domed or bedded salt deposits as the storage medium for the waste. These deposits will be located 800 to 4,000 feet below the earth's surface. The radioactive waste will be shipped by rail or truck to surface facilities at the repository, where it will be unloaded in shielded casks and inspected. Damaged canisters will be overpacked with an additional steel sleeve. The canisters will then be lowered down a shaft to the underground repository level.

The transporter will receive waste canisters, transport them to predrilled sleeved emplacement holes, and install a canister and a concrete shield plug in each hole. The transporter will be capable of reversing this sequence of operations so that the canisters can be retrieved if necessary. The waste canister will be shielded during all operations so that contact with the cask surface results in an exposure no greater than 25 millirems per hour.

The transporter configurations developed in this report are based on tractor-trailer combinations and modified forklifts. These configurations were selected on the basis of load-carrying capacity, maneuverability, economic factors, and commercially available prime movers which could be utilized without expending a great deal of funds developing a new species of vehicle.

2.2 RADIOACTIVE WASTE CANISTERS

Four types of radioactive waste canisters are to be transported: spent fuel, high-level waste (HLW), cladding waste (CW), and intermediate-level waste (ILW). Handling of low-level waste (LLW) is not within the scope of this

contract. All four types of waste will be handled in cylindrical steel canisters as depicted in Figure 1. The spent fuel will be at least 3 years old and the HLW will be at least 5 years old.

Figure 1 DESCRIPTION OF WASTE FORMS

2.3 OBJECTIVES

The requirements of the contract were that the FMC Corporation, Engineered Systems Division (FMC ESD), develop conceptual designs of transporters

to carry the four waste forms and to install them in vertical, horizontal, or inclined storage holes. Specifically, FMC ESD performed the following services:

- Using preliminary criteria supplied by Union Carbide Corporation, Nuclear Division (UCC-ND), Office of Waste Isolation (OWI), developed general equipment concepts, sized structural members, determined the arrangement and size of subassemblies, prepared overall utility requirements, and developed basic performance characteristics and control schemes.
- Prepared preliminary drawings, sections, elevations, outline specifications, parts lists, preliminary structural investigations, expanded operational performance characteristics, and control system flow sheets.
- Identified and performed engineering analyses needed to derive or confirm structural, utility, and control system designs.
- Consulted with UCC-ND/OWI to expand preliminary criteria and determine requirements which will govern subsequent design efforts; established criteria for preliminary design (Title I), and definitive design (Title II).
- Prepared an estimate of capital costs subdivided by item and subgrouped by systems and equipment categories.
- Collaborated with UCC-ND/OWI in preparing schedules for the design and construction of the transporter.

2.4 ORGANIZATION

To assist in accomplishing the objectives, a subcontract was let to Los Alamos Technical Associates (LATA) of Los Alamos, New Mexico.

The contract with FMC ESD was administered by UCC-ND/OWI. Mr. M. K. Preston was principal engineer for UCC-ND Engineering Division and Mr. P. D. Fairchild was OWI Project Manager.

3.0 SUMMARY

Three basic concepts for transporters have been developed:

- A tractor-trailer concept for the vertical installation and transporting of spent fuel
- A modified forklift for the vertical installation and transporting of high-level waste (HLW), cladding waste (CW), and intermediate-level waste (ILW)
- A tractor-trailer unit for horizontal and inclined storage.

The spent fuel transporter (see Section 4.0) is a tractor-trailer unit consisting of a Caterpillar 621 tractor and a specially designed trailer. On the basis of determination of operating cycles and an economic analysis, a two-canister cask capacity was established. Each spent-fuel canister would be 14 to 16 inches in diameter and approximately 16 feet long, and would weigh as much as 5,000 pounds. This capacity will require that three transporters be used two shifts per working day, 252 days per year, at the peak of repository operation. The estimated average cost over the life of the repository to transport and bury each spent-fuel canister is \$66. The cask for two spent-fuel canisters will weigh approximately 95,000 pounds.

An 80,000-pound-capacity modified forklift (see Section 5.0) is recommended to transport and vertically install two high-level waste or two cladding-waste canisters. These canisters will be 12.75 to 14 inches in diameter and 10 to 10.25 feet long, and will weigh a minimum of 3,000 pounds. One transporter working two shifts, 252 days per year, will be sufficient to handle the entire input of these waste forms. The estimated cost to transport and install each canister is \$32. The cask for this application weighs approximately 76,000 pounds.

The 36,000-pound-capacity modified forklift (see Section 6.0) is recommended to carry a single canister of intermediate-level waste, 24 to 25.5 inches in

diameter, 10 to 10.25 feet long, weighing 12,000 pounds. One transporter will be sufficient to handle the anticipated volume of ILW. The estimated cost to transport and install each canister is \$28. The cask weight is approximately 21,000 pounds.

A tractor-trailer unit has been developed to carry two HLW or CW canisters for horizontal or inclined storage. Unlike the vertical installation in which the casks can rely on gravity to guide the grapple onto the canister, the horizontal installation requires a rigid mechanism to support the grapple in a cantilevered manner. This mechanism must be placed inside the cask, increasing the internal volume and the cask weight to 175,000 pounds. This horizontal-installation transporter vehicle is shown in Figure 20, Section 7.0, on Page 117.

Calculations have been made for these waste canisters to determine the shielding requirements to restrict the dose rate on contact with the cask to 25 millirems per hour. Requirements are as listed in Table 1.

Table 1 CASK SHIELDING REQUIREMENTS

Waste type/canister description	Shielding requirements for contact dose rate of 25 millirems per hour, inches and cm
Spent-fuel canister, containing one pressurized water reactor (PWR) or two boiling water reactor (BWR) elements, 3 years old	4.02 (10.2 cm) depleted uranium 3.94 (10.0 cm) borated polyethylene 2.00 (5.1 cm) structural steel
High-level waste canister, 5 years old	4.33 (11.0 cm) depleted uranium 7.87 (20.0 cm) borated polyethylene 2.00 (5.1 cm) structural steel
Cladding waste	4.02 (10.2 cm) depleted uranium 2.00 (5.1 cm) structural steel
Intermediate-level waste	4.92 (12.5 cm) structural steel

Operating cycles were developed for the vertical-installation transporters for the spent-fuel repository and for the repository for HLW, CW, and ILW. The cycles were developed for transporters with capacities of up to five canisters. Each operating cycle was analyzed to determine the number of shifts required per year for each type of transporter. This data was then used to select an

optimum transporter capacity in terms of the cost to transport each canister and the effect of increased capacity on the size and shape of the transporter. It was determined that a two-canister capacity was optimum.¹

When it was directed that the ILW canister be 24 inches in diameter, a single-canister capacity was selected for the ILW transporter. The large diameter could accommodate about four times the mass of radioactive material held by the original 12.75-inch-diameter canister; this large diameter offsets the advantages of a two-canister capacity transporter.

The cycle times and shielding properties of the casks were analyzed to determine the total dose received by the transporter operators. Results are listed in Table 2. While these doses are below the allowable annual exposure of 5 rems per year, it should be noted that these are neither maximum nor minimum values but are estimates of what the operators will actually receive. If current trends to reduce exposure to very low levels continue, it will become desirable to place a layer of shielding on the transporter cabs between the operators and the cask. Additionally, there is one short period of time, as a canister is actually traveling up or down in a storage hole, that a short segment of the canister has a minimal amount of shielding consisting of several inches of salt. A gamma shield between operators and cask would greatly reduce the operator exposure during this time.

Rigid adherence to the process of Title I and Title II design is not recommended. Instead, an 18-month program is envisioned for the concurrent (overlapping) design, fabrication, and testing of any one of the spent-fuel or HLW/CW transporters. The ILW transporter is simpler, and fabrication could be accomplished in a shorter period. The development cost, including fabricating the first transporter, is estimated at \$2,100,000

-
1. Directions to analyze horizontal and inclined storage were received midway through the program. It was assumed that these transporters would be similarly affected by operating cycles, mine plan, etc. A two-canister capacity was similarly considered optimum for the horizontal and inclined storage transporters.

for the spent-fuel and HLW/CW transporters. Costs for the ILW transporter would be slightly less. Estimated costs for additional transporters, assuming no further investment in engineering, are listed in Table 3. An alternate 37-month schedule has been developed which has distinct design and fabrication phases separated by a 5-month period of procurement activities. This program has the disadvantage of increased cost due to inflation, inefficiency, and added management effort.

Table 2 DOSE RATES RECEIVED BY OPERATORS

Transporter	Person	Total annual dose for 252 shifts, rems
Spent-fuel, vertical installation	Operator	1.1
	Helper	1.4
High-level waste, vertical installation	Operator	3.0
	Helper	3.0

Both the 18- and 37-month programs are based on continuing with the concepts developed in this report. If continuing refinement of the repository design dictates extensive revision of these concepts, an additional 7-month preliminary design phase should precede both the 18- and 37-month programs.

About 40 percent of the cost of the spent fuel and HLW/CW transporters is for depleted-uranium shielding. The cask costs would be reduced by using lead. Use of lead, however, would result in a wider, longer, higher, and heavier transporter which will require large mine openings and added mining costs. The higher costs for mine development greatly exceed the cost difference between uranium and lead.

Table 3 COSTS OF ADDITIONAL TRANSPORTER UNITS

Transporter	Cost
Spent-fuel, vertical installation	\$1,007,000
HLW/CW, vertical installation	877,000
ILW, vertical installation	292,000
HLW/CW, horizontal installation	1,565,000

Artist concepts have been developed to show how the transporters could be used to transport casks that were loaded with canisters on the surface and then lowered down a shaft to the underground repository level.

4.0 SPENT-FUEL TRANSPORTER, VERTICAL INSTALLATION

The spent-fuel transporter is a tractor-trailer combination (Figure 2) designed to carry and emplace two spent-fuel canisters in vertical holes in the floor of a repository. Prior to selection of the tractor-trailer design, several other concepts were considered. The following list briefly describes each candidate concept:

- A dual-canister transporter for 120-day-old spent fuel (Figure 3). This design is much like the selected design, but it is heavier and wider. As the study progressed it was directed that there was no need to haul spent fuel less than 3 years old.
- A single-canister transporter. This method was rejected because it was more efficient to haul two canisters at one time (see economic analysis, Section 4.7). Placement of two canisters in a cask does not adversely affect entry or room size.
- Hauling the cask in an upright position with a tractor-trailer arrangement. This means was quickly rejected because it would be relatively unstable and would require mining all passageways to about 22-foot height.
- A large lift truck. Because it was decided that the cask should be carried horizontally during transport, it would be necessary to carry the 18-foot-long cask required for spent fuel on top of the lift truck. The lift truck concept was higher and wider than the proposed transporter and weighed much more. The mechanism for reclining the cask was also complex.
- A large dump truck. The dump truck body could be used to elevate the cask to a vertical position. Study revealed, however, that travel heights would be wider and higher with the dump truck than with the proposed system. The operator also could not clearly see cask alignment and other procedures.
- A cask with a very large base shield (Figure 4). This shield would protect personnel in any location in the repository while the canister was being emplaced. "Streaming radiation" would be reduced at floor level by this design configuration.

The base shield was judged heavy and cumbersome, and it was decided that personnel should be confined to the cab or removed from the site while canisters are being transferred from the cask to the hole.

- Removing all personnel from the site and making cask-hole transfers by means of umbilical-cord control and television surveillance. This concept was rejected because of the considerable amount of time required to string out an umbilical control cord, the vulnerability of such a cord, the additional complexity of control/instrumentation, and the loss of the general benefits provided by on-site surveillance.

The selected tractor-trailer design is 43 feet 8 inches long, 10 feet 7 inches wide, and 10 feet 8 inches high. The tractor is a Caterpillar 621B model that was designed to be part of a wheeled tractor-scraper unit, with a modified shift mechanism to control speeds to a maximum 12 mph.¹ The trailer is specially designed to haul a cask containing compartments for two canisters.

Each canister will contain either one pressurized-water-reactor (PWR) or two boiling-water-reactor (BWR) spent-fuel elements. Each canister should measure 14 inches outside diameter and about 187 inches in length. In addition, each cask compartment will accommodate the added dimensions of the overpack sleeve which will be used on damaged canisters. The overpack will increase the canister diameter to 16 inches, the length to approximately 190 inches, and the weight from 3,000 to 5,000 pounds. During operations, the transporter cask will handle either standard-sized canisters or overpacked canisters in either canister compartment.

When the cask is carrying two 5,000-pound overpacked canisters, the resultant cask weight is 105,000 pounds. If the cask were redesigned

1. The contract requires a 10 mph speed on level terrain, and all economic and impact calculations have been calculated at this value. Speed is being limited by blocking out the sixth, seventh, and eighth transmission ranges. Blocking the fifth range also would limit speed to 9 mph. This type of speed control is very straightforward, but speed control to exactly 10 mph can, if necessary, be provided.

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Figure 2 SPENT-FUEL TRANSPORTER
FOR 3-YEAR-OLD SPENT FUEL,
TWO-CANISTER CAPACITY
(FMC Drawing 5135378)

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Figure 3 TRANSPORTER FOR 120-DAY-OLD SPENT FUEL, TWO-CANISTER CAPACITY (FMC Drawing 5135273)

Figure 4 CASK WITH LARGE BASE SHIELD (FMC Drawing 5135384)

so that the compartments were sized to handle either two standard canisters or one canister with an overpack and one standard canister, the cask weight would be reduced. The weight when carrying an overpacked canister and a standard canister would be 98,000 pounds.

A possible storage hole placement configuration and other features of the repository that would be compatible with the transporter design are shown in Figure 5. The depicted hole spacing of the repository permits emplacement of the canisters and safeguards against the transporter tires running over adjacent rows of holes.

The room width required for the transporter to turn 90-degree corners with one turn is 20 feet, with the corner trimmed 3 feet (Figure 6). If the tractor were backed into the corner once or twice in the turn, the room width could be decreased to 17-1/2 feet (with the corner trimmed 5 feet).

The following paragraphs describe the transporter components in detail.

4.1 TRANSPORTER CASK

Radiation protection and transportation requirements resulted in a two-canister cask design 18 feet by 39 inches by 57 inches, weighing 95,000 pounds (see Figure 7).

The radiation shielding provided by the cask will reduce the gamma-ray and neutron flux to less than 25 millirems per hour at the cask surface.

The shielding will consist of a 4-inch layer of depleted uranium, a 4-inch layer of borated polyethylene, and 2-9/16 inches of steel. The steel shielding will also provide the structural containment for the other shielding materials. Appendix A documents the evaluation which determined the shielding specifications. The uranium and borated polyethylene shields are designed to be made in sections to facilitate cask construction and maintenance. The cracks joining the sections will be stepped to avoid slight separations which could cause gamma-ray and neutron "windows." Chevron joints could also be used, although making and inspecting the stepped joints to close tolerances would be simpler.

Figure 5 REPOSITORY PLAN, SPENT FUEL (FMC Drawing 5135334)

Figure 6 TRANSPORTER TURN CAPABILITY, SPENT FUEL (FMC Drawing 5135380)

FMC FMC Corporation
Engineered Systems Division

Figure 7 TRANSPORTER CASK, TWO
3-YEAR-OLD SPENT-FUEL
CANISTERS (FMC Drawing
5135379)

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To maintain the desired sealed environment within the cask, a 70-cfm fan and a HEPA filter will be used to keep the cask interior (when the cask door is closed) under a vacuum of 1 inch of water.¹ The selected filter, a Flanders Filters, Inc., G-1 1R BB-D SS, incorporates a bag-out feature which allows removal of the filter without personnel coming in direct contact with the filtered materials (see Appendix B). The blower will be a Joy Manufacturing Company Model X702-213B (92 cfm at 2 inches of water and 2 amperes at 28 volts DC) or an equivalent unit.

The cask design also provides for passive heat removal to avoid excessive temperatures in the canister or cask interior. Three-year-old PWR canisters produce 1.8 kw of energy; BWR canisters produce less. Aluminum heat-conduction strips (see Section C-C of Figure 7) will conduct heat through the polyethylene shielding layers. This provision will limit the temperature differential across the cask to 40°F. The cooling strips will provide passive cask cooling and will be oriented so as not to form a radiation window for neutrons. Thermocouples in the cask will monitor the temperature of each cavity.

The maximum recommended temperature (without some softening) of Reactor Experiments, Inc., Number 201 borated polyethylene shielding is 180°F. The temporary excursion caused by the maximum 150°F outside ambient during retrieval probably will cause no adverse effects to the borated polyethylene, but adequacy of this material must be evaluated during the detail design phase. If the borated polyethylene Number 201 is found inadequate, more cooling paths can be added or a more expensive, higher-temperature material such as borosilicone can be used.

Several other cask features involve hydraulically operated mechanisms. The specified sizes of the cylinders operating the mechanisms are such that the 2,000-psi hydraulic systems will provide adequate power but not enough power to break or deform linkages or cables. Hydraulic systems are discussed in Section 4.5.

1. The contract stipulates that "an absolute filter and blower system shall be provided to maintain 1/2 inch negative pressure within the waste canister cavity."

The following paragraphs describe key components of the transporter cask.

4.1.1 Canister Grapple Mechanism

Mechanisms will be provided within the cask to grasp the top of each spent-fuel canister and hold it securely during transport and installation/retrieval operations. The grapple eventually selected must be suitable not only for use with the transporter concepts shown, but also for use in the mine-level hot cell, repository surface facilities, and perhaps at the reactor sites. Because only the transporter is within the scope of this effort, no specific mechanism is recommended; however, several concepts are presented and discussed in Section 8.0, Common Features and Utility Systems.

4.1.2 Canister Hoist

The canister hoist is designed to raise and lower the canister through one canister length and 9 feet into a floor well (25 feet of travel). Hoisting will be accomplished by means of a special leaf chain (described in Section 8.0) and a cylinder and multipulley arrangement as shown in View A-A of Figure 7. This cylinder-pulley combination will multiply cylinder travel distance by a factor of 5 so that 60 inches of cylinder stroke will result in 25 feet of canister latch travel. The leaf chain exit point is above the canister. Because the point is not radially in line with any part of the canister, no radiation window results. The cylinder-pulley arrangement was selected for the following reasons:

- It works well with a leaf chain.
- Hydraulic cylinders are well-developed commercial products.
- Hoisting speed can be controlled well with hydraulic circuitry. At full tractor engine rpm, hoisting speed will be 15 inches per second and lowering speed will be 14 inches per second. This speed can be reduced by decreasing the tractor engine rpm and by feathering the control valve.
- Lifting tension can be controlled. The cylinder size (6 inches in diameter with a 2-inch rod) will provide a canister lifting force of 10,000 pounds.

A hoist mechanism is provided for each canister compartment. Although deleted for clarity in Figure 7, it is recommended that an expanded metal guard be placed over the cylinder rods and the hoist chains. The guard will provide protection for the mechanism and for personnel and also permit visual inspection of hoist components.

4.1.3 Plug Hoist

When the cask is rotated to the vertical position for placement of a canister in the predrilled and sleeved storage hole in the floor, it will also serve as a structure for removing the concrete plug from the hole. Figure 7 shows the plug in phantom lines and indicates the manner in which it will be hoisted from the repository hole. The plug will measure 7 feet in length and will weigh approximately 2,350 pounds.

Hoisting of the plug will be accomplished with a hydraulic cylinder and a 1/2-inch-diameter wire rope. A pulley at the cylinder end will amplify the 80-inch stroke so that it will provide enough cable to connect to the concrete plug and lift it 13 feet. The cable and cylinder rod will also be enclosed with an expanded metal guard (also deleted from Figure 7 for clarity). The maximum lift (at 2,000 psi hydraulic pressure) will be 3,100 pounds. Lifting speed will be 1 foot per second at full tractor engine rpm. Lowering speed will be 8 inches per second at full engine speed.

4.1.4 Door Opening and Latching Mechanism

The door opening mechanism will open and close the door on the bottom of the cask when it is in a vertical position (Figure 7). A latching mechanism will hold the door closed and minimize the gap between the door and the cask, minimizing the possibility of air leakage.

Door operation (starting with the door closed) will be sequenced as follows:

- The door longitudinal cylinder and the door latch cylinder (Figure 7, Section B-B) are extended to the respective maximum displacements. (These cylinders are operated in parallel by the same valve.) This action moves the cask door 5 inches downward so that the door shielding no longer protrudes into the cavity.
- The door is opened by the door rotation cylinder, as is shown in the cask end view.
- The door longitudinal cylinder and door latch cylinder are retracted their maximum displacements to provide a flat surface at the cask end that can be lowered against the jackplate which rests on the repository floor.
- The door is closed by reversing the steps.

Pilot check valves will be mounted to both the door latch cylinder and the door longitudinal cylinder. These check valves will hold the door closed even if there is a leaky hydraulic valve or line.

Hydraulic flows and cylinder sizes were selected to provide adequate, but not excessive, speeds and forces. The operating speed is given in a time sequence explanation in Subsection 4.4.2.

4.1.5 Lateral Trailer Movement Mechanism

During the transporter operating sequence (Subsection 4.4.1) the bottom rear portion of the cask is lowered until a foot pad lodges against the floor and causes the transporter trailer to be lifted until the tires clear the floor (see inset, Figure 8, Page 43).

By means of a foot-pad cylinder, the entire trailer can be moved sideways so that when the cask is in the upright position it will align with the storage hole. The foot pad is pressed against the floor as before to anchor the cask. The movable trailer carriage is then used to position the jack plate longitudinally. Extension and retraction of the foot-pad cylinder then moves the trailer sideways (at a rate of 2 inches per second) until the trailer aligns with the hole.

4.2 TRANSPORTER TRAILER (Figure 2)

The transporter trailer will haul the cask in a near-horizontal position, locate it over the repository hole, and rotate it to a vertical position. Components are described in the following paragraphs.

4.2.1 Trailer Frame

The trailer frame design is essentially a structure of 8- by 20- by 1-1/2-inch box-section steel members that will attach to the wheels, provide the gooseneck that attaches to the tractor, and support the carriage. Box sections were selected for torsional stiffness to react the moments imposed by the wheels. This arrangement allows trunnion mounting of the wheels, leaving a large central area with no cross members to interfere with cask motion. The frame gooseneck, built to mate with the tractor cushion hitch and its steering cylinders, will provide clearance for the tractor wheel and fender so that the tractor can be turned 90 degrees relative to the trailer.

4.2.2 Tires, Wheels, Hubs, and Brakes

Four 29.5 by 29 (34-ply) tires will support the trailer, cask, and canisters, which represent a total weight of approximately 145,000 pounds. The allowable weight per tire is 42,850 pounds at 80 psi and 10 mph, although manufacturers will honor the warranty at 15-percent overload (49,280 pounds per tire). The 145,000-pound trailer weight will impose a load of 36,250 pounds per tire, which is 74 percent of the warrantee load. Tire manufacturers have indicated, however, that tire performance would be improved if air pressure were reduced so that the load on the tires approaches the 100-percent rating.

This information suggests that a better operating pressure would be 60 psi. The reduced pressure would improve flexibility and reduce ground pressure, so the tire would be less susceptible to cuts and bruises and more equal tire loading on uneven terrain would be achieved.

The brakes will be air operated in conjunction with the tractor brakes, using the tractor 125-psi system.

A pad of high-strength ground steel on top of the side longitudinal members will react the weight of the carriage rollers.

4.2.3 Trailer Carriage

The trailer carriage is designed to travel a total of 57 inches relative to the trailer frame to provide longitudinal cask movement. It will support the cask by means of bearings, trunnions, and hydraulic cylinders. The cask will be rotated about the trunnions by means of a three-stage cylinder on each side of the cask.

Carriage travel will be controlled by two cylinders: a 7-inch-bore, 39-inch-stroke cylinder that will position the carriage for handling the storage hole plug and Canister 1; and a 7-inch-bore, 18-inch-stroke cylinder that will shift the carriage from the Canister 1 to the Canister 2 handling position. These cylinders will be mounted piggy-back so that the following operations are possible:

- Retracting both cylinders will correctly locate the carriage longitudinally for concrete plug removal and placement.

- Fully extending the Plug/Canister 1 cylinder and fully retracting the Canister 1/Canister 2 cylinder will correctly index the carriage for insertion or removal of Canister 1.
- Fully extending both cylinders will index the carriage for installation or retrieval of Canister 2.

Precise adjustment of the indexing points for the two separate cylinders will be made by screwing the cylinder rod into the carriage or trailer cross members and adjusting the length of the spacers that limit cylinder stroke. Maximum carriage movement speed caused by the Plug/Canister 1 cylinder index will be 7.5 inches per second; when the Canister 1/Canister 2 cylinder is activated, the speed will be 2 inches per second.

The different rates allow for adequate carriage speed (at 7.5 inches per second) and precise adjustment when the cask-carriage is used to align the trailer with the storage hole (at 2 inches per second).

Ten cam rollers (Torrington TCR-86), each with a maximum load capability of 46,100 pounds, will be used to support the carriage on the trailer frame. The anticipated actual average load on each cam roller is 14,000 pounds, depending on cask orientation.

Eight smaller cam rollers (Torrington TCR-64) will be used to keep the carriage aligned with the trailer frame and to support the frame when it is lifted by the cask during alignment procedures with the repository hole. The load capacity of each roller is 19,600 pounds.

The cask will be rotated in the carriage by two single-acting, three-stage cylinders with bores of 7-5/8 by 6-1/2 by 5-3/8 inches and an 86-inch total stroke. The most severe pressure requirements (about 1,300 psi) will be imposed on these cylinders when they are used to lift the trailer.

A cask-door lock arc on the trailer carriage will prevent inadvertent extension of the door hinge. The door therefore cannot be opened when the cask is in a travel position (or when the cask is less than 45 degrees from vertical). This door lock arc is included as a safety device.

4.2.4 Jacks and Jack Plate

The trailer will be lifted by two hydraulic jacks and a jack plate that will index on the repository hole. The jacks are a modification of an FMC (Link-Belt Part Number 18J1361-C) crane outrigger hydraulic cylinder. Lifting the trailer with the jacks will require about 1,700 psi pressure.

The transporter jacks have 7.5-inch-diameter bores and 35-inch strokes. A pilot-operated check valve, mounted directly to the top of the cylinder, will prevent jack creepdown in the event of a leaky valve or hose.

The jack plate hole diameter, as shown in Figure 2, is about 3/8 inch larger than the plug sleeve. The plug sleeve, which would extend from 0 to 4 inches above the salt, will mate with this hole to assure alignment.

4.2.5 Stabilizer Jacks

Two jacks, identical to the jacks described in Subsection 4.2.4, will provide stability during certain phases of the operation (Figure 2). The stabilizer jacks are oversized for any potential load and were selected to avoid introducing another part into the spares system. They will also provide additional resistance to any side loads.

Two additional stabilizer jacks will be mounted on the tractor (see Section 4.3). The stabilizer jacks will react the inertia forces of the cask as it comes to a sudden stop following the rapid shifting of the carriage to the plug removal position (see Subsection 4.4.1). Hydraulic circuitry will be such that retraction of the trailer plate jacks will cause the stabilizer jacks to bleed down by overpressure relief.

The stabilizers are not designed to support the trailer alone. Operation of the stabilizer jacks is described in the controls and hydraulics section, Section 4.5.

4.2.6 Control Panels

A control panel on each side of the trailer will allow the operator's helper to do much of the work associated with emplacing or removing a canister.

From this location, he can best observe the cask movements. A panel on each side will allow the helper to work on the transporter side away from the salt rib. The control panel is described in detail in the controls section, Section 4.5.

It is planned that the operator's helper will visually align the jack plate with the sleeve, although the operator can also see and control the alignment from the cab. Nonvisual alignment would be possible with the addition of three magnetic proximity switches to the jack plate and inclusion of associated indicators at the control station. The jack plate would be constructed of nonmagnetic steel.

4.3 TRANSPORTER TRACTOR

The basic transporter power unit is the tractor of a Caterpillar 621B wheeled tractor scraper. The previously described trailer is attached to the tractor as the scraper would be attached. The tractor is 10 feet 8 inches high and 11 feet 4 inches wide, and weighs 31,400 pounds. It was selected because of good maneuverability, ease of control, and naturally good operator vision of the trailer. It also incorporates the following features that make it useful for this application:

- The hydraulic system that would be used for scraper operation can be used to power trailer functions (see the controls and hydraulics section).
- The diesel engine is relatively nontoxic. This type of engine is being used without exhaust modification in salt mines (spark ignition engines are not used). Scrubbers can also be added to make the diesel exhaust fumes less toxic, as is commonly done in coal mines.
- Steering cylinders provided for the scraper unit can be used with the trailer unit.
- The -125 psi, 10-cfm air system (for tractor and scraper braking) can be used for tractor and trailer braking and may be used for other functions, such as operation of the canister grapples.
- A cushion hitch contributes to a better ride for the operator and can be locked out when the transporter and trailer is lifted on jacks.
- Tractor tire size is the same as that to be used on the trailer: 29.5 by 29 (34 ply).

