MASTER

HIGH LEVEL WASTE CANISTER EMPLACEMENT AND RETRIEVAL CONCEPTS STUDY

September 1976

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CARBIDE**

OFFICE OF WASTE ISOLATION
OAK RIDGE, TENNESSEE

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The Office of Waste Isolation
Union Carbide Corporation
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Oak Ridge, Tennessee

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ABSTRACT

This document describes several concepts for the interim (20 to 30 year) storage of canisters containing high level waste, cladding waste, and intermediate level-Tru wastes. It includes requirements, groundrules and assumptions for the entire storage pilot plant. Concepts are generally evaluated and the most promising are selected for additional work. Follow-on recommendations are made.

KEY WORDS

High Level Waste
Intermediate Level Waste
Interim Storage
Emplacement

Retrieval
Canister
Salt

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1.0 INTRODUCTION

Successful long term interim storage of high and intermediate level radioactive waste products requires an efficient waste canister emplacement and retrieval system. This report documents the results of an engineering concept study, performed by Boeing Engineering and Construction (BEC) under contract 86Y-16509V for the Office of Waste Isolation of the Union Carbide Corporation, Nuclear Division. The study determines preliminary system level requirements, performs gross conceptual trade studies and provides recommendations for follow-on effort.

The purpose of this study was to determine the best high and intermediate level waste canister emplacement and retrieval concept based on existing requirements. Horizontal and vertical storage techniques were explored and schematic diagrams of different concepts were generated.

The scope of this study was limited to a Bedded Salt Pilot Plant (BSPP) as the reference facility and considers only emplacement and retrieval of a canister.

2.0 SUMMARY

The primary task of this study was to develop storage concepts for the emplacement of high and intermediate level waste canisters in salt. Both vertical and horizontal concepts were generated utilizing sleeves to aid in retrievability. Concepts without sleeves were to be explored only if they were readily retrievable. Available assumptions were given on the canister, plug, sleeve and overpack. In addition to the available assumptions, study groundrules were established through Boeing/UCC coordination and agreement.

Preliminary systems analysis work was done on the emplacement and retrieval of the canisters to gain an insight into the total problem. System flow charts were developed to describe the basic canister handling operations required at the initial pilot plant. The initial systems planning revealed possible problems in emplacing and retrieving the quantity of canisters in the pilot plant during the given time frame. Canisters would have to be emplaced at a rate of 1.5* per hour to achieve a satisfactory planned pilot plant operation.

Four vertical, two horizontal concepts and a 45° concept were generated under this study. Only concepts with sleeves were developed as the salt may be structurally inadequate. The sleeve adds structural stability to the hole to maintain ready retrievability and also adds a thermal shield which balances the canister and salt maximum temperatures. The prevention of canister corrosion would appear to be enhanced by using a sleeve in the salt environment.

The vertical concepts were found to be superior to the horizontal concepts. The transporter handling system would be simpler, requiring only a hoist to attach to the canister lift pin for emplacement and retrieval operations. Horizontal concepts would require the transporter to provide full-length horizontal canister support after the canister has been rotated from the vertical position as well as a push/pull loading device to emplace and retrieve the canister.

* See paragraph 4.2 for calculation of emplacement rate.

Horizontal concepts considered included:

- 1) A floor coffin concept in which the canister would be emplaced lengthwise into a rectangular box embedded in the salt floor.
- 2) A wall sleeve and plug concept in which the sleeve is embedded in the wall perpendicular to the wall and parallel to the floor, with internal rollers to aid in horizontal canister emplacement and retrieval.

Vertical concepts considered included:

- 1) A sleeve and plug concept in which a sleeve is grouted in a bored hole and sealed with a stepped plug.
- 2) A sleeve and plug concept which incorporates an additional plug storage hole for use when a canister is not stored in the sleeve.
- 3) A sleeve and plug concept in which the plug is electrically actuated to open and close.
- 4) A canister cask concept in which the canister is shielded in a thick steel cask.

Other concepts:

- 1) A wall sleeve and plug concept with its centerline oriented 45° from vertical and located in a lower corner of the storage bay.

Vertical sleeve and plug concepts are recommended for follow-on development and analysis work. A sleeve with a plug that is mechanically inserted and withdrawn looks most promising at this time. The other vertical concepts have features that may be desirable in reducing the transporter time-line and shielding requirements.

The following activities are recommended to be performed as follow-on to this study. The recommended activities will provide the basis for configuring the canister shielding, handling, and emplacement hardware to meet the site technical requirements and operating goals.

- 1) Perform a thermal and radiation analysis of the canister from the time the shipping cask is opened above ground through loading on site, emplacement, and storage. These data will support design of the hardware and allow optimization of materials, spacing and component configuration. A definition of the waste radiation source terms and thermal load would be generated as part of this activity and would be more complete and detailed than those used in this study.

- 2) Perform a time-line analysis of the handling and emplacement operation from the time a cask arrives at the Repository to completion of emplacement. This analysis will provide the basis for determining quantities of handling equipment, personnel, size of working areas and design requirements for each component in the system to meet the planned waste disposal rate for the Repository.
- 3) Each of the seven concepts has a slight impact on the total volume of mined space. Essentially there is a sharp difference between vertical and horizontal emplacement. This is another area for a follow-on study.

3.0 REQUIREMENTS

Develop concepts for emplacement and retrieval of high-level radioactive waste canisters in bedded salt. Concepts for both vertical and horizontal emplacement with sleeves are to be explored. Canisters are to be stored with a protective shielding plug. Determine the sensitivity of these concepts to variations in canister length, diameter, thermal power, material, and emplacement residence time.

Concepts explored will be for a bedded salt pilot plant with potential growth to a federal repository.

3.1 OWI Requirements

Canister and sleeve requirement used in this study were obtained from the OWI statement of work.

3.1.1 Canister Configuration and Parameters

The canister configuration and parameters used in this study are:

- 1) Canister overall length is ten feet including the "standard lifting pin".
- 2) Canister to be fabricated from a stainless steel pipe with a 12.75 inch outside diameter and a 12.0 inch inside diameter.
- 3) Canister to have hemispherical ends with the lower end inverted.
- 4) Canister weight of about 8,000 pounds.
- 5) Level, or depth of waste, is a nominal eight feet.
- 6) Thermal power is five kw homogenously distributed.
- 7) Retrievable lifetime of 20 to 30 years.
- 8) Canister shall not be in contact with either salt or storage sleeve.
- 9) Canister gamma radiation source strength is 1×10^6 R/HR at three feet from its surface.
- 10) Five percent to one hundred percent of the canisters will have been overcanned prior to emplacement.
- 11) The canister lifting pin configuration as shown in the document entitled "Conceptual Facility Design Description of a Bedded Salt Pilot Plant", page 11-7, dated May 31, 1974.
- 12) Canister to be fabricated from 304L stainless steel.
- 13) Maximum allowable surface temperature of the canister is 700°F.

3.1.2 Overcan Configuration and Parameters

The overcan configuration and parameters used in this study are:

- 1) Overcan to be fabricated from 14 inch schedule 40 pipe.
- 2) Overcan overall length to be 11 feet including the "standard lift pin".
- 3) The overcan lifting pin configuration as shown in the document entitled "Conceptual Facility Design Description of a Bedded Salt Pilot Plant", page 11-7, dated May 31, 1974.
- 4) Overcan to be fabricated from 304L stainless steel.

3.1.3 Sleeve Configuration and Parameters

- 1) Bottom of sleeve set at 20 feet below storage level floor grade.
- 2) Sleeve to be fabricated from schedule 40 pipe.
- 3) Sleeve to be installed in the salt to within 1° plumb.
- 4) Sleeve maximum allowable bow is 1-1/2 inches.
- 5) Plug for sleeve to be seven feet long by 16 to 18 inches diameter and 2,000 to 7,000 pounds.
- 6) Sleeve to be fabricated from carbon or stainless steel.

3.2 Study Groundrules/Assumptions

The following groundrules and assumptions were obtained from coordination with OWI and the referenced documents:

- 1) Canisters may be stored either horizontally or vertically.
- 2) "Emplacement" begins with the canister at the bottom of the mine shaft in a position accessible to the transporter.
- 3) "Retrieval" terminates with canister placement in the mine shaft elevator.
- 4) Maximum allowable radiation in the transporter cab is .25 mrem/hr.
- 5) Temperature, pressure, radiation monitors will be selectively installed in the canister sleeve.
- 6) Maximum allowable salt surface radiation in the storage rooms to be .25 mrem/hr.
- 7) Maximum allowable salt temperature to be one percent less than 250°C, 25% less than 200°C.
- 8) Allowable salt bearing stress is 3,000 psi.
- 9) Below grade access door openings are 30 feet by 18 feet.

