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Retrieval System for Emplaced Spent Unreprocessed Fuel (SURF) in Salt Bed Depository

BASELINE CONCEPT CRITERIA SPECIFICATIONS AND MECHANICAL FAILURE PROBABILITIES

E.E. Hudson and J.E. McCleery

COPY NO. 12 of 12

May 1979

This is a final report primarily intended for internal use of Lawrence Livermore Laboratory with limited external distribution. This work was prepared by **International Engineering Company** under subcontract No. 3157109 with Lawrence Livermore Laboratory.

This work was supported by the U.S. Nuclear Regulatory Commission under Interagency Agreement DCE 40-550-75 with U.S. Department of Energy.

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1.0 ABSTRACT

One of the integral elements of the Nuclear Waste Management Program is the material handling task of retrieving Canisters containing spent unprocessed fuel from their emplacement in a deep geologic salt bed Repository. A study of the retrieval concept data base predicated this report. In this report, alternative concepts for the tasks are illustrated and critiqued, a baseline concept in scenario form is derived and basic retrieval subsystem specifications are presented with cyclic failure probabilities predicted.

The report is based on the following assumptions:

- a) During retrieval, a temporary radiation seal is placed over each Canister emplacement;
- b) A sleeve, surrounding the Canister, was initially installed during the original emplacement;
- c) The emplacement room's physical and environmental conditions established in this report are maintained while the task is performed.

2.0 SUMMARY

The efficiency of the retrieval of spent unprocessed fuel contained in Canisters stored in deep geologic halite deposits (salt beds) is dependent on the following governing restraints: a) the physical dimensions of the emplacement room; b) the integrity of the Canister at the time of retrieval; c) monitoring accuracy; and d) subsurface environmental control.

To summarize this report and introduce the retrieval methodology, the following scenario is presented in procedural sequence utilizing retrieval subsystems derived in this study.

Scenario Prologue

Many years have passed since the emplacement room was filled with spent fuel Canisters, each of which was inserted into a protective sleeve. The sleeve was installed in an upright (vertical) position in the emplacement room floor and was of sufficient depth to accommodate a Canister and a seal plug. The installation is depicted in Figure 1.

2.1 Step 1. Survey, Reference Figure 1 "Survey Procedures"

It is reasonable to assume that the emplacement room survey monuments will have deteriorated or been obscured and the floor and ceiling will have shrunk and been distorted ⁽¹⁾⁽²⁾ from the original profile. Presurveying and remining the room to original contours will then be required.

(1)(2) Numbers correspond to reference articles listed in the Bibliography Section.

Figure -1-
SURVEY PROCEDURES

The presurvey procedure will require hazardous gas and radiation level monitoring prior to entry into the room of a survey team whose primary functions are as follows:

- a) Determine emplacement room existing profiles (mapping);
- b) Locate and determine exact location, orientation and condition of each Canister;
- c) Set survey stakes for remining operation.

To expedite the survey process, the input data will be entered immediately into a computer programmed to issue the remining instructions.

2.2 Step 2. Remining, Reference Figure 2. "Remining Procedures"

The remining operation will be a manned operation, computer assisted. The operation will require regrading the emplacement room floor to a reasonably level grade and reestablishing ceiling and walls to the design dimensions. The elevation of the floor and the amount of inclination or declination are determined by the elevation of the Canister emplacements. The floor area around each Canister emplacement will be graded down to expose the top of the concrete plug and leveled perpendicular to the longitudinal axis of the sleeve over an area exceeding the size of the floor flange.⁽¹⁾⁽²⁾

(1)(2) Numbers correspond to reference articles listed in the Bibliography Section.

Figure -2-
REMINING PROCEDURES

Figure -3-
FLOOR FLANGE PLACEMENT

2.3 Step 3. Floor Flange Placement, Figure 3

A motorized self-contained multiple drill unit will then be moved to the area and accurately positioned over the Canister emplacement. This unit will drill the rock bolt holes concentric to and on the periphery of the cover plate. Secondly, another machine will insert the rock bolts and pressure grout, each anchor bolt in place. Then a Floor Flange emplacement device will:

- a) Place a Floor Flange unit over each Canister emplacement;
- b) Bolt the Floor Flange to the floor;
- c) Seal the interface joint between floor and Floor Flange using pressure grout.

The Floor Flange consists of a radiation shielding frame and sliding gate designed to serve as: a radiation and closure seal when the concrete plug is removed; and centering guide and platform for the plug and Canister extraction devices.

2.4 Step 4. Extraction, Figures - 4a, 4b, 4c, 4d and 4e

The retrieval operation begins at the far end of the emplacement chamber and proceeds towards the entrance. Turnouts shall be incorporated into the emplacement room configuration for traffic management. Multiple units are used and operated sequentially to minimize the height of the emplacement room and reduce the extraction time. The operation of the units is as follows: The units traverse

to location under automatic guidance control with on-board operator override. The operator then exits the room and operates the extraction process by remote control. On-board monitoring instruments and cameras are provided to allow him visual access as well as indication of the units' operation.

The Plug Removal Machine (PRM), shown in Figures 4a and 4b, is used to open the Floor Flange cover door and remove the Canister emplacement plug. The PRM is equipped with an integral plug lifting device, and space is provided to temporarily store the plug within the machine's radiation shielded housing (cask). The Floor Flange gate and the apparatus gate must be closed and confirmed latched before the PRM can propel away.

In the following sequence, the assumptions are that the sleeve is intact and the Canister is degraded and therefore special extraction procedures are required. The Canister Extraction/Transporter (CET), as shown in Figures 4c, 4d and 4e is indexed, its telescoping ram extended inside the sleeve to surround the Canister, grab the Canister's bottom support and remove the Canister with support.