- A 24-volt, 50-ampere alternator system (1,200 watts) furnishes power to the solenoid valve controls, instrumentation, and lighting (the estimated requirement is 30 amperes; see Section 4.5).

4.3.1 Tractor Modifications

Certain modifications to the 621B tractor are planned to make it best serve as a transporter power unit. The following modifications are planned:

- Modifying and adding to the number of controls in the cab to provide control capability for all trailer functions.
- Adding another cab on the right side of the transporter for the operator's helper. This addition requires relocating the fuel tank, hydraulic oil tank, and engine exhaust.¹
- Adding a bumper to the front of the transporter which will include two shock absorbers with 24-inch strokes to provide 1.7 g deceleration if the transporter runs into a solid wall at 10 mph.²
- Adding jacks to the front of the tractor to lift it while the trailer jacks lift the trailer for cask alignment with a repository hole (see Subsection 4.2.4). Two jacks are required because the tractor-trailer hitch does not restrain rotational pivoting. These jacks will be identical to those described for the trailer.
- Provisions for adding an air conditioner for each cab.
- Blocking out the sixth, seventh, and eighth transmission shift ranges, which will limit maximum transporter speed to 12 mph.

-
1. There is not necessarily a need for the operator's helper to ride on the transporter. He may either be taken to the repository site and remain there during the shift or he may have his own transportation, such as a battery-operated golf cart. If the operator's helper does not ride on the transporter there will be no need for a second cab, and the modification effort will be simpler.
 2. The longitudinal placement cylinders protect the cask by limiting cask deceleration to 1.5 g (see Subsection 4.2.3). The bumper shock absorbers protect personnel and the tractor to a greater degree than is common for construction-type equipment.

- Shielding the cabs by making the rear cab walls of 5-inch lead or an equivalent gamma shielding should be considered in the final design. As the canister moves from the cask into the repository, the operator and the operator's helper are shielded by a relatively small salt layer (about 7 inches) and by the jack plate. These provide adequate shielding, as shown in Table 2, page 20. However, human error (and possibly other malfunctions) could expose the operators to excessive radiation. Shielded cabs with leaded glass windows or with periscope vision would provide a safe housing for personnel in the event of an accident.

4.4 MACHINE OPERATIONS AND CYCLE TIMES

The transporter is designed to be loaded from the bottom with two canisters by lowering the grapples into a hot cell and attaching them to the canisters. Hot cell loading will allow viewing the attachments and making a visual inspection of the canisters, grapples, and hoisting chain. In the economic analysis, a canister loading time ranging from 5.83 to 12.83 minutes and a travel time (both ways) varying from 19.4 to 34.4 minutes are projected. The following paragraphs describe the procedure and project the time requirement for transferring two canisters from the transporter to the repository holes.

4.4.1 Cask to Vault Transfer Process

Figure 8 details how a concrete plug will be removed from the repository hole, a canister transferred from the cask to the hole, and the concrete plug replaced. Except for operations involving potentially dangerous radiation levels, all necessary functions will be performed by an operator or helper adjacent to the canister hole. With the exception of initial alignments and hooking and unhooking the concrete plug, all operations could be performed with equal ease from the operator's cab. The room may be uncomfortably warm during canister retrieval. The operator's helper may elect to leave the cab only to connect and disconnect the concrete plug hoists and perform all other functions from within the air-conditioned cab. Performing operations at the hole site has the advantage of allowing for a continuous inspection of the transporter working parts.

1. THE TRANSPORTER IS IN THE TRAVEL POSITION. THE CASK, CONTAINING TWO SPENT FUEL CANISTERS (SHADED), IS IN A REARWARD POSITION SO THAT THE CASK DOOR RESTS AGAINST THE FRAME CROSS MEMBER. THE DOOR LOCK ARC PROVIDES ADDITIONAL PROTECTION AGAINST THE DOOR'S OPENING WHILE THE CASK IS IN THE NEAR-HORIZONTAL TRAVEL POSITION. THE PLUG/CANISTER 1 PLACEMENT CYLINDER PROVIDES A SHOCK ABSORBER EFFECT IN THE EVENT OF A FRONT-END COLLISION. DURING A COLLISION AT A MAXIMUM SPEED OF 10 MILES PER HOUR, THE CASK AND CARRIAGE SHIFT FORWARD IN THE TRAILER FRAME AND PUSH AGAINST THE CYLINDER. THE COMPRESSION OF THE CYLINDER CAUSES THE CASK AND CARRIAGE TO DECELERATE AT A MAXIMUM RATE OF 1.5 g. THE BUMPER SHOCK ABSORBER IN THE FRONT OF THE VEHICLE PROTECTS THE DRIVER AND OTHER EQUIPMENT.

Figure 8 OPERATIONAL SEQUENCE FOR VERTICAL INSTALLATION OF SPENT-FUEL CANISTERS
(Sheet 1 of 7)

Figure 8 OPERATIONAL SEQUENCE FOR VERTICAL INSTALLATION OF SPENT-FUEL CANISTERS
(SHEET 2 OF 7)

7. THE OPERATOR'S HELPER EXTENDS THE TWO TRACTOR AND THE TWO TRAILER JACKS TO THE MAXIMUM VERTICAL POSITIONS AND STABILIZES THE ELEVATED TRAILER BY EXTENDING THE REAR STABILIZER JACKS.

8. THE OPERATOR'S HELPER EXTENDS THE CASK-ROTATE CYLINDERS TO FULL EXTENSION, BRINGING THE CASK INTO THE VERTICAL POSITION.

Figure 8 OPERATIONAL SEQUENCE FOR VERTICAL INSTALLATION OF SPENT-FUEL CANISTERS
(SHEET 3 OF 7)

9. THE HELPER FULLY RETRACTS THE CANISTER PLACEMENT CYLINDERS. THIS ACTION SHIFTS THE CARRIAGE IN RELATION TO THE TRAILER FRAME UNTIL THE HOIST CABLE IS DIRECTLY OVER THE PLUG.
10. THE HELPER UNHOOKS THE HOIST CABLE FROM THE SIDE OF THE CASK AND PLACES THE CABLE HOOK THROUGH THE PLUG LATCH. IF RETRIEVING WASTE, THE HELPER THEN RETURNS TO THE CAB.
11. THE HELPER (OR OPERATOR, IF RETRIEVING) ACTIVATES THE HOIST TO PULL THE PLUG FROM THE REPOSITORY HOLE.

Figure 8 OPERATIONAL SEQUENCE FOR VERTICAL INSTALLATION OF SPENT-FUEL CANISTERS
(SHEET 4 OF 7)

12. THE OPERATOR'S HELPER (OR OPERATOR, IF RETRIEVING) EXTENDS THE PLUG/CANISTER 1 PLACEMENT CYLINDER TO FULL EXTENSION TO POSITION CANISTER 1 DIRECTLY OVER THE DEPOSITORY HOLE, INDEXING VIA HOLE IN JACKPLATE. THE HELPER THEN RETURNS TO THE CAB.

13. USING CONTROLS WITHIN THE CAB, THE OPERATOR UNLATCHES THE CASK DOOR AND ROTATES IT TO THE DOOR-OPEN POSITION.

14. THE OPERATOR LOWERS THE TRAILER, TRACTOR, AND STABILIZER JACKS UNTIL THE CANISTER RESTS ON THE JACK PLATE. USING INSTRUMENTATION AND VALVES LOCATED WITHIN THE CAB, THE OPERATOR PLUMBS THE CANISTER.

15. THE OPERATOR ACTIVATES THE CANISTER HOIST CYLINDER TO LOWER THE CANISTER INTO THE RE-DEPOSITORY HOLE. HE THEN UNLATCHES THE CANISTER FROM THE HOIST CHAIN.

Figure 8 OPERATIONAL SEQUENCE FOR VERTICAL INSTALLATION OF SPENT-FUEL CANISTERS
(SHEET 5 OF 7)

16. THE OPERATOR AGAIN ACTIVATES THE HOIST CYLINDER TO RAISE THE HOIST GRAPPLE INTO THE CASK.
17. THE OPERATOR RAISES THE TRACTOR AND TRAILER JACKS.
18. THE OPERATOR ROTATES THE CASK DOOR TO THE CLOSING POSITION AND LATCHES IT.
19. THE OPERATOR PLUMBS THE CASK.
20. THE OPERATOR EXTENDS THE STABILIZER JACKS TO ASSURE AND MAINTAIN THE PLUMB POSITION.
21. THE OPERATOR RETRACTS THE PLUG/CANISTER 1 PLACEMENT CYLINDER TO RETURN THE CASK TO THE PLUG-REMOVAL/PLACEMENT POSITION
22. THE OPERATOR LOWERS THE PLUG INTO THE HOLE.

Figure 8 OPERATIONAL SEQUENCE FOR VERTICAL INSTALLATION OF SPENT-FUEL CANISTERS
(SHEET 6 OF 7)

23. THE HELPER DISCONNECTS THE CABLE FROM THE PLUG LATCH AND RETURNS IT TO THE HOIST-CABLE LATCH ON THE SIDE OF THE CANISTER.
24. THE HELPER ACTUATES THE PLUG/CANISTER 1 PLACEMENT CYLINDER TO MOVE THE CARRIAGE TO THE CANISTER 1 PLACEMENT/REMOVAL POSITION.
25. THE HELPER ROTATES THE CASK TO THE NEAR HORIZONTAL TRAVEL POSITION.
26. THE HELPER RETRACTS THE JACKS, LOWERING THE TRANSPORTER ONTO THE WHEELS.
27. THE OPERATOR DRIVES TO ANOTHER PREDRILLED REPOSITORY HOLE. THE PROCESS IS REPEATED FOR EMPLACEMENT OF CANISTER 2.

Figure 8 OPERATIONAL SEQUENCE FOR VERTICAL INSTALLATION OF SPENT-FUEL CANISTERS
(SHEET 7 OF 7)

Connecting the plug hoist to the concrete plug could also be accomplished remotely if the plug were redesigned. This possible modification, along with other modifications to the proposed design, is covered in Subsection 4.5.5.

Canisters are retrieved by reversing the sequence shown in Figure 8.

4.5 CONTROLS, INSTRUMENTATION, HYDRAULICS, AND LIGHTS

The controls for tractor functions will remain the same as those provided by the manufacturer for use with the scraper. Trailer operations will use hydraulic power supplied by the tractor, except the trailer braking which will be air operated. Other exceptions include the cask filter blower which will be electrically operated and the canister grapple, which may be powered by air (125 psi), electricity (28 volts DC), or hydraulics.¹

All power requirements will be met with standard tractor equipment except that an inverter will be added to convert 24-volt DC power to 115-volt AC power for trailer lighting (Subsection 4.1.4).

The transporter control system will depend on visual observation by the operator and operator's helper. Because of the simplicity of the system, it will provide satisfactory control with minimal developmental effort. An alternate control system that will be totally operated from within the cab is discussed in Subsection 4.5.5.

4.5.1 Controls

The functions listed below will be controlled by two banks of hydraulic valves in the operator's cab. The following valves will be provided at this location:

- All tractor controls
- Canister 1 hoist
- Canister 2 hoist

1. Grapples will be hydraulically powered only if all hydraulic circuitry is outside the cask.

- Canister 1 grapple (if grapple with hydraulic actuation is used)
- Canister 2 grapple (if hydraulic)
- Cask door and cask door latch
- Cask door rotation
- Leveling control for each trailer jack (two) and tractor jack (two) (stabilizer jacks not included).

The following functions will be hydraulic valve controlled at the operator's cab and will also be electrically operable from a control panel on either side of the trailer (solenoid valves with manual override will be used):

- Plug hoist
- Plug/Canister 1 positioning
- Canister 1/Canister 2 positioning
- Tractor and trailer jacks (one valve will extend or retract all four jacks simultaneously)
- Trailer lateral positioning
- Cask rotation
- Cask stabilizer jacks.

4.5.2 Instrumentation

The following instrumentation will be available to the operator at his cab location:

- Pump oil pressure gages (will determine if pressure is normal for many functions).
- Plug removal cylinder pressure gage (will sense the weight of the plug and whether or not it is pulling free).
- Cask leveling instrumentation. It is anticipated that the cask will be plumbed to a vertical position to mate with repository holes that will also be vertical. However, this instrumentation will also read angles of deviation from the vertical in two planes. The cask thereby could be aligned with a nonvertical repository hole by first measuring the vertical attitude of the hole with a special instrument that will rest on the lip of the hole sleeve, and then plumbing the cask to the same attitude. This feature may prove especially useful during canister retrieval following a considerable storage period.

- Canister 1 hoist pressure gage (senses the presence and weight of the canister).
- Canister 2 hoist pressure gage.
- Canister 1 and Canister 2 cavity temperature sensors.¹
- Cask air flow sensor (possibly a streamer-type indicator at the filter exhaust).
- Cask cavity vacuum sensor.
- Radiation-intensity indicators for the following locations (instrument readouts will also be located in the helper's cab):
 - (1) Operator's cab
 - (2) Helper's cab
 - (3) Helper's left trailer station
 - (4) Helper's right trailer station
 - (5) The jack plate (four measurement points).
- Canister grapple instrumentation (see discussion, Section 8.4).

In addition to the cab instrumentation, both the operator and the operator's helper will carry radiation detection instrumentation with them during the installation/retrieval operations.

4.5.3 Hydraulics

Figure 9 shows the hydraulic system schematic for the trailer. The tractor system (except for the addition of trailer controls and the tractor jacks) will not change. Hydraulic power will be provided by 75- and 55-gpm pumps. The flows of these pumps will be divided and combined to provide the desired pressures and flow rates indicated on the schematic. Hydraulic oil will be the same as that used for the tractor engine. The following features of the hydraulic system provide built-in controls and system safeguards:

- Overcenter valves for canister and plug hoist controls will assure that these hoists will lower respective loads at a rate determined by flow from the hydraulic pump and valve feathering.

1. Several thermocouples will probably be used in parallel for each cavity so that an average temperature reading is provided.

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- Pilot check valves on the canister hoist cylinder rod ends will safeguard against a hose or valve leak allowing the canister grapple to lower.
- A pressure relief valve system on the Plug/Canister 1 position cylinder will assure that in the event of a frontal collision, forces on the cask will not exceed 1.5 g.
- Pilot check valves on the trailer jacks, tractor jacks, and stabilizer jacks will prevent valve or hose leakage from allowing these jacks to settle.
- Cylinder ports will be at the top of the cylinders to minimize system air bleeding effort (operating each cylinder over its stroke once will bleed the system).
- A canister rotation cylinder pilot check valve system will isolate the cylinders so that a seal leak in one cylinder will not allow the cask angular position to shift.

4.5.4 Lighting

Lighting on the transporter will be adequate for the following capabilities:

- Driving and backing the transporter at 10 mph on the level
- Quick observation of transporter operations and conditions
- Observation of roof and wall safety hazards
- Observation of floor and repository vault conditions.

The minimum lighting requirement for coal mining machinery is 4 foot-candles of incident light on the surrounding walls and machine surfaces, with coal having a 2-percent reflectivity. Salt reflectivity is much greater, but it does lose some reflectivity as diesel engine fumes and other contaminants coat the walls and roof. Projecting from coal mine requirements, 1 foot-candle of incident light on the floor, walls, and roof should provide adequate lighting.

Extrapolating from light tests done by FMC on a coal mine face drill indicates, that 420 watts of high-pressure sodium vapor or fluorescent lighting will illuminate the surfaces of a 50-foot-long, 20-foot-wide, 22-foot-high room with a minimum of 1 foot-candle of incident light. It is therefore proposed that:

- The standard tractor incandescent light system be maintained for driving.
- The trailer be provided with an incandescent tail light and a clearance light system for travel.

- The operator and operator's helper each be provided a battery-powered cap lamp.
- Additional trailer lights be turned on at the repository to provide or maintain:
 - (1) Illumination of the roof, walls, and floor portions not in shadow to 1 candle power from a distance 10 feet to the rear of the trailer to a distance 1 foot forward of the trailer (about 50 feet).
 - (2) Placement of lights so that the operator or operator's helper is safeguarded from glare.
 - (3) Illumination of the front/top of the cask so that it is easy to judge if there is adequate roof clearance as the cask is rotated upright.
 - (4) Adequate brilliance for work to progress immediately after lights are turned on. This requirement probably will exclude use of mercury-vapor lighting which requires several minutes to turn on and will limit use of high-pressure sodium-vapor lights which require about 2 minutes to come to full brilliance. Therefore, much of the lighting will be fluorescent. Incandescent lighting tends to be impractical for as much illumination as will be required, although the standard tractor rear floodlight system may be useful -- especially while backing.

4.5.5 Considerations for Further Remote Operation

The proposed control system requires manually hooking and unhooking a cable from the concrete hole plug. It also recommends, but does not require, that many of the operations be controlled from stations adjacent to the repository hole. It would not be difficult to modify the proposed system so that all operations could be performed from the operator's cab. Although a concrete plug grapple system similar to those proposed for the canisters could be devised, this arrangement would leave a pintle projecting from the floor which would be unnecessarily hard on tires that might run over it. A better solution would be to build a recess into the top of the plug and to place the pintle in this recess and use a grapple similar to a canister grapple to seize the plug. Or the grapple could be redesigned to grasp the inside surfaces of the recess, thereby eliminating the pintle.

It appears the operator will be able to see misalignment of the hole and baseplate when the cask is slightly raised (as it would be when the tractor is being aligned) so no additional instrumentation for remote alignment would be required. It might be desirable to provide television surveillance of some transporter functions which are difficult to see. Proximity switches can also be used to align the jack baseplate with the repository hole (Subsection 4.2.6).

4.6 STABILITY ANALYSIS

The proposed transporter will be stable because the cask lies in a near-horizontal position during transport. The distance between wheel centerlines is 8 feet; and the center of gravity of the trailer including the cask is approximately 56 inches above the floor. The tractor wheels are 7 feet 3 inches between centerlines with a center of gravity height of 49 inches. The height-to-width ratio is therefore approximately the same for the tractor as for the trailer. An engineering layout indicates that the trailer (or tractor) will not upset on a 35-degree side slope with the tires flat on the down slope side. On level ground the deviation from horizontal caused by flat tires on one side is 8 degrees.

4.7 SPENT-FUEL REPOSITORY OPERATING CYCLES, OPTIMIZATION, AND ECONOMICS

Selection of an optimum canister capacity for the spent-fuel transporter involves consideration of several factors, including the repository layout, number of canisters to be deposited, canister receiving rate, mine entry opening size, pillar corner radii, transporter size as a function of canister capacity, installation and loading cycle times, transporter speeds, and the cost of mining salt to provide adequate travel ways. Each factor eventually must be considered, evaluated, or calculated to arrive at a transporter which is both functional and economically efficient.

4.7.1 Time to Emplace Two Canisters in Storage

Table 4 details 47 steps of operation consistent with the sequence drawings, (Figure 8, 1-7), but including all steps required to install or retrieve two spent-fuel canisters. The amount of time required to accomplish each task is listed.

4.7.2 Canister Installation and Loading Cycles

The time required to install two canisters is developed in Subsection 4.7.1 above. It is assumed that the first canister carried by the transporter will require 5 minutes 50 seconds to unload and that each additional canister will requires 5 minutes 34 seconds (total time 11 minutes 24 seconds).

Table 4 TIME REQUIRED TO EMPLACE TWO SPENT-FUEL CANISTERS
(Sheet 1 of 2)

Sequence number	Description Emplacement operation only - Transporter already loaded.	Time, seconds
1.	Transporter arrives at emplacement room vault.	
2.	The operator's helper dismounts from his cab, inspects the site, and guides the operator to position the trailer so that the trailer jack plate is within 6 inches of the repository hole. The operator locks out the cushion hitch.	35
3.	The operator's helper shifts the cask and carriage forward so that the cask will not strike the frame cross member when it is rotated upright (7 inches and 1 second of travel).	4
4.	The operator's helper lowers the tractor and trailer jacks so that the trailer jack plate just clears the hole (12 inches and 5 seconds of travel).	7
5.	The operator's helper rotates the cask so that the cask foot pad lifts the trailer wheels from the floor (17 inches and 6 seconds of cylinder travel).	10
6.	The operator's helper locates the jack plate over the hole. Lateral positioning and longitudinal positioning is at 2 inches per second. If misalignment is 4 inches, travel time will be 2 seconds.	5
7.	The operator's helper extends all jacks to the maximum position (23 inches and 10 seconds of travel).	15
8.	The operator's helper rotates the cask to the vertical attitude and positions the cask and carriage to the maximum aft position (14 seconds of cask rotation and 37 inches and 5 seconds of carriage travel).	18
9.		
10.	The operator's helper lowers the plug-lifting hoist cable (40 inches and 5 seconds) and hooks it to the plug. The operator plumbs the cask.	20
11.	The operator's helper removes the plug from the hole (160 inches and 13 seconds of travel). The helper then inspects the hole.	30
12.	The operator shifts the carriage to Canister 1 position as the operator's helper returns to the cab (39 inches and 5 seconds carriage travel).	20
13.	The operator (in his cab position) turns off the cask ventilation, unlatches the cask door, and rotates it into the open position (13 seconds total door travel time).	17
14.	The operator lowers the cask onto the jack plate and plumbs it (about 13 inches and 5 seconds of travel).	15
15.	The operator lowers the canister into hole and unlatches it (260 inches and 19 seconds of travel).	25
16.	The operator raises the canister hoist grapple into the cask (260 inches and 17 seconds of travel).	20
17.	The operator extends the transporter jacks (16 inches and 7 seconds of travel).	10
18.	The operator closes and latches the cask door (13 seconds total door travel time).	17
19.	The operator plumbs the cask, extends the stabilizer jacks, and moves the cask to the aft position (5 seconds of cask travel time).	11
20.		
21.		
22.	The operator lowers the plug into the hole (160 inches and 13 seconds of travel).	17

Table 4 TIME REQUIRED TO EMPLACE TWO SPENT-FUEL CANISTERS
(Sheet 2 of 2)

Sequence number	Description	Time, seconds
23.	The operator's helper leaves the cab, unhooks the cable from the plug, hooks it to a loop on the cask, and pulls it taut. (The helper may also mark the plug to indicate the presence of a canister.)	25
24.	The helper moves the carriage to the Canister 1 position (5 seconds of cask travel time).	8
25.	The helper rotates the cask to the near-horizontal travel position (10 seconds cask travel time).	12
26.	The helper lowers the transporter onto the wheels (25 inches and 7 seconds travel).	9
	Subtotal for Canister Number 1	5 minutes, 50 seconds
27.	The operator locates the trailer so that the trailer jack plate is within 6 inches of another repository hole. The operator's helper provides guidance.	20
28.	The operator's helper rotates the cask so that the cask foot pad lifts the trailer wheels from the floor.	10
29.	The operator's helper locates the jack plate over the hole.	5
30.	The operator's helper extends all the jacks to the maximum positions.	15
31.	The operator's helper rotates the cask to the vertical position and positions cask and carriage to the maximum aft position.	18
32.	The operator's helper lowers the plug lifting hoist cable and hooks it to the plug. The operator plumbs the cask, if required.	20
33.	The operator's helper removes the plug from the hole and inspects the hole.	30
34.	The operator shifts the carriage to the Canister 2 position as the operator's helper returns to the cab (9 seconds of carriage travel for Canister 1/Canister 2 cylinder and 5 seconds of plug/canister 1 cylinder travel).	20
35.	The operator opens the cask door.	17
36.	The operator lowers the cask onto the jack plate and plumbs it.	15
37.	The operator lowers the cask into the hole and unlatches it.	25
38.	The operator raises the canister hoist grapple into the cask (120 inches and 8 seconds of travel). The grapple need not be raised to the top of the cask.	11
39.	The operator retracts the transporter jacks.	10
40.	The operator closes and latches the cask door and turns on the cask ventilation blower.	17
41.	The operator plumbs one cask, extends the stabilizer jacks, and moves the cask to the aft position.	11
42.	The operator lowers the plug into the hole.	17
43.	The operator's helper leaves the cab, unhooks the cable from the plug, hooks it to a loop on the cask, and pulls it taut. (The helper may also mark the plug.)	25
44.	The helper moves the carriage to the Canister 1 position.	8
45.	The helper rotates the cask to the near-horizontal travel position.	12
46.	The helper lowers the transporter onto the wheels, retracts the jacks the maximum distance (35 inches and 9 seconds), and moves the cask so that the door rests against the cross member (13 inches and 2 seconds).	12 13
47.	The helper returns to the cab and the operator drives away.	15
Total time required		11 minutes, 24 seconds

The transporter drives to the loading area, the cask is aligned with some type of loading port, the cask is opened, and the canister grapples and winches of the transporter are used to grasp the canisters and raise them into the cask. It is assumed that all loading is done at one port, so that only one alignment and setup is required. The time required to load one canister then is the same as the time required to install one canister, 5 minutes 50 seconds.

To load each additional canister, however, requires only the time necessary to lower the grapple, seize the canister, and raise the canister, plus a nominal 60 seconds for the hot cell operator to bring each additional canister into position for loading (this assumes any required re-indexing of casks occurs concurrently). The additional time per canister is 1 minute 45 seconds.

4.7.3 Mine Layout and other Logistics Considerations

Table 5 projects receiving rates for spent-fuel canisters between 1985 and 2005. Note that the BWR fuel elements are packed two per canister. A total of 278,616 canisters are to be installed during the 21 years.

The mine plan for the repository area is shown in Figure 10; details of an individual panel are shown in Figure 11. Figures 10 and 11 are modifications of drawings developed by Kaiser Engineers. In Figure 10 it is assumed that only two of the eight main entries are used for transporter traffic; one for traffic outbound from the loading station and one for traffic inbound toward the loading station. The loading station is assumed to be in the center of the central loading area. Each of the 40 storage panels is assumed to hold 1/40 the total number of canisters, or 6,966 canisters per panel. A more detailed picture of how the actual spent-fuel storage area might look is shown in Figure 5.

Figure 10 shows the full pattern of main entries and air bleeds. Bolder lines have been used to designate entries that have arbitrarily been selected as travel ways for transporter traffic.

The 40 panels in Figure 10 are grouped into eight groups of five panels each, designated as A, B, or C based on distances from the loading area.

It is assumed that the panel groups will be filled with canisters beginning with panels farthest from the loading station in the order of groups B, C, and A.

Because low-level waste (LLW) storage is outside the scope of this study, that part of the mine plan will not be given further consideration.

Table 5 SPENT-FUEL ELEMENT RECEIVING RATES^{1,2}
AND CUMULATIVE TOTALS

Year	Annual rates			Cumulative totals		
	Fuel elements received		Canisters ³ Buried	Fuel elements received		Canisters Buried
	PWR	BWR		PWR	BWR ³	
1985	1,906	2,596	3,204.0	1,906	2,596	3,204.0
1986	2,100	2,933	3,566.5	4,006	5,529	6,770.5
1987	2,346	3,548	4,120.0	6,352	9,077	10,890.5
1988	2,717	4,024	4,729.0	9,069	13,101	15,619.5
1989	3,210	4,445	5,432.5	12,279	17,546	21,052.0
1990	4,898	7,891	8,843.5	17,177	25,437	28,895.5
1991	5,568	9,051	10,093.5	22,745	34,448	39,989.0
1992	6,156	10,180	11,246.0	28,901	44,668	51,235.0
1993	6,796	11,113	12,352.5	35,697	55,781	63,587.5
1994	7,450	12,082	13,491.0	43,147	67,863	77,078.5
1995	6,955	10,445	12,177.5	50,102	78,308	89,256.0
1996	7,637	11,436	13,355.0	57,739	89,744	102,611.0
1997	8,323	12,441	14,543.5	66,062	102,185	117,154.5
1998	9,026	13,498	15,775.0	75,088	115,683	132,424.5
1999	9,739	14,575	17,026.5	84,827	130,258	149,956.0
2000	10,506	15,734	18,373.0	95,333	145,992	168,329.0
2001	11,240	16,838	19,659.0	106,573	162,831	187,988.0
2002	11,953	17,903	20,904.5	118,526	180,733	208,892.5
2003	12,642	18,938	22,111.0	131,168	199,671	231,003.5
2004	13,301	19,910	23,256.0	144,469	219,581	254,259.5
2005	13,915	20,882	24,356.0	158,384	240,463	278,616.5

1. Age is 3 years minimum.

2. 480 GW(E) in year 2,000.