- 10) Placement/retrieval operations, including plug removal and replacement are to be accomplished remotely.
- 11) Canister "overcan" dimensions are 11 feet long, including standard lifting pin and is made from 14 inch schedule 40 pipe.
- 12) Plant/facility availability is 250 days/year.
- 13) Plant/facility will be available 24 hours/day.
- 14) Facility working efficiency will be 70%.
- 15) Canisters will have been cleaned, above grade, to remove surface contaminants prior to emplacement.
- 16) Personnel radiation dosages are limited to .5 rem/year.
- 17) Emplacement/retrieval operations may be conducted simultaneously, but not in the same room.
- 18) The average one way distance to be traveled by the canister transporter is 2,000 feet.
- 19) Canisters are to be emplaced and retrieved at an average rate of 6,321 cans/year (total).
- 20) Five percent of the canisters may be removed per year for inspections.
- 21) Canister transporter shall have canister emergency cooling provisions.
- 22) Emplacement/retrieval operations to be conducted within the pilot plant with considerations given to the federal repository.
- 23) Storage sleeve and plug concepts developed per high level waste canister and overcan criteria will satisfy requirements of and be used in the cladding and IL-Tru waste storage areas.
- 24) High level waste storage bay is 18 feet wide, 18 feet high by 560 feet long.
- 25) High level waste storage sleeves (32) to be placed in line on 17 foot centers in storage bay.
- 26) IL and cladding waste storage bay is 18 feet high and 18 to 38 feet wide.
- 27) IL and cladding waste storage sleeves to be placed on six foot centers.
- 28) A five year pilot plant operation will store:
 - a) 1,000 canisters high level waste utilizing 34 acres.
 - b) 3,100 canisters cladding waste utilizing four acres.
 - c) 26,000 canisters IL-Tru waste utilizing 33 acres.

30,100 Total (+5%/Year to be Retrieved = 31,605)

29) Canister plug will remain in storage chamber.

3.3 Facility Storage Description

The repository will utilize a multi-acre site with a waste receiving and handling facility. A bored shaft will be provided for transferring the waste from the above ground receiving area to the emplacement receiving area. A transporter with shielding and remote handling capabilities will transport the waste canister to the emplacement site.

3.3.1 Pilot Plant/Federal Repository

The pilot plant and federal repository will provide areas of storage for high level waste, cladding waste and intermediate level waste. An idealized plan for a potential pilot plant and federal repository is shown in Figure 3-1.

Waste types, waste quantities, acres required and years of operation for waste storage are shown in the following matrix:

Waste Type	Initial 5-Years		Growth to 18 Years	
	Pilot Plant	Acres	Federal Repository	Acres
HLW	1,000 Canisters	34	50,000 Canisters	1,580
Cladding	3,100 Canisters	4	84,000 Canisters	60
Intermediate Level	26,000 Canisters	33	364,000 Canisters	130

3.4 Storage Bay Description

Storage bays, for waste canister emplacement, are cavities mined from bedded salt deposits. Cavities are separated by a center pillar connected by a corridor and are 18 feet high. An array of waste canister storage sleeves is embedded in each corridor.

3.4.1 Storage Bay Site

Cavity size and embedment array spacing is shown in Figure 3-2.

NOTE: THE ACTUAL PLAN OF THE STORAGE AREA MAY CHANGE. THIS SCHEMATIC IS INTENDED ONLY TO SHOW THE AREAL RELATIONSHIPS OF THE DIFFERENT WASTE STORAGE AREAS

FIGURE 3-1
FEDERAL REPOSITORY/PILOT PLANT PLAN

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HIGH LEVEL WASTE

CLADDING AND INTERMEDIATE LEVEL WASTE

EMBEDDMENT PLAN HIGH LEVEL, CLADDING AND INTERMEDIATE LEVEL WASTE

FIGURE 3-2

4.0 FACILITY SYSTEM FLOW DESCRIPTION

It is necessary to determine the order and position that the emplacement and retrieval functions occupy, in the waste storage facility, to efficiently determine the total requirements, both systematically and operationally, imposed on the canister and the canister emplacement/retrieval system.

The first level of ordering is the generation of the top level, or Tier 1, block flow diagram. This is a basic assessment of the overall waste cycle and the interfaces which are involved. The Tier 1 is further described in paragraph 4.1.

The next level of assessment is to determine what functions and operations the canister must undergo during processing. This flow, a Tier 2, traces the operational path that a waste canister would take to reach final emplacement and retrieval operations. This flow shows the canister interface points and provides a convenient place to levy system level functional requirements. This expanded detail provides for operational evolution of the functions that the canister must undergo during emplacement/retrieval and shows continuity of operations to ensure that all critical tasks have been accounted for.

It is recognized that the scope of this study is limited to only emplacement/retrieval techniques, however, it was felt that the Tier 2 flows would show system level assessments which affect the canister itself and which might be pertinent to the study.

4.1 Tier 1 Block Flow Diagram

The overall waste cycle flow is shown on Figure 4-1. This figure depicts the waste product generator, e.g., fuel reprocessing plants; waste transportation, and the waste repository.

Block 1.0

It is anticipated that the bulk of the waste will be produced in the LWR fuel cycle with a majority being generated by fuel recycling centers. These plants (for high level wastes) would solidify, either by glassification or calcining the liquid by-products of the reprocessing cycle. Either of the solidifications could be carried out within the storage canister. After the waste is placed in the canister, by either of the above methods, then a cap

TIER 1
HIGH LEVEL WASTE GENERATION AND STORAGE
FLOW

FIGURE 4-1

or plug is welded on the canister. This cap would have the standard lifting pin as an integral part. The sealed container would then be placed in storage awaiting shipment.

Block 2.0

A transporter, either road or rail, would arrive at the reprocessing plant to pick up waste canisters and transport them to the repository. In the case of LWR fuel reprocessing plants, the transporters will undoubtedly belong to the reprocessing plant, although internal cask configuration alterations would undoubtedly be required to accommodate the canisters. The canisters would be emplaced in the transporter cask and the cask sealed for transport. The transporter would then be dispatched to the waste storage facility.

Block 3.0

The third block of the Tier 1 is the waste storage facility. All operations which culminate in the storage of waste canisters are in this block. This block encompasses the transporter arrival and receiving, canister unloading, above grade canister processing (including temporary storage), mine shaft operations, below grade transporting, emplacement and retrieval of the canister. Only this block is carried forth in the remainder of this study.

Although only Block 3 of the Tier 1 will be carried further in the analysis, there are some important areas of concern, from Blocks 1 and 2, which must be noted:

- 1) All waste producers must use one canister design suitable to or prescribed by the repository.
- 2) Serious interface problems may exist between transporter casks and the reprocessing and storage facilities.
- 3) A "delivery plan" must be developed to prevent simultaneous shipment/arrival at the storage plant; i.e., this becomes a costly tie-up of hardware awaiting unloading.
- 4) Facilities for both road and rail transporters should be provided.
- 5) Canister closure welding must be under the strictest Quality Control.

4.2 Tier 2 Block Flow Diagram

The Tier 2 block flow diagram shows a "reference" waste repository. It could be applicable to any of the geologic formations and either pilot plant or full scale repository operations. Its primary purpose is to provide a continuous path for functional requirements and criteria for the canister.

Since there are 35 blocks on the Tier 2 flow, no attempt will be made to describe each one. Figure 4-2 does, however, quite readily depict the canister scenario.

There are certain aspects of the Tier 2 which should be brought out. This is the point where system level requirements are levied. It is also the point where facility system timelines and "critical paths" are established. The systems operational analysis should be conducted at this point. The system throughput has been established in the groundrules for a five year operating life and is a major parameter in the canister handling hardware design.

For example:

There are 30,100 canisters (total) to be emplaced and 1,505 (5%) to be retrieved.

There are only 250 facility on-line days per year.

There is only a 70% operational efficiency.

Plant availability is 24 hours per day.

Therefore:

$$(.7)(24)(250) = \text{Real Hours/Year} = 4,200 \text{ Hours}$$

and

$$(31,605)/5 \text{ Years} = 6,321 \text{ Canisters/Year}$$

and

$$(6,321)/(4,200) = 1.51 \text{ Canisters/Hour}^*$$

- * This is the case if the plant starts at the maximum emplacement rate at day one and finishes at the same rate at the end of the five year period. This is an unlikely condition. If the plant's first year of operation is used to obtain the maximum rate, in a linear fashion, the emplacement/retrieval rate becomes about 1.7 canisters/hour.

This hourly throughput must be maintained for successful plant operation. It also dictates the rate at which canisters must arrive from the waste producers. This number, in conjunction with the number of canisters per transporter cask, will determine the quantities of plant hardware items necessary to unload and process canisters. There are, of course, other parameters which must be considered and which have an influence in the plant design; cost, maintainability, state-of-the-art, and availability.

5.0 CONCEPTS

The following concepts describe storage vaults for the storage of waste canisters to be stored in the Bedded Salt Rock Formations of the initial Pilot Plant and future Federal Repository Plant described in Section 3.0. The vault concepts are based on the storage of high level waste canisters with a 17 foot center-to-center spacing and are also to be utilized for storage of both cladding and intermediate level transuranic waste canisters on six foot center-to-center spacings.