Figure 4a
 PLUG EXTRACTION

Figure 4b
PLUG EXTRACTION
xxi

Figure 4c
 CANISTER EXTRACTION
 xxii

Figure 4d
CANISTER EXTRACTION
xxiii

Figure 4e
CANISTER EXTRACTION

Figure 4f
CANISTER TRANSPORT

The CET's telescoping ram is designed to serve as overpack for retrieval and handling purposes, it will remain with the Canister and is removed at the surface waste handling facility. As the ram will be restricted in capacity, if the Canister cannot be enveloped or raised, the hole will be abandoned by this unit. After extraction (or abandonment) the Floor Flange gate and machine gate are closed and the CET propels away toward the CWSRS. Irrespective of the success or failure in extraction of the Canister, the concrete plug is reinserted by the Plug Removal Machine (PRM) completing its cycle.

2.5 Step 5 Transport, Figure 5

The Canister extraction unit is also designed to transport the retrieved Canister from the Depository.

At the base of the hoist shaft, the retrieved Canister is transferred to a shielded confinement container⁽¹⁾⁽³⁾ mounted on a transporter located in an isolation room below. The confinement container, entitled "Canister Transport Basket (CTB)," is moved and raised to the surface. (The equipment and facilities at the hoist station were installed for the emplacement operation.)

Plan View - CWSRS Transporter Level

Canister Waste Subsurface Receiving Station (CWSRS)
Canister Transfer from Canister Extraction/Transporter (CET)
To Canister Transfer Basket (CTB)

2.6 Step 6. Extraction by Sleeve Overcoring, Figures 6a, 6b, 6c, 7a, 7b, 7c, 8a and 8b

When the PRM and CET's have completed their retrieval operation in an emplacement room and have departed, the previously abandoned Canisters remaining in the emplacement room will be removed using overcoring methods. Again multiple units are used and the operation is as follows: The units traverse to location under automatic guidance control with on-board operator override. The operator then exits the room and operates the extraction process by remote control. On board monitoring instruments and cameras are provided to allow him visual access as well as indication of the units's operation.

The Plug Overcore Machine (POM), shown in Figures 6a, 6b and 6c, is first used to: open the floor flange cover door, remove the Canister emplacement plug, overcore around the sleeve to about nine feet below the floor, collect the drilling debris, cut and remove the upper portion of the sleeve. The POM is equipped to perform these tasks utilizing individual mechanisms. Space is provided to store the plug, upper sleeve and drill debris within the machine's radiation shield housing (cask). The Floor Flange gate and the apparatus gate must be closed and confirmed latched before the POM can propel away.

Figure 6a
PLUG REMOVAL

Figure 6b

PLUG OVERCORE DRILLING

xxx

Figure 7a
 LOWER HALF OF SLEEVE OVERCORE DRILLING

Figure 7b
 LOWER HALF OF SLEEVE EXTRACTION
 xxx111

Figure 7c

Figure 8a
BACKFILL OF EMPTY EMPLACEMENT

Figure 8b

BACKFILL OF EMPTY EMPLACEMENT

In the following sequence, the assumptions are that the sleeve and Canister are degraded and therefore overcoring procedures are required. The Canister Overcore/Transporter (COT), as shown in Figures 7a, 7b and 7c is indexed, the Floor Flange gate is opened, its telescoping drill unit overcores around, below and under the sleeve, grabs the sleeve from the bottom and removes the sleeve with the Canister inside. The drilling debris is temporarily collected inside the COT and redeposited into the emptied hole.

The COT's drill barrel is designed to serve as overpack for retrieval and handling purposes; it will remain with the Canister and is removed at the surface waste handling facility. After extraction, the Floor Flange gate and machine gate are closed and the COT propels away toward the CWSRS. The concrete plug, upper half of the sleeve and the drilling debris are redeposited in the hole by the Plug Overcore Machine (POM) completing its cycle (refer to Figures 8a and 8b).

2.7 Step 7. Transport, Figure 9

The Canister Overcore unit (COT) is also designed to transport the retrieved Canister from the Depository.

At the base of the hoist shaft, the retrieved Canister is transferred to a shielded confinement container⁽¹⁾⁽³⁾ mounted on a transporter located in an isolated room below. The confinement container, entitled "Canister Transport Basket (CTB)," is moved and raised to the surface. (The equipment and facilities at the hoist station were installed for the emplacement operation.)

Plan View - CWSRS Transporter Level

Canister Waste Subsurface Receiving Station (CWSRS)
Canister Transfer from Canister Overcore/Transporter (COT)
To Canister Transfer Basket (CTB)

2.8 General Considerations - Canister Extraction Unit

The retrieval device which performs the dual functions of Canister extraction and subterranean cartage is mounted on a rubber tired vehicle designed for maneuverability. A radiation shield is provided around the extraction chamber and all equipment used for the extraction process.⁽²⁾ The ram concept was chosen as a principal retrieval means because it is the most reliable and requires less than two hours to complete the task (see Appendix 3). Based on the results of a survey discussed in Section 9, it was determined that a core drill sleeve extraction procedure will require approximately four hours to complete.

2.9 General Considerations - Radiation Shielding

The use of Floor Flange permits proper alignment of extraction equipment and also provides a means of forming a tight seal with the floor for radiation shielding around the open hole.

2.10 General Considerations - Canister Transport Basket

It is assumed in this study that the Canister Transport Basket (CTB) was originally used for emplacement operations, as well as the hoist (CWC) and subsurface facility (CWSRS). The design criteria for this unit should be based on the retrieval operational requirements. The parameters should include the dictum that proper distances between Canisters should be maintained to allow for oversized overpack equal to the core barrel diameter and that clamps or some other means be provided to grasp smaller diameter cylinders.

2.11 Conclusion

This report analyzes the retrieval concepts excerpted from the data sources referenced in the succeeding sections. The culmination is a baseline retrieval concept for SURF Canisters presented herein before in scenario form. Section 10 contains criteria type specifications of the equipment mentioned in this section. Based upon these specifications, the failure probabilities of the equipment are tabulated on Figure 12.5 in Section 12.