3. BWR fuel elements are packed two per canister; PWR fuel elements are packed one per canister.

Figure 10 REPOSITORY PLAN SHOWING PANEL GROUP TYPES, AVERAGE TRAVEL DISTANCES TO THE GROUPS, AND ASSUMED TRANSPORTER TRAVEL WAYS

Figure 11 TYPICAL PANEL ARRANGEMENT

4.7.4 Transporter Travel Times

Average transporter travel times are developed for each group of panels by type (A through C) in Table 6. Note that these travel times are based on minimum horsepower requirements which are a function of gross vehicle weight only. These times then apply to any spent-fuel transporter.

Table 6 TRANSPORTER TRAVEL DISTANCE AND TIMES

Operation		Group		
		A	B	C
To reach main entries	Distance, feet	2,560	2,560	2,560
	Time, seconds	190	190	190
First turn	Distance, feet	30	30	30
	Time, seconds	10	10	10
Average main entry travel	Distance, feet	1,630	7,950	6,040
	Time, seconds	127	557	427
Second turn	Distance, feet	30	30	30
	Time, seconds	10	10	10
Average travel into panel	Distance, feet	2,540	2,540	2,540
	Time, seconds	189	189	189
Third turn	Distance, feet	30	30	30
	Time, seconds	10	10	10
Average lateral travel in panel	Distance, feet	325	325	325
	Time, seconds	34	34	34
Fourth turn (made for one-half the canisters)	Distance, feet	30	30	30
	Time, seconds	10	10	10
Additional travel (made for one-half the canisters)	Distance, feet	40	40	40
	Time, seconds	14	14	14
One-way total travel time, minutes, seconds		9, 42	17, 12	14, 42
		9, 42	17, 12	14, 42
Round-trip travel time, minutes, seconds				
		19, 24	34, 24	29, 24

Notes:

1. Turns made at 2 mph, 2.9 feet per second.
2. 10 mph is 14.67 feet per second.
3. See Section 9.0 for acceleration and braking times.

4.7.5 Transporter Capabilities

The capabilities of transporters with varying canister capacities are shown in Tables 7 through 11. Capabilities listed based on the following assumptions:

- Maximum speed = 10 mph
- One canister per storage hole

- Operating time per 8-hour shift = 360 minutes.
- Two 8-hour shifts per working day. (It is common practice in mining operations to leave the third shift open for maintenance. Leaving this shift open also provides some degree of redundancy for overtime shifts which may be required to handle surges.)
- Working days per year = 252. This figure is based on the National Bituminous Coal Wage Agreement of 1974 between the International Union, United Mine Workers of America, and Bituminous Coal Operators Association, effective December 6, 1974. This agreement provides for an 8-hour shift, portal to portal, including staggered 30 minute lunch periods without intermission or suspension of operations. It also provides for a 40-hour work week.

365.25 days per year (including leap year)

-104.35 weekend days per year

- 9.00 paid holidays¹

252.00 working days per year.

- The most distant panel groups are filled first (B, C, then A).

The data in Tables 7 through 11 are plotted in Figure 12 to show the relationship between the number of transporters required each year and their capacity. Figure 13 shows the average time required to install one canister in a B group of panels.

It is apparent that there is some advantage to carrying more than one canister per transporter. Most of this advantage is gained by carrying two canisters, although some additional advantage is gained by carrying three canisters. Additional small gains can be achieved by carrying four or five canisters.

1. In addition to the nine scheduled holidays, employees are paid for birthdays off, in honor of John L. Lewis.

Table 7 TRANSPORTER CAPABILITIES, ONE-CANISTER CAPACITY

Year	Panel group ¹	Time, minutes		
		a Round-trip travel	b Load and install	c Per canister (c = a + b)
1985	3B	34.40	11.67	46.07
1986	3B	34.40	11.67	46.07
1987	3B	34.40	11.67	46.07
1988	3B	34.40	11.67	46.07
1989	3B	34.40	11.67	46.07
1990	3B	34.40	11.67	46.07
1991	3B, 5B	34.40	11.67	46.07
1992	5D	34.40	11.67	46.07
1993	5B	34.40	11.67	46.07
1994	5B, 8B	34.40	11.67	46.07
1995	8B	34.40	11.67	46.07
1996	8B	34.40	11.67	46.07
1997	8B, 1C	30.05 ⁵	11.67	41.72
1998	1C	29.40	11.67	41.07
1999	1C, 4C	29.40	11.67	41.07
2000	4C	29.40	11.67	41.07
2001	4C, 6C	29.40	11.67	41.07
2002	6C	29.40	11.67	41.07
2003	2A	19.40	11.67	31.07
2004	2A, 7A	19.40	11.67	31.07
2005	7A	19.40	11.67	31.07

1. Panel capacity 6,966 canisters, five panels per group, or 34,830 canisters per panel group.
2. Rounded down.
3. Based on one-shift operation.

Number of canisters			g Number of transporter shifts (f ÷ e)	h Number of transporters required ⁴	i Actual number of shifts per year (f ÷ d)
d Installed per shift (360 ÷ c) ²	e Installed by this transporter per year (d × 252) ³	f Scheduled this year			
7	1,764	3,204	1.82	1	458
7	1,764	3,567	2.02	1	510
7	1,764	4,120	2.34	2	589
7	1,764	4,729	2.68	2	676
7	1,764	5,433	3.08	2	777
7	1,764	8,844	5.01	3	1,264
7	1,764	10,094	5.72	3	1,442
7	1,764	11,246	6.38	3	1,607
7	1,764	12,353	7.00	4	1,765
7	1,764	13,491	7.65	4	1,928
7	1,764	12,178	6.90	4	1,740
7	1,764	13,355	7.57	4	1,908
8	2,016	14,544	7.21	4	1,818
8	2,016	15,775	7.82	4	1,972
8	2,016	17,027	8.45	4	2,129
8	2,016	18,373	9.11	5	2,297
8	2,016	19,659	9.75	5	2,458
8	2,016	20,905	10.37	5	2,614
11	2,772	22,111	7.98	4	2,011
11	2,772	23,256	8.39	4	2,115
11	2,772	24,356	8.79	4	2,215

4. Based on two-shift operation and up to 20 percent overtime (8 hours) per week per transporter (i.e., each transporter can operate 2.2 transporter shifts per week).

5. Weighted average of Types B and C panel groups.

Table 8 TRANSPORTER CAPABILITIES, TWO-CANISTER CAPACITY

Year	Panel group ¹	Time, minutes		
		a Round-trip travel	b Load and install	c Per canister (c = a + b)
1985	3B	34.40	18.98	53.38
1986	3B	34.40	18.98	53.38
1987	3B	34.40	18.98	53.38
1988	3B	34.40	18.98	53.38
1989	3B	34.40	18.98	53.38
1990	3B	34.40	18.98	53.38
1991	3B, 5B	34.40	18.98	53.38
1992	5B	34.40	18.98	53.38
1993	5B	34.40	18.98	53.38
1994	5B, 8B	34.40	18.98	53.38
1995	8B	34.40	18.98	53.38
1996	0D	34.40	18.98	53.38
1997	8B, 1C	30.05	18.98	49.03
1998	1C	29.40	18.98	48.38
1999	1C, 4C	29.40	18.98	48.38
2000	4C	29.40	18.98	48.38
2001	4C, 6C	29.40	18.98	48.38
2002	6C	29.40	18.98	48.38
2003	2A	19.40	18.98	38.38
2004	2A, 7A	19.40	18.98	38.38
2005	7A	19.40	18.98	38.38

1. Panel capacity 6,966 canisters, five panels per group, or 34,830 canisters per panel group.

2. Rounded down.

3. Based on one-shift operation.

Number of canisters			g Number of transporter shifts (f ÷ e)	h Number of transporters required ⁴	i Actual number of shifts per year (f ÷ d)
d Installed per shift (360 ÷ c) ²	e Installed by this transporter per year (d × 252) ³	f Scheduled this year			
12	3,024	3,204	1.06	1	267
12	3,024	3,567	1.18	1	298
12	3,024	4,120	1.36	1	344
12	3,024	4,729	1.56	1	395
12	3,024	5,433	1.80	1	453
12	3,024	8,844	2.92	2	737
12	3,024	10,094	3.34	2	842
12	3,024	11,246	3.72	2	938
12	3,024	12,353	4.08	2	1,030
12	3,024	13,491	4.46	2	1,125
12	3,024	12,178	4.03	2	1,015
12	3,024	13,355	4.42	2	1,113
14	3,528	14,544	4.12	2	1,029
14	3,528	15,775	4.47	2	1,127
14	3,528	17,027	4.83	3	1,217
14	3,528	18,373	5.21	3	1,313
14	3,528	19,659	5.57	3	1,405
14	3,528	20,905	5.93	3	1,494
18	4,536	22,111	4.87	3	1,229
18	4,536	23,256	5.13	3	1,292
18	4,536	24,356	5.37	3	1,354

4. Based on two-shift operation and up to 20 percent overtime (8 hours) per week per transporter (i. e., each transporter can operate 2.2 transporter shifts per week).

5. Weighted average of Types B and C panel groups.

Table 9 TRANSPORTER CAPABILITIES, THREE-CANISTER CAPACITY

Year	Panel group ¹	Time, minutes		
		a Round-trip travel	b Load and install	c Per canister (c = a + b)
1985	3B	34.40	26.30	60.70
1986	3B	34.40	26.30	60.70
1987	3B	34.40	26.30	60.70
1988	3B	34.40	26.30	60.70
1989	3B	34.40	26.30	60.70
1990	3B	34.40	26.30	60.70
1991	3B	34.40	26.30	60.70
1992	3B	34.40	26.30	60.70
1993	3B	34.40	26.30	60.70
1994	3B	34.40	26.30	60.70
1995	3B	34.40	26.30	60.70
1996	3B	34.40	26.30	60.70
1997	3B	30.05	26.30	56.35
1998	3B	29.40	26.30	55.70
1999	3B	29.40	26.30	55.70
2000	3B	29.40	26.30	55.70
2001	3B	29.40	26.30	55.70
2002	3B	29.40	26.30	55.70
2003	3B	19.40	26.30	45.70
2004	3B	19.40	26.30	45.70
2005	3B	19.40	26.30	45.70

1. Panel capacity 6,966 canisters, five panels per group, or 34,830 canisters per panel group.

2. Rounded down.

3. Based on one-shift operation.

Number of canisters			g Number of transporter shifts (f ÷ e)	h Number of transporters required ⁴	i Actual number of shifts per year (f ÷ d)
d Installed per shift (360 ÷ c) ²	e Installed by this transporter per year (d x 252) ³	f Scheduled this year			
15	3,780	3,204	0.85	1	214
15	3,780	3,567	0.94	1	238
15	3,780	4,120	1.10	1	275
15	3,780	4,729	1.25	1	316
15	3,780	5,433	1.44	1	363
15	3,780	8,844	2.34	2	590
15	3,780	10,094	2.67	2	673
15	3,780	11,246	2.98	2	750
15	3,780	12,353	3.27	2	824
15	3,780	13,491	3.57	2	900
15	3,780	12,178	3.22	2	812
15	3,780	13,355	3.53	2	891
18	4,536	14,544	3.21	2	808
18	4,536	15,755	3.47	2	876
18	4,536	17,027	3.75	2	946
18	4,536	18,373	4.05	2	1,021
18	4,536	19,659	4.33	2	1,093
18	4,536	20,905	4.61	2	1,162
21	5,292	22,111	4.18	2	1,053
21	5,292	23,256	4.39	3	1,108
21	5,292	24,356	4.60	3	1,160

4. Based on two-shift operation and up to 20 percent overtime (8 hours) per week per transporter (i.e., each transporter can operate 2.2 transporter shifts per week).

5. Weighted average of Types B and C panel groups.

Table 10 TRANSPORTER CAPABILITIES, FOUR-CANISTER CAPACITY

Year	Panel group ¹	Time, minutes		
		a Round-trip travel	b Load and install	c Per canister (c = a + b)
1985	3B	34.40	33.63	68.03
1986	3B	34.40	33.63	68.03
1987	3B	34.40	33.63	68.03
1988	3B	34.40	33.63	68.03
1989	3B	34.40	33.63	68.03
1990	3B	34.40	33.63	68.03
1991	3B	34.40	33.63	68.03
1992	3B	34.40	33.63	68.03
1993	3B	34.40	33.63	68.03
1994	3B	34.40	33.63	68.03
1995	3B	34.40	33.63	68.03
1996	3D	34.40	33.63	68.03
1997	3B	30.05	33.63	63.68
1998	3D	29.40	33.63	63.03
1999	3B	29.40	33.63	63.03
2000	3B	29.40	33.63	63.03
2001	3B	29.40	33.63	63.03
2002	3B	29.40	33.63	63.03
2003	3B	19.40	33.63	53.03
2004	3B	19.40	33.63	53.03
2005	3B	19.40	33.63	53.03

1. Panel capacity 6,966 canisters five panels per group, or 34,830 canisters per panel group.

2. Rounded down.

3. Based on one-shift operation.

Number of canisters			g Number of transporter shifts (f ÷ e)	h Number of transporters required ⁴	i Actual number of shifts per year (f ÷ d)
d Installed per shift (360 ÷ c) ²	e Installed by this transporter per year (d × 252) ³	f Scheduled this year			
20	5,040	3,204	0.64	1	161
20	5,040	3,567	0.71	1	179
20	5,040	4,120	0.82	1	206
20	5,040	4,729	0.94	1	237
20	5,040	5,433	1.08	1	272
20	5,040	8,844	1.75	1	443
20	5,040	10,094	2.00	1	505
20	5,040	11,246	2.23	1	563
20	5,040	12,353	2.45	2	618
20	5,040	13,491	2.68	2	675
20	5,040	12,178	2.42	2	609
20	5,040	13,355	2.65	2	668
20	5,040	14,544	2.89	2	728
20	5,040	15,775	3.13	2	789
20	5,040	17,027	3.38	2	852
20	5,040	18,373	3.65	2	919
20	5,040	19,659	3.90	2	983
20	5,040	20,905	4.15	2	1,046
24	6,048	22,111	3.66	2	922
24	6,048	23,256	3.89	2	969
24	6,048	24,356	4.03	2	1,015

4. Based on two-shift operation and up to 20 percent overtime (8 hours) per week per transporter (i.e., each transporter can operate 2.2 transporter shifts per week).

5. Weighted average of Types B and C panel groups.

Table 11 TRANSPORTER CAPABILITIES, FIVE-CANISTER CAPACITY

Year	Panel group ¹	Time, minutes		
		a Round-trip travel	b Load and install	c Per canister (c = a + b)
1985	3B	34.40	40.94	75.34
1986	3B	34.40	40.94	75.34
1987	3B	34.40	40.94	75.34
1988	3B	34.40	40.94	75.34
1989	3B	34.40	40.94	75.34
1990	3B	34.40	40.94	75.34
1991	3B	34.40	40.94	75.34
1992	3B	34.40	40.94	75.34
1993	3B	34.40	40.94	75.34
1994	3B	34.40	40.94	75.34
1995	3B	34.40	40.94	75.34
1996	3B	34.40	40.94	75.34
1997	3B	30.05	40.94	70.99
1998	3B	29.40	40.94	70.34
1999	3B	29.40	40.94	70.34
2000	3B	29.40	40.94	70.34
2001	3B	29.40	40.94	70.34
2002	3B	29.40	40.94	70.34
2003	3B	19.40	40.94	60.34
2004	3B	19.40	40.94	60.34
2005	3B	19.40	40.94	60.34

1. Panel capacity 6,966 canisters, five panels per group, or 34,830 canisters per panel group.
2. Rounded down.
3. Based on one-shift operation.

Number of canisters			g Number of transporter shifts (f ÷ e)	h Number of transporters required ⁴	i Actual number of shifts per year (f ÷ d)
d Installed per shift (360 ÷ c) ²	e Installed by this transporter per year (d x 252) ³	f Scheduled this year			
20	5,040	3,204	0.64	1	161
20	5,040	3,567	0.71	1	179
20	5,040	4,120	0.82	1	206
20	5,040	4,729	0.94	1	237
20	5,040	5,433	1.08	1	272
20	5,040	8,844	1.75	1	443
20	5,040	10,094	2.00	1	505
20	5,040	11,246	2.23	2	563
20	5,040	12,353	2.45	2	618
20	5,040	13,491	2.68	2	675
20	5,040	12,178	2.42	2	609
20	5,040	13,355	2.65	2	668
25	6,300	14,544	2.31	2	582
25	6,300	15,775	2.50	2	631
25	6,300	17,027	2.70	2	682
25	6,300	18,373	2.92	2	735
25	6,300	19,659	3.12	2	787
25	6,300	20,905	3.32	2	837
30	7,560	22,111	2.92	2	738
30	7,560	23,256	3.08	2	776
30	7,560	24,356	3.22	2	812

4. Based on two-shift operation and up to 20 percent overtime (8 hours) per week per transporter (i.e., each transporter can operate 2.2 transporter shifts per week).

5. Weighted average of Types B and C panel groups.

Figure 12 SPENT-FUEL TRANSPORTER REQUIREMENTS

4.7.6 Economic Considerations

To make a final choice of transporter canister capacity, the average cost to install a single canister is estimated. The following assumptions are made:

- The repository is federally owned and operated and, therefore, income taxes and depreciation do not enter into the cost of repository operation.
- Constant 1977 dollars are assumed over the life of the repository.

Figure 13 TRANSPORTER CANISTER CAPACITY

- There are two operators per transporter. It is quite possible to design a transporter that can be operated entirely by one person; however, trends in labor agreements and the law requiring underground miners to be within sight of another miner indicate a strong probability that two operators will be utilized. Either operator would have sufficient training to operate all functions of the transporter, or would be in training to learn those functions.
- The estimates rely heavily on data from the Caterpillar Performance Handbook, 7th edition, Caterpillar Tractor Company, Peoria, Illinois, October 1976.
- The cost of capital is neglected.

The cost of transporting and installing spent-fuel canisters is calculated in Table 12. The owning and acquisition costs are spread over a 15,000-hour life, including the cask. The cask should actually have a much longer life, but this value is used on the basis that wear and tear on the inner sleeves of the casks and the canister mechanisms will result in repair costs which are not otherwise listed here. No allowance is made for salvage if the transporter does not reach 15,000 hours before the repository is filled. It is assumed that the transporter is shipped to another repository and continues to operate.

The cask and vehicle weights are known fairly closely for the two-canister-capacity cask. The weights for the one-, three-, four-, and five-canister transporters will be estimated as follows.

The cask weights will be approximated by taking the ratio of the cross-sectional area of the uranium in each cask to that of the two-canister cask and multiplying it by the two-canister cask weight. (This technique is accurate to within 3 percent.) Variations in shielding thickness due to geometry and self-shielding will be ignored and a constant 4-inch thickness of uranium will be used.

For a single-canister cask the uranium shielding is simply a ring (Figure 14) with inside diameter of 18 inches and outside diameter of 26 inches. For a two-canister cask this annulus is simply cut in two halves and two 18-inch segments are inserted, and so on for the different casks. These areas are tabulated in Table 13, in which cask weights and transporter weights are also estimated.

Operating costs, specifically for fuel, lubricants, filters, grease, and repair reserve for the tractor, are estimated by multiplying these costs for a Caterpillar 768B off-highway tractor by the ratio of transporter horsepower (see Section 8.0) to rated horsepower of the 768B (415 horsepower). These costs are probably high, as the transporter duty will not be as severe as that of an off-highway tractor and the transporter will operate at lower speeds.

Table 12 COST OF TRANSPORTING AND INSTALLING SPENT-FUEL
CANISTERS (Sheet 1 of 2)

Factor	Transporter capacity, canisters				
	1	2	3	4	5
1.0 Acquisition and owning costs (incurred 6 hours per shift)					
1.1 Basic transporter					
1.1.1 Cask cost					
Cask weight, pounds (less canisters)	63,000	95,000	111,000	127,000	143,000
Number pounds x \$7 ¹	\$ 441,000	\$ 665,000	\$ 777,000	\$ 889,000	\$1,001,000
1.1.2 Vehicle cost					
Payload, pounds	68,000	105,000	126,000	147,000	168,000
\$2.76 per pound payload ²	\$ 188,000	\$ 290,000	\$ 348,000	\$ 406,000	\$ 464,000
1.1.3 Allowance for cabs, instrumentation, falling object protective structures, controls	50,000	50,000	50,000	50,000	50,000
1.1.4 Shipping allowance	2,000	2,000	2,000	2,000	2,000
Allowance for labor to dis- assemble transporter and reassemble underground ⁴	2,000	2,000	2,000	2,000	2,000
1.1.5 Delivered price	\$ 683,000	\$1,009,000	\$1,179,000	\$1,349,000	\$1,519,000
1.1.6 Less cost of tires					
$(1.72)(\text{payload})(\$3,140)^3$ 40,000	-9,000	-14,000	-17,000	-20,000	-23,000
Total	\$ 674,000	\$ 995,000	\$1,162,000	\$1,329,000	\$1,496,000
Hourly cost of owning, based on 15,000-hour life	\$44.93	\$66.33	\$77.47	\$88.60	\$99.73

1. Range of values is \$5 to \$7 per pound.
2. \$2.76 per pound based on delivered prices for two-canister capacity transporter of \$1,007,000.
3. Letter from R. E. Dagnall, Goodyear Tire and Rubber Company, August 9, 1977; \$3,140 is cost for one 24.00-35, 36-ply hard rock lug tire, 40,000-pound capacity.
4. Labor estimated to be 104 hours at \$20.00 per hour.

Table 12 COST OF TRANSPORTING AND INSTALLING SPENT-FUEL CANISTERS (Sheet 2 of 2)

Factor	Transporter capacity, canisters				
	1	2	3	4	5
2.0 Operating costs (incurred 6 hours per shift)					
2.1 Transporter GVW, pounds	117,000	181,000	217,000	253,000	289,000
2.2 Transporter horsepower ⁵	143	182	204	226	246
2.3 Fuel, using low-load factor for consumption of 11.9 gallons per hour for the 768B tractor ⁶ $\frac{\text{horsepower}}{415} \times \frac{11.9 \text{ gallons}}{\text{hours}}$ $\times \$0.428 \text{ per gallon}$	\$1.76	\$2.23	\$2.50	\$2.77	\$3.02
2.4 Lubricants, filters, grease ⁶ $\frac{\text{horsepower}}{415} \times \frac{\$0.42}{\text{hour}}$	\$0.14	\$0.18	\$0.21	\$0.23	\$0.25
2.5 Tires; assume black 24.00-35, 36-ply hard rock lug tires with 3,000-hour life each ⁶ $\frac{(1.72)(\text{payload})(\$3,140)}{(40,000)(3,000)}$	\$3.06	\$4.73	\$5.67	\$6.62	\$7.56
2.6 Repair reserve (parts and labor) ⁶ $\frac{\text{factor} \times (1.1.6) \times \text{horsepower}}{1,000 \times 415}$ Factor for off-highway trucks 0.06	\$13.93	\$26.13	\$34.27	\$43.42	\$53.21
Total hourly operating cost	\$18.89	\$33.27	\$42.65	\$53.04	\$64.04
3.0 Wages (incurred 8 hours per shift)					
Total cost per hour for two operators	\$ 40	\$ 40	\$ 40	\$ 40	\$ 40
4.0 Cost per canister					
4.1 Total cost per transporter shift	\$ 703	\$ 918	\$1,041	\$1,170	\$1,303
4.2 Number of transporter shifts required over life of repository	34,293	20,027	16,073	13,359	11,716
4.3 Total transporter costs	\$24.1 x 10 ⁶	\$18.4 x 10 ⁶	\$16.7 x 10 ⁶	\$15.6 x 10 ⁶	\$15.3 x 10 ⁶
4.4 Total number of canisters stored	278,616				
4.5 Cost per canister	\$87.00	\$66.00	\$60.00	\$56.00	\$55.00

5. Section 8.5.

6. Caterpillar Performance Handbook, seventh edition, Chapter 28.

Figure 14' RELATIVE CROSS-SECTIONAL AREAS OF URANIUM FOR VARIOUS CASKS

Table 13 ESTIMATED URANIUM AREAS AND WEIGHTS

Line	Factor	Transporter canister capacity				
		1	2	3	4	5
1	Estimated cask uranium cross-sectional area, square inches	276.5	420.5	492.5	564.5	636.5
2	Ratio of line 1 to 420.5 square inches	.66	1	1.17	1.34	1.51
3	Estimated cask weight; line 2 x 95,000, pounds	63,000	95,000	111,000	127,000	143,000
4	Weight of spent-fuel canisters at 5,000 pounds each, pounds	5,000	10,000	15,000	20,000	25,000
5	Total payload; Line 3 + line 4, pounds	68,000	105,000	126,000	147,000	168,000
6	Gross vehicle weight; Line 5 x 1.72 ¹	117,000	181,000	217,000	253,000	289,000
7	Horsepower requirements (See Section 8)	143	182	204	226	246

1. Two-canister transporter GVW is 181,000 pounds; $1.72 = 181,000 \text{ pounds} / 105,000 \text{ pounds}$.

Wages are based on a rate of \$8 per hour, the maximum wage under the National Bituminous Coal Wage Agreement of 1974; two operators; and an overhead factor of 2.5, which includes all benefits. Operators are paid for 8 hours per shift. The effect of overtime is overlooked on the assumption that over the life of the repository all transporters will be affected equally. It is also assumed that the operators can perform other duties in the repository, as in some years the transporter crews will be only partially utilized.

4.7.7 Selection of Transporter Capacity

Figure 15 graphically shows the results of Table 12. It is apparent that significant savings may be realized by carrying two or three canisters per transporter, but very little additional advantage is gained by carrying four or five. When consideration is given to the fact the transporter will operate in an entry nominally 20 feet wide and must make 90-degree turns

where these entries intersect, and that it is also desirable to keep the transporter narrow so that canisters can be placed as near the wall as possible, the four- and five-canister transporters are eliminated. It also becomes necessary to carry the three canisters in line, rather than in the triangular pattern shown in Figure 14.

Figure 15 AVERAGE COST TO INSTALL A SPENT-FUEL CANISTER AS A FUNCTION OF TRANSPORTER CANISTER CAPACITY

This requirement results in a three-canister cask with the same weight as a four-canister cask and a transporter with essentially the same cost per shift as a four-canister cask.

Multiplying the per-shift cost of a four-canister transporter by the number of shifts for a three-canister cask and dividing by the number of canisters stored yields

$$\frac{\$1,170 \times 16,073 \text{ shifts}}{278,616 \text{ canisters}} = \$67.50 = \$68.00 \text{ per canister}$$

This actually results in a cost increase per canister to carry three rather than two canisters in the cask. Coupled with the added complexity of a three-canister cask, and the sheer size and weight of a three-canister cask, it was decided to design for a two-canister-capacity transporter.

5.0 HIGH-LEVEL WASTE AND CLADDING WASTE TRANSPORTER, VERTICAL INSTALLATION

The proposed HLW/CW transporter is a diesel-powered lift truck which can be selected from current production models. Specifications shown in this report are those of the Hyster Model H800A, which has a rated capacity of 80,000 pounds at a 48-inch load center (see Figure 16).

No structural modifications to the basic truck chassis are necessary. The standard front-end equipment, which consists of a two-stage, telescoping upright, fork-positioning carriage and forks, is replaced by the following specially designed equipment:

- Single-stage upright with 31-inch lift
- Three-function carriage with $\pm$ 40-inch side-shift, $\pm$ 6-inch push/pull, and 90-degree rotator mechanisms.

The overall height of the machine with the cask rotated to the horizontal traveling position will be less than 11 feet.

Other modifications to the basic truck include the following:

- Enlarged cab for two operators
- Cab air-conditioning system for operation at ambient temperature of 150°F.
- Transporter drive controls suitable for a normal travel direction of counterweight end first (i.e., lift truck reverse) and also suitable for maneuvering in the cask-end-first direction (i.e., lift truck forward) for loading and unloading operations.
- Hydraulic system, transmission, and engine cooling systems sized for operation at ambient temperature of 150°F.
- Energy-absorbing bumper to provide a deceleration rate that prevents damage to the cask on frontal collision with an immovable object (e.g., mine rib) at 10 mph
- Falling object protective structure (FOPS) around cab.