Only vertical and horizontal concepts with sleeves are presented. Concepts that do not use sleeves would allow direct salt-canister contact thus allowing the possibility of canister corrosion directly. A sleeve offers an additional protective barrier while providing structural stability to the salt bed storage vault.

All concepts have standardized on the following parameters: schedule 40 pipe, sleeve, seven foot plug length, either canister or overcan storage and standard lifting pin.

5.1 Vertical Concepts

5.1.1 Sleeve and Plug (Figure 5-1)

The sleeves are made from carbon steel. The four foot long upper sleeve is 24 inch schedule 40 pipe while the lower 16 foot sleeve is 20 inch schedule 40 pipe. Upper and lower guides are inserted through cutout slots in the lower sleeve and plug welded in place from the outside to provide positive centering of an overcan or canister within the sleeve at all times.

The stepped plug is made from a steel casing and concrete filler. The 22.0 inch and 18.0 inch diameters provides clearance for plug removal and installation. The step in the plug will control radiation leakage to the storage bay floor surface. Salt fill material could be used in place of concrete if an economical dense packing method for the salt can be found, and if corrosion control proved not to be a problem.

The installation of the sleeve requires that a hole 28.0 inches in diameter and 20 feet deep be bored in the salt bed rock floor. Due to the 18 foot storage bay ceiling height, the lower sleeve (16 foot) must be partially inserted into the hole and the upper sleeve (4 foot) field welded in place.

Figure 5-1. Sleeve and Plug

After full insertion of the assembly, the centerline of the lower sleeve is to be aligned to within 1° of vertical and shimmed in place. Grout will be filled around the sleeves to maintain the alignment.

The transporter must interface with both the sleeve storage plug and canister or canister overcan: Two separate hoists will be used on the transporter. Each hoist will be capable of interfacing with the standard lift pin design. The transporter would align with the plug, and the hoist attached. The plug would be removed and translated out of the way. The canister cask would be aligned to the sleeve and the canister emplaced. The plug would be re-installed.

5.1.2 Sleeve and Plug with Plug Storage (Figure 5-2)

This concept is exactly the same as the sleeve and plug concept described in Section 5.1.1 except that an additional plug storage hole will be located approximately six feet from the centerline of the storage sleeve. The plug storage hole will be seven feet deep and made from the same materials as the upper and lower sleeves described in Section 5.1.1. The installation of the plug storage sleeve requires that an oversize hole be bored and the plug sleeve be firmly set in grout.

The plug will remain in the storage hole unless an overcan or canister is stored in the sleeve. This minimizes the number of trips required of the transporter during either emplacement or retrieval activities. A transporter would receive an overcan or canister from the elevator and transport it to the storage sleeve and insert it. Then the plug would be lifted into place with the same hoist to complete the emplacement operation. Retrieval operations could be just the reverse procedure of emplacement; i.e., the plug would be lifted and stored then the overcan or canister retrieved. This system would require only one trip from the elevator to complete an emplacement or retrieval operation as well as provide out of the way plug storage.

NOTE

This technique of storing the plug somewhere other than the canister storage sleeve obviously has many variations which could be analyzed. It was felt, however, that this concept best exemplified the method of separate plug storage and adequately characterized all of the other concepts. For this reason, no others were presented.

Figure 5-2. Sleeve and Plug With Plug Storage

5.1.3 Sleeve with Activated Plug (Figure 5-3)

The lower sleeve of this concept is the same as the lower sleeve described in Section 5.1.1. The upper sleeve is a 24 inch by 48 inch by seven foot deep steel box. After the lower sleeve has been aligned to vertical within 1° and set in grout, the upper box is installed and field welded to the lower sleeve.

The plug is 24 inch by 24 inch by seven foot long and made from concrete contained with 0.5 inch thick stainless steel. The plug is opened and closed by synchronized linear actuators (2) which are electrically controlled from the transporter power supply. This system allows the plug to be open and closed remotely from the transporter or other location without the usage of a hoist.

5.1.4 Sleeve and Plug with Canister Cask (Figure 5-4)

A sealed cask around the canister reduces the radiation dose rate when handling the wastes. The cask reduces transporter shielding requirements. It also provides another leak proof barrier for long term storage.

The cask is centered in the lower sleeve which is made from 24 inch schedule 40 stainless steel pipe.* The lower sleeve (16 foot) must be partially inserted into a 32 inch diameter hole in the salt in order that the upper sleeve made from 30 inch schedule 30 pipe may be field welded to the lower sleeve. The lower sleeve centerline is aligned to within 1° of vertical and filled all around with grout to maintain its position.

Each cask could be handled by the transporter using the standard lift pin. The plug would require removal and replacement using either the existing canister hoist or an auxiliary hoist.

* The sleeve of this concept is considerably larger than that of the other concepts. This is due to the "canister cask" in which the canister has been permanently placed. The canister cask has a wall thickness of 2-1/2 inches which provides a degree of shielding.

Figure 5-3. Sleeve With Activated Plug

Figure 5-4. Sleeve and Plug With Canister Cask

5.2 Horizontal Concepts

5.2.1 Floor Coffin (Figure 5-5)

The floor coffin concept incorporates a concrete box lined with carbon steel and a concrete hatch to provide radiation shielding. The hatch is seven feet thick and weighs approximately 45,000 pounds. Saddle brackets in the box serve to restrain either an overcan or a canister in the center of the box.

Installation of the coffin requires that a hole 9.5 feet deep, 3.5 feet wide and 15.0 feet long be excavated in the salt. After installation of this coffin, salt back fill or grout will be packed around its periphery.

Overcan or canister emplacement and structural operations require the hatch be removed and replaced by the transporter. The canister hoist would be inadequate for the 45,000 pound hatch. Transporter provisions to lift the overcan or canister horizontally would also be required.

5.2.2 Wall Sleeve and Plug (Figure 5-6)

The plug, upper sleeve and lower sleeve of this concept are the same as those described in Section 5.1.1. Rollers are placed on the lower side to aid in overcan or canister insertion and withdrawal. The retaining fins are inserted through slots in the lower sleeve and plug welded in place. The fins keep the overpack or canister on the rollers.

The installation of the sleeve requires that a horizontal hole 28.0 inches in diameter and 20 feet long be bored in the salt wall. Due to the 18 foot storage bay width, the "lower" sleeve (16 foot) must be partially inserted into the hole and the "upper" sleeve (4 foot) field welded to the lower sleeve. After full insertion of the assembly, grout fill will be pumped around the sleeve to maintain its position and provide a protective barrier between the salt and steel sleeve.

The transporter must be designed to handle both the plug and canister in a horizontal position.

Figure 5-5. Floor Coffin

Figure 5-6. Wall Sleeve and Plug

5.3 Miscellaneous Concept

5.3.1 Wall Sleeve and Plug at Angle (Figure 5-7)

This concept is exactly the same as the wall sleeve and plug concept described in Section 5.2.2 except that the sleeve centerline is located on the wall near the floor and at an angle of 45° to vertical. This arrangement allows the lower sleeve and upper sleeve to be installed into the hole in one piece (20 feet long) due to storage bay diagonal length of approximately 25 feet. Installation and removal of the plug and canister will require transporter guidance during the lifting operation.

Figure 5-7. Wall Sleeve and Plug at Angle

6.0 CONCEPT EVALUATION

The selection of the "optimum" waste storage concept, at this depth of analysis can only be founded on basic engineering assessments of certain general parameters which affect the overall storage performance and the ease of emplacement and retrievability.

The following "optimization" will be used to evaluate storage concepts for both the horizontal and vertical methods, including the 45° technique. They are, however, not necessarily in order of importance nor have the relative importance (i.e., weighting) of the parameters been established.

1) Matrix Material Stress

The interim storage period, for the waste canisters, has been defined as 20 to 30 years. During this period the basic geologic media will become "hot" and, in some instances be subject to plastic creep or flow. This is a known phenomenon in salt mines and may be accelerated with elevated temperatures and downward vertical loads. The contributing factors, for plastic flow, are stress, time and temperature. The stress level is determined by the combined weight of the sleeve, canister/overcan, and plug and the normal cross-sectional area presented to the matrix material. It should be pointed out that there is a certain amount of "piling effect" which is present: this is the skin friction present between the sleeve and the matrix and is a shearing force. This force is dependent upon many parameters which will permit only a general assessment.

2) Heat Load

The heat generative capacity of the high level waste storage canister has been specified as five kilo-watts. This is a homogeneous heat load (i.e., constant power per length of cylinder). There have been analyses performed on irradiated spent fuel assemblies which shows that in a vertical position they tend to get very hot in a short time and that temperature limits of materials may be exceeded. It is expected that the vertical cylinder will become hotter near the top than at the bottom and this may cause local hot spots in the sleeve/canister. See Appendix B for a basic thermal analysis and conclusions.