3.0 INTRODUCTION

"The Nuclear Regulatory Commission (NRC) has the Nuclear Waste Management (NWM) responsibility for developing high-level and spent-fuel waste regulations, regulatory guides and licensing requirements in a timely manner consistent with the Department of Energy (DOE) NWM needs. The Lawrence Livermore Laboratory (LLL) Waste Management Project is developing macroscopic element simulation models to evaluate the risks involved. The models developed need to be validated against data bases."

NWM is a complex problem which requires storage of spent unprocessed fuel (SURF) from pressurized water reactors (PWR) and boiling water reactors (BWR). The decision to reprocess fuel has been deferred and is not a condition of this program. The concept of sealing SURF in a steel Canister and emplacing it in a steel Canister and emplacing it in a deep geologic halite deposit is the design base for this document. In situ salt bed emplacement tests have been conducted in the United States, a wealth of data has been obtained establishing the feasibility of salt mine emplacement ⁽⁶⁾ and additional tests are being performed. ⁽⁷⁾

The storage concept requires efficient and reliable emplacement and retrieval systems. The retrieval of SURF Canisters will be required for the study and verification of the storage concepts. Also, an effective retrieval method is essential if the stored nuclear waste must be removed from the Depository for any reason. During emplacement operations, degraded Canisters may have to be removed, repackaged and reemplaced to avoid contamination leading to premature cessation of emplacement operations. The length of the retrievability period has been established at 60 years for this study.

The Canister could be degraded by accidental and undiscovered damage during emplacement or by corrosion due to brine. Consequently, this report is based on the assumption that all Canisters may be degraded.

A sleeve protects the emplaced Canister from the pressures due to salt creep⁽⁸⁾ and from corrosion by salt and brine.⁽⁹⁾ This sleeve must be designed to permit the retrieval of the Canister by the emplacement machinery or by special retrieval equipment. In the event that the sleeve fails in its function to protect the Canister, the retrieval of a degraded Canister from a degraded sleeve will require a technique different from the procedures for ordinary retrieval of degraded Canisters from intact sleeves.

The primary purpose of this study is to:

- a) Present various concepts for the retrieval of the degraded Canister from an intact sleeve and a degraded sleeve;
- b) Evaluate the different concepts;
- c) Evolve a baseline retrieval concept;
- d) Predict the failure probability for the major system components.

The limits of the study are established in Chapter 5. Alternate retrieval system concepts constitute Chapter 8, and Chapter 9 offers an evaluation of the study's Canister extraction concepts. Chapter 10 focuses on the baseline design for retrieval of a degraded Canister, and Chapter 12 deals with the mechanical failure probabilities of

the major retrieval subsystems. Essentially, almost all facets of SURF canister retrieval are considered in this report.

4.0 DEFINITION OF TECHNICAL TERMS

- 4.1 A "retrieval system" is a total system which locates the spent fuel package, extracts it, moves it to a hoist facility, and brings it to a surface receiving facility.
- 4.2 A "subsystem" is any single major component of the total system. For example, subsystems are the hoist, the subsurface transport, or the Canister extraction machine.
- 4.3 "Failure probability" is the probability of failure during a single cycle of operation of a component or subsystem.
- 4.4 A "degraded Canister" is a Canister which is deteriorated so that it cannot be retrieved by using the standard lifting device and equipment similar to that used for emplacement.
- 4.5 The "emplacement room" is a room wherein the SURF Canisters are emplaced in vertical position as herein described.
- 4.6 A "Canister" is a spent fuel container which is packaged at the repository site surface facility.
- 4.7 "Operation control" (OC) is a central subterranean control room wherein retrieval and emplacement operations are monitored and controlled.
- 4.8 "Overcoring" means drilling around an emplaced sleeve.
- 4.9 "Overpack" is an additional cylinder placed over a Canister to serve as a containment vessel.

4.10 "Depository" refers to the entire subsurface facility.

4.11 Equipment Legend

CET	-	Canister Extraction/Transporter
PRM	-	Plug Removal Machine
POM	-	Plug Overcore Machine
COT	-	Canister Overcore/Transporter
CTB	-	Canister Transport Basket
CWC	-	Canister Waste Cage (Hoist)
CWSRS	-	Canister Waste Subsurface Receiving Station
FF	-	Floor Flange
FED	-	Floor Flange Emplacement Device
ABD	-	Anchor Bolt Drill Unit
ABI	-	Anchor Bolt Insert Unit

5.0 LIMITS OF THE STUDY

This study is limited to the retrieval of intact or degraded Canisters containing spent unprocessed fuel (SURF) only, and is not intended to apply to the retrieval of waste form packages containing high-level waste.

The spent fuel assemblies will be received by rail or truck in transport casks and removed from the casks at the Depository site surface receiving facility. This report is based on the assumption that the spent fuel assemblies are canistered on site.

The baseline design of SURF retrieval systems will be based on retrieving the SURF Canisters from intact or degraded sleeves for a period of up to 60 years.

This study does not define the precise survey and remining procedures required, because it is assumed that no radiation accident is caused during these operations and furthermore, these operations closely parallel those of emplacement. Where accidents could occur as a result of improper survey and mining operations, the required procedures for survey and remining are detailed in this report.

6.0 DEPOSITORY BASELINE DESIGN CONDITIONS

6.1 Purpose

The purpose of this section is to provide a description of the Depository in order to develop a baseline design of a retrieval system for the degraded SURF Canister.

6.2 Sources of Data

Canister, sleeve, and emplacement design data were obtained from the publications numbered 14, 15, 16, 18, 19, 20 and 21 listed in the bibliography.

6.3 Reference Figures

Figure 6.3.1 Canister Placement Elevation

Figure 6.3.2 Lifting Arrangement

Figure 6.3.3 Baseline Canister Design

6.4 Emplacement Configuration

Canister, sleeve, and emplacement configuration and parameters used in this report are derived from bibliography references 1 and 3.