The Hyster H800A unit is equipped with a power-shift transmission with three ranges in both directions and a planetary final reduction drive axle.

5.1 CASK DESCRIPTION

Both HLW and CW canisters will be 10 feet long and 12.75 to 14 inches in diameter and weigh a maximum 3,000 pounds. The transporter cask will carry two canisters of HLW or CW. The cask will be mounted to the 90-degree rotator mechanism of the carriage. The cask is designed for HLW shielding requirements and will weigh approximately 76,000 pounds, including two overpacked canisters.

HLW, CW and ILW will be stored in the same mine facility. Shielding requirements for HLW and CW are similar; therefore, it is recommended that the HLW transporter also be used to transport CW.

One hoist mechanism for each canister will be mounted to the outside of the cask. Each hoist mechanism comprises a 6-inch-bore hydraulic cylinder and a leaf chain block and tackle arrangement to give 20 feet of lift with 4 feet of cylinder stroke. Various canister grapples are discussed in Section 8.0.

The two plug hoist mechanisms are similar, with 4-inch-bore cylinders and 2:1 stroke multipliers to provide 8 feet of lift. Plugs are raised vertically beside the cask through guide rings. The hook on the lift chain is manually connected to the plug by the second operator. Plugs are assumed to have a maximum length of 7 feet and maximum weight of 3,000 pounds.

A hydraulically actuated roll-out door of full shielding thickness is provided at the bottom of the cask for canister entry and exit.

An HEPA blower-filter system and passive cask cooling will be provided. Similar systems are described in Section 4.1 for the spent-fuel cask.

5.2 STABILITY

The stability of the transporter will be the same as that designed into the lift truck by the manufacturer because the weight of the loaded cask (76,000 pounds) does not exceed the rated capacity of the truck.

FMC FMC Corporation
Engineered Systems Division

Figure 16 HIGH-LEVEL WASTE
TRANSPORTER, TWO-
CANISTER CAPACITY
(FMC Drawing 5135361)

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The specially designed front-end equipment also represents less weight and moment than the highest standard upright with carriage and forks.

When fully loaded, the transporter is laterally stable on a 10-percent side slope and resting on one load-end corner of the chassis. This extreme condition of resting on the chassis is unlikely, however, because the drive axle housing itself is structurally capable of supporting the loaded vehicle in the event of a wheel or axle failure.

Various conditions of lateral tipping are shown in Figure 17. A 10-percent down slope condition is also tabulated in Figure 17.

The American National Standards Institute "Safety Standard for Powered Industrial Trucks," ANSI B56.1, specifies tilting platform tests for lateral stability. Stacking stability requirements (i. e., static, raised load) are met if the truck does not tip over when the platform supporting the truck is tilted to a 6-percent slope about the tipping axis of the truck. Note that the lateral tipping axis of a conventional lift truck is on a line from the drive tire ground contact point to the center of oscillation of the steering axle (see Figure 17) because the steering axle articulates about a longitudinal shaft at its center.

Similarly, ANSI B56.1 traveling stability requirements at 10 mph are met if the truck does not tip over with the load lifted 12 inches and the platform tilted to a 32-1/2-percent slope. The HLW/CW transporter exceeds both of the referenced ANSI B56.1 lateral stability requirements.

5.3 MACHINE OPERATIONS AND CYCLE TIMES

The loaded transporter will travel to the storage rooms with the cask to the rear of the vehicle. This allows frontal collision protection by the shock absorber mounted bumper on the counterweight end of the vehicle. The 90-degree rotator mechanism will turn the cask from the vertical loading and burial position to the horizontal traveling position. This provides a vehicle-overall-traveling height of less than 11 feet. To allow spotting of the cask centerline within ± 6 inches of the storage hole centerline, the transporter will approach the storage hole cask end first.

All final positioning and plug and canister handling operations will be controlled in the cab with manually operated hydraulic valves. The side-shift and push-pull mechanisms will provide the necessary movement for final positioning of the cask centerline over the storage hole centerline. Operating pressures, cylinder sizes and control valve feathering capabilities typical of existing lift truck systems will provide the specified 1/4-inch centerline positioning accuracy to the storage hole. The second operator, who will be out of the cab to hook up the plug, will provide visual cues for final cask alignment.

Additional electrical system requirements will be for the operation of the cask vacuum blower, air conditioner blower, external area lighting, etc.

Burial operations only (excluding cask loading and travel times) for one canister are estimated to require 5.6 minutes. Loading and burial operations cycle times are estimated in Tables 14 and 15.

Total HLW and CW cycle times as shown in Tables 16 and 20 include canister loading into the cask, travel to the storage room, canister burial and return travel to the loading area. Factors considered are horsepower limited acceleration, braking performance, average travel distance to each panel of rooms, slowing for turns, cask alignment to burial position, and plug and canister handling.

The following travel speeds are used in the cycle time analysis:

- 10 mph in straightaways long enough to allow acceleration to 10 mph
- 5 mph in straightaways not long enough to allow acceleration to 10 mph
- 2 mph around all corners.

A constant braking deceleration of 0.15 g was used in determining travel times (see Section 8.0). Average travel distance to each panel of storage rooms was determined from the ILW/CW/HLW Mine Master Plan shown in Figure 18.¹

1. Waste Isolation Facility Description, Bedded Salt, Parsons, Brincherhoff, Quade and Douglas, Inc., September 1976, Y/OWI/Sub-76/16506, Appendix D, Drawing 6.

MOMENT ARMS AND SAFE LATERAL MOMENTS ABOUT LATERAL TIPPING AXIS

LEVEL	68.0"	12,270,124 LB-IN (LOAD POSITION)
6%	63.8	11,512,263 LB-IN (LOAD POSITION)
LEVEL	66.0	11,909,238 LB-IN (TRAVEL POSITION)
10%	60.2	10,862,669 LB-IN (TRAVEL POSITION)
FLAT	56.0	10,104,808 LB-IN (TRAVEL POSITION)
10% FLAT	49.4	8,913,884 LB-IN (TRAVEL POSITION)
31 1/2%	45.4	8,192,112 LB-IN (TRAVEL POSITION)
10% ON	44.6	8,047,758 LB-IN (TRAVEL POSITION)

MOMENT ARMS AND SAFE MOMENTS ABOUT DRIVE AXLE

LEVEL	13.3"	2,407,910 LB-IN (LOAD POSITION)
10% DOWN	8.4	1,515,263 LB-IN (LOAD POSITION)
LEVEL	18.7	3,367,910 LB-IN (TRAVEL POSITION)
10% DOWN	15.5	2,796,867 LB-IN (TRAVEL POSITION)

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Engineered Systems Division

Figure 17 STABILITY ANALYSIS,
HLW TRANSPORTER,
TWO-CANISTER CAPACITY
(FMC Drawing 5135362)

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Table 14 BURIAL CYCLE TIMES,
HLW/CW AND ILW TRANSPORTER (Sheet 1 of 2)

Step	Estimated time, seconds	Total time, minutes:seconds
1. Rotate cask to vertical position and position transporter with plug hoist centerline within ± 6 inches of hole centerline	20	
2. Align plug hoist over hole within $\pm 1/4$ inch	15	
3. Remove plug (lower hoist, manually attach hook to plug, raise plug; 8-foot lift at 20 fpm)	65	
4. Side-shift cask to Canister 1 over hole and align within $\pm 1/4$ inch (side-shift, push-pull, tilt)	15	
5. Open cask door	10	
6. Store canister in hole (lower canister, release grapple, raise hoist; 20-foot lift at 20 fpm)	120	
7. Close cask door	10	
8. Side-shift cask to plug over hole and adjust alignment as required (side-shift, push-pull, tilt)	15	
9. Replace plug (lower plug, manually disconnect hook, raise hoist; 8-foot lift at 20 fpm)	55	5:25
10a. Rotate cask to horizontal travel position or	10	5:35
10b. Travel to next hole (20 feet at 120 fpm)		
11. Position transporter with plug hoist centerline within ± 6 inches of hole centerline	10	
12. Align plug hoist over hole within $\pm 1/4$ inch	15	
13. Remove plug (same as Step 3)	65	
14. Side-shift cask to Canister 2 over hole and align within $\pm 1/4$ inch (same as Step 4)	15	
15. Open cask door	10	
16. Store canister in hole (same as Step 6)	120	

1. Single canister ILW transporter times are through Step 10a. Two-canister HLW/CW transporter times are through Step 20, omitting Step 10a.

Table 14 BURIAL CYCLE TIMES,
HLW/CW AND ILW TRANSPORTERS (Sheet 2 of 2)

Step	Estimated time, seconds	Total time, minutes:seconds
17. Close cask door	10	
18. Side-shift cask to plug over hole and adjust alignment as required (same as Step 8)	15	
19. Replace plug (same as Step 9)	55	10:50
20. Rotate cask to horizontal travel position	10	11:00

1. Single canister ILW transporter times are through Step 10a. Two-canister HLW/CW transporter times are through Step 20, omitting Step 10a.

Table 15 CASK LOADING CYCLE TIMES
HLW/CW AND ILW TRANSPORTER

Step	Estimated time, seconds	Total time, ¹ minutes:seconds
1. Rotate cask to vertical position and position transporter with Canister Cavity 1 centerline within ± 6 inches of hole centerline	15	
2. Align canister cavity within $\pm 1/4$ inch	10	
3. Open cask door	10	
4. Load canister into cask (lower hoist, engage grapple, raise canister; 25-foot lift at 20 fpm)	150	3:05
5a. Close cask door and rotate cask to horizontal travel position (single-canister cask) or	20	3:25
5b. Shift cask to next loading position and position transporter with Canister Cavity 2 centerline within ± 6 inches of hole centerline	10	3:15
6. Align canister cavity within $\pm 1/4$ inch	10	
7. Load canister into cask (same as Step 4)	150	5:55
8. Close cask door and rotate cask to horizontal travel position	20	6:15

1. Single-canister ILW transporter times are through Step 5a. Two-canister HLW/CW transporter times are through Step 8, omitting Step 5a.

Table 16 HLW STORAGE CYCLE TIMES

Operation		Canisters per transporter (A)				
		1	2	3	4	5
Travel time to and from burial holes, minutes, panel averages (B)	Pilot panel (992 canisters)	14.4	14.4	14.4	14.4	14.4
	Panels 1 and 2 (5,120 canisters)	32.0	32.0	32.0	32.0	32.0
	Panels 3 and 4 (5,120 canisters)	29.4	29.4	29.4	29.4	29.4
	Panels 5 and 6 (5,120 canisters)	26.8	26.8	26.8	26.8	26.8
	Panels 7 and 8 (5,120 canisters)	24.0	24.0	24.0	24.0	24.0
	Panels 9 and 10 (5,120 canisters)	21.4	21.4	21.4	21.4	21.4
	Panels 11 and 12 (5,120 canisters)	18.6	18.6	18.6	18.6	18.6
	Panels 13 and 14 (3,628 canisters; 3,840-canister capacity)	17.8	17.8	17.8	17.8	17.8
Burial time, minutes (C)		5.6	11.0	16.4	21.8	27.3
Load time, minutes (D)		3.4	6.3	9.1	11.9	14.8
Total cycle time, minutes, panel averages (E=B+C+D)	Pilot panel	23.4	30.7	39.9	48.1	56.5
	Panels 1 and 2	41.0	48.3	57.5	65.7	74.1
	Panels 3 and 4	38.4	45.7	54.9	63.1	71.5
	Panels 5 and 6	35.8	43.1	52.3	60.5	68.9
	Panels 7 and 8	33.0	40.3	49.5	57.7	66.1
	Panels 9 and 10	30.4	37.7	46.9	55.1	63.5
	Panels 11 and 12	27.6	34.9	44.1	52.3	60.7
	Panels 13 and 14	26.8	34.1	43.3	51.5	59.9

Table 17 HLW CANISTER STORAGE RATES

Operation		Canisters per transporter (A)				
		1	2	3	4	5
Number of complete cycles per 360-minute shift (F=360 ÷ E)	Pilot panel	15	11	9	7	6
	Panels 1 and 2	8	7	6	5	4
	Panels 3 and 4	9	7	6	5	5
	Panels 5 and 6	10	8	6	6	5
	Panels 7 and 8	11	9	7	6	5
	Panels 9 and 10	11	9	7	6	5
	Panels 11 and 12	13	10	8	6	6
	Panels 13 and 14	13	10	8	7	6
Number of canisters per transporter shift (G=F×A)	Pilot panel	15	22	27	28	30
	Panels 1 and 2	8	14	18	20	20
	Panels 3 and 4	9	14	18	20	25
	Panels 5 and 6	10	16	18	24	25
	Panels 7 and 8	11	18	21	24	25
	Panels 9 and 10	11	18	21	24	25
	Panels 11 and 12	13	20	24	24	30
	Panels 13 and 14	13	20	24	28	30

Table 18 HLW TRANSPORTER SHIFTS

Storage panel	Year	Canisters to be received ¹ (H)	Transporter shifts required, (I=H+G)				
			Canisters per transporter				
			1	2	3	4	5
	1983						
	1984						
	1985						
	1986						
	1987						
Pilot	1988	230	16	11	9	9	8
	1989	510	34	24	19	19	17
1 and 2	1990	850	107	61	48	43	43
	1991	1,020	128	73	57	51	51
	1992	1,020	128	73	57	51	51
	1993	1,020	128	73	57	51	51
	1994	1,240	155	89	69	62	62
3 and 4	1995	1,470	164	105	82	74	59
	1996	1,750	195	125	98	88	70
5 and 6	1997	2,150	215	135	120	90	86
	1998	2,030	203	127	113	85	82
	1999	2,320	232	145	129	97	93
7 and 8	2000	2,540	231	142	121	106	102
	2001	2,830	258	158	135	118	113
9 and 10	2002	3,110	283	173	149	130	125
11 and 12	2003	3,450	266	173	144	144	115
	2004	3,730	287	187	156	156	125
13 and 14	2005	4,070	313	204	170	146	136
Totals		35,340	3,343	2,078	1,733	1,520	1,389

1. Waste Isolation Facility Description, etc..

Table 19 CW CANISTER RECEIVING RATES

Year	CW and ILW canisters to be received ¹	CW cubic meters to be received ¹	CW canisters to be received, 0.177 meter per canister
1983	1,930	40	226
1984	4,360	70	396
1985	8,080	130	735
1986	9,890	150	848
1987	8,760	150	848
1988	7,070	150	848
1989	7,850	190	1,074
1990	9,150	220	1,243
1991	9,950	260	1,469
1992	11,420	320	1,808
1993	8,480	300	1,695
1994	9,260	340	1,921
1995	11,190	380	2,147
1996	12,570	420	2,373
1997	14,500	460	2,599
1998	15,880	510	2,882
1999	17,260	560	3,164
2000	18,750	610	3,447
2001	20,790	670	3,786
2002	22,720	730	4,125
2003	25,360	790	4,464
2004	28,560	860	4,859
2005	31,250	930	5,255
Totals	315,030		52,212

1. Waste Isolation Facility Description, Bedded Salt, etc..

Table 20 CW STORAGE CYCLE TIMES

Operation		Canisters per transporter (A)				
		1	2	3	4	5
Travel time to and from burial holes, minutes, panel averages (B)	Pilot panel (27,650 canisters)	12.2	12.2	12.2	12.2	12.2
	Panel 1 (36,340 canisters)	18.0	18.0	18.0	18.0	18.0
	Panel 2 (36,340 canisters)	15.4	15.4	15.4	15.4	15.4
	Panel 3 (36,340 canisters)	13.4	13.4	13.4	13.4	13.4
	Panel 4 (55,300 canisters)	13.6	13.6	13.6	13.6	13.6
	Panel 5 (55,300 canisters)	12.4	12.4	12.4	12.4	12.4
	Panel 6 (55,300 canisters)	9.8	9.8	9.8	9.8	9.8
Burial time, minutes (C)		5.6	11.0	16.4	21.8	27.3
Load time, minutes (D)		3.4	6.3	9.1	11.8	14.8
Total cycle time, minutes (E=B+C+D)	Pilot panel	21.2	29.5	37.7	45.9	54.3
	Panel 1	27.0	35.3	43.5	51.7	60.1
	Panel 2	24.4	33.7	40.9	49.1	57.5
	Panel 3	22.4	30.7	38.9	47.1	55.5
	Panel 4	22.6	30.9	39.1	47.3	55.7
	Panel 5	21.4	29.7	37.9	46.1	54.5
	Panel 6	18.8	27.1	35.3	43.5	51.9

Table 21 CW STORAGE RATES

Operation		Canisters per transporter (A)				
		1	2	3	4	5
Number of complete cycles per 360-minute shift (F=360÷E)	Pilot panel	17	12	9	7	6
	Panel 1	13	10	8	7	6
	Panel 2	14	11	8	7	6
	Panel 3	16	11	9	7	6
	Panel 4	16	11	9	7	6
	Panel 5	16	12	9	7	6
	Panel 6	19	13	10	8	7
Number of canisters per transporter shift (G=F×A)	Pilot panel	17	24	27	28	30
	Panel 1	13	20	24	28	30
	Panel 2	14	22	24	28	30
	Panel 3	16	22	27	28	30
	Panel 4	16	22	27	28	30
	Panel 5	16	24	27	28	30
	Panel 6	19	26	30	32	35

Figure 18 MINE MASTER PLAN

5.4 REPOSITORY OPERATING COSTS

Estimates of HLW/CW transporter operating costs have been made for both one- and two-canister-capacity transporters. The following factors were considered in the estimates:

- Transporter operating cycles developed in Tables 14 through 23.
- Costs of transporter operation developed in Tables 24 through 26 which include capital cost of cask and vehicle over a 15,000-hour life; operating costs for fuel, lubricants, repairs and tires; and labor costs.¹
- Yearly waste receiving rates and the location of the storage room panels being filled in the respective years.

Transporter shifts required to store HLW alone, CW alone, and HLW and CW combined are listed in Tables 18, 22, and 23. The number of transporter shifts is the number of transporters operating 6 hours in an 8-hour shift times the number of shifts worked per day. Therefore, for 252 working days per year, a requirement of 504 transporter shifts means either one transporter must operate two shifts per day or two transporters must operate one shift per day.

A two-shift-per-day operation is recommended whenever it is necessary to reduce the number of machines required and at the same time leave a third shift available for downtime or surges in the receiving rates.

The cycle time and economic analyses give the following information on operating cycles, transporter capacity, and costs:

- A single-canister transporter used for CW alone will be used to 50 percent capacity after the twelfth year (1994) of repository operation and 100 percent capacity only during the last two years (2004 and 2005) based on a single-shift-per-day operation. See Table 22.
- A double-canister transporter used for HLW alone will be used to 50 percent capacity after the fourteenth year (1996) of repository operation and will reach 80 percent capacity only during the last year (2005) based on single-shift-per-day operation. HLW will not be received until the sixth year (1988) of repository operation. See Table 18.

1. "Caterpillar Performance Handbook," Edition 7.

Table 22 CW TRANSPORTER SHIFTS

Storage Panel	Year	CW canisters to be received ¹ (H)	Transporter shifts required, (I=H÷G)				
			Canisters per transporter				
			1	2	3	4	5
Pilot	1983	226	14	9	9	8	8
	1984	396	24	16	15	15	14
	1985	735	44	29	28	27	25
	1986	848	50	33	32	31	29
1	1987	848	66	43	36	31	29
	1988	848	66	43	36	31	29
	1989	1,074	83	54	45	39	36
	1990	1,243	96	63	52	45	42
2	1991	1,469	105	67	62	53	49
	1992	1,808	130	83	76	65	61
	1993	1,695	121	77	71	61	57
	1994	1,921	138	88	80	69	64
3	1995	2,147	135	90	80	77	72
	1996	2,373	149	99	88	85	80
	1997	2,599	163	109	97	93	87
4	1998	2,882	181	131	107	103	96
	1999	3,164	198	144	118	113	106
	2000	3,447	216	157	128	124	115
5	2001	3,786	237	146	141	136	127
	2002	4,125	258	159	153	148	138
6	2003	4,464	235	172	149	140	128
	2004	4,859	256	187	162	152	139
	2005	5,255	277	203	176	165	151
Totals		52,212	3,242	2,202	1,941	1,811	1,682

1. Waste Isolation Facility Description, etc.,.

Table 23 HLW/CW TRANSPORTER SHIFTS

Year	Total transporter shifts required, HLW + CW ¹				
	Canisters per transporter				
	1	2	3	4	5
1983 (CW only)	14	9	9	8	8
1984 (CW only)	24	16	15	15	14
1985 (CW only)	44	29	28	27	25
1986 (CW only)	50	33	32	31	29
1987 (CW only)	66	43	36	31	29
1988 (CW + HLW)	82	54	45	40	37
1989 (CW + HLW)	117	78	64	58	53
1990 (CW + HLW)	203	124	100	88	85
1991 (CW + HLW)	233	140	119	104	100
1992 (CW + HLW)	258	156	133	116	112
1993 (CW + HLW)	249	150	128	112	108
1994 (CW + HLW)	293	177	149	131	126
1995 (CW + HLW)	299	195	162	151	131
1996 (CW + HLW)	344	224	186	173	150
1997 (CW + HLW)	370	244	217	183	173
1998 (CW + HLW)	384	258	220	188	178
1999 (CW + HLW)	430	289	247	210	199
2000 (CW + HLW)	447	299	249	230	217
2001 (CW + HLW)	495	304	276	254	240
2002 (CW + HLW)	541	332	302	278	263
2003 (CW + HLW)	501	345	293	284	243
2004 (CW + HLW)	543	374	318	308	264
2005 (CW + HLW)	590	407	346	311	287

1. Sum of Transporter-shifts (I) shown in Tables 18 and 22.

Table 24 COST ESTIMATE, HLW/CW TRANSPORTER,
ONE-CANISTER CAPACITY

Factor	Amount
1.0 Acquisition and ownership costs (incurred 6 hours per shift)	
1.1 Cask, 48,300 pounds shielding at \$6 per pound.	\$289,800
1.2 Vehicle, 51,300 pound load x \$1.50 per pound of load ¹	76,950
1.3 Accessories (cabs, instrumentation, falling object protective structures, controls, etc.)	50,000
1.4 Shipping	2,000
Allowance for labor to disassemble transporter and reassemble underground (104 hours x \$20/hour).	2,080
1.5 Less cost of tires	
GVW, ¹ $(1.27 \times 51,300) + 51,300 = 116,450$ pounds	
Maximum tire load for forklift = $0.47 \times 116,450 = 54,730$ pounds	
~ Use four 30.00 x 51, 46-ply tires at \$6,300	-25,000
1.6 Total less tires	\$395,830
1.7 Transporter cost per hour for 15,000-hour life	\$ 26.39
2.0 Operating costs ^{2,3} (incurred 6 hours per shift)	
CAT 992:	
GVW is 167,000 pounds.	
Flywheel horsepower is 550	
Fuel flow is 12.8 gph	
Lubrication, grease, and filter cost is \$0.68 per hour	
Repair cost per hour is $\$0.04 \times \frac{(\text{price-tire costs})}{1,000}$	
Transporter:	
GVW is 116,450 pounds	
Horsepower is $72.45 + 5.93 \times 10^{-4} (\text{GVW}) = 141.5$	
Fuel cost per hour, $\frac{141.5}{550} \times 12.8 \text{ gph} \times \frac{\$0.45}{\text{gallon}}$	\$ 1.48
Lubrication, etc., cost per hour, $\frac{141.5}{550} \times \frac{\$0.68}{\text{hour}}$	.18
Repair reserve, cost per hour, $\frac{141.5}{550} \times \frac{0.04(395,830)}{1,000}$ (parts and labor)	4.07
Tires cost per hour, $\frac{\$25,000}{3,000 \text{ hours (life)}}$	8.33
Total operating cost per hour	\$ 14.06
3.0 Labor costs, per hour (incurred 8 hours per shift)	\$ 40.00
Cost of transporter per 8-hour shift, $6 (26.39 + 14.06) + 8(40)$	\$563.00
1. Reference memo from M. Wallis to M. K. Preston, July 19, 1977.	
2. "Caterpillar Performance Handbook," Edition 7.	
3. Based on data for the CAT 992B wheel loader with GVW approximately the same as that of the transporter; cost multiplier is transporter hp + 550B hp.	

Table 25 COST ESTIMATE, HLW/CW TRANSPORTER,
TWO-CANISTER CAPACITY

Factor	Amount
1.0 Acquisition and ownership (incurred 6 hours per shift)	
1.1 Cask, 70,000 pounds shielding at \$6 per pound	\$420,000
1.2 Vehicle, 76,000 pound load at \$1.50 per pound of load ¹	114,000
1.3 Accessories	50,000
1.4 Shipping	2,000
Allowance for labor to disassemble transporter and reassemble underground (104 hours x \$20/hour),	2,080
1.5 Less cost of tires	
GVW ¹ = (1.27 x 76,000) + 76,000 = 172,520	
Maximum tire load = 0.47 x 172,520 = 81,084	
Use four 30.00 x 51, 46-ply tires at \$6,300 each	-25,000
1.6 Total less tires	\$563,080
1.7 Transporter cost per hour, 15,000-hour life	\$ 37.54
2.0 Operating costs ^{2,3} (incurred 6 hours per shift)	
Transporter:	
GVW is 172,520 pounds	
Horsepower is $72.45 + 5.93 \times 10^{-4} (GVW) = 174.8$	
Fuel cost per hour, $\frac{174.8}{550} \times 12.8 \text{ gph} \times \frac{\$0.45}{\text{gallon}}$	\$ 1.83
Lubrication, etc., cost per hour, $\frac{174.8}{550} \times \frac{\$0.68}{\text{hour}}$	.22
Repair reserve, cost per hour $\frac{174.8}{550} \times \frac{0.04(\$563,080)}{1,000}$ (parts and labor)	7.16
Tires cost per hour, $\frac{\$25,000}{3,000 \text{ hours}}$	8.33
Total operating cost per hour	\$ 17.54
3.0 Labor costs per hour (incurred 8 hours per shift)	\$ 40.00
Cost of transporter per 8-hour shift	
6 (37.54 + 17.54) + 8(40)	\$650.00

- Reference memo from M. Wallis to M. K. Preston, July 19, 1977.
- "Caterpillar Performance Handbook," Edition 7.
- Based on data for the CAT 992B wheel loader with GVW approximately the same as that of the transporter; cost multiplier is transporter hp ÷ 550B hp.

Table 26 TOTAL ESTIMATED COSTS, HLW/CW TRANSPORTERS

Year	Cost per year at \$563 per shift for one-canister transporter	Cost per year at \$650 per shift for two-canister transporter
1983	\$ 7,882	\$ 5,850
1984	13,512	10,400
1985	24,772	18,850
1986	28,150	21,450
1987	37,158	27,950
1988	46,166	35,100
1989	65,871	50,700
1990	114,289	80,600
1991	131,179	91,000
1992	145,254	101,400
1993	140,187	97,500
1994	164,959	115,050
1995	168,337	126,750
1996	193,672	145,600
1997	212,814	158,600
1998	216,192	167,700
1999	242,090	187,850
2000	251,661	194,350
2001	278,685	197,600
2002	304,583	215,800
2003	282,063	224,250
2004	305,709	243,100
2005	332,170	264,550
Total cost (87,552 canisters)	\$3,707,355	\$2,782,000
Cost per canister	\$42	\$32

- One double-canister transporter used for both HLW and CW will be able to handle the entire HLW/CW input of the repository by operating two shifts per day.
- A double-canister transporter with shielding for HLW and used for both CW and HLW will be used at 100 percent capacity for single-shift operations after the sixteenth year (1998) and reach 80 percent capacity for double-shift operations in the last (2005) year of repository operation. See Table 23.
- The use of a single-canister transporter for both HLW and CW would require either a third shift operation or a second transporter for the last two years (2004 and 2005) of repository operation. See Table 23. Also, a single-canister transporter would result in significantly higher per-canister and overall costs. See Tables 24, 25, and 26.

6.0 INTERMEDIATE-LEVEL WASTE TRANSPORTER, VERTICAL INSTALLATION

The proposed ILW transporter is a diesel-powered lift truck which can be selected from current production models. Specifications shown in this report are those of the Hyster H360A which has a rated capacity of 36,000 pounds at a 36-inch load center (see Figure 19).

No structural modifications to the truck chassis are necessary. The following special front-end equipment will replace the standard upright, carriage, and forks:

- Single-stage upright with 35-inch lift.
- Three-function carriage with 47-inch side-shift, $\pm$ 6-inch push/pull, and 90-degree rotator mechanisms.