3) Radiation and Shielding

Critical importance is attached to the salt surface (or other matrix material) radiation levels for personnel protection. The waste canister must be emplaced at a sufficient depth, below grade of the mine floor, to reduce the radiation levels to acceptable dose levels. The plug/sleeve interface must be designed such that neutron streaming or "shine" into the mine tunnel is eliminated. This may be accomplished by close fitting construction which utilizes a stepped plug/sleeve or by over packing with a sufficient layer of attenuating material. In all cases a Poisoning material, such as Boron 10 in the form of B_4C powder, or cadmium, should be added to the grouting or construction materials to control secondary emissions due to neutron bombardment. See Appendix C for additional comments on radiation and shielding.

4) Sleeve Installation (Costs, Complexity)

Each method for storage will require some excavation by either horizontal or vertical boring or trenching. The ease and speed in which this can be accomplished is of concern because of the number of canisters to be ultimately emplaced. It is desirable that the amount of material to be removed be maintained at a minimum since it must be disposed of in some manner. The complexity of actually installing the sleeve or vault must be minimized and should use generally accepted techniques (i.e., no experimental or state-of-the-art methods). The one degree verticality restriction does not appear to present any special problems; in terms of technical requirement this means that the top of the sleeve may be located within a four and three sixteenths radius circle when referenced to the bottom of the sleeve. It is suggested that this tolerance be revised to one inch instead of one degree.

5) Materials

The materials used in construction must be considered for their ability to resist radiation and thermal effects over a projected period of time. Generally, stainless steels are the best economical materials for construction in respect to corrosion. It has been indicated, in the literature, however, that in environments which contain salt that stainless steels are subject to severe stress corrosion cracking. Carbon steel, which has less resistance to corrosion does not exhibit

the stress corrosion cracking to the extent of stainless steels but does corrode at a more uniform and predictable rate which is much higher than stainless steel. Other materials should be considered for use as the liner material. One candidate is Monel Alloy 400 which has excellent salt corrosion properties and has a useful upper temperature limit of 1000°F in an oxidizing atmosphere. Another candidate is Inconel Alloy 600 which is satisfactory in severely corrosive environments and has a working temperature upper limit at about 2000°F. Hasteloy C is another example of an acceptable material. One technique might be to plasma arc spray a corrosion resistant material to the outside of the liner. For the purposes of this study, however, it will be assumed that the sleeve liner is carbon steel (since all concepts use the same material, this is an acceptable way of ranking the sleeve concepts). The sleeve liner must be firmly positioned and located within the matrix. There are several basic methods and materials which could be used. Ordinary silica sand could be poured around the liner to fill in the annular space. Sand has a low coefficient of thermal conductivity and would tend to keep the heat in the liner/canister. This would keep the outlying salt at a lower temperature. Crushed salt, the material removed from the boring could be backfilled around the liner much the same as sand. Both sand and loose salt, however, are not stable. The possibility that the liner could migrate to the side of the bore hole exists. Another material is high temperature cement with silica flour replacing the normal aggregate of concrete. This becomes a high temperature grouting material which when set will withstand 700°F and will develop about 15,000 psi ultimate strength. Concrete spalling will undoubtedly occur, however, the sleeve liner will prevent any material from encroaching on the waste storage canister. The thermal conductivity of this grout is twice as high as sand but six times less than solid salt. It would tend to keep the salt matrix temperature down. Poisoning material is added to a grout slurry more easily than a dry mixture of sand or crushed salt. This is the technique of anchoring the sleeve that will be evaluated against, although by no means should sand or crushed salt be discarded as viable alternatives at this time.

6) Canister Emplacement and Retrieval (Including Overcan)

One of the primary considerations of this study was canister emplacement and retrievability. All of the concepts meet this goal, however, the degree of emplaceability/retrievability is different. The vertically stored techniques straight forward requiring no translation of the canister. The horizontal concepts require that the canister be translated from the vertical to horizontal. It also requires some sort of guide and support system in the cask and a bridging device to span the plug area of the sleeve. Additionally, it must have a push/pull mechanism for emplacing the canister and removing it later. The analysis example in Section 4.2 showed that canisters must be emplaced at a rate of 1.5 per hour to meet the canister emplacement (with 5% retrieval) throughput for a 5-yr. pilot plant life. Very little time can be allowed for the actual emplacement (or retrieval) since during a single canister emplacement time allowances must be made for canister removal from the elevator, transportation below grade, transporter/sleeve alignment, plug removal, canister emplacement; these functions must be accomplished in a timely manner which will allow the throughput rate to be met.

7) Sealing

Sealing of the sleeve and plug is an area that should receive consideration in the final design although at present it has not been deemed necessary. The following scenario could exist in a high level waste canister storage sleeve, however, the likelihood or probability of its occurring has not been established. A canister is emplaced in a sleeve and in which the sleeve and/or canister are not clean. After 20 to 30 years of hard radiation some particles may become activated. These particles could then migrate to the tunnel area if there were not a mechanical barrier between plug and sleeve. Rubber or polymer type seals would be ideal because of their deformation capabilities, however, they are susceptible to radiation damage. Metallic seals would probably be the best choice. The seal could be either a closed tube type or an open "C" type. It will be assumed that a seal is used in the concept in the evaluation.

6.1 Vertical Concepts

All of the vertical concepts explored utilized the same basic configuration: an oversized bored hole in the salt floor into which a sleeve liner is placed. A grouting material is used to keep the liner in place.

6.1.1 Sleeve and Plug (Figure 5-1)

1) Matrix Material Stress

This concept provides only a small cross-sectional area to the bearing matrix. This loaded area is determined from the diameter of the sleeve liner and is 314 square inches. The vertical load is the combined weights of the plug, sleeve liner, and canister. The canister is 8000 lbs, the plug is 7000 lbs and the sleeve liner is 2700 lbs for a total weight of 17,700 lbs. The matrix stress, then, is 54 psi.

2) Heat Load

This concept stores the waste canister vertically which means that the upper end of the sleeve and canister will become hotter than the lower sections. It would be desirable that the heat be removed uniformly over the length of the sleeve liner or have some intermediate heat flux trap (i.e. another wall inside the liner between liner and canister). This will be given a rating of 4 on a scale of 1 to 10.

3) Radiation and Shielding

This concept is well shielded radially at the canister level. The 20 foot storage depth provides more than the required amount of gamma radiation shielding. The silica flour concrete, with its water of hydration, is an effective neutron moderator and attenuator. The poisoning material added to the concrete grout provides an additional amount of protection. The depth of the plug (7 feet) provides adequate axial shielding for both gamma and neutron radiation. The step in the plug/sleeve provides a barrier to neutron streaming. This concept is rated at 8 on a scale of 1 to 10.

4) Sleeve Installation (Costs, Complexity)

This concept requires only a minimum amount of salt removal. The excavation technique is by simple drilling or boring. It requires only one drilling set up and is a constant diameter bore. Since there is a 24 inch diameter pipe as part of the sleeve then the drill bit required will need to be about 30 inches in diameter. The amount of material removed would be 3.6 cubic yards. The installation of the sleeve liner would be a two step operation: the lower 13 sleeve would be emplaced in the bored hole and located such that the upper surface is exposed above the floor. The upper sleeve is placed on top and joined by welding. The assembly is fully lowered into the hole then. The unit is plumbed, to within one degree of vertical, and grouted in place. Based on the minimum material removal and the apparent ease of installation this concept rates a 9 on the scale from 1 to 10.

5) Materials

All concepts were defined to use carbon steel pipe as the sleeve liner: the amount of steel will be reduced to pounds in all concepts, and compared. This concept uses 16 feet of 20" schedule 40 pipe which is 2016 pounds. There are 4 feet of 24 inch pipe which is 700 pounds. There are 4 feet of 22 inch pipe which is 468 pounds. There are 3 feet of 18 inch diameter pipe which is 252 pounds. If 2 percent by weight is added for miscellaneous material the total weight of steel becomes 3504 pounds.

The amount of concrete with poison is maintained at a minimum in this concept. The annular space around the sleeve liner will require about 2 yards to fill and the plug will require only 3/4 of a yard of concrete. The total material then is 2-3/4 yards. The concept will be given a 10.

6) Canister Emplacement and Retrieval (Including Overcan)

This concept uses a simple vertical hoist for moving the canister into and later out of the storage cell. The emplacement is a straight-forward operation: align the transporter over the plug;

remove the plug with the plug hoist; align canister transporter cask and interface with the sleeve; lower the canister into the storage cell; disconnect and retract hoist; re-align plug; lower plug into sleeve; disconnect plug hoist. Retrieval is the reverse of these steps. The plug is manufactured such that there is a reasonably large clearance gap between the plug and sleeve. Only the guides inside the sleeve might touch the canister but there would be sufficient clearance to allow easy retrieval. The only improvement might be the use of a sleeve which would eliminate the extra transporter functions such as plug removal. This method rates a nine (9).