6.5 Canister Data

The spent fuel Canisters will be similar, but of different size for Boiling Water Reactor (BWR) SURF and for Pressurized Water Reactor (PWR) SURF.

- a) Canister dimensions for the PWR SURF will be 14" diameter by 16'-0" high.
- b) Canister dimensions for the BWR SURF will be 10.75" diameter by 16'-0" high.
- c) Canister material will be mild steel.
- d) The Canister will have hemispherical ends with the lower end dimple inverted.
- e) The Canister weight will be approximately two (2) tons maximum.
- f) The Canister should be suitable for retrieval 60 years after emplacement.
- g) The surface temperature of the Canister at retrieval is assumed to be 300 F maximum. Derivation of the exact value is not within the purview of this study.

6.6 Sleeve Data

- a) The sleeve will be fabricated from steel pipe with corrosion protection ⁽⁹⁾ for the retrieval life as follows:

PWR - 20"

BWR - 16"

- b) To facilitate installation, the sleeve may be in two parts joined by means of a flanged connection.

c) The sleeve will be designed to support the concrete plug, to protect the Canister from radial stress and to provide a salt barrier to allow retrieval of the Canister.

d) The bottom of the sleeve will be approximately 27 feet below the floor surface of the emplacement room.

e) A Canister support pad with wiper designed to clear debris from the interior surface of the sleeve will be provided.

6.7 Emplacement Data

a) Allowable salt bearing stress is 3,000 psi for temporary stabilizing jacks.

b) Storage room dimensions are 18'-0" width and 30'-0" height. See Figure 6.7.1 for dimensional study.

c) If the emplacement room shrinks to less than 30 feet in height, the ceiling will be remined to 30 feet high. If floor plane changes relative to the sleeve and plug, it will be regarded normal to the sleeve.

6.8 Retrieval System Initial Criteria

a) The Canister will be emplaced in a salt Depository.

b) Retrieved Canisters will be handled by the emplacement equipment and facilities where possible.

c) Maximum allowable personnel exposure by radiation will be as low as reasonably achievable (ALARA), as defined in Code 10 CFR 20.

d) Maximum transporter height is to be limited to 25'-0" in transport mode; and 29'-0" in retrieval mode.

e) All Canister extraction operations from the emplacement are to be accomplished by remote control.

f) Retrieval can be conducted simultaneously with the emplacement operations, but not in the same room.

g) Average distance traveled each way by the transporter unit is estimated to be approximately 6,500 feet (see Appendix 5).

h) Canister plug will remain in emplacement room.

i) There will not be adequate ventilation to permit the use of diesel engine as drive for retrieval and transport machinery. Energy storage systems will be needed for motive power.

j) The concrete plug placed over the Canister will be designed to include a protruding collar which will maintain the Canister's position in the center of the sleeve.

FIGURE 6.3.1 CANISTER PLACEMENT ELEVATION

Figure 6.3.2 Lifting Arrangement

Detail based on
reference (11) listed
in Bibliography Section

Figure 6.3.3 Baseline Canister Design

Figure 6.7.1
DIMENSIONAL STUDY OF EMPLACEMENT ROOM

7.0 GENERAL CONSIDERATIONS

7.1 Abandonment

One of the options in dealing with a degraded Canister is temporary or permanent abandonment in place. An example of a retrieval sequence leading to abandonment is:

The first attempt at retrieval with the emplacement equipment fails due to deterioration of the Canister or failure of the lifting system.

The second attempt at retrieval with the specially designed degraded Canister retrieval equipment (PRM and CET) fails due to inability to thrust the retrieval ram to the bottom of the sleeve as required for the baseline design retrieval concept.

Having failed to retrieve the Canister by either the normal retrieval or the degraded Canister retrieval procedures, a decision is made to either remove the Canister and sleeve by the standby core drill unit or to abandon the Canister and replace the concrete sleeve plug or backfill with salt.

The sleeve could also require abandonment if it has been longitudinally bent by radial stress to such an extent that the sleeve extraction core barrel will not clear. This condition can be prevented if a continuous position monitoring program of all sleeves is maintained, and the retrieval is performed when sleeve distortion exceeds preset limits. The limitations and ramifications of abandonment have not been explored in this study and could be the subject of further study.

7.2 Intact Sleeve Versus Degraded Sleeve

The previously proposed designs for the emplacement of the Canisters for interim storage ⁽¹⁾⁽²⁾ have been made on the basis of a "sacrificial" sleeve designed to allow for corrosion. The wall thickness of the protecting sleeve is determined by using a known corrosion penetration rate assigned to remain structurally sound for 25 years.

At the end of a 60 year retrieval period, the sleeve could have deteriorated and allowed the Canister to be considerably weakened by corrosion.

For a 60 year retrieval period, the required thickness of the uncoated steel sleeve may become economically unfeasible. Therefore, in this study it is proposed that the sleeve be designed with a protective coating ⁽⁹⁾ designed to last through the 60 year retrieval period.

Shield removal after extraction of Canister and replacement of sleeve plug will have to be delayed until the radiation level of the irradiated surface of the gate has decreased ALARA. The procedure will be as follows:

- a) Remove anchor bolts.
- b) Knock the shield loose.
- c) Remove the shield.
- d) Clean the shield.
- e) Break up the grout. (Optional).
- f) Clean up the debris. (Optional).

8.0 ALTERNATIVE RETRIEVAL SYSTEM CONCEPTS

The alternative concepts for the Canister retrieval are presented by a sequence of operations. Finite examination of the operation has been confined to the procedures which could give rise to an accidental release of radiation. The probability of release is the governing factor in the derivation and the ultimate selection of baseline concepts for each retrieval subsystem.