Other modifications to the basic truck are those listed for the HLW/CW transporter (Section 5.0). The Hyster H360A unit is equipped with a power-shift transmission with three ranges in both directions and a planetary final reduction drive axle.

6.1 CASK DESCRIPTION

The cask configuration shown in Figure 19 is designed to handle one ILW canister 24 inches in diameter and 10 feet long. Maximum weight of the canister is assumed to be 12,000 pounds.

Due to lower radiation levels of the ILW, cask construction can be simpler than that for HLW and CW. An all-steel cask is proposed with 4.9-inch wall thickness and an approximate weight of 33,000 pounds including the canister. The cavity will be 11 feet long and 26-1/2 inches in diameter to accept a 25.5-inch overpack. Plug and canister hoists are similar to those on the HLW/CW cask as well as a roll-out door for canister entry and exit. An HEPA blower-filter system will be provided to maintain 2 inches of vacuum in the cask cavity.

6.2 STABILITY

The stability of the transporter will be the same as that designed into the lift truck by the manufacturer. The rated load center of the H360A for 36,000 pounds is 36 inches from the face of the forks or 76 inches from the drive axle. The ILW transporter will carry the lesser load of 33,000 pounds at 83 inches from the drive axle to give the same load.

The ILW transporter will exceed the lateral and longitudinal stability criteria applied to the HLW/CW transporter (see Section 5.2).

6.3 MACHINE OPERATIONS AND CYCLE TIMES

All transporter operations including traveling to and from storage sites, vehicle and cask positioning over burial holes, and canister and plug handling will be similar to those of the HLW/CW transporter.

ILW transporter cycle times are shown in Table 27. Average round-trip travel times to panels shown on the mine plan in Figure 11 range from 18.0 to 21.8 minutes. Development of the travel times is based on the same parameters that were used for the HLW/CW transporter. Burial and loading operations for the ILW transporter also will be the same as those for the HLW/CW transporter. The time to bury one canister is estimated as 5.6 minutes.

6.4 REPOSITORY OPERATING COSTS

Acquisition and operating cost estimates are shown in Table 28. The receiving rate of 24-inch ILW canisters was calculated from volumetric data in the Waste Isolation Facility Description. Table 29 shows the required transporter shifts and resulting costs. It can be seen that after Year 2001 more than one shift per day will be required with the use of one transporter.

The estimated total cost of depositing ILW waste in 24-inch canisters is \$1.9 million. The average cost per canister is \$28.

FMC FMC Corporation
Engineered Systems Division

Figure 19 INTERMEDIATE-LEVEL
WASTE TRANSPORTER,
24-INCH CANISTER
(FMC Drawing 5135383)

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Table 27 ILW STORAGE CYCLE TIMES, ONE-CANISTER TRANSPORTER

Operation		
Travel time to and from burial holes, minutes panel average (A)	Pilot panel	12.2
	Panel 1	18.0
	Panel 2	15.4
	Panel 3	13.4
	Panel 4	13.6
	Panel 5	12.4
	Panel 6	9.8
Burial time, minutes (B)		5.6
Load time, minutes (C)		3.4
Total cycle time, minutes (D=A+B+C)	Pilot panel	21.2
	Panel 1	27.0
	Panel 2	24.4
	Panel 3	22.4
	Panel 4	22.6
	Panel 5	21.4
	Panel 6	18.8
Number of canisters per transporter shift (E=360÷D)	Pilot panel	17
	Panel 1	13
	Panel 2	14
	Panel 3	16
	Panel 4	16
	Panel 5	16
	Panel 6	19

Table 28 ILW TRANSPORTER COST ESTIMATE

Factor	Amount
1.0 Acquisition and ownership (incurred 6 hours per shift)	
1.1 Cask, 21,000 pounds shielding at \$6.00 per pound	\$ 126,000
1.2 Vehicle, 33,000-pound load x \$1.50 per pound of load ¹	49,500
1.3 Accessories	50,000
1.4 Shipping	2,000
Allowance for labor to disassemble transporter and reassemble underground (104 hours x \$20/hour).	2,000
1.5 Less tires	-10,000
1.6 Total less tires	\$ 219,500
1.7 Transporter cost per hour (less tires), 15,000-hour life	\$ 14.63
2.0 Operating costs ^{2,3} (incurred 6 hours per shift)	
2.1 Transporter GVW, 86,000 pounds	
2.2 Transporter horsepower, 130	
2.3 Fuel cost per hour, $\frac{130}{375} \times 9.6 \text{ gallons per hour} \times \frac{\$0.45}{\text{gallons}}$	\$ 1.50
2.4 Lubrication, etc., cost per hour, $\frac{130}{375} \times \frac{\$0.52}{\text{hours}}$	\$ 0.18
2.5 Repair reserve, cost per hour $\frac{130}{375} \times \frac{.04 (219,500)}{1,000}$ (parts and labor)	\$ 3.04
2.6 Tires, cost per hour, $\frac{\$10,000}{3,000 \text{ hours}}$	\$ 3.33
Total operating cost per hour	\$ 8.05
3.0 Labor costs per hour (incurred 8 hours per shift)	\$ 40.00
Cost per 8-hour shift $6(14.63 + 8.05)8(40)$	\$ 456.00

1. Reference memo from M. Wallis to M. K. Preston, July 19, 1977.

2. Caterpillar Performance Handbook, Edition 7.

3. Based on CAT wheel loaders of similar GVW. Cost multiplier applied to CAT figures is transporter horsepower+wheel loader horsepower.

4. 104 hours at \$20.00 per hour = \$2,080 = \$2,000.

Table 29 ILW TRANSPORTER SHIFTS AND TOTAL ESTIMATED COSTS

Year	Panel	24-inch canisters to be received	Transporter shifts required	Cost per year at \$456 per shift
1983	Pilot	426	25	\$ 11,400
1984		991	59	26,904
1985		1,836	108	49,248
1986		2,260	133	60,648
1987	1	1,978	153	69,768
1988		1,555	120	54,720
1989		1,694	131	59,736
1990		1,977	152	69,312
1991	2	2,120	152	69,312
1992		2,403	172	78,432
1993		1,696	122	55,632
1994		1,835	131	59,736
1995	3	2,261	142	64,752
1996		2,549	160	72,960
1997		2,975	186	84,816
1998	4	3,250	204	93,024
1999		3,524	221	100,776
2000		3,826	240	109,440
2001	5	4,251	266	121,296
2002		4,649	291	132,696
2003	6	5,224	275	125,400
2004		5,925	312	142,272
2005		6,499	342	155,952
Total		65,704		\$1,868,232 ¹

1. \$28.00 per canister.

7.0 HIGH-LEVEL WASTE AND CLADDING WASTE TRANSPORTER, HORIZONTAL AND INCLINED INSTALLATION

The transporter used for horizontal installation of high-level and cladding waste canisters will be operated by two people. At a storage area, the transporter loading mechanism will retrieve from storage and emplace two canisters into a shielded cask on the transporter for transport to a repository area located as far as 2 miles from the pickup area. Canisters will then be mechanically off-loaded by transporter-mounted machinery, and buried horizontally in steel-lined storage holes.

The transporter-mounted mechanism will perform removal and subsequent replacement of the repository hole plug and will also be used for retrieval of waste canisters at the repository site.

The transporter, shown in Figure 20, consists of two main parts, a two-wheel tractor and a towed trailer. The tractor is pivot-pin connected to the trailer, which allows a 42-degree steering capability, and pin-connected to the tractor axle to allow 20 degrees of oscillation. A two-wheeled tractor was selected to give the entire unit short turning and maneuvering capabilities, and a shorter overall length.

The transporter will initially be conveyed from ground level to the below-ground repository area either in an elevator or by being lowered down the mine shaft. Some parts will be sized to fit in a cage 7 feet by 15 feet and will weigh no more than 52,000 pounds.¹ Longer parts that cannot be sized will be lowered down the mine shaft under the cage. The transporter will be reassembled belowground.

1. Waste Isolation Facility Description Bedded Salt Y/OWI/SUB-76/16506, Office of Waste Isolation. Page B-3, Page II-4.

Transporter installation and retrieval operations, whether with plugs or with canisters at the burial or receiving area, will be performed by one operator outside the cab. During retrieval operations, when the operating temperature may be 150°F, the operator will wear an environmental bubble suit. The control panel is located on the transporter trailer on the side opposite the cask door. An umbilical line attachment to the panel will allow the operator to move back and forth parallel to the rib face.

Prior to the transporter entering the canister burial area, readings will be taken to determine the pitch, yaw, elevation, and horizontal distance from a mine base reference station. This reference data will then be correlated to the base reference station(s) on the trailer and necessary adjustments for alignment will be made (see Section 7.5).

Once the trailer has been aligned with the burial rib, it is possible to install or retrieve two canisters or plugs without moving the transporter. The cask will accommodate two burial holes on approximately 5-foot centers.

The transporter as designed measures 51 feet 9-1/2 inches long and 16 feet 3-1/2 inches wide at the cask. When the cask is loaded with two canisters and one plug, the transporter weighs 251,000 pounds. It will negotiate cross corners in 20-foot-wide entries with the corners trimmed to a 9 foot radius. The transporter will be equipped with a four-wheel, planetary-axle drive mechanism with all wheels braked with an air-over-hydraulic braking system. The transporter will be steered from either of two air-conditioned cabs. It has been designed to preclude the possibility of overturning either the tractor or the trailer in case of tire or axle failure while on a 10-percent side slope (see Section 7.9).

7.1 TRANSPORTER TRAILER

The transporter trailer is specially designed to permit carrying a cask containing two canisters in a horizontal position perpendicular to the transporter line of travel. This orientation of the cask reduces the amount of maneuvering required to align the truck with the repository holes predrilled in the mine rib. As a result, rooms can be narrower. During transport, the cask is securely locked in the travel saddles on the trailer frame.

FMC FMC Corporation
Engineered Systems Division

Figure 20 HIGH-LEVEL WASTE AND
CLADDING WASTE
TRANSPORTER, HORIZONTAL
INSTALLATION (FMC Drawing
5135289)

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The trailer frame consists of two rail-like, fabricated box sections, 14 inches wide and 24 inches high. Located on each rail structure on either side of the cask is a vertical structural heavy pipe that houses a hydraulic jack with a pad that lowers to the mine floor to elevate the trailer and another hydraulic jack that controls the elevation of the cask adjustment assembly spanning the top of the trailer.

A steering pivot connection attaches the trailer to the transporter tractor. Two 18 by 33, 32-ply tires at the opposite end support an air-conditioned cab containing driving and operating controls for an operator and a helper. The trailer cab will be used on the return trip from the repository area.

7.2 TRANSPORTER TRACTOR

The tractor selected for horizontal installation is manufactured by Wagner Mining Equipment Company. It is powered by a Caterpillar diesel engine with either an Oxy Catalyst or Englehart exhaust purifier. The transporter is capable of traveling 10 mph on the level and at least 1-1/2 mph on a 10-percent slope.

Two 5-inch, double-acting steering cylinders, with chrome-plated rods, are mounted at the trailer pivot pin to provide the tractor with a steering range 42-1/2 degrees to either side of the transporter longitudinal centerline. The four-speed, bidirectional transmission, the torque converter, and the planetary-drive axles are from the Clark Manufacturing Company. The tractor is supported by two 33.5 by 33, 38-ply tires. Brakes on both the trailer and the tractor will be 22 inches in diameter and 7 inches wide, air over hydraulic. The parking brake will be spring set and hydraulically released.

To compensate for heat problems encountered when operating in 150°F ambient temperatures, the tractor radiator is heavy-duty, bolted, and of large capacity. High-capacity coolers are furnished for the converter and transmission.

The tractor cab, like the trailer cab, accommodates two occupants. Both cabs are insulated, air-conditioned, soundproofed to 87 decibels, furnished with FOPS, and are equipped with identical control functions.

7.3 TRANSPORTER BUMPERS

Because the unit may be steered from either direction, two hydraulic bumpers are furnished for the two directions of travel. The bumpers selected are Taylor 10-inch Series absorbers, each rated for a maximum work level of 250,000 pound-feet at 24 inches of deflection. In a collision with a stationary object while traveling 10 mph, the bumpers deflect 22-3/8 inches to absorb all the collision energy, so that the transporter and the operators experience deceleration force of 1.8 g for less than 0.5 second.¹

The bumpers will be suitably guided to contain and prevent side loading which could impair the bumper's free linear motion.

7.4 CASK

A cask design (Figure 21) to accommodate radiation shielding, structural integrity, and mechanical devices to handle two canisters and one plug resulted in a cask weight, without canisters and plugs, of 175,000 pounds. Respective length, width, and height dimensions are 16 feet 3-1/2 inches; 10 feet 0-1/8 inches; and 4 feet, 5-5/8 inches. This weight, roughly 85 percent more than that of the vertical storage cask, is due to the greater inside dimensions required for housing the canister installation machinery and to provide a tube housing for the plugs.

Shielding provided by this cask reduces gamma-ray and neutron intensity to less than 25 millirems per hour at the cask outer surface when it encloses two canisters of 5-year-old high-level waste fuel elements. Shielding consists of layers of 4.33 inches of depleted uranium, 7.87 inches of borated polyethylene, and 2.5 inches of steel.

The uranium and borated polyethylene shields are cast in sections to facilitate cask construction and future maintenance. The joints between the sections are stepped to avoid the possibility of separations providing "windows" for gamma rays and neutrons.

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1. Rocket sled test data indicate that a person can withstand a force of 10 g for 1.7 seconds without ill effects. See Morgan, et al, Human Engineering Guide to Equipment Design, 1st Edition, 1963, Page 449.

FMC FMC Corporation
Engineered Systems Division

Figure 21 CASK LAYOUT,
HORIZONTAL INSTALLATION
(FMC Drawing 5130822)

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A 70-cfm suction HEPA filter will be used to keep the cask interior (when the cask door is closed) under a 1-inch water vacuum. This filter (Flanders Filters, Inc., Model G-1 1R BB-D SS) incorporates a bag-out feature which allows removal of the filter without personnel coming in direct contact with any of the filtered materials (see Appendix B). The blower will be either a Joy Manufacturing Company X702-213B (92 cfm at 2 inches of water and 2 amperes at 28 volts DC) or an equivalent unit.

The cask will also provide for passive heat removal to avoid excessive canister or cask interior temperatures. Two 5-year-old high-level waste containers produce approximately 10 kw of heat. Heat-conduction strips will be added to the cask structure to act as stiffeners and to conduct heat through the polyethylene layers so that the inside cask liner to outside cask differential temperature will not exceed 40°F. The cooling strips will be oriented so as not to form a radiation window for neutrons. Thermocouples in the cask will monitor the temperature of each cavity.

Other cask features consist of several hydraulically operated mechanisms.

7.5 CASK ADJUSTMENT ASSEMBLY

Each of the the four vertical, large-diameter steel pipes on the transporter trailer will house two separate hydraulic systems:

- Cask installation jacks (see Section 7.6)
- Cylinders for raising and lowering the cask adjustment assembly along with the cask (vertical support cylinders).

The cask adjustment assembly (Figure 20) contains all adjustment mechanisms necessary for positioning the cask plug recesses and the canisters for installation or removal. Attached to the cask are screw jacks which control cask motion toward and away from the rib (lateral movement).

An endless-chain trolley mechanism provides parallel and angular movement of the cask along the repository rib (longitudinal movement). Raising and lowering the two vertical support cylinders in pairs inby or outby the rib controls the cask height and pitch.

The capabilities for adjustments in the three planes are as noted in Figure 20. Cask pitch will be adjustable to within ± 2 degrees. Longitudinal angular movement will be adjustable to within ± 3 degrees. All movements are controlled from an operator's control panel on the side of the transporter away from the repository rib.

Initial alignment of the cask with the burial hole is done in a coordinated effort between the transporter operator in the cab and the operator's helper on the mine floor. The plan is to have vertical and horizontal cask reference lines located on the canister centerline horizontally and on a point midway between the plug and canister centerline. The initial alignment done by the operator's helper will be by eye and directing the transport operator until the vertical centerline is within 6 inches of coinciding with a storage hole.

7.6 TRACTOR/CASK INSTALLATION JACKS

To avoid making compensating adjustments for tire spring, weight shift, etc., during installation or retrieval, jacks with large foot plates are provided to raise the tractor and trailer off the ground. Controls for the jacks will be located on the control panel on the side of the trailer opposite the repository rib. In the traveling position, the bottom of the jack pads will be 7 inches above the ground. The jack pads also act as stabilizing devices in case of axle or tire failure during transport. Maximum movement of the jacking pads is 16 inches from the travel position.

7.7 CANISTER AND PLUG INSTALLATION/REMOVAL MECHANISMS

The canister installation/removal mechanism consist of two separate push/pull arms with grab devices that latch onto the canister. Each arm is driven by a endless chain-actuated trolley. Use of two installation arms and trolley mechanisms reduces both the arm length and the cask length that would be required for one push/pull arm to install a canister a sufficient distance in the repository hole. Each canister is provided with an independent system.

The grab device on the shorter arm will first engage the canister head in the cask and push it forward through the cask door until the first pusher trolley is at the end of its travel. This action will partially install the canister in the repository hole. When the first arm travel is complete, the arm will

withdraw slightly, disengage the grab device from the canister, withdraw another 5 inches, and rotate upward out of the line of movement. The rotation of the first arm will be such that the crank end of the first arm will form a guide for the second longer arm, which will simultaneously rotate into position. The longer arm grab device will then advance and automatically engage the canister, and the movement of the second trolley mechanism will complete the canister installation in the repository hole.¹ Canister removal from the repository hole will be accomplished by reversing the installation procedure.

The mechanism designed for installation and removal of the repository hole plugs is essentially the same as that designed for canister installation/removal. The plug mechanism, however, consists of one push/pull arm and one single trolley drive unit.

7.7.1 Grab Device For Horizontal Storage

One grab device design is used for both the canister and the plug installation/removal mechanisms. As shown in Figure 22, the device consists of spring-loaded grab faces, which are opened and locked by the action of an air cylinder. The design is such that the device will engage the canister even if misaligned 3-3/16 inches vertically or 3/8 inch horizontally. During installation or removal of canisters, an alignment collar will be fabricated immediately to the rear of the grab to center the installation arm in the 15-inch inside-diameter canister repository receptacle. (This is not shown on the drawing).

Operation of the grab devices is remotely controlled by the operator's helper at the transporter control panel. Once the helper moves the control for either the plug or the canister installation mechanism to the installation position, the canister or plug installation arm advances and the grab device air cylinder is actuated to open the grab faces. Continued forward movement of the arm until the canister or plug pintle pushes against the arm tube end plate triggers the air cylinder to lock and close the grab faces.

-
1. The force of the grab device pushing against the canister or plug also will open the spring-loaded grab faces.

Figure 22 GRAB DEVICE, HORIZONTAL INSTALLATION (FMC Drawing 5135342)

The canister is now captured and pushed into the burial hole. When the installation arm reaches full travel, the air cylinder automatically unlocks, opening the grab faces. For canister installation, the procedure repeats for the second installation-arm grab device. When installation is complete, the installation arm is retracted into the cask.

When operated in the removal mode, the grab devices remain closed until the force of the canister or plug against the spring-loaded grab faces forces them to open. As before, the air cylinder then is triggered by the arm tube end plate to lock the grab faces about the canister or plug pintle. The grab faces remain locked during the removal procedure. During canister removal, the procedure repeats for the engagement of the second installation/removal arm with the canister pintle.

Following removal, the plug will be carried, if transportation is necessary, in one of the plug receptacles on either side of the cask. It will be encased in a steel pipe, but will not be provided further shielding. For transit, the plug will probably be held by pins. No door will be provided.

7.7.2 Storage Hole Geometry

The repository hole steel sleeve for the plug and canister has two inside diameters: 20 inches and 15 inches. The larger diameter fits the plug diameter; the smaller diameter fits the canister. A conical section is welded between the large- and the small-diameter pipes. The bottom surface of the canister is rounded at its outer periphery and is easily pushed up the conical section ramp. The maximum force necessary during installation or retrieval, barring jamming, is estimated as 1,650 pounds. The use of low-friction materials on matching sliding surfaces would reduce this figure.

7.8 TRANSPORTER OPERATIONS AND CYCLE TIMES

The transporter is designed to be loaded with two HLW or two CW canisters while the cask is in a horizontal position. The transporter will then transport the canisters to the repository site and install each canister in a horizontal hole in the repository rib.

7.8.1 Operations Sequence

An operator and an operator's helper are specified for the transporter operations. Once at the repository site, the helper will work outside the cab to assist the operator in positioning the transporter and to control transporter functions from a control panel on the side of the trailer. Because the helper will stand on the side of the trailer away from the repository rib, the transporter itself will shield him during the installation/removal operation. Figure 23 details the operating sequence for the horizontal installation.

7.8.2 Time to Emplace Two Canisters in the Repository Hole

Table 30 lists the steps required to horizontally emplace two canisters following the procedure delineated in the sequence drawings. Times required for each task are shown.

7.9 STABILITY

A stability analysis for the trailer only is shown in Figures 24 and 25. In this approach the transporter acts as two units. The tractor has a pinned-bridge connection over the axle, which provides for oscillation of the axle. The pinned-bridge connection is in turn joined to a yoke, which provides a steering pivot connection to the trailer. The tractor oscillates ± 10 degrees in a vertical plane with respect to the trailer.

In Figure 24, two cases are shown in which a failure of the axle or tire has occurred on a 10-percent side slope. Case 1 assumes the tire reaction is transferred to the trailer raising jacks. Case 2 assumes the reaction is transferred to the trailer frame. Because Case 2 is the most pessimistic, it was analyzed for the trailer only. In the failure condition shown in Case 2 the trailer would, as previously stated, rotate about the longitudinal tractor axle centerline. The tractor would furnish an additional stabilizing effect on the trailer if the 10-percent slope were exceeded.

Loading and analysis of Case 2 is shown in Figure 25. Because the center of gravity of all loads falls between the truck supports, the unit is stable.

SIDE VIEW

1. THE TRANSPORTER ARRIVES AT THE REPOSITORY SITE. THE CASK IS RESTING IN THE TRAVEL SADDLES. THE LOCKING MECHANISMS ARE ACTIVATED.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 1 OF 13)

PLAN VIEW

2. THE OPERATOR'S HELPER LEAVES THE CAB TO INSPECT THE SITE AND GUIDE THE OPERATOR IN STEERING THE TRANSPORTER UNTIL THE CASK REFERENCE CENTERLINE 1 IS WITHIN 6 INCHES OF THE CENTER OF THE REPOSITORY HOLE. HE ASSUMES HIS POSITION AT THE CONTROL PANEL TO REMOTELY CONTROL THE ENTIRE INSTALLATION/REMOVAL PROCEDURE.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 2 OF 13)

3. THE OPERATOR'S HELPER, STANDING AT THE CONTROL PANEL, LOWERS THE JACK PLATES TO LIFT THE TRANSPORTER FROM THE FLOOR. HE CHECKS THE POSITION AND SECURITY OF THE JACK PADS.
4. THE HELPER PRESSES THE SWITCH AT THE CONTROL STATION TO RELEASE THE CASK LOCKING MECHANISMS.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 3 OF 13)

5. THE OPERATOR'S HELPER ACTUATES THE VERTICAL SUPPORT CYLINDERS THAT RAISE THE CASK ADJUSTMENT ASSEMBLY AND SIMULTANEOUSLY LIFT THE CASK OUT OF THE TRAVEL SADDLES.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 4 OF 13)

6. FROM THE CONTROL STATION THE OPERATOR'S HELPER FOLLOWS THREE STEPS TO ALIGN THE CASK REFERENCE CENTERLINE TO WITHIN $\pm 1/4$ INCH OF THE CENTER LINE OF THE REPOSITORY HOLE:

- HE ACTUATES THE VERTICAL SUPPORT CYLINDERS FOR HEIGHT AND PITCH ADJUSTMENTS.
- HE ACTUATES THE LOGITUCINAL TROLLEYS FOR POSITIONING THE CASK ALONG THE RIB FACE AND FOR MAKING YAW ADJUSTMENTS.
- HE ACTUATES THE LATERAL POSITIONING MECHANISMS TO BRING THE CASK INSTALLATION FACE $1/2$ INCH FROM RIB FACE.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 5 OF 13)

7. THE OPERATOR'S HELPER ACQUATES THE LOGITUDINAL POSITIONING TROLLEY TO TRAVERSE THE CASK UNTIL THE PLUG 1 RECESS CENTERLINE IS WITHIN 1/4 INCH OF THE REPOSITORY HOLE 1 CENTERLINE.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 6 OF 13)

8. THE HELPER EXTENDS THE PLUG REMOVAL/INSTALLATION MECHANISM UNTIL THE GRAB DEVICE ENGAGES AND LOCKS ON THE END OF THE REPOSITORY PLUG. RETRACTING THE PLUG REMOVAL MECHANISM, THE HELPER EXTRACTS THE PLUG AND STORES IT IN THE PLUG 1 RECESS.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 7 OF 13)

9. THE HELPER ACTUATES THE LONGITUDINAL TROLLEY TO ALIGN THE CANISTER 1 WITH THE REPOSITORY HOLE.
10. THE HELPER ACTUATES THE SLIDE MECHANISM TO OPEN THE CANISTER 1 CASK DOOR.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 8 OF 13)

11. THE HELPER EXTENDS THE CANISTER INSTALLATION/REMOVAL MECHANISM, WHICH ENGAGES THE CANISTER AND PUSHES IT INTO THE REPOSITORY HOLE. HE DISENGAGES THE GRAB DEVICE AND RETRACTS THE INSTALLATION MECHANISM INTO THE CASK.

12. THE HELPER OPERATES THE SLIDE DOOR MECHANISM, CLOSING THE CANISTER 1 CASK DOOR.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 9 OF 13)

13. THE HELPER TRAVERSES THE CASK, USING THE LONGITUDINAL POSITIONING TROLLEY, TO REALIGN THE REPOSITORY PLUG IN THE PLUG 1 RECESS WITH THE REPOSITORY HOLE.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 10 OF 13)

14. THE OPERATOR'S HELPER ACTUATES THE PLUG INSTALLATION/REMOVAL MECHANISM TO REMOVE THE PLUG FROM THE PLUG 1 RECESS FROM THE CASK AND RETURN IT TO THE REPOSITORY HOLE. HE THEN DISENGAGES THE GRAB AND RETRACTS THE MECHANISM INTO THE CASK.

15. THE HELPER REPEATS STEPS 6 THROUGH 14 FOR INSTALLATION OF CANISTER 2.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 11 OF 13)

16. THE HELPER RETURNS THE CASK TO THE TRAVEL POSITION AND LOWERS THE VERTICAL SUPPORT CYLINDERS UNTIL THE CASK RESTS IN THE TRAVEL SADDLES. HE THEN ACTIVATES THE CASK LOCKING MECHANISMS.

17. THE HELPER RETRACTS THE INSTALLATION JACKS SO THAT THE TRANSPORTER TIRES REST ON THE MINE FLOOR AND THE JACKS ARE IN THE TRAVEL POSITION.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 12 OF 13)

18. THE HELPER CHECKS THE TRANSPORTER FOR TRAVEL READINESS, COMPLETES NECESSARY COORDINATION WITH THE TRANSPORTER OPERATOR, AND THEN ENTERS THE REAR OPERATOR CAB FOR THE TRANSPORTER RETURN TRIP.