7) Sealing

Although sealing has as yet not been determined to be necessary, the existence of a sealing requirement is a possibility. The step in the plug provides an excellent position for an O-ring gland. This would be machined into the sleeve and an O-ring placed into the groove. This O-ring could be of many different configurations, however, it should plastically yield enough to allow the plug to rest on the sleeve interface. The seating pressure is small but sufficient - 110 pounds per inch (P.P.I.). The simplicity of sealing this concept rates it a 10.

6.1.2 Sleeve and Plug with Plug Storage (Figure 5-2)

1) Matrix Material Stress

The basic storage cell sleeve, in this concept, is identical to that of Figure 5-1, Sleeve and Plug; 6.1.1. That concept showed a stress level of 54 psi: this concept is the same.

2) Heat Load

This concept is identical to that presented in 6.1.1. It will have the same characteristics as presented there and should receive the same rating: 4 out of 10.

3) Radiation and Shielding

The basic storage cell is virtually identical to the concept described in paragraph 6.1.1. The plug storage pit may,

however, be placed too close to the storage sleeve. It is possible that a straight line distance from the high level waste could be less than 7 feet which means that some radiation streaming could occur. This would be accentuated if for some reason the salt was soft (i.e. the density was less than expected) between the sleeve and plug storage pit (the amount of attenuation would be less). This concept will be graded as a six (6).

4) Sleeve Installation (Costs, Complexity)

The storage cell is identical to the first concept. It requires only 3.6 yards of salt removal. The storage pit, however, requires another 1.3 yards of salt to be removed. This total is 4.9 or a 36% increase in the amount of salt to be disposed of above grade. The basic sleeve installation is the same as concept 1 but the plug pit must now be aligned and grouted into the salt. This concept requires about 30 percent more effort than the concept in 6.1.1 and rates a six (6).

5) Materials

This concept uses the same basic sleeve storage cell of 6.1.1. This was 3504 pounds of steel. The storage pit, however, requires another 1100 pounds for a 31% increase in steel. The amount of poisoned concrete grout, for the is the same at 2 yards: the storage pit will require another 1/2 yard, or 2-1/2 yards total. This is a 25% increase in concrete. Pro-rating the cost of concrete per pound to the cost of steel the amount of materials required is about 30% more than concept 1 in 6.1.1. This concept therefore rates a seven (7).

6) Canister Emplacement and Retrieval (Including Overcan)

Emplacement and retrieval is the same as concept 1 in 6.1.1 except that additional transporter functions are required. The plug must be set down in its storage pit and released. This extra function will require about 20% more time (10% more when being returned to the sleeve). This concept, then, rates a 7 when compared to concept 1 of 6.1.1.

7) Sealing

Sealing of the plug to sleeve is identical to concept 1 and has the same rating 10.

6.1.3 Sleeve with Activated Plug (Figure 5-3)1) Matrix Material Stress

This concept provides only a small cross-section area to the bearing matrix, much the same as the first concept discussed. The cross-section area is the same at 314 square inches. The canister weight is 8000 pounds, the liner weight is 2515 pounds, and the plug weight is 7000 pounds for a total weight of 17,515 pounds. The matrix stress is then 56 psi.

2) Heat Load

The heat transfer and thermal characteristics of this concept are approximately the same as that presented in 6.1.1 (concept 1). It should receive the same rating: 4 out of 10.

3) Radiation and Shielding

This concept is the same as the first and second concepts evaluated at the level of the canister. It is well shielded radially and axially, however, radiation streaming will be a problem because of the vacant area in the plug cavity. About seven feet of material, the density of salt, is required and in this case there is only about 2 to 3 feet of intervening attenuating material. This concept will receive only a score of 3 when compared to concept 1.

4) Sleeve Installation (Costs, Complexity)

This concept requires removal of a considerable amount of salt matrix. Both boring and trenching techniques will be required. A 30 inch diameter drilling will be required for 13 feet and a hole, 86" x 28" x 52", will need to be dug out. This is 5.1 yards of salt to be mined and disposed of above grade. This is 42% more than concept 1 of paragraph 6.1.1.

Installation of the sleeve and box is more complex than the other concepts. The lower sleeve must be lowered into the bored hole, aligned and grouted into place. The box would then be emplaced, aligned to the lower sleeve and welded. The upper box structure would then be grouted into the salt. The plug would then be set into place and precisely aligned with the actuators. The actuators themselves will require precision installation and synchronization. This concept is judged to require at least 50% more effort for installation than the first concept evaluated. The rating is 4 out of 10.

5) Materials

This concept uses 13 feet of 20 inch pipe which is 1638 pounds. The plug is 2 ft. x 2 ft. x 7 ft. x 1/2 inch plate which is 1340 pounds. The box structure is 7 ft. x 7 ft. x 2 ft. x 1/2 inch and includes a 7 ft. x 2 ft. x 1/2 inch reaction plate: this is 2200 pounds. This is 5178 pounds or a 48% increase in the amount of steel required. The amount of grout required is 2.0 yards which is the same as the first concept. This concept rates a 5 when compared to concept 1.

6) Canister Emplacement and Retrieval (Including Overcan)

Emplacement in this concept is easiest of all. The transporter aligns over the plug and the plug remotely actuated and moved out of the way. The canister would be lowered into the sleeve and released. The hoisting mechanism would be returned inside the cask and the plug returned to its position. This makes the transporter plug winch and controls unnecessary, which would reduce the transporter cost. This technique rates a 10.

7) Sealing

Sealing of this concept is much more difficult than the other concepts because of the sliding plug. The seal would tend to be destroyed as the plug moves over it. This concept rates a 3 in this category.

6.1.4 Sleeve and Plug with Canister Cask (Figure 5-4)

1) Matrix Material Stress

This concept is almost identical to the first concept evaluated in 6.1.1. The difference is in the canister cask which will require that the sleeve be larger. The sleeve liner is 24 inch pipe which has a cross sectional area of 452 square inches. There are 16 feet of 24 inch pipe which weighs 2800 pounds. There are 4 feet of 30 inch pipe which weighs 800 pounds. There are 3 feet of 22 inch pipe and 4 feet of 28 inch pipe (part of the plug) which have a combined weight of 1100 pounds. The grout, or concrete, in the plug weighs about 7000 pounds. The canister weighs 8000 pounds. The canister cask, which is a 20 inch diameter, 2.5 inch wall tube, 11 feet long weighs 5300 pounds. The total weight of the system, then, is 25,000 pounds. The matrix stress is therefore 55 psi.

2) Heat Load

As in the other concepts, the canister and in this case, the canister cask also, are stored vertically. The thickness of the canister cask, however, provides a barrier to heat flow from the waste canister to the sleeve liner and salt. It is expected that this system will allow the salt matrix to be cooler with less of a potential for plastic creep. When compared to the first concept, this system rates a 6.

3) Radiation and Shielding

Radial shielding capabilities at the 20 foot storage depth, are better than the first vertical concept described, although at that depth no additional shielding is necessary. It is well shielded axially, and is also better than the concept in 6.1.1 due to the canister cask. The uniqueness of this concept is generated from the fact that the extra shielding afforded by the canister cask may reduce shielding requirements for the cask transporter. This concept rates a 10 when compared to the concept in 6.1.1.

4) Sleeve Installation (Costs, Complexity)

This concept is almost identical to the first concept except that it is larger in diameter. The excavation technique will be simply drilling or boring with a constant diameter bit. The upper sleeve is 30 inches in diameter so the bit will have to be at least 38 inches in diameter. This will allow sufficient space for the grout. The amount of salt to be removed is 5.8 yards. This is 61% more salt to be disposed of than the first concept. Installation of the sleeve liner is virtually the same as in the first concept, although handling of the sleeve will be more difficult because of the heavier weight. Sleeve welding will be more expensive because of the extra length of weldment, approximately 13 more inches. These factors, combined, indicate that this concept is only 30% as effective as concept 1 and therefore rates a 3 on the 1 to 10 scale.

5) Materials

The first concept used 3504 pounds of steel: this concept requires about 4800 pounds. This is a 37% increase in the amount of structure and is due to the increased diameter necessary for the canister cask. The amount of poisoned concrete grout increases significantly: 3-1/2 yards compared to 2 yards for a 75% increase. The amount of concrete in the plug will be approximately the same. These factors combine to give a 40% efficiency decrease when compared to concept 1 and therefore deserves a rating of 6.

6) Canister Emplacement and Retrieval (Including Overcan)

Emplacement and retrieval of the canister and canister cask are identical to the initial concept. The transporter, however, will require a hoist capable of heavier loads: the combined weight of the canister and canister cask is 13,300 pounds. The added weight is almost insignificant but it does increase the transporter cost slightly. When compared to the first concept it is about 95% as efficient and therefore rates an 8.