8.1 Alternatives to a Floor Flange

As alternatives to a Floor Flange/Gate Unit described in Section 2.3, the following concepts were considered:

- a) The extraction unit would self-mine (burrow) below the top of the sleeve and displace mined material outward for sealing purposes;
- b) The extraction unit would excavate below the top of the concrete plug, grab and seal around the sleeve, and extract the sleeve with plug and Canister contained within the sleeve;
- c) No additional equipment would be used since the extraction unit weight would constitute an adequate seal.

In the above concepts, there is no provision for isolation of an opened hole (concrete plug removed), which could lead to a radiation release. In this event, the emplacement room would have to be immediately vacated and sealed. Then the synergistic effects could be determined and corrective action instituted.

The alternative concepts predicate that the plug extraction unit would also have to remove the Canister, thereby increasing the probability of the unit's failure while over an open emplacement hole. This situation would necessitate in situ machine abandonment and detour tunneling. The desirability of individual extraction units is addressed in Section 8.2.

Since the probability of accidental radiation release is sufficiently increased by using concepts a and c, these alternatives are withdrawn from further study.

Similarly, alternative concept b offers no provisions for isolation of an opened hole. Should the machine fail in midmode, especially after the plug-draw-in cycle is completed, the machine could not be moved away from the opened hole and safely repaired. Consequently, alternative b is excluded from further study.

8.2 Evaluation of Plug Extraction Methods

Two plug removal systems are considered; one system would have the plug removal apparatus integral with the Canister extraction and transport machine; the other system would have the plug removal apparatus in a separate machine.

The advantages of having the plug removal apparatus integral with the retrieval transport machine are: having all retrieval functions under one operator's control; and avoiding the exposure to radiation release caused by the repositioning of a second machine over the emplacement.

The advantages of having a separate machine for plug removal are as follows:

a) The separation of operations into two machines allows more efficient operation by having the plug removal machine service more than one Canister emplacement.

b) The Canister Extraction/Transporter (CET) need not carry the plug handling machinery back and forth to the Canister Waste Subsurface Receiving Station (CWSRS).

c) A breakdown of the retrieval and/or travel function does not affect the function of the plug removal machine (PRM) and vice versa.

8.3 Degraded Canister Extraction Concepts

8.3.1 General

The retrieval concepts presented herein are based on emplacement of spent unprocessed fuel (SURF) in a thick steel sleeve as previously conceived in other reports ⁽¹⁾⁽³⁾. In this report a 60 year retrieval life is assumed rather than the 25 years expectancy cited in the former reports. The emplacement details are as shown on Figure 8.3.1.

Five of the concepts considered require extracting the sleeve from the salt with the Canister inside the sleeve; one concept retrieves the Canister only. This last concept requires a clear space between the Canister and the sleeve to permit insertion of a retrieval tool. The sequence of operations for all concepts is summarized on Figure 8.3.2.

Figure 8.3.1
EMPLACEMENT DETAILS (DEFINITION OF TERMINOLOGY)

NO	SEQUENCE OF OPERATIONS	CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D	CONCEPT E	CONCEPT F
1.	Attach floor flange with gate over hole.						
2.	Locate and index drill vehicle over hole.						
3.	Open gate.						
4.	Overcore drill to a point below Canister top.						
5.	Remove and store salt from drilling.						
6.	Retract drill.						
7.	Attach hook to concrete hole plug.						
8.	Remove and store concrete plug.						
9.	Cut off upper sleeve.						
10.	Attach clamp device to upper sleeve.						
11.	Remove and store upper sleeve.						
12.	Lower transporter cask into hole.						
13.	Lower clamp mechanism into hole.						
14.	Attach clamp mechanism to lower sleeve.						
15.	Lower core drill into hole.						
16.	Overcore lower sleeve to the bottom of sleeve.						
17.	Withdraw core drill and clamp mechanism with sleeve and Canister into cask.						
18.	Raise transporter cask out of hole.						
19.	Backfill hole with salt and/ or plug.						
20.	Close hole cover door.						
21.	Detach floor flange.						
22.	Transport sleeve, plug and Canister to underground receiving facility.						
23.	Locate transporter over Canister transfer basket.						
24.	Lower sleeve and Canister into transfer basket.						
25.	Move transfer basket into elevator.						
26.	Elevate transfer basket to surface receiving facility.						
27.	Deposit cutoff part or sleeve in TRU scrap.						

Figure 8.3.2
CANISTER RETRIEVAL SYSTEMS
CONCEPT OF OPERATIONS MATRIX

An additional concept not included in this study is the retrieval of a sound Canister by the same or similar equipment to the emplacement equipment. This current study considers essentially the retrieval of degraded Canisters.

8.3.2 General Conditions

The drift must be remined to dimensions required for the retrieval machinery, or approximately 18 feet wide by 30 feet high.

The emplacement room must be ventilated with decontaminated air to reduce the room temperature to a level suitable for men and machines (see Subsection 10.3.4).

The Canister must be located by survey or monitoring instruments and the position of the sleeve and Canister accurately determined as to depth and declination.

A radiation shield must be provided either as a separate piece called a "floor flange," or as an integral part of the retrieval-transport machine, covered in Section 8.1. The shield must provide a means to contain the radiation hazard when the concrete plug in the top of the sleeve is removed.

In all concepts requiring removal of the sleeve from the salt, the sleeve must be cut into two pieces with a dividing line at approximately the same level as the top of the Canister to allow retrieval within the room height assumed.

An alternative to the midpoint separation of the sleeve would be to require that the overcore unit be equipped with a ceiling mining device to automatically undercut the ceiling as it is raised from the horizontal to the vertical position. The minimum floor to ceiling height of the emplacement room above the machine must be 45'-0" to allow complete removal of the sleeve in one operation. This latter method was preferred by the Drilling Contractors surveyed (see Section 9.2).

8.3.3 Concept A: Retrieval by Overcore

This retrieval concept consists of overcoring around the periphery of the sleeve and retrieving the sleeve, with the Canister inside, by means of undercutting latches or lighting fingers that are extended under the sleeve at the end of the drilling operations.