Figure 23 SEQUENCE OF OPERATIONS FOR HORIZONTAL INSTALLATION OF HIGH-LEVEL OR CLADDING WASTE (SHEET 13 OF 13)

Table 30 TIME REQUIRED TO EMPLACE TWO HLW/CW CANISTERS

Task		Time, seconds
Sequence number	Description	
1.	The transporter arrives at the repository site with the cask locked in the saddles.	0
2.	The operator's helper leaves the cab to inspect the site and guide the operator in steering the transporter until the Cask Reference Centerline 1 is within 6 inches of the repository hole. He then assumes a position at the control panel to remotely control the installation/removal procedure in the following steps:	35
3.	Jack plates are lowered lifting the entire transporter from the floor. Security and position of the jack pads are checked.	15
4.	The cask locking mechanism is unlocked.	30
5.	The vertical support cylinders are activated to raise the entire cask adjustment assembly and cask from the traverse saddles.	5
6.	The cask reference centerline is lined up within $\pm 1/4$ inch of the repository hole centerline. <ul style="list-style-type: none"> The vertical support cylinders are actuated for height and pitch adjustment. The longitudinal adjustment trolleys are actuated for positioning the cask along the rib face and for making yaw adjustments. The lateral positioning screws are actuated to bring the cask face $1/2$ inch from the rib. 	50
7.	The longitudinal positioning trolley is actuated to traverse the cask until the plug #1 recess-centerline is within $\pm 1/4$ inch of the repository hole centerline.	10
8.	The plug removal/installation mechanism is advanced from the cask plug recess until the grab device engages and locks on the "head" of the repository plug. The mechanism is retracted and the plug is drawn back into the plug #1 recess.	15
9.	The longitudinal positioning trolley is actuated to align the canister #1 centerline with the repository hole centerline.	10
10.	Cask door #1 is opened.	5
11.	The canister installation/removal grab mechanism engages the canister head and pushes #1 canister into the repository hole. The grab is then disengaged and the installation/removal mechanism is retracted into the cask.	20
12.	Cask door #1 is closed.	5
13.	The longitudinal positioning trolley traverses the cask to realign the #1 plug recess with the #1 repository hole $\pm 1/4$ inch.	10
14.	The #1 plug installation/retrieval mechanism is actuated to remove the #1 plug from the cask recess and install it in the repository hole.	10
15.	Repeat steps 6 through 14 for installation of canister #2.	135
16.	The cask is returned to a position over the travel saddles and lowered into the travel saddles by lowering the vertical support cylinders. The cask locking mechanism locks the cask in the travel position.	30
17.	The transporter weight is transferred back to the tires by retracting the jacks to travel position.	15
18.	The operator's helper checks the transporter for travel readiness, checks with the operator for readiness, enters the rear cab, and prepares for the return trip.	35
Total time required		7 minutes, 15 seconds

Figure 24 STABILITY ANALYSIS, FAILURE ON 10-PERCENT SIDE SLOPE

Figure 25 STABILITY ANALYSIS, REACTION TRANSFERRED TO TRAILER FRAME

7.10 CASK DOOR (Figure 20)

The cask is equipped with separate doors for each of the two canisters. They will always be closed except when canisters are being on-or off-loaded. Each door is supported on the bottom by guided rollers.

Opening and closing of the door is accomplished by the action of a double-acting air cylinder. A safety latch (not shown on the drawing) will be designed to ensure against the door opening in case of air-line failure. The latch will be mechanically spring set and air released.

7.11 CONTROLS, INSTRUMENTATION, HYDRAULICS, AND LIGHTS

Specifications for controls, instrumentation, hydraulics, and lights are as described for the spent-fuel transporter in Section 4.5. Hoists needed for the vertical canister/plug installations are eliminated in the horizontal-and inclined-installation design, however. Additional instrumentation and controls may be required to accomplish alignment of the cask with the rib repository holes.

7.12 INCLINED INSTALLATION

The mechanics of inclined installation would be the same as those for horizontal installation. The same machinery, with minor additions, can be used. It is advantageous to transport the cask in an inclined rather than horizontal position. In this way advantage can be taken of the short cylinders on the installation side, thus keeping the transporter height the same as for horizontal installation. Transporting the cask in the horizontal position and then making the necessary adjustments for inclined installation would require a higher mine excavation. An artist's rendering of the inclined storage transporter is shown in Figure 26.

Figure 26 ARTIST'S CONCEPT, INCLINED INSTALLATION

8.0 COMMON FEATURES AND UTILITY SYSTEMS

This section covers an assortment of topics which are either common to all the transporters or several transporters, general topics which pertain to transporter design, and utility systems.

8.1 CANISTER GRAPPLE MECHANISMS

Several concepts were developed of latching devices for use in vertical installation and retrieval to gain some idea as to sizes and design problems associated with grapples. (Grapples for horizontal and inclined installation and retrieval are discussed in Section 7.)

The following factors must be considered in the design of a canister grapple:

- Reliability

Reliability is the most important requirement. The nature of the canisters prohibits visual inspection or maintenance of the grapple in the presence of a canister, except in a hot cell. The canister can be loaded into the cask in a hot cell. This is the best time for attaching a grapple and assuring that a connection has been made. Canister retrieval from the repository will present a greater challenge because of inability to see the connection, the possible accumulation of debris or salt on the canister top, or possibly corrosion of the canister top.

- Radiation Resistance

Organic materials such as are used for air hoses, electrical insulation, and seals deteriorate in the presence of gamma and neutron radiation. If these materials are used in a grapple, they must be carefully selected, periodically inspected, and replaced prior to failure.

- Grapple Length

The longer the grapple, the longer the cask. This increases the height of the repository room and the quantity of salt that must be mined. Cask and transporter weights are increased, increasing the loading on the tires and decreasing the margin of safety or requiring use of larger

tires. Each additional inch of grapple length requires one additional inch of cask length. For the spent-fuel transporter, each additional inch of length results in a weight increase of 416 pounds and a transporter cost increase of \$2,912, based on \$7 per pound.

- Grapple Shape

As the canister and grapple assembly (or grapple alone) is lowered into the depository hole and withdrawn from this hole, it will encounter a change in the surrounding hole diameter and may tend to hang up. The grapple shape must include tapered lead-ins to preclude this possibility.

- Canister Top Shape

Because many canister tops will be required, a top that is simple, of moderate cost, and durable is an important requirement.

8.1.1 Canister Grapple Designs

All grapple designs described in the following paragraphs are operated by an air hose, electrical cable, or steel tension ribbon that precludes use of a grapple design in conjunction with wire rope. A wire rope might allow the canister to rotate and entangle the hose or other grapple operating device. Therefore, all grapples use a modification of a leaf chain.

A chain with the hose, electrical cable, or tension ribbon interior to the chain link provides the best activation device protection. All leaf chains shown in Figures 27, 28, and 29 are modifications of the Diamond BL-646 chain, with rated tensile strength of 27,200 pounds.

8.1.1.1 Sliding-Lock Grapple

The sliding-lock grapple (Figure 30) incorporates a movable plate with a keyhole-shaped slot. Pulling on the tension tape, which is inside the lifting chain in Figure 29, moves the plate against spring force and releases the grapple. The grapple can then be lifted from or lowered onto a canister. Release of tape tension allows the springs to return the sliding plate to the locked position. The sliding plate is counterbored 1/8 inch so that the canister pintle interlocks the plate and body of the grapple and precludes the operator releasing the grapple by pulling on the tape unless lifting tension is removed from the lift chain.

Figure 27 LIFTING CHAIN WITH
INTERNAL TENSION TAPE,
SLIDING-LOCK GRAPPLE

Figure 28 LEAF CHAIN
CONTAINING HOSE
OR ELECTRICAL CABLE

Figure 29 LEAF CHAIN CONTAINING HOSE OR ELECTRICAL WIRE

The sliding-lock grapple offers the following advantages:

- Length is short, thereby reducing cask length and machine height.
- The exterior shape of the grapple is such that it can be raised and lowered into the various diameters of the cask cavity and the depository hole with no danger of hanging up. (All grapple designs can be shaped to provide this feature.) Figure 30 shows the diameters that would exist in the cask and repository hole.
- None of the grapple materials, including the steel tension tape, are susceptible to radiation damage.
- Tape tension is required to release the lock plate. Tape failure will not inadvertently release the grapple.
- The grapple is mechanically simple.
- The attaching canister pintle is of a simple shape which is easily fabricated. The pintle shape will tend to shed salt and other material that may fall on it.
- The grapple is heavy and rugged enough to be dropped onto the pintle to break any salt particles interfering with attaching.
- Because of the openness of the mechanism, it will be easy to view the grapple condition in a hot cell to see if it is solidly latched onto the canister. Once on the canister it will remain latched until the canister is in the repository hole. It then can be released.
- The position of the tension tape actuation device outside the cask permits determining the position of the sliding lock from outside the cask.

8.1.1.2 Locking-Pin Grapple

The locking-pin grapple (Figure 31) was developed and tested at the Union Carbide Oak Ridge facility. Developed for use with a smaller canister, the grapple diameter is 6 inches and fits over a 1-1/2-inch-diameter canister pintle, but the design can be scaled up to match spent-fuel canister dimensions. Lead-ins could be added.

The grapple works by introducing air into the top chamber which moves the latch outer sleeve in opposition to the springs in the bottom, causing four lifting pins to move angularly outward and releasing the grapple. (Tractor standard equipment includes a 125-psi, 10-cfm air system for braking. This system would provide adequate air for grapple operation.)

TOP VIEW

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Figure 31 LOCKING-PIN GRAPPLE (FMC Drawing 11362EK)

Compression forces provided by the springs engage the grapple pins. The air hose would be contained inside a leaf chain as shown in Figure 28 (refer to Section 8.3).

The locking-pin grapple offers the following advantages:

- It is compact, although it may require a slightly longer cask than the grapple described in Subsection 8.1.1.1.
- Loss of air pressure will not release the latch; and the latch will not release with air pressure if the canister weight provides some load on the grapple.
- The canister pintle can be designed to shed salt and other debris.
- Condition of the grapple can be viewed in the loading hot cell to determine that it is locked onto the canister (determination is made by noting the relative position of the top nut and the lifting yoke). The yoke shank could be provided with a colored ring to indicate that the grapple was engaged when this ring was visible.
- Because of the large piston area and the large area that can be used for compression springs, very large forces can be employed to engage and release the grapple. This will help to overcome problems which would result from salt encrustation and corrosion of the pintle.

The potential disadvantage of this grapple is as follows:

- Operation is by an air hose and cylinder that has elastomer seals. Even if the grapple provides shielding for the hose, it is subject to full radiation when one canister is in the cask and the other grapple is out of the cask to install or retrieve a canister. This will increase maintenance requirements in that hoses and seals would require periodic replacement.

8.1.1.3 Electromagnetic Latch

The electromagnetic grapple (Figure 32) supports the canister by electromagnetic means. Power requirements would be about 10 amperes at 28 volts.

Advantages of this grapple are as follow:

- Electromagnets are used extensively for handling massive steel parts.
- The canister pintle is of simple construction. A good material choice would be high-purity iron or wrought iron.

Figure 32 ELECTROMAGNETIC GRAPPLE (FMC Drawing 5130997)

- Attachment of the grapple to the canister is easiest with the electromagnetic designs. If the grapple is in close proximity to the canister it will pull itself on. Figure 33 shows the force exerted by one model magnet as a function of distance to the attached object.
- The mating canister pintle would shed salt and other materials. Salt particles could be crushed by dropping the magnet on the canister top.
- By superimposing an AC signal on the DC current (and by use of a suitable filter in the DC line), the presence of the canister top can be detected; therefore, it is possible to determine whether or not the grapple is on the canister and also whether or not it is solidly on (no appreciable air gap).
- A redundancy of conductors in the power cable is possible. In this way an open wire (or shorted wire)¹ in the cable can be detected and yet the redundant conductor will carry the power until the cable can be replaced. A failure can thus be detected before it causes a problem.

Disadvantages are as follow:

- A power interruption disconnects the grapple. Mechanical designs can be made such that the grapple will not disconnect if the grapple is loaded, even if an UNLOCK signal is given.
- The electromagnet windings can be aluminum with aluminum oxide insulation (anodized) to provide excellent resistance to radiation, but the power cable to the magnet must be made of wire and insulation with good flexibility to travel on small-diameter pulleys (tentatively 4 inches in diameter). As with air hoses, the cable will require periodic replacement.

8.1.1.4 Pivoting Dog Grapple (Figures 34 and 35)

The pivoting dog grapple (Figure 34) is another air-operated grapple that, with no canister present and no air pressure in the air operation cylinders, is automatically open to receive a canister pintle. Pressurizing one air cylinder closes the grapple and, if it is supporting the weight of a canister, it will not open.

1. A positive cable wire to ground or positive wire to negative wire short would cause a circuit breaker to open.

Figure 33 ELECTROMAGNETIC ATTRACTION AS A FUNCTION OF AIR GAP

FEATURES

1. AIR PRESSURE IS REQUIRED FOR LATCHING TO CANISTER
2. LOSS OF AIR PRESSURE WHEN LOADED WILL NOT CAUSE CANISTER TO DROP. LATCH MECHANISM MUST BE UNLOADED (CANISTER SET DOWN) BEFORE UNLATCHING CAN OCCUR.
3. RELEASE OF CANISTER IS BY SPRING ACTION WHEN AIR PRESSURE IS RELEASED. THEREFORE, WHEN AIR PRESSURE IS LOST, CANISTER CAN BE DEPOSITED AND UNLATCHED BEFORE PERFORMING MAINTENANCE ON AIR SYSTEM.
4. CONICAL RAMP SHOWN WILL ALWAYS "FIND" AND LATCH TO A 12.75 O.D. X 16" LONG CANISTER IN A 15 I.D. HOLE.

SECTION A-A

Figure 34 PIVOTING DOG GRAPPLE (FMC Drawing 5130970)

Figure 35 PIVOTING DOG GRAPPLE, SCHEMATIC

The pivoting dog grapple offers the following advantages:

- It uses standard commercial air cylinders, springs, etc.
- It can be designed to detect the presence of the canister pintle and the fact that it is grappled by using an air relief valve and another pintle-operated valve in the system (Figure 35). For instance, if a 125-psi air system were used, the relief valve on the grapple could be set to release air at 90 psi (the grapple is designed to operate at 60 psi); with the canister pintle present and the air valve on, gage pressure will be 90 psi. If the pressure valve is on and the pintle is not present, the air pressure reading will be 120 psi. This canister detection system appears simpler than would be the case for grapples that employ air pressure to release the canister.
- It can be designed so it will not hang up on the canister or repository hole shelves.

Disadvantages are as follow:

- It uses air hoses, seals, etc., that are deteriorated by gamma radiation.
- It is longer than some designs, so cask length and weight would be increased.

8.1.2 Lead-In Geometry

During installation and retrieval of vertical canisters, it will be necessary for the grapple to guide itself through several diameters, despite misalignment that may be present, and align itself on the canister. If the sleeve has tilted more than a few degrees over a period of several years, the pintle could be displaced from the storage sleeve centerline. Figure 36 shows a 12.75-inch-diameter HLW (or CW) canister tilted inside a 15-inch-diameter sleeve.

Figure 36 HLW CANISTER,
12.75-INCH DIAMETER,
AT MAXIMUM TILT IN
15-INCH-DIAMETER SLEEVE

The angle of tilt, assuming 9 feet of straight side, is

$$\theta \approx -1 \frac{15 - 12.75}{103} = 1.19 \text{ degrees}$$

$$r \approx 12 \tan^{-1} = 0.25 \text{ inch}$$

$$R = 7.5 - 6.375 + r = 1.375 \text{ inches.}$$

The center of the pintle then could be anywhere within a 2.75-inch-diameter circle around the centerline of the storage sleeve.

The outside diameter of the lead-in and the diameter of the apex of the lead-in is calculated by simultaneous equations. From Figure 37:

$$d = 2(7.5 + 1.375 - x)$$

$$x = 2(7.5) - d$$

Substituting,

$$d = 15 - x = 15 + 2.75 - 2x$$

$$x = 2.75 \text{ inches}$$

$$d = 12.25 \text{ inches.}$$

The outside diameter of the lead-in should be 12.25 inches; the diameter of the apex should be 5.5 inches. The slope of the sides of the lead-in should be at least 45 degrees ensure the grapple will self-align on the pintle. The lead-in should be massive and rugged so that debris on the pintle can be broken.

Figure 37 LEAD-IN GEOMETRY

8.2 ANGULAR MISALIGNMENT BETWEEN CASK AND SLEEVE

A basic problem which developed during this project was to determine the degree of angular misalignment which could occur between the centerline of the sleeve in the cask and the centerline of the sleeve in the storage hole. If the misalignment is too great the canisters will bind and will not pass from the cask into the storage hole. The Preliminary Design Criteria provided at the start of the contract specified that the transporter be able to place the cask within $\pm 1/4$ inch of the storage hole centerline using X- and Y-axis motions of the cask support, but did not specify angular misalignment.

It is important to know how much misalignment can be allowed. This number is an input as to how precisely the cask angularity must be controlled to ensure that the canisters can be installed. At this time it is not known how much movement or deformation of the storage sleeve will occur due to geotechnical pressures or movements of the salt. When such information is developed it can be used in conjunction with this information to determine how accurately the two centerlines must be matched before canisters can be installed or retrieved. Figure 38 shows the mechanism by which binding occurs.

8.2.1 Binding

The mechanism of binding is analogous to trying to slide a wooden dowel through a garden hose. If the hose is straight the dowel slides freely. As the hose is bent into an arc of increasingly smaller radius, eventually the dowel binds. In this case the casks do not bend, but the angular misalignment between the casks approximates an arc of very large radius.

It is apparent from Figure 38 that if a relatively long canister passes between two casks of similar diameters, which are only slightly larger than the diameter of the canister itself, the allowable angular misalignment is a very small angle. The angular misalignment between the two casks is ϕ , which is approximately twice the angular misalignment β between the canister and cask centerlines. It is an approximation because the diameter of the storage hole is nominally 17 inches and the diameter of the cask sleeve is nominally 16.875 inches. The $1/8$ -inch difference, however, is only 0.75 percent of the canister diameter.

Figure 38 BINDING OF SPENT-FUEL CANISTER DUE TO ANGULAR MISALIGNMENT BETWEEN CASK AND STORAGE HOLE

Angle β is found from

$$\beta = \tan^{-1} \frac{AB}{AC}$$

but $AC = BC = L/2$

L = length of the straight side of a canister.

AB is simply the diametral clearance of the canister in the cask sleeve

AB = diameter of cask sleeve - diameter of the canister

for $\phi = 2\beta$

$$\phi = 2 \tan^{-1} \frac{D \text{ cask sleeve} - D \text{ canister}}{\frac{1}{2} \text{ canister length}}$$

Table 31 gives values of ϕ for various types of canisters.

Table 31 ALLOWABLE ANGULAR CANISTER MISALIGNMENT

Item	Canister Contents	Nominal diameter, (inches)	Assumed straight length (inches)	Cask sleeve diameter, (inches)	Approximate allowable angular misalignments, degrees
1	Spent-fuel	14	186	16.875	3.5
2	Spent-fuel overpacked	16	189	16.875	1.1
3	HLW, CW	12.75	114	15.00	4.5
4	HLW, CW overpacked	14	117	15.00	2.0
5	ILW	24	114	26.5	5.0
6	ILW, overpacked	25.5	117	26.5	2.0

These values indicate that the overpacked canisters will be the greatest problem. Canisters not overpacked should present little difficulty if the centerline of the storage sleeve can be detected, either directly or by reference to the top lip of the storage sleeve. For the spent fuel, 3.5 degrees is allowed for installing/retrieving nonoverpacked canisters. If the cask is nominally 18 feet long, then the end of the cask opposite the door must be within a 13.2-inch radius of the centerline of the storage hole.

For the HLW and CW with a nominal cask length of 13.5 feet and an allowable misalignment of 4.5 degrees for nonoverpacked canisters, the radius becomes 12.8 inches.

The situation is slightly more difficult for overpacked canisters. For the spent fuel the radius is 4.1 inches, and for HLW and CW it is 5.7 inches.

Actually the HLW canisters will not present a binding problem even with the overpack, as there is a 7-foot-long plug sleeve above the HLW storage sleeve, and its inside diameter is 20 to 21 inches. Inasmuch as the total length of the HLW is 10 feet 3 inches when overpacked, and about 6 inches of this length is not straight sides, all but 2 feet 9 inches of the straight sides of the overpack is out of the cask before the canister begins to enter the actual storage sleeve. The cladding waste will not require a 7-foot-long concrete plug as its radioactivity is much lower; therefore, it may bind.

Angular misalignment is not really a practical concern during the early stages of repository operation, because all storage holes will be nearly perfectly oriented and this orientation will be known. The cask can then be oriented with sufficient accuracy based on knowledge of the nominal orientation of the sleeves. However, it can be expected that over a period of several years both linear and rotational movement of the storage sleeves will occur. Geotechnical studies will determine the magnitude of rotational displacement that may occur by some future date when it may be desirable to retrieve the canisters. This data can then be used to size the cask sleeves so as to minimize retrieval problems.

8.2.2 Geometry of the Ends of the Canisters

The succeeding discussion concerns binding which occurs when the canister is moving inside the cask sleeve and the storage sleeve. It is possible that the canister may not enter the storage sleeve but could hang up in the plug sleeve.

This condition is shown in Figure 39 for a spent-fuel canister with overpack being installed vertically. The canister center of gravity is assumed to be exactly in line with the centerline of the cask sleeve. It is assumed to be acted on only by gravitational forces and the tension in the hoisting cable.

Figure 39 INTERFERENCE CAUSED BY ANGULAR MISALIGNMENT BETWEEN CASK CENTERLINE AND STORAGE SLEEVE CENTERLINE

From Figure 40, the interference E is given by

$$E = r_c + B - r_s$$

r_c = canister radius
 r_s = storage sleeve radius
 D = diameter

$$B = 0.25 + L \tan A$$

$$E = 1/2 (D_c - D_s) + 0.25 + L \tan A.$$

Table 32 gives the maximum interference for each of the canisters and angles listed in Table 31.

Table 32 MAXIMUM CANISTER INTERFERENCE

Condition	Item and canister					
	1 Spent fuel	2 Spent fuel, overpacked	3 HLW, CW	4 HLW, CW, overpacked	5 ILW	6 ILW, overpacked
Canister diameter, inches (D_c)	14.00	16.00	12.75	14.00	24.00	25.50
Storage sleeve diameter, inches (D_s)	17.00	17.00	15.00	15.00	26.50	26.50
Plug sleeve length, inches (L)	84.00 ¹	84.00 ¹	84.00 ¹	84.00 ¹	36.00 ²	36.00 ²
Misalignment angle, degrees (A_1)	3.50	1.10	4.50	2.00	5.00	2.00
Interference, inches (E_1)	3.90	1.40	5.80	2.70	2.20	1.00
Allowable misalignment angle, degrees (A_2)	1.10	1.10	2.00	2.00	2.00	2.00
Interference, inches (E_2)	0.40	1.40	2.10	2.70	0.26	1.00
Allowable canister end diameter, inches ($D_c - 2E_2$)	13.20	13.20	8.60	8.60	23.50	23.50

1. Because the spent fuel, HLW and CW all require approximately the same gamma shielding it is assumed that they all use seven foot long concrete plugs.

2. This is an approximation made as follows:

$$\frac{\text{ILW cask gamma shielding thickness}}{\text{HLW cask gamma shielding thickness}} \times 7 \text{ feet of concrete}$$

$$\frac{5.2 \text{ cm Pb} \times \frac{11.34}{18.3}}{11 \text{ cm U}} \times 7 \text{ feet} = 2.1 \text{ feet} \quad 3 \text{ feet}$$

$$\frac{11.34}{18.3} = \text{ratio of densities of lead to uranium.}$$

This approximation does not consider the steel gamma shielding, but rounding up from 2.1 to 3 feet probably results in conservative plug length.

The misalignment angles A_1 shown in of Table 32 are too high for the non overpacked canisters. as there is no reason to presume that the rotational movement of a nonoverpacked canister storage sleeve will be greater than that for an overpacked canister. The allowable available misalignment A_2 for overpacked canisters is used instead to calculate interference E_3 . These interferences are then used to calculate the maximum allowable canister end diameter which will ensure that the canisters enter the storage sleeve and do not hang up in the plug sleeve.

If the bottom end of the canister is of reduced diameter, then there must also be a lead-in angle on the canister to allow it to slip sideways as it enters the storage sleeve. Using a factor of safety of 2 and a coefficient of friction of 0.7, the minimum lead-in angle with respect to the bottom of the canister is 54.5 degrees.

A nominal lead-in angle of 60 degrees would be more than adequate. Note that this angle and the maximum allowable canister diameters should be applied to both ends of the canister, as these problems could occur either when the canisters are entering the storage sleeve during installation or when the canisters are entering the cask during retrieval.

An alternate solution would be to place a 60-degree ramp inside the end of the plug sleeve and the end of the cask sleeve. This arrangement would allow the use of the full canister diameter at both ends of the canister and would allow the use of any end geometry.

8.3 FALLING OBJECT PROTECTIVE STRUCTURE (FOPS)

A falling object protective structure (FOPS) is a structural framework built over an operator's station to protect the operator from falling objects, such as roof falls and rib rolls. FOPS are similar to rollover protective structures (ROPS), which are now required on many types of construction and surface mining equipment. Because of the stipulation that the transporter not upset in the event of flat tires, broken rims, or axle failure, and because of the maximum repository grade of 10 percent, it does not seem necessary to provide ROPS on the transporter.

FOPS are required by law in most coal mines. There is no statutory requirement for FOPS on equipment used for metal and nonmetallic underground mines. There is a requirement that the operator be able to see without straining, that cabs be reasonably comfortable, that cab windows be of safety glass, and that cabs be kept free of extraneous materials.¹ There is, however, a history of injury experience for salt and all nonmetal mines, as shown by Table 33.

Table 33. INJURY EXPERIENCE IN SALT AND NONMETAL MINES,^{2, 3}
1970 THROUGH 1972

Year	Fatal roof falls		Temporary nonfatal roof falls	
	Salt mines ¹	All nonmetal mines (except stone and coal) ²	Salt mines ¹	All nonmetal mines (except stone and coal) ²
1970	4	6	6	41
1971	0	3	3	32
1972	0	1	5	32

1. Roof falls in salt mines, per these reports for 1970, 1971, and 1972, resulted in "fatal" or "temporary nonfatal" accidents. There are no reports of "permanent total disability" or "permanent partial disability" accidents.

2. Examples of nonmetal mines are clay, gypsum, phosphate rock, potash, salt, and sulfur mines.

Inquiries were made of salt and nonmetallic mining operations, and the consensus was that some type of FOPS should be provided if work was to be done under a high roof. When this is considered with the history of fatal roof falls, a FOPS is recommended. There is no standard for FOPS in a salt mine, but it is felt that the criteria used for coal mines should be adequate. CFR 30, Paragraph 75.1710-1-(d), states:

For purposes of this section, a canopy or cab will be considered to be substantially constructed if a registered engineer certifies that such canopy or cab has the minimum structural capacity to

1. Part 57, Health and Safety Standards, Metal and Nonmetallic Underground Mines.
2. IR-1014, Injury Experience in the Nonmetallic Metal Industries (Except Stone and Coal), 1970-71, MESA Informational Report/1975, Reference Tables A-10 and B-10.
3. IR-1043, Injury Experience in the Nonmetallic Mineral Industries (Except Stone and Coal), 1972, MESA Informational Report/1976, Reference Table 11.

support elastically: (1) A dead weight load of 18,000 pounds, or (2) 15 p.s.i. distributed uniformly over the plan view area of the structure, whichever is lesser.

The reason for recommending this FOPS criterion is that salt is friable and will tend to break into small pieces, which will result in relatively lighter loads on the FOPS as opposed to coal mine roof falls. Coal mine roofs are not necessarily friable, are seldom homogeneous, and are not as stable as salt roofs. Note that it is not considered feasible to protect an operator from massive roof falls (thousands of tons).¹

Several cab and construction equipment manufacturers were contacted for data on FOPS/ROPS. The consensus was that the SAE ROPS criteria were more severe than the coal mine FOPS criteria. On this basis, if a prime mover can be purchased with a ROPS-certified cab, that cab will probably satisfy the recommended FOPS requirement. An additional FOPS over the operator's station at the trailer would provide increased protection.

8.4 AIR CONDITIONING

The Preliminary Design Criteria specified that the transporter be able to operate in ambient temperatures of up to 130°F. Hydraulic systems, engines, and power transmission components are available which will operate at this temperature, although performance will be derated.

It is recommended that the operators be provided an air-conditioned cab and heat-resistant clothing, perhaps having integral cooling provisions. There are miners working in the United States at temperatures of up to 120°F; in Africa mine temperatures range to 145°F. The operators may elect not to wear heat-resistant clothing when aligning casks or hooking/unhooking plug hoists, but suits should be available and the cabs should be maintained at about 70°F.

-
1. Design Criteria and Guidelines for Falling Object Protective Structures (FOPS), Woodward Associates, Redlands, California, U.S. Department of Commerce, NTIS Number PB 259 254.

Higher ambient temperatures will occur during retrieval operations, which is also when the possibility of operational difficulties is greatest and could require prolonged exposure to the heat. Operational difficulties could include stuck canisters, misaligned storage sleeves, stuck plugs, leaking canisters, debris on top of the canisters, or excessive room closure.