7) Sealing

Sealing of the plug to sleeve is identical to concept 1 and has the same rating, 10.

6.2 Horizontal Concepts

There are two horizontal concepts explored in this section. One uses a sleeve liner and plug concept that is identical in every way to the first vertical concept except that it is horizontal. The other concept is unique in all respects: it is a coffin type structure which is embedded in the mine floor in which the canister resides horizontally.

6.2.1 Floor Coffin (Figure 5-5)

1) Matrix Material Stress

The storage cell presents a cross sectional area to the salt matrix which is 14 feet x 3-1/2 feet or 7100 square inches. The total combined weight of the system is approximately 65,000 pounds. The matrix stress then is 9 psi. This is by far better than concept one of paragraph 6.1.1.

2) Heat Load

This concept stores the canister horizontally: the canister can eliminate its heat more efficiently in this position. The heat load is more uniform over the full length of the canister in this configuration. Most of the heat is transferred directly to the cell lid and not to the salt as in previous concepts. This concept will be given a rating of 8.

3) Radiation and Shielding

This concept is satisfactory for shielding. The thickness of the cell lid provides the same level of shielding as the vertical concepts. The lid as shown in Figure 5-5 has a double stepped plug which prevents or reduces the amount of neutron streaming or shine. This concept will be given a rating of 9.

4) Sleeve Installation (Costs, Complexity)

This concept requires that a large amount of salt be removed, and disposed of above grade. The volume is 26 yards. This is 7 times the amount removed in concept 1 in 6.1.1. This concept will require about 7 yards of concrete grout to firmly position the storage cell. Installation of the storage cell would proceed in the following

sequence. The cell liner would be fabricated from steel and placed in concrete forms (probably inverted). The concrete is cast into place and allowed to set. This unit is then placed in the excavation and leveled. Grout is then put around the lower cell member. Forms are made for the remainder of the grout (7 ft. tall) and given sufficient clearance for the lid. The walls of the excavation are then poured and allowed to set. The forms are then removed and the lid liner placed into the hole and in-place on the lower cell member. The concrete is then poured into the lid structure and allowed to set. The lid is then removed and the seal and canister saddles installed. This concept, by virtue of the extreme amount of effort involved, is given a score of 2.

5) Materials

This concept uses 7 yards of grouting material to secure the installation. This is an increase of 250% over the amount required in the first vertical concept. If the amount of concrete in the lid is considered then the increase becomes 620%. The amount of steel required is about 6500 pounds, if 1/2 inch plate is used. This is an 81% increase in the amount of steel required for concept 1 described in 6.1.1. This concept rates only 20% of concept 1 or 2.

6) Canister Emplacement and Retrieval (Including Overcan)

Emplacement and retrieval functions are difficult in this configuration. The transporter must accurately align over the 45,000 pound lid, attach four separate hoist winches and lift the lid from the excavation. The lid is translated laterally and the canister lowered into place. The lid is then re-installed. Retrieval is the reverse of the above process. The transporter has at least one magnitude of degree of additional complexity involved in its design when compared to concept 1 of 6.1.1. This concept rates a 1 for emplacement and retrievability ease.

7) Sealing

This concept requires a seal that is rectangular in shape and is approximately 144 inches by 18 inches in size. Sealing pressure is 140 pounds per inch. The extreme size of this seal and the potential handling problems cause this concept to rate only a 4.

6.2.2 Wall Sleeve and Plug (Figure 5-6)1) Matrix Material Stress

The stress developed in the salt matrix is developed from the horizontal cross sectional area of the sleeve under the canister and plug. If the canister is 11 feet long the area becomes 2640 square inches. The canister and liner weight for a section this long is 8000 pounds plus 1386 pounds or 9386 pounds. The stress is, then, only 4 psi.

2) Heat Load

The heat from this concept is uniformly distributed into the salt pillar into which it is placed. This reduces the wall temperature and certainly the floor temperature because the thermal plume rises into the bedrock above. When compared to concept 1 this system is better and rates an 8.

NOTE

There is a consideration which must be explored and is beyond the evaluation presented so briefly here. The salt pillars which will support the mine ceiling are undoubtedly under a certain amount of stress. The increase in temperature in the pillar due to the canister heat may cause the vertical closure rate of the mine to be accelerated. The pillars may actually fail if the ultimate stress is reduced by heat from the canisters.

3) Radiation and Shielding

This concept is identical to the first concept, as described in 6.1.1, except that it is oriented horizontally. It rates the same score, 8.

4) Sleeve Installation (Costs, Complexity)

Installation of the sleeve, in this concept, is identical to the concept evaluated in 6.1.1 except that it is horizontal. There is no increase in difficulty in installation and therefore this concept rates the same score, 9.

5) Materials

The materials of construction are the same as and in the same quantities as concept 1 except that this system uses a set of rollers in the sleeve. The rollers have to be aligned and welded into the liner and must be able to roll after 20 to 30 years of canister emplacement. Special lubricants must be used and the roller/axle materials must be prevented from being welded to one another during the protracted period of heat and load. It is expected that this will cause the service life to be only about 30% that of concept 1 which has no rollers. This concept is scored as a 3.

6) Canister Emplacement and Retrieval (Including Overcan)

This concept is very difficult in emplacing/retrieving the canister. The plug must be removed horizontally which requires some sort of support as it comes out of the sleeve. The plug and bridge are translated out of the way and a canister bridge remotely installed. This is necessary to clear the plug/sleeve interface step and to present the canister to the liner rollers. The canister is rotated from the vertical to the horizontal and pushed into the sleeve. The bridge is remotely removed and stored in the cask. The plug bridge is remotely emplaced and the plug re-installed. This concept requires many more transporter functions and a hoisting mechanism that must push as well as pull. Obviously, this concept is much more difficult to use than concept 1 of paragraph 6.1.1 and rates only a 4.

7) Sealing

The fully horizontal plug of this concept does not allow for accurate sealing because of the lack of control of seal seating pressure. This concept will be scored as a 1.

6.3 Miscellaneous Concept

The single concept presented in this section is one which is in-between horizontal and vertical. It is included as a transition concept; one that fills in between the horizontal and vertical methods.

6.3.1 Wall Sleeve and Plug at Angle (Figure 5-7)

1) Matrix Material Stress

This concept is identical, in every way, to the initial concept, except it is placed at a 45 degree angle. There are two points of stress to consider; the end of the sleeve and along the sleeve. The stress on the end will be $(\sin 45) (54)$ or 38 psi. The stress along the sleeve will be $(\sin 45) (4)$ or 2.8 psi. The larger will be used in rating the concept.

2) Heat Load

The heat load in this concept will also be well distributed into the salt pillar. Some heat will be radiated into the flow area, however. The upper area around the canister will become slightly warmer due to vertical heating. This concept is judged to score a 6.

3) Radiation and Shielding

This concept is identical to the first concept, as described in paragraph 6.1.1, except that it is 45 degrees from vertical. The verticality has no effect on radiation shielding, therefore this concept rates the same score, 8.

4) Sleeve Installation (Costs, Complexity)

Installation of the sleeve is identical to the concept as described in paragraph 6.1.1 except that it is at 45 degrees, and the two piece sleeve liner can be one piece. This eliminates the welding operation and makes this concept more attractive: it will be scored a 10.

5) Materials

The materials and quantities in this concept are identical to the first vertical concept: there is no difference. The rating is, therefore, the same - 10.

6) Canister Emplacement and Retrieval (Including Overcan)

This concept is almost the same as the second horizontal concept as described in 6.2.2. The same transporter functions need to be accomplished except they only need be done at a 45° angle instead of horizontal. This would cause some slight amount of simplification but not to the point where the rating is the same as vertical. The score for this concept is 5.

7) Sealing

The plug/sleeve seal is identical to the first vertical concept except that it is at a 45 degree angle. This reduces the seal seating load to 78 psi for a 30% reduction. This one will be scored as a 7.

6.4 Evaluation Parameter Summation

The basic parameters used for evaluation of each concept are shown on Figure 6-1.

The scoring technique used was to assign numbers from 1 to 10 for each parameter for each concept: 10 was the best score, and 1 was the worst. The total of these numbers provided a concept ranking, which shows the technique best able to satisfy the requirement.

The matrix stresses were so small as to be insignificant: no particular one even reduced the stress to a 95% level. Each was subsequently given a score of 10.

The score spread is not large, however, it must be pointed out that even small considerations can become very significant when compounded by the 30,100 canisters to be emplaced in the pilot plant or by the 498,000 in the repository.

It must be understood that the procedure outlined above does not take into account the relative importance of each parameter: they were all weighted the same in this analysis.