Retrieval by overcoring is a technique commonly used in drilling large diameter holes in relatively soft material. The coring bucket is fitted with teeth and the core is lifted out of the hole with the bucket.

The concept is shown on Figure 8.3.1A1, and a sequence of operation to retrieve a degraded Canister is shown on Figure 8.3.1A2.

8.3.4 Concept B: Extraction by Overcore Clamp and Hoist

This extraciton concept uses the lower sleeve as a "bucket" to contain the degraded Canister which would be lifted out of a hoist. The procedure would be as shown on Figure 8.3.2B1.

CONCEPT A
LIFTING OUT SLEEVE WITH CANISTER AS CORE DRILL TYPE OPERATION

Figure 8.3.1A1

CONCEPT A
SEQUENCE OF OPERATION TO RETRIEVE A
DEGRADED CANISTER FROM A DEGRADED SLEEVE

Figure 8.3.1A2

CONCEPT B
OVERCORE SLEEVE AND RAISE SLEEVE WITH CLAMP AND HOIST

Figure 8.3.2B1

CONCEPT B
SEQUENCE OF OPERATION TO RETRIEVE A
DEGRADED CANISTER FROM A DEGRADED SLEEVE

Figure 8.3.2B2

The sequence for extraction of a degraded sleeve would be as shown on Figure 8.3.2B2.

This concept is similar to Concept A, except that a clamp is attached to the sleeve, instead of using the undercutting latches.

8.3.5 Concept C: Extraction by Conventional Excavating

This concept uses conventional excavating methods to uncover the sleeve and retrieve the sleeve with the Canister inside. The previous concepts require custom-designed machinery which would be relatively expensive.

The equipment required for excavating would have to be capable of excavating to approximately 27'-0" deep within the room dimensions of 30'-0" high by 18'-0" wide. The transporter cask would be mounted to permit the cask to be supported off the rear of the transporter so that transporter wheels are clear of the excavation. The excavation procedure is approximately as shown on Figure 8.3.3C1.

The excavating machine is assumed to be similar to a trenching machine with chain and bucket line. The machine would require means of collecting the excavated material, and radiation shielding in some manner not now defined. A separate or integral means would be provided to pull the sleeve with the Canister into the transporter.

The sequence of retrieval of a degraded sleeve would be as shown on Figure 8.3.3C2.

CONCEPT C
EXCAVATE WITH CONVENTIONAL EXCAVATING TOOLS

Figure 8.3.3C1

CONCEPT C
SEQUENCE OF OPERATION TO RETRIEVE A DEGRADED CANISTER

Figure 8.3.3C2

8.3.6 Concept D: Extraction by Partial Overcore and Pull

This extraction concept is similar to Concept B in that an overcore drill would be used to expose the sleeve down to a point below the top of the Canister, then a clamp would grip the lower sleeve and pull it out of the salt as in post or pole-pulling. The procedure would be as shown on Figure 8.3.4D1.

The sequence for retrieval of a degraded sleeve would be as shown on Figure 8.3.4D2.

8.3.7 Concept E: Retrieval by Excavation, Drill and Hoist

This concept is similar to Concept A except that the height limitation of the room is overcome by excavating a trench over the lower sleeve to allow added height for the transporter drill mechanism, as shown on Figure 8.3.5E1.

The sequence for retrieval of a degraded Canister would be as shown on Figure 8.3.5E2.

8.3.8 Concept F: Extraction from Inside the Sleeve

The previous concepts were all based on extracting the Canister by retrieving the sleeve with the Canister inside. Concept F extracts only the Canister leaving the sleeve intact, as shown on Figure 8.3.6F1.

The sequence for retrieval of a degraded Canister would be as shown on Figure 8.3.6F2. This concept requires an annular space between the Canister and the sleeve for insertion of the retrieval tool, and presumes that good alignment is maintained between equipment, sleeve and Canister.

CONCEPT D
OVERCORE SLEEVE TO THE TOP OF CANISTER
AND PULL SLEEVE AS IN POLE OR POST PULLING

Figure 8.3.4D1

CONCEPT D
SEQUENCE OF OPERATION TO RETRIEVE A DEGRADED CANISTER

CONCEPT E EXCAVATE DRILL AND LOWER THE TRANSPORTER CASK INTO THE HOLE

Pro:

1. Permits lower room height.
2. Minimum radiation hazard.
3. Minimum hazard of sealing failure.

Procedure:

1. Excavate hole around upper sleeve large enough to accommodate the barrel of the transporter cask.
2. Cut and remove the upper sleeve and plug.
3. Lower the transporter cask into the hole.
4. Overcore the sleeve and Canister list into transporter.

Con:

1. The sleeve must be sound to contain the Canister.
2. The sleeve must be cutoff.
3. The floor shield opening will be large.

Figure 8.3.5E1

CONCEPT E

SEQUENCE OF OPERATION TO RETRIEVE A DEGRADED CANISTER

Figure 8.3.5E2

CONCEPT F
EXTRACTION OF CANISTER FROM INSIDE INTACT SLEEVE

Figure 8.3.6F1

CONCEPT F

SEQUENCE OF OPERATION TO RETRIEVE A DEGRADED CANISTER FROM AN INTACT SLEEVE

Figure 8.3.6F2

This concept also requires the installation of a precast concrete base in the bottom of the sleeve prior to emplacement of the Canister. The concrete base will support the Canister above the bottom of the sleeve to provide a space for remote actuated harpoon-type grabs to grip the base and enclose the Canister for removal from the sleeve.

8.4 Alternatives for Subterranean Transport

An alternative concept to the baseline concept of having the extraction device transport the Canister to the Canister Waste Subsurface Receiving Station (CWSRS) would be to transfer the retrieved Canister from the extraction vehicle to a separate transport vehicle at the site of extraction. The Canister would be transferred at the CWSRS to another vehicle for transfer to the hoist system as shown on Figure 5.