Several manufacturers were contacted regarding air conditioners which would cool a cab to 70°F in an ambient temperature of 150°F. Based on a cab volume of 95 cubic feet (for one person), a surface area of 105 square feet of steel and insulation, 22 square feet of single-pane glass, and a recommended air flow rate of 360 cfm (for initial pulldown), the air-conditioning load for a single-operator cab is calculated as

● Heat due to conduction	3,200 Btu per hour
● Operator's body heat	650 Btu per hour
● Cooling incoming ventilation air	<u>27,000 Btu per hour</u>
● Total	30,850 Btu per hour at initial pulldown.

This compares to a typical automobile air conditioner which has a capacity of approximately 20,000 Btu per hour.

During normal operation, when as little as 25 cubic feet of circulating air may be fresh air from outside the cab, 4 to 6 horsepower would be required for a one-operator cab.

Eaton manufactures the air-conditioning units currently used on the Caterpillar 621 tractors. These units are nominally rated to work in 120°F ambient air. The unit is capable of maintaining a 72°F cab temperature in a 150°F, 2-percent-humidity environment. While operating in the 150°F environment the unit is capable of pulling the cab temperature down from 100°F to 72°F. This standard unit then can be utilized if an effort is made to keep the cab closed. Some thermal mass, such as a layer of gamma shielding in the back wall of the cab, will help greatly to level out fluctuations in cab temperature due to opening and closing doors when exiting or entering the cab.

8.5 TRANSPORTER PERFORMANCE

8.5.1 Transporter Horsepower Requirements

The function of the transporter is, as its name implies, to transport a very massive load. The actual cargo is relatively light, perhaps 10,000 pounds at the most. The shielding required to contain the radiation from this cargo is the actual load. To gain some indication as to the horsepower that would be required, the coal hauler family of vehicles was analyzed. These vehicles are essentially tractor-trailer units with the same function as the transporter in that they primarily haul a load between two points. They differ from other haulage vehicles in that the weight capacity is very large, similiar to the weight anticipated for a shipping cask. They are different from highway tractor-trailers in that they are off-the-road vehicles and travel at speeds of up to 40 mph on unimproved roads. Unlike most mining and construction equipment, they do not cut, doze, drill, load, or break the earth, so horsepower requirements are determined by haulage requirements only. A typical coal hauler is shown in Figure 40.

Figure 40 TYPICAL COAL HAULER

The data in Table 34 was accumulated for this family of vehicles.

Table 34 COAL HAULER SPECIFICATIONS

Item	Nomenclature	GVW, ¹ 10 ³ pounds X	Flywheel brake horsepower ² Y	Rated speed, ³ mph	Theoretical horsepower required, ⁴ X ₁
1	Caterpillar 772	339	600	25.0	452
2	Caterpillar 776	496	870	27.0	714
3	Euclid CH-150	506	975	28.5	769
4	Euclid B-100/110	325	607	26.7	463
5	Euclid B-30	107	291	34.3	196
6	Euclid B-63/70	219	442	28.0	327
7	Athey 772	352	600	23.0	432
8	Athey PD768B	216	415	28.0	323
9	Euclid CH-120	385	718	30.5	626
10	Wabco 75B	394	665	N/A	-

1. GVW is the total weight of the vehicle and cargo.
2. Brake horsepower, typically at 1,900 to 2,100 engine rpm (after allowances for fan, alternator, etc.).
3. Approximate speed on level terrain at 2-percent rolling resistance.
4. Theoretical horsepower = $(5.33 \times 10^{-5}) \times (\text{GVW, pounds}) \times (\text{speed, mph})$. This is the brake horsepower required at the driving wheels to maintain speed against a 2-percent rolling resistance.

The data shown in Columns X and Y is plotted in Figure 41. A regression line was fitted to this data to obtain the following equation:

$$\text{Flywheel horsepower} = 78.29 + 1.62 \text{ GVW (GVW = 1,000-pound units)} \quad (1)$$

or

$$\text{Flywheel horsepower} = 78.29 + 0.00162 \text{ GVW (GVW = pounds)}.$$

The correlation coefficient for this equation is 0.98.

The flywheel horsepower exceeds that which is theoretically required in Column X. These data were plotted in Figure 42 and a regression line fitted to show that:

$$\text{Flywheel horsepower} = 72.45 + 1.1131 \text{ theoretical hp.} \quad (2)$$

The correlation coefficient for this equation is 0.99.

Figure 41 COAL HAULER HORSEPOWER REQUIREMENTS AS A FUNCTION OF GVW

Figure 42 COAL HAULER FLYWHEEL HORSEPOWER AS A FUNCTION OF THEORETICAL HORSEPOWER REQUIREMENTS

The differences between the theoretical horsepower and the rated horsepower account for drive line losses, variations in engine performance (typically guaranteed to be within 5 percent of ratings), and some margin for deteriorating performance with age and wear.

Note that Equation (1) cannot be used to size an engine for a transporter. The transporter is intended to run at 10 mph maximum, whereas the coal haulers described by Equation (1) run at about 30 mph. To size engines for the coal hauler, the theoretical horsepower at the wheels must first be determined, then Equation (2) applied to obtain the flywheel brake horsepower. When this is done the following equation results.

$$\text{Transporter flywheel horsepower} = 72.45 + 5.93 \times 10^{-4} \text{ GVW}$$

(GVW = pounds).

This equation, plotted in Figure 43, gives the minimum recommended flywheel brake horsepower for a transporter. It could be necessary to use more horsepower than the recommended minimum if a significant air-conditioning load is added, but current estimates of air-conditioning power requirements are approximately 5 horsepower per operator with an ambient air temperature of 150°F.

If a standard tractor or vehicle is normally equipped with a standard engine which is excessively powerful, it may be desirable to retain that engine because it is standard and refitting a nonstandard engine could result in additional initial expense.

Diesel engine performance should be derated approximately 8 percent for operation at 150°F.

8.6.2 Gradeability

The basic contract for this project stipulates that the transporter be able to negotiate a grade of 10 percent at a speed of not less than 1 mph. In this section it is shown that any transporter with an engine sized by the criteria in Subsection 8.6.1 can climb a 10-percent grade, if sufficient weight is on the driving wheels.

Figure 43 TRANSPORTER FLYWHEEL HORSEPOWER AS A FUNCTION OF GROSS VEHICLE WEIGHT

From Figure 44:

$$\sum F_N = 0$$

$$RD + RS = 0.995 \text{ GVW}$$

where

RD = reaction to the load on the driving axle

RS = reaction to the load on the steering axle.

$$\sum F_T = 0$$

$$FD = RR + 0.0995 \text{ GVW}$$

where

$$FD = C \times RD = \text{driving force}$$

C = coefficient of traction

$RR = 0.02 \times \text{normal force}$

for

$C = 0.4 \text{ to } 0.7$,¹ use the lowest value

$0.4 \text{ RD} = (0.02)(0.995 \text{ GVW}) + 0.0995 \text{ GVW}$

$\text{RD} = 0.2985 \text{ GVW}$.

Figure 44 FREE-BODY DIAGRAM OF TRANSPORTER ON 10-PERCENT SLOPE

Therefore, a minimum of 29.9 percent of the GVW must be on the driving axle if the vehicle is to climb a 10-percent grade using a coefficient of traction of 0.4.

The maximum speed which the vehicle can sustain on a 10-percent slope is found by considering the transporter as a constant power source.

Horsepower = $FD \times V$

V = transporter speed, mph

FD driving force = $0.4 \times 0.2985 \text{ GVW}$, pounds.

1. Letter, R. E. Dougall of Goodyear Tire and Rubber Company, August 9, 1977.

$$\text{Horsepower} = \frac{(0.4)(0.2985) \text{ GVW} \times V \times 5,280}{3,600 \times 550}$$

$$\text{Horsepower} = 3.184 \times 10^{-10} \text{ GVW} \times V.$$

This gives the horsepower required to drive a transporter of weight GVW up a 10-percent grade at V mph. The engine of the transporter can be considered to be a constant-power source providing, at a minimum, the theoretical horsepower required in Subsection 8.6.1 for 10 mph travel on flat ground.

$$\text{Theoretical horsepower} = 5.33 \times 10^{-5} \text{ GVW} \times 10 \text{ mph.}$$

Equating these two,

$$3.184 \times 10^{-4} + V = 5.33 \times 10^{-5} \times 10 \text{ mph}$$

$$V = 1.67 \text{ mph.}$$

The practical significance of these calculations is that any transporter with 30 percent of the gross vehicle weight on the driving axle, and with an engine which has at least the minimum horsepower rating required by the calculations in Subsection 8.6.1, will be able to climb a 10-percent grade at a maximum speed of 1.67 mph. This assumes that the transporter is equipped with a suitable transmission.

Note that the spent-fuel repository will not contain any 10-percent grade in it; 1 percent is the maximum. For this reason, the spent-fuel transporter could have less than 30 percent of the GVW on the driving axle.

8.6.3 Transporter Acceleration

To develop travel times for the transporter as it moves about the repository, it is necessary to know not only the top speed of 10 mph, but also the times required for acceleration and braking. This section is devoted to developing data on acceleration and distances and times for acceleration.

The acceleration is determined by considering that the transporter engine is a constant power source. Part of the energy output is used to overcome

rolling resistance; the remainder becomes the kinetic energy of the transporter. The rate of change in kinetic energy, hence the rate of change of the velocity, determines the acceleration.

Energy input = kinetic energy + work done.

8.6.3.1 Energy Input

The energy input is the horsepower delivered to the rear wheels multiplied by the elapsed time. If the input is exactly the theoretical horsepower required to overcome rolling resistance, theoretically an infinite amount of time would be required to reach the full speed of 10 mph.

From Subsection 8.6.1 it can be seen that the actual brake horsepower at the flywheel is greater than the theoretical requirement, even if a typical power train efficiency of 90 percent is applied. The excess horsepower covers wear and deterioration, variation among engines, and probably some margin to ensure that minimum performance is achieved. For these reasons, it is assumed that the horsepower delivered to the rear wheels is 101 percent of the theoretical minimum, which assures that the top speed of 10 mph is reached in a finite amount of time.

$$\begin{aligned}\text{Horsepower} &= 1.01(5.33 \times 10^{-5}) \text{ GVW} \times 10 \text{ mph} \\ &= 5.38 \times 10^{-4} \text{ GVW}.\end{aligned}$$

Changing from horsepower to foot-pounds per second, the energy input rate is:

$$E = 0.296 \text{ GVW foot-pounds per second.}$$

8.6.3.2 Kinetic Energy

The kinetic energy occurs in two places. There is the linear component, caused by the vehicle velocity, and the rotary component, caused by the mass moment of inertia of the rotating elements, including the engine, power train, and tires.

The linear kinetic energy is given by:

$$KE_L = \frac{1}{2} \frac{GVW}{g} V^2$$

The rotational kinetic energy can be estimated as a function of the linear component by examining the rotational kinetic energy of the tires on the spent-fuel transporter.

$$KE_R = \frac{1}{2} I \omega^2 \text{ (per tire)}$$

$$\omega = 0.48 V \text{ revolutions per second.}$$

Considering the tire to be a thin cylindrical shell,

$$I = mr^2$$

$$m \cong 1,550 - g \text{ (slugs)}$$

$$r \cong 3.23 \text{ feet (taken as one-half unloaded inflated diameter).}$$

For a total of six tires, the ratio of KE_R to KE_L is

$$\frac{KE_R}{KE_L} = \frac{6 \times 1,550 \times 3.23 \times 0.48^2 V^2}{GVW} = 0.11$$

assuming $GVW \cong 200,000$ pounds.

The rotational kinetic energy of the tires is large compared with the other rotating members because of the relatively large radius and relatively large mass. Other members will, however, exhibit a rotational velocity much greater than $0.48 V$. Omitting details of the entire power train, the rotational kinetic energy will be taken as 15 percent of the linear kinetic energy. The transporter kinetic energy is then given by

$$KE = \frac{(1.15)(1/2) GVW \times V^2}{g}$$

For $\omega = GVW$ in pounds, V in mph, $g = 32.2$ feet per second squared, the total kinetic energy in foot-pounds is:

$$KE = 0.0385 GVW \times V$$

8.6.3.3 Work Done

The work done is the force exerted to overcome rolling resistance times the distance traveled. The rate at which work is done is the rolling resistance times the velocity.

$$\frac{d\omega}{dt} = RR \times V.$$

The velocity is a function of time

$$\frac{d\omega}{dt} = RR \times V(t)$$

$$\omega = FR \int V dt.$$

Using a rolling resistance of 0.02, GVW in pounds, V in mph, and in foot-pounds

$$\omega = 0.0293 \text{ GVW} \int V dt.$$

8.6.3.4 Conservation of Energy

From conservation of energy

$$\dot{E}_t = KE + \omega \quad t = \text{seconds}$$

Substituting and canceling out the GVW gives:

$$0.296t = 0.0385 V + 0.0293 \int V dt.$$

Differentiating and dividing through by 0.296

$$dt = 0.260 V dV + 0.099 V dt.$$

Separating variables and integrating yields:

$$(1 - 0.099V) dt = 0.26 V dV$$

$$dt = 0.26 \int \frac{V dV}{1 - 0.099V}$$

$$t = -2.626V - 26.53 \ln(1 - 0.099V) + C.$$

The constant of integration C is evaluated at the initial conditions of $t = 0$, $V = 0$ to yield $C = 0$ to give:

$$t = -2.626V - 26.53 \ln(1 - 0.099V) \quad (3)$$

This equation gives the relationship for the velocity of any transporter at time t , if the engine is sized as detailed in Subsection 8.6.1. A more powerful engine will result in faster acceleration and some increase in performance. (The increase will be small when compared to the total time to install a canister.)

Note that by using 101 percent horsepower, it is actually possible to reach a speed of 10.1 mph.

Equation (3) above is plotted in Figure 45 on two time scales; 95.9 seconds are required to reach full speed of 10 mph.

Figure 45 HORSEPOWER-LIMITED ACCELERATION, SPEED VERSUS TIME

8.6.3.5 Traction Limitations

From Figure 45 it is apparent that the velocity increases very rapidly in the first few seconds of motion. The initial acceleration is actually limited by traction.

The tractive force available for accelerating the transporter is limited by the coefficient of traction and the fraction of the gross vehicle weight which is on the driving axle. From Figure 44:

$$FD - RR \equiv \frac{GVW}{g} a$$

$$FD = D \times C \times GVW$$

where D = fraction of GVW on the driving axle.

$$D \times C - 0.02 = \frac{a}{g}$$

$$a = (D \times C - 0.02) g$$

where $g = 32.2$ feet per second squared.

To find a in mph per second:

$$a = 21.95 (D \times C - 0.02) \text{ mph per second.}$$

To find a in g's

$$a = D \times C - 0.02.$$

The spent-fuel transporter would have as little as 26 percent of GVW on the driving axle. The forklift-type transporters would have as much as 95 percent of GVW on the driving axle. The acceleration possible for these values is calculated in Table 35 for coefficients of traction of 0.4 and 0.7 and is also graphed in Figure 45.

Table 35 TRANSPORTER ACCELERATION

Item	Percent of GVW on driving axle	Coefficient of traction	Acceleration	
			mph	g
1	26	0.4	1.84	0.08
2	26	0.7	3.56	0.16
3	95	0.4	7.90	0.36
4	95	0.7	14.16	0.65

Note, in Figure 45, that the horsepower-limited velocity curve represents the maximum velocity possible at time t . Where a traction-limited velocity line lies below this curve, the traction curve (0.08 g) crosses the horsepower curve at less than 2 seconds. Considering that 95.9 seconds are required to reach 10 mph, this is insignificant. On this basis, the horsepower-limited velocity curve was integrated by Simpson's rule to obtain Figure 46, which shows distance traveled as a function of time during the acceleration period.

Figure 46 HORSEPOWER-LIMITED ACCELERATION, DISTANCE VERSUS TIME

After 95.9 seconds have elapsed, the transporter is considered to exhibit a constant speed of 10 mph.

Figure 46 can be used to determine travel times in the repository for a specified mine plan. Some argument can be made that much more powerful engines than are specified in Subsection 8.6.1 will result in faster acceleration and hence faster cycles for installing waste. When the effect of faster acceleration on the total cycle of loading, transporting, installing, and return is considered, however, the actual gain is small.

8.6.4 Braking and Deceleration

The braking capability of the transporter is not controlled by engine size or other machine parameters, but is determined by what is accepted as customary and safe braking performance. The average decelerations in Figure 48 were compiled from SAE J 1152, Minimum Performance Criteria for Braking Systems for Off-Highway, Rubber-Tired, Self-Propelled Construction Machines (July 1976), which lists recommended stopping distances for various classifications of vehicles grouped by gross vehicle weights and maximum speeds.

From Figure 47 it is apparent that the lowest deceleration rate is approximately 0.1 g for vehicles traveling 10 to 15 mph. For all classes of vehicles, higher deceleration rates are required for higher speeds. The duty cycles for the dumpers¹ (200,000 to 400,000 pounds GVW) and tractor scrapers (more than 150,000 pounds GVW) most closely resemble that of the transporter, especially the dumpers. For this reason an average deceleration rate of 0.15 g was selected as the minimum performance value. This value is conservative, but in no case should the rate be allowed to drop below 0.1 g. To provide some indication of the sensation of these braking values, Table 36 was compiled.

Figure 48 shows that distance traveled while braking at 0.15 g from 10 mph as a function of time. The values in parentheses are the time elapsed and the distance traveled during a full stop. It is apparent that the times required for a full stop will vary about 3.5 seconds for the difference between a quick stop at 0.15 g and a slow stop at 0.07 g.

No problem is expected with the brakes on the lift truck concepts as they are being used within their rated capacities and speed. The tractor-trailer spent-fuel transporter is being used at a greater trailer weight than the tractor normally pulls when used as part of a scraper. SAE J 1152, however, specifies that "all tractor scrapers and dumpers shall have braked wheels on at least one axle of the prime mover and one axle of each trailing unit."

1. Typically bottom or rear dump coal haulers.

Figure 47 MINIMUM BRAKING PERFORMANCE FOR OFF-HIGHWAY VEHICLES
(RECOMMENDED PRACTICE, SAE J1152)

Table 36 TYPICAL ACCELERATIONS¹ AND DECELERATIONS

Item	Vehicle	Condition	Acceleration/ deceleration, g's	Duration, seconds
1	Automobile	Normal stop	0.25	5 to 8
2	Automobile	Quick stop	0.45	3 to 5
3	Automobile	Emergency stop	0.70	3
4	Train	Normal acceleration	0.10 to 0.20	5
5	Train	Normal deceleration	0.10 to 0.20	5
6	Aircraft	Takeoff	0.50	Greater than 10

1. Morgan, Cook, Chipains, and Lund, editors, Human Engineering Guide to Equipment Design, First edition, McGraw-Hill, 1963, page 447.

Figure 48 CONSTANT DECELERATION FROM 10 MPH, DISTANCE VERSUS TIME

For this reason and its increased weight, at least one axle of the trailer should be braked to ensure adequate performance. Further analysis during detailed design may indicate that both axles of the trailer should be braked.

8.7 POWER SOURCES

The following types of transporter power were considered:

- Diesel power selected because:
 - (1) It is used extensively for salt haulage in salt mines.
 - (2) It is relatively nontoxic as compared to a spark ignition engine.
 - (3) Much of this toxicity can be removed by means of an exhaust scrubber such as is added to diesel units used in coal mines.
- Battery power. This is a reasonably satisfactory type of power but diesel power appears better for the transporter purposes. Projecting coal mine scoop vehicle weight/battery weight ratios a battery-operated spent-fuel transporter would weigh an additional 40,000 pounds (a total of 220,000 pounds), which would make the machine longer and wider because of increased structure and larger tires. Battery-powered vehicles also require a relatively long time for recharging the battery (as compared with filling the vehicle fuel tank with diesel oil); care is required to assure the vehicle will not lose battery power during a working day.
- Spark ignition engines were not really considered because of toxic nature of the fumes and higher operating costs. This type of power is not known to be used in underground mines.
- Diesel locomotive power with plug-in electrical power at the repository. This would result in a simple reliable system but the time required for plugging and unplugging and stowing the power cord would be excessive for the many operations per year required. The maximum repository site power requirement for the spent-fuel transporter is about 100 hp. For 480-volt AC three-phase power, the power cord would be 1.5 inches in diameter and weigh 1.9 pounds per foot.

9.0 SCHEDULES AND ESTIMATED COST

9.1 SCHEDULE FOR DELIVERY OF FIRST OPERATIONAL TRANSPORTER

Two schedules are shown for the design, fabrication, and testing of the first operational transporter. The first schedule, Figure 49, shows the recommended program of 18 months. This program is applicable to the transporters for spent fuel and high-level waste if installed horizontally or on an incline; the program could be reduced slightly for the forklift-type transporters, as they do not require the design of a trailer. This program does not follow the typical pattern of Title I and Title II designs, which pertain to the management of construction projects. The transporter could be built by the process of preliminary design (Title I), definitive design (Title II), followed by an entirely separate phase for fabrication and testing. Although this process is not mandated by the relatively low level of complexity of designing and building a transporter, an alternative 44-month schedule with design and fabrication phases separated by a 5-month period for procurement activities is shown in Figure 51.

Note that the first schedule has the design activities lumped together instead of being split into Title I and Title II. At this point in time it appears that commercially available prime movers will be used for all of the transporter concepts; and that the design effort actually consists of making modifications to these machines, designing trailers and carriages, and designing casks. The second schedule has a 7-month preliminary design effort (Title I) preceding a 14-month design program (Title II) which illustrates the possibility that the continuing refinement of the repository design could possibly make all of the concepts in this report untenable as presently shown. It would then be necessary to revise the concepts presented here. If revising these concepts is not necessary, the preliminary design (Title I) could be deleted and the alternate program accomplished in 37 months.

	Months					
	3	6	9	12	15	18
I. CASK DETAIL DESIGN Structural Heat transfer Cask doors and grapples Canister hoist Canister grapple Plug hoist Cask disassembly for shaft haulage Cask-to-carriage mounting features Shielding review Development of test plans
II. CASK FABRICATION AND TESTING Fabrication Testing <ul style="list-style-type: none"> • Passive cooling • Verification of shielding properties
III. TRAILER/CASK CARRIAGE DETAIL DESIGN Structural Tractor/prime mover interface Carriage details Trailer details Tires and brakes, selection and attachment Development of test plan
IV. TRAILER/CASK CARRIAGE FABRICATION AND TESTING Fabrication Testing <ul style="list-style-type: none"> • Cask door cycling • Canister mechanism cycling • Plug mechanism cycling • Indexing mechanism • Alignment mechanism • Cask erection mechanism
V. CONTROL, POWER, AND INSTRUMENTATION SYSTEMS Selection of sensors Detailing of hydraulic and electrical power systems Selection of control techniques; design of control system
VI. PRIME MOVER DESIGN Operator's cab(s) Air conditioning Human factors <ul style="list-style-type: none"> • Controls locations • Seating • Visibility • Lighting Falling object protective structure Impact-absorbing bumper Development of plan for acceptance testing
VII. FINAL ASSEMBLY AND FACTORY ACCEPTANCE TESTING Tractor/prime mover subassembly fabrication Tractor/prime mover assembly Assembly of transporter Testing <ul style="list-style-type: none"> • Qualification <ol style="list-style-type: none"> (1) Speed (2) Gradeability (3) Braking (4) Cycle time (5) Load test FOPS (6) Impact • Durability testing Operation and maintenance manual

Figure 49 SCHEDULE FOR RECOMMENDED TRANSPORTER PROGRAM

The combined program shown in Figure 49 is the result of two considerations:

- The principal obstacle to designing a transporter is finalizing the repository design and knowing exact canister, overpack, and sleeve configurations. It is realized that the repository design cannot be finalized without some knowledge of transporter capabilities and size. However, this report should be sufficient for that purpose. When the repository plan is finalized to the extent that exact canister geometry, canister spacing, room widths and heights, and storage hole configuration are known, the transporter design can be finalized. Additional extensive preliminary design is not necessary.
- Reliability of the transporter and its mechanisms will be very important when underground operations are begun. This reliability could be assured to some extent by conducting extensive reliability analyses during Title I and Title II. However, dependable performance can be ensured only by an extensive testing program in which all the machine elements are cycled several thousand times prior to shipping the transporter from the factory.

The testing programs shown in Figure 49 and 51 eliminate early component failures usually described as infant mortality, and weak points in the design become apparent and can be corrected at the factory rather than underground. As the testing overlaps the design effort to some extent, design changes can be incorporated into the design if they will result in significant improvements.

The most efficient way to accomplish these objectives is through the program outlined in Figures 49 and 50.

Note that this 18-month program allows no time for Nuclear Regulatory Commission or Department of Transportation approvals of the cask or vehicle. Telephone conversations with personnel of these agencies indicate that their approvals are not required as the transporter will not be exposed to the public.

The task of designing the cask will be undertaken first because of the longer lead time for uranium shielding and the fact that cask weight and dimensions

Figure 50 FLOW CHART FOR DESIGN, FABRICATION, AND TEST

Figure 51 ALTERNATE TRANSPORTER
SCHEDULE USING
CONVENTIONAL APPROACH
OF COMPLETELY SEPARATE
DESIGN AND FABRICATION
PHASES

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govern much of the transporter design. The lead times shown in Table 37 are current as of November 1977, and were given consideration in establishing this program.

Table 37 LEAD TIMES

Concept	Item	Prime mover	Lead time
Vertical installation	Spent fuel	621 Caterpillar tractor (standard)	6 to 8 weeks
	HLW/CW	H800A Hyster forklift (standard)	8 weeks
	ILW	H360A Hyster forklift (standard)	8 weeks
Horizontal/inclined	HLW/CW	Wagner mining equipment tractor (special)	8 months
Shielding		Uranium casting	1 year
		Lead casting	9 weeks

9.1.1 Project Plan for Recommended Transporter Program

9.1.1.1 Timing

The sequence of tasks to be accomplished begins with designing the cask; and progresses to designing the cask carriage and/or trailer and mast or other devices which attach the carriage to the prime mover. When these projects are underway and the actuators and machine movements are defined, control techniques can be selected, and the control, power, and instrumentation systems can be designed. The last task, changes to the design of parts of the prime mover such as cab, control devices, falling object protective structure (FOPS), impact-absorbing bumper, and human factors will commence as the the previous tasks are completed and personnel become available.

Fabrication of the major subassemblies (cask, trailer/carriage, prime mover) will begin at the end of each design task. Testing of each sub-assembly will begin as soon as fabrication is completed. The cask will be completed first and will be tested immediately. Testing of the cask will be completed at approximately the same time the trailer/carriage is complete. This scheduling allows for the timely assembly of cask and trailer/carriage, followed immediately by further testing. The design changes to the prime

mover and fabrication of these changes will be completed prior to arrival of the prime mover so that it can be assembled immediately and joined to the trailer/carriage (with cask already mounted) and factory testing can begin.

9.2 TASKS

9.2.1 Cask Detail Design

The detail design of the cask will consist of designing for structural strength and passive cooling; and detailing the cask door, canister hoists, plug hoists, canister handling mechanisms, filter system, and cask mounting provisions. Disassembly of the cask for shaft haulage must be possible. The design will be reviewed for shielding adequacy, reliability, and accessibility for maintenance. A test plan for testing the cask will be developed.

Task Product: A complete set of fabrication drawings for the cask.

9.2.2 Cask Fabrication and Testing

A complete cask will be fabricated and tested for the following parameters:

- Passive cooling will be assured.
- Shielding attenuation will be assured by taking specimens of shielding materials at the time they are fabricated and performing laboratory tests to ensure that they conform to the manufacturer's specifications.
- Shielding integrity will be verified by laboratory tests of shielding joints and the cask.

Task product: A functional cask ready for the next phase of testing.

9.2.3 Cask Carriage/Trailer Detail Design

The trailer (for spent fuel and horizontal installation of HLW or CW), mast (for HLW, CW, and ILW), and cask carriage for manipulating and aligning the cask will be detailed. This task will consist of structural analyses for both normal operation and impact conditions, interface with the prime mover (tractor, forklift), selection of actuators, and selection and mounting of wheels, tires, and braking systems. A test plan for testing the alignment, indexing, and canister and plug handling mechanisms will be developed.

Task product: A complete set of manufacturing drawings ready for shop release.