		EVALUATION PARAMETERS								
		1) MATRIX STRESS	2) HEAT LOAD	3) RADIATION AND SHIELDING	4) SLEEVE INSTALLATION	5) MATERIALS	6) EMPLACEMENT & RETRIEVAL	7) SEALING	TOTAL	
CONCEPT	VERTICAL	5.1.1 (FIG 5-1)	10	4	8	9	10	9	10	60
		5.1.2 (FIG 5-2)	10	4	6	6	7	7	10	50
		5.1.3 (FIG 5-3)	10	4	3	4	5	10	3	39
		5.1.4 (FIG 5-4)	10	6	10	3	6	8	10	53
	HORIZONTAL	5.2.1 (FIG 5-5)	10	8	9	2	2	1	4	36
		5.2.2 (FIG 5-6)	10	8	8	9	3	4	1	43
	OTHER	5.3.1 (FIG 5-7)	10	6	8	10	10	5	7	56

PARAMETER RANKING SUMMARY

FIGURE 6-1

7.0 RECOMMENDED FOLLOW-ON ACTIVITY

The following activities are recommended to be performed as follow-on to this study. The recommended activities will provide the basis for configuring the canister shielding, handling, and emplacement hardware to meet the site technical requirements and operating goals.

- 1) Perform a thermal and radiation analysis of the canister from the time the shipping cask is opened above ground through loading on site, emplacement, and storage. These data will support design of the hardware and allow optimization of materials, spacing, and component configuration. A more complete definition of the waste radiation source terms and thermal load would be generated as part of this activity.
- 2) Perform a time line analysis of the handling and emplacement operation from the time a cask arrives at the Pilot Plant/Repository to completion of emplacement/retrieval. This analysis will provide the basis for determining quantities of handling equipment, personnel, size of working areas, and design requirements for each component in the system to meet the planned waste disposal rate for the Pilot Plant/Repository.

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APPENDIX A
TIER 3 BLOCK FLOW DIAGRAMS

The flow blocks, from the Tier 2 flow, which are part of canister emplacement/retrieval operations are 3.16 through 3.30. Although the scope of this study is limited to emplacement and retrieval storage techniques, flows for each of the above blocks were prepared. These are shown on Figures A-1 through A-15. The title for each figure serves to adequately describe the operations conducted in the Tier 3 flow. Two of the most important aspects of these Tier 3 flows are the visualization of operations and the further development of timelines.

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TIER 3
3.16
POSITION TRANSPORTER AND
PREPARE FOR REMOTE CANISTER PICK-UP

FIGURE A-1

TIER 3
3.17
REMOVE CANISTER FROM ELEVATOR

FIGURE A-2

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TIER 3
3.18
TRANSFER TO CANISTER
EMPLACEMENT POSITION

FIGURE A-3

TIER 3

3.19

PREPARE FOR REMOTE EMPLACEMENT

FIGURE A-4

TIER 3
3.20
EMPLACE CANISTER REMOTELY

FIGURE A-5

TIER 3
3.21
EMPLACE SLEEVE PLUG REMOTELY

FIGURE A-6

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TIER 3
3.22

RETURN FOR NEXT CANISTER

FIGURE A-7

3.23.1
DISPATCH
TRANSPORTER TO
CANISTER
EMPLACEMENT
SITE

TIER 3
3.23
RETURN FOR CANISTER RETRIEVAL

FIGURE A -8

TIER 3

3.24

PREPARE FOR REMOTE RETRIEVAL

FIGURE A -9

TIER 3
3.25
REMOVE SLEEVE PLUG

FIGURE A-10

TIER 3
3.26
REMOVE CANISTER

FIGURE A-11

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TIER 3
3.27

RETURN TO ELEVATOR

FIGURE A-12

TIER 3

3.28

POSITION TRANSPORTER AT MINE ELEVATOR

FIGURE A-13

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TIER 3
3.29
PREPARE FOR REMOTE TRANSFER OPERATIONS

FIGURE A -14

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TIER 3
3.30
TRANSFER CANISTER FROM
TRANSPORTER TO ELEVATOR

FIGURE A-15

APPENDIX B
THERMAL CALCULATIONS AND CONCLUSIONS

Thermal Groundrules

- 1) Maximum canister temperature allowed $\leq 1100^{\circ}\text{F}$.
- 2) Maximum salt temperature allowed $\leq 500^{\circ}\text{F}$ and:
 - 99% must be $< 482^{\circ}\text{F}$
 - 75% must be $< 392^{\circ}\text{F}$
- 3) Maximum allowable floor surface temperature = 100°F
- 4) Waste stored in 12.75 diameter stainless steel canister.
- 5) Waste heat is 5000 watt over eight foot length in canister.

B1.0 RESULTS OF THERMAL STUDY - CONCLUSIONS

B1.1 A balance must be maintained - the heat transport from the canister must be great enough that the waste material does not overheat, but not so great that the salt is overheated.

B1.1.2 With the baseline configuration (5.1.1) the greater problem will be the salt temperature.

- 1) Fins should not be used to reduce temperature difference across air gaps as this raises the temperature of the sleeve-salt interface.
- 2) Emissivity of the canister and overcan should be kept low ($\epsilon \leq .2$) to keep the sleeve temperature low.
- 3) Thermal conduction paths from canister to overcan and from overcan to sleeve should be minimized - "heat dams" may be required.

B1.3 The above problem can be reduced by filling the space between sleeve and salt with "grout" material. This material should be capable of withstanding temperature in the range of 600 to 800°F and should have a thermal conductivity in the range of 0.1 to 1.0. Candidate materials would include sand, crushed rock, and concrete, etc. The material could be tailored by mixing to produce the desired thermal properties for all configurations.

B1.4 Other configurations including horizontal storage, variation in length, diameter, heat dissipation, center to center distance will require similar treatment to maintain proper temperature distribution. This type of problem is easily modeled on the various thermal analyzer programs used in the aerospace industry ("BETA" at Boeing, CINDA at NASA and Crysler, SINDA at TRW, etc.). These programs allow material properties to vary with both time and temperature. The variables above (length, pitch) can be examined parametrically for the effects on waste material and salt temperature. Other constraints such as thermal stress can be modeled.

B2.0 ALTERNATE CONFIGURATIONS COMPARED TO 5.1.1

- 1) Analysis of 5.1.2, Sleeve and Plug with Plug Storage (Figure 5-1)
No significant thermal difference when compared to 5.1.1. Grout material and/or thickness would be adjusted to meet constraints.

2) Analysis of 5.1.3, Sleeve with Activated Plug (Figure 5-3)

No significant thermal difference when compared to 5.1.1. Grout material and/or thickness would be adjusted to meet constraints.

3) Analysis of 5.1.4, Sleeve and Plug with Canister Cask (Figure 5-4)

No significant thermal difference when compared to 5.1.1. Grout material and/or thickness would be adjusted to meet constraints.

4) Analysis of 5.2.1, Floor Coffin (Figure 5-5)

The casket type configuration must be buried in a trench and then overfilled to meet floor surface temperature constraints - depth estimated at six to ten feet to top of casket. Very few overfill materials (including ground salt) have the same thermal properties as undisturbed salt. A different geometry exists since the caskets would lay across the salt chambers - new thermal parameters such as pitch, pattern, etc. would have to be developed. The number of canisters per acre would be less. Long, skinny canisters would not have to be buried as deep as short, fat ones.

5) Analysis of 5.2.2, Sleeve and Plug (Figure 5-6)

Plugs drilled from the salt cave wall allow the canister to be inserted horizontally - this creates essentially the same thermal geometry as the vertical holes in the floor. The natural convection flow would be slightly different due to gravitational effects but not significant. The holes in the wall should be 1/2 pitch from floor (approximately 8-1/2 feet). Cave room should have height of at least one pitch length. Conduction path through rollers might require that the grout under the hole be a different thickness than the sides, top.

6) Analysis of 5.2.3, Sleeve and Plug at Angle (Figure 5-7)

The 45° inclination creates unique thermal problems - heat generated by the waste is ultimately transferred to the air by natural convection at the surface of the storage room. The effect of the longer heat path to the surface is offset by the better geometry for natural convection. Pitch distance is likely to be less. This configuration could provide for the greatest number of cylinders stored per volume of salt excavated. Two cylinders could be stored at each pitch length along the chamber. Distance horizontally and vertically between chambers would be greater, but less excavation would be required. The skewed geometry makes the thermal modeling more complex but well within the capabilities of the thermal analyzer programs.