The advantages of this concept are:

- a) Each vehicle would have a fully utilized limited function. The retrieval vehicle would remain in the emplacement room doing only retrieval work. The transporter would be used only for transport.
- b) The transporter, by being relieved of the retrieval machinery, may be able to carry more Canisters.

The disadvantages of the concept:

a) Since the retrieval machine precedes and draws the grapple end of the Canister into the chamber, the grapple cannot be transferred to another machine.

b) A transfer to the emplacement room increases the opportunities for accident and malfunction.

Since an increase in the accident or malfunction frequency is undesirable, this concept is not considered further.

8.5 Alternative Methods of Electric Power Distribution

8.5.1 General

Three basic types of power systems are considered:

- a) Overhead catenary wire system;
- b) Power (third) rail;
- c) On board power source with plug in power centers equally distributed in the emplacement rooms.

The plug-in power centers would provide recharging current and power for extraction. All systems require power distribution from a central source; fully redundant systems are recommended.

8.5.2 Overhead Catenary Wire System

The overhead catenary system would be practical for ordinary mining operations. In a salt mine, especially a neglected emplacement chamber, the system would have to be either removed after emplacement or before remining because of ceiling displacements. Furthermore, continuous maintenance would be required to assure system reliability.

8.5.3 Power Rail

The power rail concept is not practical for the retrieval operations because:

- a) The rail would interfere with tie mining and emplacement operations;
- b) The rail would have to be interrupted at the corridor/emplacement room intersection, requiring an alternate motive power design accommodation;
- c) In a mine with the possibility of power outage, and under the normal circumstances of poor illumination, the system would be an extreme hazard to personnel.

8.5.4 "On Board" Power Source

The mine locomotive on board-type battery system has advantages in travel flexibility, switching, conductor corrosion, and freedom from accidental contact, and will be used in this study.

For the extraction and other operations within the emplacement room, power centers would be used as suggested in other Nuclear Waste Management Project studies.⁽¹⁶⁾

9.0 CANISTER EXTRACTION CONCEPT EVALUATION

Six concepts for the extraction of degraded Canisters were developed in Section 8.3, five concepts involving removal of the Canister and the sleeve, and one concept involving insertion of a removal tool in the space between the Canister and the inside wall of the sleeve to remove the Canister only.

Most of the attention in this report is given to the method of extracting the degraded Canister from its Depository in the salt, since it is the governing step in the retrieval operation. Retrieval also includes transport and handling of the retrieved Canister in the corridor and at the subterranean receiving station.

Each of the extraction concepts is evaluated by judging a set of parameters which affects the ease and safety of the retrieval operation.

9.1 Rating Scale

A rating scale to evaluate the retrieval concepts will be used with numeric values assigned to each parameter. This scale is shown as Figure 9.1.1.

Figure 9.1.1 RATING SCALE

Concept	Solution	Undesirable Event	Rating
Bad	Not feasible	Will occur	1
Poor	Has problems	Likely to occur	3
Good	Can be done	Unlikely to occur	5
Very good	No major problems	Very unlikely to occur	7
Excellent	Excellent solution	Will not occur	9

9.2 Technical Feasibility

Although Canister retrieval may be carried out from five to sixty years after activation of the disposal facility, each retrieval concept will be judged on the basis of technical feasibility using existing technology.

The technical feasibility requirements include retrieval operations which can be performed by equipment within the limits of today's technology for design and manufacture, and which can be operated remotely.

9.2.1 Overcoring Telephone Survey

Thirty-five firms were contacted and twenty-nine replied with thirteen responses from manufacturers and sixteen responses from drilling contractors. A list of firms contacted and the questions asked are included in Appendix 1 and summarized on Figure 9.2.1.

Of the sixteen responses from drilling contractors, approximately two-thirds indicated that overcoring a 20-inch diameter pipe could be done and is being done at the present time.

The method of drilling referred to by most drilling contractors was a coring bucket.

Of the various primary power sources, most drilling contractors and manufacturers prefer to have electric power supplied to them rather than pneumatic or hydraulic power although most would convert the electric power to hydraulic power at the unit.

QUESTION	ANSWER	EQUIPMENT (CONTRACTORS)			
		NUMBER	NUMBER	NUMBER	TOTAL
Q1. Does core drill exist that can overcore 22" I.D.?	A1. Yes	5	38	8	50
	No	6	46	5	31
	No Answer	2	16	3	19
Q2. What type of drill would you use?	A2. Rotary	9	70	7	44
	Coring auger	0		1	6
	Coring auger w/core bucket	0		3	19
	Other	0		1	6
	No answer	4	30	4	25
Q3A. What length sections would be used for core barrel?	A3A. Single Barrel	1	8	1	6
	2 to 4 feet sections	3	23	4	25
	5 to 7 feet sections	1	8	3	19
	8 to 10 feet sections	1	8	2	13
	No answer	7	53	6	37
Q3B. Would coupling of sections be a problem?	A3B. Yes	3	24	4	25
	No	5	38	6	38
	No answer	5	38	6	37
Q4. Would drilling be rapid in salt?	A4. Yes	6	46	11	69
	No	0		1	6
	No answer	7	54	4	25
Q5. How much time would you estimate for drilling operation?	A5. Less than one per shift	0		2	13
	One or two per shift	1	8	5	31
	More than two per shift	1	8	1	6
	Other	0		0	
	No answer	11	84	8	50
Q6A. Would remotely supplied hydraulic or air power source be feasible?	A6A. Air	0		3	19
	Hydraulic	4	30	2	12
	Either	1	8	3	19
	Other	3	24	4	25
	No answer	5	38	4	25
Q6B. Which power source would you choose: air, hydraulic or electric?	A6B. Air	0		2	13
	Hydraulic	4	31	1	6
	Electric	4	31	6	38
	Air or electric	0		1	6
	Hydraulic or electric	0		1	6
	No answer	5	38	5	31
Q7. If pipes were installed in granite or basalt and backfilled with same material, would over-coring be feasible?	A7. Yes	5	38	6	38
	No	1	8	5	31
	No answer	7	54	5	31

Figure 9.2.1
TELEPHONE SURVEY RESULTS

Telephone Survey Conclusions

Question 1.