9.2.4 Trailer/Cask Carriage Fabrication and Testing

The trailer and carriage will be fabricated and assembled. The cask, previously fabricated, will be mounted on the carriage and the trailer, or on the carriage and a mockup of the forklift. The following tests will be performed:

- Cask door cycling
- Canister mechanism cycling
- Plug mechanism cycling
- Alignment mechanism cycling
- Cask erection and indexing mechanism cycling.

Task product: Prototype carriage/trailer and cask which are tested and ready for the next phase of qualification and durability testing.

9.2.5 Control, Power, and Instrumentation System Design

As soon as the actuators are sized for the cask, trailer, mast, and carriage mechanisms, the design of the control, power and instrumentation systems can begin. Instrumentation systems will include sensors for monitoring the location of the canister, cask, plug, cask doors, cask internal pressure and temperature, cask position with respect to the storage hole, shielding temperature, and operator location. The electrical and hydraulic systems necessary to power these actuators will be designed. The controls system can then be detailed, including electrical, mechanical, and hydraulic interlocks; control power sources (electrical, piloted, or manual); remote controls; and controls devices for the operator's station.

These designs are an input to both the cask and the trailer/carriage design in terms of locating and mounting sensors and control devices. They are a necessary input to the design and human engineering of the operator's stations.

Task product: Complete control, electrical, and hydraulic schematics; parts list of control devices and hardware.

9.2.6 Prime Mover Design

A commercially available prime mover (tractor, forklift) will be modified by adding one or more operator's cabs (the machine geometry may prohibit putting both operators at the same location, so two separate stations may be required), air conditioning (for use in high ambient temperatures, such as during recovery), human factors engineering of the controls, seating, visibility and lighting, design of a falling object protective structure (FOPS), and design of an impact-absorbing bumper. The test plan for factory acceptance testing will be prepared.

The nature of this task is such that it can be initiated after the previous tasks are well underway. The major constraint is to be able to order the prime mover early enough to ensure a delivery date that will not delay final assembly or factory testing.

Task product: Purchase order for a prime mover; detailed fabrication drawings for cab, control panels, FOPS, and bumper.

9.2.7 Final Assembly and Factory Acceptance Testing

With detail design of the prime mover complete and a purchase order placed for the basic vehicle, fabrication of vehicle subassemblies will be initiated. These subassemblies should be complete when the basic vehicle arrives, so that the prime mover can be assembled to coincide with the completion of testing of the cask and trailer/carriage. The complete transporter can then be assembled and factory testing can be performed. Factory testing will consist of qualification testing to ensure that contract specifications (such as speed, braking, distance, and cycle times) are met, and debugging and durability testing by installing dummy canisters into lined holes in the ground several hundred times. The FOPS will be load tested. Impact testing will be performed and an overall transporter safety review will be completed. Operation and maintenance manuals will be prepared.

Task product: A complete transporter, tested and ready for service, complete with manuals.

9.3 QUALITY ASSURANCE

Quality assurance objectives in a machinery development program include ensuring that a quality product is developed (i.e., dependable, efficient, safe, and economical), ensuring that the results of the project are reproducible, and providing documentation which will permit quick identification and solution of problems in design, fabrication, testing, or use.

A quality product can be ensured only by an extensive testing program. Careful analyses and the application of sound engineering judgment will result in a good design, but even the best of designs include deficiencies which are minimized by a thorough testing program.

The materials of which the transporter components are made must be carefully selected if they will be exposed to radiation, and when the components are received they should be examined to ensure that proper materials have been used. At a minimum, letters of certification should be obtained from manufacturers. Components which should receive particular attention are hydraulic and pneumatic hoses, electrical insulation, adhesives, paints, seals, lubricants, hydraulic fluid, and plastics. Components which are remote from the radiation sources or which receive additional shielding from engine blocks, transmissions, or structural members are not a matter of concern.

Periodic design reviews should be conducted to ensure that the vehicle will be safe and that it meets the objectives of the development program.

The reproducibility of the finished product is ensured by maintaining meticulous drawing files and parts lists. This documentation becomes the basis for requesting competitive bids for successive transporters.

In addition to a drawing system, detailed records should be kept of all calculations and the rationale for a design decision. Thorough records are invaluable when a rigorous test program reveals a problem. These records can be consulted to determine what the design basis was, revise the basis, and rapidly develop and implement a solution.

9.4 CAPITAL COSTS

9.4.1 Development Costs

The cost of designing, fabricating, and testing one complete spent-fuel transporter is estimated as \$2,100,000 for a project beginning in the first quarter of 1978 and extending 18 months as shown in Section 9.1. This cost includes the cost of the transporter and cask. The cost would be slightly lower for an HLW/CW transporter for vertical installation and still lower for an ILW transporter. Transporters for horizontal or inclined storage of HLW and CW would cost slightly more.

The cost for the second program would be approximately the same as the first because the same design tasks must be accomplished and the same parts fabricated. Some additional expense could be anticipated because of additional requirements for formal reports at the end of Title I and Title II, increased management effort due to the extended time frame, and engineering design changes. By engineering design changes, it is meant that a long-term project with a long overlap with the repository design schedule will probably begin with one set of design criteria which will then change several times as the repository design is refined. A relatively shorter-term transporter design program can have its beginning delayed until a later date in the repository design process, at which time the design criteria would be less subject to change. Hence, the design effort would be more efficient and less costly.

9.4.2 Cost of Subsequent Transporters

The cost of purchasing subsequent transporters identical to the first unit is estimated in Table 38. Actual quotations were used where available.

The major cost item for most of these machines is the cask. One manufacturer quoted the following price for providing 12 uranium castings for the spent-fuel cask shown in Figure 8, Section 4.

● Cost of labor, molds, etc.	\$374,000
● Cost of uranium, \$1.00 to \$1.20 per finished pound	<u>68,000</u>
● Total	\$442,000

Table 38 COST OF SUBSEQUENT TRANSPORTERS

Cost items	Transporter			
	Vertical installation			Horizontal/inclined installation
	Spent fuel	HLW/CW	ILW	HLW/CW
Cask	\$ 665,000 ³	\$490,000 ³	\$ 74,000 ⁴	\$1,225,000 ³
Prime mover	95,000	169,000	99,000	95,000
Cask carriage/trailer	125,000	96,000	33,000	100,000
Air conditioning for two operators at 150°F	2,000	2,000	2,000	2,000
Cab, including FOPS	5,000	5,000	5,000	5,000
Impact/absorbing bumper	6,000	6,000	3,000	6,000
Controls devices	9,000	9,000	6,000	12,000
Miscellaneous and testing	100,000	100,000	70,000	120,000
Total	\$1,007,000	\$877,000	\$292,000	\$1,565,000

1. Based on parts and materials costs current in November 1977.
2. All transporters with two-canister capacity except ILW which carries a single 24-inch-diameter canister.
3. Based on \$7 per pound
4. Based on \$3.50 per pound, all-steel construction.

This cost does not cover the cost of steel, borated polyethylene, or cask assembly. By using lead, this cost would be reduced substantially. One manufacturer estimated that providing the lead equivalent of the above 12 uranium castings would cost \$107,000, perhaps less with some design revisions. However, the actual tradeoff is not in the cost of the transporter, but rather in the amount of salt to be mined. If depleted uranium is used for gamma shielding, 4 inches are required on the spent-fuel cask. If lead is used, approximately 6.5 inches would be required.

This additional 2.5 inches means that the transporter must be 5 inches wider than if uranium were used. (Also, an 8- to 10-percent weight increase would occur.) This width requires that all travelways and storage rooms also be 5 inches wider for their full length to a height at least several inches above the tires, and probably all the way to the roof.

The mine plan in Figure 10 (refer to Section 4) contains approximately 650 miles of roadway that would have to be mined 5 inches wider to a height of 11 feet; this represents an additional 1,060,000 tons of salt to be mined. Assuming a mining cost of \$10 per ton, additional mining costs would be \$10,600,000. A similiar analysis applies to the horizontal installation of HLW and CW.

10.0 CRITERIA FOR TITLE I AND TITLE II DESIGN

As discussed in Section 9, rigid adherence to the process of Title I and Title II design is not recommended. Several criteria can be finalized only when repository design is finalized. There should be an input to the repository in terms of what a transporter can do, how big it is, and how the repository affects transporter design, which is provided in this report. Criteria discussed in the following paragraphs are applicable to all transporter designs.

10.1 CASK DESIGN CRITERIA

10.1.1 Canister and Storage Sleeve

The starting point for designing a cask is the canister and storage sleeve designs. The sleeve diameter should be selected to minimize the probability of a canister binding or hanging up, as described in Section 8. To correctly size the canister, mean values and standard deviations, or a range of values, must be known for the following items, both at the time of installation and at the time of retrieval:

- Storage room geometry, including floor and rib curvature
- Storage sleeve orientation
- Storage and plug sleeve dimensions
- Canister geometry and dimensions.

10.1.2 Grapple Mechanism

The second item to be determined for the cask is the grapple mechanism to be used to handle the canisters. Selection of the mechanism involves more than just operations of the transporter; however, it is recommended that the mechanism be as short and as simple as possible to minimize cask length and weight, which affect size and weight of the transporter (the effect of grapple size is discussed in Section 8.4). The grapple should incorporate a lead-in as described in Section 8. Exact size of the lead-in depends on canister and sleeve dimensions.

A purely mechanical device such as that shown in Figure 33 is preferred to designs employing radiation-sensitive materials. A reliable mechanical device reduces the need for periodic inspection and replacement of radiation-damaged hoses, seals, and electrical wires.

10.1.3 Shielding

Shielding requirements must be determined based on a description of the radiation source and the allowable dose rate. Total doses are within currently allowable limits.

It is recommended that the gamma shielding material be depleted uranium for the spent-fuel, HLW, and CW casks. As discussed in Section 9.2, use of depleted-uranium shielding permits reducing the mine opening widths about 5 inches, thereby reducing the quantity of salt mined and the mining costs. Borated polyethylene is recommended for neutron shielding. If detailed thermal analysis shows that temperatures are excessive, use of a sandwich of borosilicone and borated polyethylene may be necessary.

The ILW cask shielding should be solid steel. Use of steel will result in some increase in weight, but the ILW cask is lighter than the HLW and spent-fuel casks. The use of solid steel will simplify fabrication of the cask and provide the necessary attenuation of the radiation.

10.1.4 Cask Exterior

The exteriors of the casks described in this report have typically consisted of 2 inches of steel. This thickness is part of the gamma shielding and provides a rigid structure to support the remaining shielding. In the detail design of the cask an optimum thickness for strength and gamma-ray attenuation should be determined.

10.1.5 Cooling System

A passive cooling system is sufficient for this application and is recommended. It will be necessary to install heat paths in the form of steel or aluminum fins that conduct heat through the borated polyethylene shielding.

10.1.6 Cask Capacity

Cask capacity is determined by an analysis of operating cycles and economic factors. It is recommended that the capacities of the spent-fuel, HLW, and CW casks be two canisters each, and that the ILW capacity be one canister. This recommendation is based on the canister capacities and mine plans used in this report.

10.1.7 Cask Use

It is recommended that the same transporter be used to carry both the HLW and the CW, because gamma shielding requirements for the two types of waste are nearly identical and a single two-canister-capacity transporter can handle the entire input of HLW and CW. The neutron shielding on the HLW cask does not benefit the CW, as cladding waste exhibits no appreciable neutron flux, but it will lower the surface dose rate.

10.1.8 Canister and Plug Hoists

It is recommended that canister and plug hoists be of the cylinder-pulley-leaf-chain type described in this report.

The hydraulic cylinder provides the advantage of a low profile, which minimizes overall size of the cask. The cylinder simplifies controls because of the direct relationship between hoist load and cylinder pressure and because of the linear relationship between piston displacement and canister location.

10.1.9 Cask Doors

Two types of cask doors are described in this report: doors that rotate open and doors that slide open. The two methods are equally effective.

10.2 TRANSPORTER DESIGN CRITERIA

10.2.1 Vehicles

It is recommended that the transporter be either a tractor-trailer combination or a modification of a forklift. The tractor-trailer should be an articulated vehicle, with a single-axle tractor. The single-axle unit is preferred to a two-axle tractor (driving and steering axles) such as is

common with highway tractor-trailer units. The transporter should be capable of maintaining a speed of 10 mph on level terrain and a speed of 1 mph on grades up to 10 percent.

10.2.2 Protective Structures

The transporters should be equipped with falling objective protective structures (FOPS) that have been certified to withstand a static load of 18,000 pounds. If separate cabs are used (for more than one operator), each cab should be capable of withstanding this loading.

10.2.3 Air-Conditioning System

The operator's cab(s) should be equipped with air-conditioning units capable of maintaining a cab temperature of approximately 70°F in an ambient air temperature of 150°F. Such air-conditioning equipment is commercially available.

10.2.4 Cooling and Hydraulic System

The engine cooling system and the hydraulic system should be designed for operation in a 150°F ambient temperature (or the highest temperature that may be encountered).

10.2.5 Materials

All components such as hoses, seals, paints, adhesives, and lubricants which are not shielded or which are interchangeable with unshielded components should be made of radiation-resistant materials. Where practicable, dosimeters should be attached to components which are known to be exposed to intense radiation; e.g., hydraulic hoses on the cask that pass over an open storage hole prior to installation of the concrete plug.

10.2.6 Bumper

The transporter should be equipped with a shock-absorbing bumper system. The bumper and shock absorbers should be designed or selected to withstand a 10-mph collision with a rigid object without extensive damage to the transporter, exposure of the operator to undue hazards, breaking loose of the

cask from its mountings, or opening of the cask doors. Peak deceleration rate of the transporter should be determined and used as a design input for mounting the cask and cask mechanisms.

10.2.7 Braking System

The transporter braking system should be capable of stopping at an average deceleration of 0.15 g and should be capable of so stopping even after it has been heat-soaked at 150°F.

10.2.8 Lighting

The lighting on the transporter should be sufficient to allow the operator to readily position the centers of the cask sleeves within ± 6 inches of the center of the storage holes.

10.2.9 Adjustment Mechanisms

Mechanisms should be provided by which the cask sleeve centerline can be positioned to within $\pm 1/4$ inch of the storage sleeve centerline. Mechanisms should be provided to adjust the angular relationship of the cask center to the storage sleeve centerline to ensure that the canister can be installed and retrieved.

10.2.10 Shielding

In the case of vertical installation and retrieval, all canister raising and lowering operations should be performed from an operator's station so as to minimize the possibility of radiation exposure of the feet and legs due to cracks between the cask and sleeve. In similarly hazardous applications, on underground coal mining equipment, tape switches have been built into the operator's seats and interlocked with the control systems so that performance of certain activities was not possible unless the operators were in their seats. Depending on the final storage sleeve configuration, it may be desirable to place as much as 5 inches of gamma shielding on the cabs.

10.2.11 Controls

If warranted, remote control by means of a cord and pendant can be provided. Many trailer/cask functions are now electrically controllable; all functions could be made electrically controllable. Designing an electrically controllable tractor is time consuming but possible.

10.2.12 Communications

A mine plan system with telephone outlets both inside and just outside the repository rooms is recommended. This system would allow communication with central facilities to report maintenance problems, hazards, and scheduling. Telephone outlets just outside the repository rooms would allow reporting excessive radiation levels in the repository. The transporter could be plugged into this system to provide onboard communications during installation and retrieval.

10.2.13 Construction

Both transporter and cask should be suitable for disassembly so sections can be lowered down a shaft to the repository level.

11.0 SURFACE-LOADED CASK CONCEPTS

The Preliminary Design Criteria provided for two distinct options for the loading of spent-fuel or waste canisters into the cask:

- Option 1: Load the canisters into the shielded cask at a mine level holding area.
- Option 2: Load the canister into the shielded cask at the surface; the cask plus components of the overall transporter will then be lowered into the mine through one of the mine shafts where it will be attached to the transporter structure.

With some small modifications, the concepts developed and analyzed in this report are applicable to both of these options. The first option will be met if the requirement that the transporter be able to retrieve emplaced canisters is met. It is apparent that any transporter or cask having the mechanisms required to remove a storage hole plug, to grasp a canister at the bottom of that storage hole, and pull it into the cask, can also pull a canister out of a hot cell in the floor of the repository and into the cask. The transporter is then capable of loading canisters into its cask from a mine level holding facility.

The second option of loading the canisters into the cask at a surface facility; then lowering the cask, canisters, and cask-mounted mechanisms down a shaft to the mine level; and finally loading the unit onto the transporter, can be achieved by the current concepts. This option would most probably be accomplished in the following sequence.

- At the surface, load the canisters into the cask.
- Lower the cask to the mine level.
- Move the cask to a holding area. (The shaft haulage would then be independent of transporter cycles.)
- Using a crane or suitable overhead lifting device, place the cask onto the cask carriage/trailer of a transporter.

- Mechanically secure the cask.
- Make the necessary hydraulic and electrical system hookups.
- Test all systems for proper function, i.e., continuity of hydraulic and electrical circuits.
- Transport and emplace canisters and return the empty cask to a second holding area.
- Remove the cask from the transporter.
- Hoist the empty cask to the surface for reloading.

The following changes to the concepts shown previously would be required:

- Design cask mechanical mountings for speed of operation (while maintaining high reliability), as opposed to the semi-permanent mountings that would be used if the cask were left on the transporter.
- Couple hydraulic hoses by quick-disconnect (snap-together) hose ends or by staple-lock hose fittings in lieu of threaded hose fittings, which are time consuming and subject to failures due to cross threading and thread stripping. (Quick disconnects and staple-lock fittings are not threaded.) Each hose should be bundled or clamped so that it can only be connected to the correct hose.
- Electrical connections should be made by slip-together connectors with positive locking devices which prevent loosening because of vibration. Connectors are readily available which can be connected only the correct way. Threaded connectors are not recommended for the same reasons that threaded hose ends are not recommended.
- All electrical and hydraulic connections should be made at one location, requiring the use of more hose and wire, but reducing the time required to install a cask.

With these changes, the casks can be readily mounted and dismounted from the transporters as shown in the artist concepts of the spent-fuel transporter (Figure 52) and the high-level waste transporter (Figure 53). These illustrations show an overhead bridge crane being used to provide X-Y-Z positioning of the cask. (The sling used to lift the spent-fuel cask will be designed to ensure that the cask has the proper angular orientation.)

THIS DRAWING IS FOR ILLUSTRATION
ONLY. ACTUAL EQUIPMENT MAY VARY
IN APPEARANCE OR DETAIL DESIGN.

Figure 52 SPENT-FUEL CASK, LOADED WITH CANISTERS, BEING
MOUNTED ON TRANSPORTER

THIS DRAWING IS FOR ILLUSTRATION
ONLY. ACTUAL EQUIPMENT MAY VARY
IN APPEARANCE OR DETAIL DESIGN.

Figure 53 HLW/CW CASK BEING INSTALLED ON TRANSPORTER
AFTER LOWERING FROM SURFACE FACILITIES

The following specific activities would be necessary to mount a spent-fuel cask onto the transporter:

- Open trunnion bearings, lower the cask so that trunnions sit in lower bearing halves, and close and secure the bearings.
- Attach lower end of both cask rotation cylinders.
- Connect 16 hydraulic hoses.
- Connect two electrical leads for the fan and other leads for instrumentation. (All leads could be encapsulated in a single connector.)

The following specific activities would be necessary to mount the high-level waste/cladding waste cask:

- Mechanically attach the cask to the 90-degree rotator.
- Connect 12 hydraulic hoses.
- Connect two electrical leads for the fan and other leads for instrumentation. (All the leads could be encapsulated in a single connector.)

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Appendix A
FLANDERS FILTERS, INC.
BULLETIN

Flanders®

In-Line Type G-1 HEPA Filter Housing With Bag-Out Feature

Flanders Filters Inc.
Washington, N.C., Burlingame, Calif.

SEPTEMBER 30, 1976

DESCRIPTION

The Flanders model G-1 filter housing has been designed for the installation of a single HEPA filter in round duct ventilation systems. It is available in four HEPA filter sizes from 8" x 8" x 5 $\frac{7}{8}$ ". Since requirements vary considerably for connections and pipe sizes there is not a specific diameter fitting for the housing. The purchaser may specify whatever pipe size he needs. The base price includes either a rolled sheet metal nipple (for connection to flexible hose with hose clamps) or any standard steel or stainless steel ASME piping up to 12" in length. Connections are not included in the base price, but can be furnished with the housing as an option.

The housing has double ribs around the mouth so that when a PVC bag is installed with the original filter it can be removed directly into the bag. This is a feature which can be used to protect the operator when the filter has trapped hazardous particulates such as dangerous viable organisms, radioactive dust, carcinogens, or other toxic material. The two ribs are used in conjunction with an elastic band around the opening of the bag to fit the bag tight to the mouth of the housing. Two ribs are necessary to the bag-out procedure.

All filters used with the G-1 housing have a channel on one side of the filter's integral frame. The housing has a knife edge which mates to the channel. When the filter is pushed into place the seal is made. The fluid filter-to-frame seal eliminates the possibility of bypass of unfiltered air around the filter which can be caused by a number of things such as the loss of memory (typical in gasket materials), separation of gasket joints, imperfections in the mating flange or misalignment at the interface between gasket and frame.

The housing is constructed from either 14 ga.

cold rolled steel with two coats of primer or of 14 ga. stainless steel. The filter can be easily fitted into place even when the operator must work through the PVC bag because the two holding clamps, when released and swung to the side, act as guides. Once the filter is installed the clamps are returned to the closed position and the wingnuts can be turned through the bag to hold the filter in place. Note that the wingnuts need only be turned finger tight as the purpose of the clamp is not to seal the filter, but to hold it in place regardless of the alignment of the housing.

A 1" wide nylon safety strap is provided with each G-1 housing. This strap fits around the lip of the bag-out port, in between the two ribs and over the mouth of the bag. It supplements the elastic band in the bag and prevents the bag from pulling off the lip in the event that the filter is dropped accidentally during replacement. The inner side of the strap has a sponge neoprene laminate so the strap can be cinched tight around the bag and the metal lip. Without the neoprene laminate the bag can be pulled off. Although the strap is not provided for this purpose it is actually possible to pick up a G-1 1R CC-F CH housing and filter by lifting the bag when the strap is tight around the lip.

In addition to the safety strap a tie-off strap is supplied with each housing. Whereas the safety strap is for use during the replacement operation the tie-off strap is to be used on the bag during the interval between changes to prevent the bag from being drawn into the plenum. It is a 1" wide x 6" long strap that can be tied around the bag at a point near the lip. This makes the bag taught across the port and the slack falls to the outside. When the door is closed the bag is inside the door.

SUGGESTED SPECIFICATIONS

Filter housing shall be Flanders type G-1 and shall be constructed from (select one) (a) 14 gauge type 304 stainless steel or (b) 14 ga. c.r. steel with 2 coats of enamel. The housing shall be cylindrical with a lid type door on the top held in place by four screw down handles. It shall also have a round inlet and outlet (specify here the pipe or nipple size and connections, if required). The filter-to-frame seal shall be effected by means of a knife edge from the filter housing which mates to a fluid-filled channel in the frame of the filter. The fluid shall be a silicone grease that will not dry out and will not run whatever the alignment of the housing.

The bag shall be 0.10" thick PVC with a $\frac{1}{4}$ " diameter elastic cord loop at the mouth.

The manufacturer shall provide a 1" wide nylon safety strap and buckle with neoprene laminate backing on the strap and a 1" wide nylon tie-off strap with buckle.

The HEPA filter shall be nuclear grade, 99.97% efficient by DOP test. (See filter chart for stock number).

CALL-OUTS FOR DRAWING ON PAGE THREE.

Notes

- (A) Available in either standard pipe sizes or in rolled and seam welded nipple connections. Buyer to specify diameter and/or piping requirements as applicable.
- (B) Up to 12" long furnished. Buyer to specify length.
- (C) FLANGE CONNECTIONS are not included in the base price. Buyer to specify by schedule, o.d., i.d., thickness, bolt hole circle diameter, bolt hole size, etc. as required.

SELECTION OF FILTER

The HEPA filters listed in the chart differ because of the components used in their construction. Selection should be based upon the operating conditions anticipated during the service life of the filter. Separatorless nuclear grade and/or industrial grade filters may also be used in these housings provided the same filter frame styles are used.

FILTER SIZE DESIGNATOR	FILTER SIZE	RATED CAPACITY*	X	Y	Z	HOUSING STOCK NO.
BB-D	8" X 8" X 5 ⁷ / ₈ "	70 CFM @ 1" W.G.	17"	19"	13"	G-1 1R BB-D CH or SS
CC-D	12" X 12" X 5 ⁷ / ₈ "	185 CFM @ 1" W.G.	22"	19"	18"	G-1 1R CC-D CH or SS
CC-F	12" X 12" X 11 ¹ / ₂ "	325 CFM @ 1" W.G.	22"	25"	18"	G-1 1R CC-F CH or SS
GG-F	24" X 24" X 11 ¹ / ₂ "	1500 CFM @ 1" W.G.	41"	25"	36"	G-1 1R GG-F CH or SS

** INSERT FILTER SIZE DESIGNATOR FROM CHART ABOVE

PARTIAL LIST OF NUCLEAR GRADE SUPER-FLOW FILTERS (99.97% BY DOP TEST)				
STOCK NO.	MEDIUM	FRAME MATERIAL	FRAME STYLE	SEALANT
7075-NL (**)	GLASS	F.R. PARTICLEBOARD, 3/4" THICK	ROUTED CHANNEL	F.R. POLYURETHANE
7085-NL (**)	GLASS	CHROMIZED STEEL, 14 GA	DOUBLE TURNED CHANNEL	F.R. POLYURETHANE
7035-NL (**)	GLASS	304 STAINLESS STEEL, 14 GA	DOUBLE TURNED CHANNEL	F.R. POLYURETHANE

* SUPER-FLOW FILTERS, ΔP ACROSS FILTER ONLY

The Bag-Out Procedure

The purpose of the bag-out operation is to prevent the operator from coming into contact with any dangerous material that may be held by the filter. When the first filter is in place the PVC bag is looped over both ribs on the outside of the lip of the housing. The tie-off strap is cinched tight around the bag near the mouth so that the slack in the bag does not fall into the plenum. Next, the lid is put on and the handles are turned until the housing is tight.

When the filter is ready for changeout the lid is removed and the operator unbuckles the tie-off strap. Then he wraps the safety strap around the lip and cinches it tight. By working through the transparent PVC bag he loosens the filter clamps and lifts the filter out and into the bag. A stand of some type should be provided on which to rest the filter.

At this point the bag is heat sealed between the filter and the lip of the housing. When the seal is airtight the operator can cut the bag with scissors along the seal making certain that both sides of the cut still remain airtight. The bag stub remains on the lip.

Then the safety strap must be untied and put aside and the bag stub worked back to the first rib (so that it only covers one rib). The elastic cord will keep the bag tight around the lip. A new filter is put into a new bag which is then fitted over both ribs of the lip while the stub is still attached.

The operator should then put the safety strap back on the lip making sure that it cinches the new bag but not the stub. Now the stub can be dropped into the new bag and worked to a position behind the filter. The filter is then fitted into place by mating the channel to the knife edge, and the clamps tightened. The tie-off strap should then be cinched

THE HOUSING CAN BE LIFTED BY THE BAG WHEN THE SAFETY STRAP IS CINCHED TIGHT AROUND THE MOUTH

back around the new bag, making certain that the bag is taught across the opening of the housing. The old stub should be in the slack portion of the bag. The bag slack can then be rolled up and the door can be closed and clamped. The safety strap can remain on the housing.

Optional Accessories

1. Pressure Taps (specify size).
2. Magnehelic Differential Pressure Gage
 - (A) Model N 2002 : 0-2.0" w.g. with .05" minor divisions.
 - (B) Model N 2003 : 0-3.0" w.g. with .10" minor divisions.
3. DOP test ports, three required; DOP In, Upstream Sample and Downstream Sample. Specify connection size.
4. Additional Bags (one is supplied with each new housing).

FOR FILTER SIZE	BAG SIZE
BB-D	17Dx30
CC-D	22Dx40
CC-F	22Dx40
GG-F	41Dx108

5. Bag-Out Shelf (A shelf which clamps to the housing and provides a support for the filter during the heat sealing).

FILTER SIZE	BB-D	CC-D	CC-F	GG-F
Door On Side	S-17	S-22	S-22	S-41
Door On Top	T-17	T-22	T-22	T-41

6. Heat Sealers
7. Second Door on bottom of housing and apparatus for installing additional filter of any type (custom work).
8. Flanges outlet. (A) Sheet Metal
(B) Standard ASME Type
9. Drain for moisture which might condense in the system (custom work).