B 2.0 THERMAL CALCULATIONS

B 2.1 SLEEVE & PLUG (FIG 5-1)

FOR CONCENTRIC CYLINDERS

$$\Delta T = \frac{Q}{L} \frac{\ln(r_2/r_1)}{2\pi K}$$

$$\frac{Q}{L} = 625 \text{ WATTS/FT}$$

TEMP DROP ACROSS OVERCAN

$$\Delta T = (625 \text{ WATTS/FT})(3.413) \frac{\text{BTO}}{\text{WATT-FT}} \times \frac{\ln(6.56/6.38)}{2\pi(10)} = 0.94^\circ\text{F}$$

TEMP DROP ACROSS SLEEVE

$$\Delta T = (625)(3.413) \frac{\ln(10/9.4)}{2\pi(10)} = 2.09^\circ\text{F}$$

B 2.2 AIR GAPS

INNER GAP

A) WORST CASE - CONDUCTION ONLY THROUGH AIR, RADIATION NEG.

$$K_{AIR} = 0.04 \text{ BTU/HR-FT-}^{\circ}\text{F}$$

$$\Delta T_{GAP} = (625)(3.4) \ln(6.56/6.38) / 2\pi(0.04) = 235^{\circ}\text{F}$$

(WITHOUT RADIATION OR CIRCULATION) - OBVIOUSLY
RADIATION & CONVECTION WILL DECREASE THIS CONSIDERABLY.

B) RADIATION: BLACK SURFACE $\epsilon = 0.92$ FOR ONE FT LENGTH; $A_{CANISTER} = \pi(12.75)/12$

$$A_{OVERCAN} = \pi(13.124)/12$$

$$F_{1-2} = \frac{F_{12}}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} = \frac{F_{12}}{\frac{2}{.92} - 1} = 0.85 F_{12} = 0.85$$

$$A_{F_{12}} = 2.51 \text{ FT}^2 \text{ FOR CANISTER TO OVERCAN}$$

$$A_{F_{12}} = 2.92 \text{ FT}^2 \text{ FOR OVERCAN TO SLEEVE}$$

$$\frac{Q}{L} = \sigma A_{F_{12}} (T_1^4 - T_2^4)$$

$$T_1^4 - T_2^4 = \frac{Q}{L} / \sigma A_{F_{12}} = (625)(3.4) / (.1714 \times 10^{-8} (2.92))$$

$$= 4.262 (10^8) \text{ }^{\circ}\text{R}^4$$

IF $T_2 \approx 492^{\circ}\text{F}$ (MAX ALLOWABLE FOR SALT)

$$T_1 = \sqrt[4]{T_2^4 + 4.262 \times 10^8} = 597^{\circ}\text{F}$$

$$\Delta T \approx 105^{\circ}\text{F} \quad \text{IGNORING CONVECTION}$$

CONVECTION ACROSS AIR GAP

CONCENTRIC VERTICAL CYLINDERS - NO DATA FOUND FOR THIS CONFIGURATION, HOWEVER SINCE THE GAP IS SMALL COMPARED TO THE DIAMETER, THE DATA FOR VERTICAL FLAT PLATES SHOULD BE A REASONABLE ESTIMATE.

$$X = \frac{L^3 \rho^2 g \Delta t \beta}{\mu^2} Pr$$

$$Y = \frac{\rho^2 \beta g C_p}{\mu K}$$

$$\therefore X = Y \frac{L^3 \Delta t K}{C_p \mu}$$

for 300°F AIR $Y = 0.3 \times 10^6 / \text{FT}^3 \text{ } ^\circ\text{F}$

$$\mu = 0.0578 \text{ LB/FT HR}$$

$$C_p = 0.24 \text{ BTU/LB } ^\circ\text{F}$$

$$K = 0.0204 \text{ BTU/FT } ^\circ\text{F HR}$$

$$Pr = 0.69$$

for $L = 4 \text{ ft. (1/2 WAY UP CYL)}$

$$X = 0.24 (10^5) L^3 \Delta T$$

$$= 0.24 (10^5) (4^3) (100^\circ\text{F}) \leftarrow \text{ASSUMED VALUE}$$

$$X = 1.6 (10^8)$$

$$\text{THUS } h_c \approx 0.19 \sqrt[3]{100} \approx 0.80 \text{ BTU/hr-FT}^2\text{-}^\circ\text{F}$$

COMBINING RADIATION & CONVECTION FOR CANISTER TO OVERCAN

$$\frac{Q}{L} = h A \Delta T + \sigma A f (T_1^4 - T_2^4)$$

$$(625)(3.4) = 0.8(\pi)(12.75/12)(T_1 - T_2) + .114(10^{-8})(2.51)(T_1^4 - T_2^4)$$

$$2133 = 2.67(T_1 - T_2) + .43(10^{-8})(T_1^4 - T_2^4)$$

A PLOT OF VALUES OF T_2 CAN BE MADE FOR ASSUMED VALUES OF T_1

$$.43 \left(\frac{T_1}{100} \right)^4 + 2.67 T_1 - 2133 = .43 \left(\frac{T_2}{100} \right)^4 + 2.67 T_2$$

$$\text{IF } T_1 = 1600 \quad T_2 = 1570^\circ R \quad (\Delta T = 30^\circ F)$$

$$\text{IF } T_1 = 1200 \quad T_2 = 1125^\circ R \quad (\Delta T = 75^\circ F)$$

$$\text{IF } T_1 = 800 \quad T_2 = 532^\circ R \quad (\Delta T = 268)$$

IF CANISTER AND OVER CAN ARE LEFT UNFINISHED
 $\epsilon = 0.11$

$$f_{12} = \frac{\frac{F_{12}}{\epsilon_1 + \frac{1}{\epsilon_2}} - 1}{\epsilon_1} = 0.062 F_{12}$$

$$A f_{12} = 0.206$$

$$\sigma A f = 0.0353(10^{-8})$$

RADIATION + CONVECTION

$$\frac{Q}{L} = h A \Delta T + \sigma A f_{12} (T_1^4 - T_2^4)$$

$$2133 = 2.67 T_1 - 2.67 T_2 + .0353 \left(\frac{T_1}{100} \right)^4 - 0.0353 \left(\frac{T_2}{100} \right)^4$$

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$$\text{OR } 0.0353 (T_1/100)^4 + 2.67 T_1 - 2133 = 0.0353 (T_2/100)^4 + 2.67 T_2$$

$$\text{IF } T_1 = 1600 \quad T_2 = 1295 \quad \Delta T = 305^\circ \text{R}$$

$$\text{IF } T_1 = 1200 \quad T_2 = 652 \quad \Delta T = 548^\circ \text{R}$$

"GROUT" THICKNESS

$$Q = K \frac{A}{\Delta x} \Delta T$$

$$\frac{Q}{L} = K \pi d \frac{\Delta T}{\Delta x}$$

$$\Delta T = \frac{Q/L}{\pi d} \frac{\Delta x}{K}$$

FOR VARIOUS GROUT MATERIALS

MATERIAL	K
SAND	0.2
CONCRETE	0.44
CRUSHED SALT	0.25
SOLIDIFIED SALT	2.4

IF THE OVERCAN & SLEEVE WERE BLACK & TO KEEP THE MAXIMUM SALT TEMP $< 490^\circ \text{F}$ THE THICKNESS OF CONCRETE & SAND WOULD BE:

$$\Delta x = \frac{K \pi d \Delta T}{Q/L} = \frac{0.44 (3.14) (22/12) (1027 - 490)}{2133}$$

$$\approx 8'' \text{ CONCRETE}$$

$$\approx 4'' \text{ SAND}$$

	BLACK COATING $\epsilon = .85$	NO COATING $\epsilon = .15$
T_1	1100°F	1100°F
T_2	1065°F	710°F
T_3	1064°F	779°F
T_4	1029°F	459°F
T_5	1027°F	457°F

APPENDIX C

RADIATION ANALYSIS

C1.0 NUCLEAR RADIATION SHIELDING IMPLICATIONS

The gamma ray and neutron dose rate at three feet from the canister surface, 10^6 R/hr and 10^3 rem/hr, respectively, is sufficiently high to impose shielding requirements for handling and storage for personnel and equipment protection. While a thickness of seven feet of uniform salt should reduce the dose to 10^{-3} rem/hr, as required, a combination 10 inch steel/50 inch concrete shield could also be used to achieve the same reduction.

In addition to the primary radiation from the canister, neutron activation of the storage areas will also present constraints on the use of the activated structures that house the canisters.

C2.0 TRANSPORTATION OF CANISTERS

The handling of such high level wastes will require substantial shielding about personnel in the transporter.

A shield of ten inch steel and 50 inches of concrete about the canister would allow close approach by personnel after the canister is emplaced. An alternate transportation concept might be a more moderate shield about the canister combined with personnel shielding. The shield about the canister could be built as a tank and remotely flooded with a liquid for neutron and gamma shielding and cooling, if required.

C3.0 CANISTER STORAGE

The equivalent of approximately seven feet of salt must uniformly cover the canisters. Vertical burial would minimize the casing thickness required as compared to horizontal emplacement. Steel-concrete plugs must be approximately ten inch steel /50 inch concrete in total thickness with control of gap streaming through steps, gap tolerance control, or gap fill. If backfill of salt is used for shielding, the continuity of the salt must be controlled to prevent excessive radiation streaming and excessive surface doses. Sand might be used for backfill, but it presents thermal and cost problems.

Long term activation of the salt will not be a problem, due to the short half life of Na, but steel and concrete will be more difficult to deal with after long term exposure.