A high percentage of those contacted (45%) indicated that overcoring can be done. Contractors who regularly do coring work in concrete were most responsive.

Question 2.

Equipment is generally assembled, or fabricated and assembled, by contractors for normal core drilling operations. However, some equipment manufacturers indicated they would build special equipment.

Due to the nature of the overcoring problem requiring shielding and remote handling, special equipment would be necessary.

Question 3.

Coupling of sections in the core barrel can be done. Most often mentioned was a screw coupling that provides a smooth interior and exterior surface.

Question 4.

The opinion of those answering was nearly unanimous that drilling in salt would be rapid.

Question 5.

Most of those contacted declined to estimate drilling speed without further study. Of those who gave an estimate, one or two holes per shift was most frequently mentioned.

9.2.2 Technical Feasibility Evaluation

Concepts A and B are straightforward core drilling operations involving overcoring to the bottom of the sleeve and retrieving the sleeve which has been freed from the salt. The core drill must include control devices designed to minimize drill drift; unrestrained, the drill could drift into and penetrate the sleeve and thereby damage the Canister.

The feasibility of overcoring has been established by the telephone survey. With drill drift control parameters assumed to be incorporated into the designs, a feasibility rating of 5 can be assigned to concepts A and B.

Concept C depends on excavating equipment to free the sleeve from the salt. It would be difficult to shield to prevent radiation release and free the sleeve from the salt. Concept C is therefore given a feasibility rating of 1.

Concept D, in addition to requiring overcoring, also requires pulling the Canister from the salt. This would necessitate a very heavy pulling force, even though the sleeve could be rotated to obviate this force somewhat.

This would not be desirable for a sacrificial sleeve weakened by corrosion, since any applied forces could rupture the sleeve. A feasibility rating of 3 is assigned to Concept D.

Concept E involves core drilling similar to Concepts A and B however Concept E has problems associated with lowering the transporter cask into the hole. Therefore, this concept is given a feasibility rating of 3.

Concept F does not involve overcoring, but is based on the assumption that the Canister, although degraded, has retained its generally vertical form and some annular space between the sleeve and Canister wall remains. The design complexity required to overcome the following problems lowers the feasibility rating:

- a) Adequate bottom base latching;
- b) Ram binding in the sleeve interior shell caused by misalignment of sleeve and machine or sleeve longitudinal distortion (bends).

For these reasons, a rating of 4 is assigned.

9.3 Radiation Shielding

Each concept is judged on the basis of ease and effectiveness in providing and maintaining a shield or seal to prevent radiation escape into the emplacement room during and after the retrieval operation.

Personnel radiation protection must be provided and maintained. In all concepts radiation shielding must be provided at the mating point of the machine and the floor of the emplacement room. The seal must be achieved prior to the removal of the concrete radiation plug and maintained intact throughout the retrieval cycle. A radiation shield receptacle must also be provided for the plug during the operation.

9.3.1 Radiation Shielding Evaluation

Concepts B, D and F would require a radiation shield with a closure to seal between the retrieval machine and the emplacement room floor during retrieval operation. It appears that this can be done and these concepts will be assigned a rating of 5 for shielding.

Concept C presents serious problems in radiation shielding and gets a rating of 1, since shielding may not be feasible.

Concept E may have shielding problems at the slip-joint between the transporter cask barrel and the shield device and gets a rating of 3.

9.4 Reliability

The reliability of a concept is judged on the basis of projected ability to retrieve the degraded Canister at any time to the end of the retrieval period. It is anticipated that the Canister's integrity may be impaired by intrusion of brine if the protective environment of the sleeve is degraded.

Based on the concept that the degree of reliability of machinery is in inverse proportion to its complexity, concepts requiring complicated equipment are rated lower than concepts requiring simpler equipment.

9.4.1 Reliability Evaluation

Concepts A, B, D and E are approximately commensurate in complexity of retrieval and get a rating of 5 for reliability.

Concept C, while using simpler equipment for excavation, has problems pulling the Canister and sleeve out of the hole and into the transporter. This concept is less reliable than the others and gets a rating of 3 for reliability.

Concept F uses simple equipment of inherent high reliability and is assigned a rating of 6.

9.5 Power Failure

Each concept is rated on the effect of a primary power system failure. The primary power source is assumed to be electric or pneumatic power brought into the emplacement room from a central station. In addition to the primary power source, each machine is expected have an emergency power source as a backup to the primary power system. The emergency power source will have sufficient stored energy to finish a partially completed retrieval cycle when power failure occurs.

9.5.1 Power Failure Evaluation

Concepts A, B, D and E all use similar equipment. In the event of a power failure, the machine operation stops until power is restored or the emergency energy source is actuated. Since all components are to be shielded, no harm should come from a power interruption. An operation halted by power failure will be able to continue when power is restored. A power failure is unlikely to have bad effects beyond delay in retrieval and these concepts are rated 5 for power failure.

For Concept C there is greater probability of radiation leakage over an extended period of power failure and this concept is rated 3.

Concept F uses less power and reserve emergency power could be easily applied to continue the operation at a slower rate and is therefore rated at 7.

9.6 Human Failure Error

An estimate of the number of human decisions and actions required for each concept has been made and compared with the other concepts in order to arrive at an assessment of the effect of human error on the retrieval cycle.

The ratings are based on the following assumptions:

- a) Retrieval extraction procedures will be performed weekly throughout the retrieval period of 60 years;

b) Weekly retrieval will be performed on a randomly selected Canister emplacement;

c) Operator training will be continuous and uniformly intensive throughout the retrieval life.

9.6.1 Human Error Evaluation

Concepts A, B, D and E use similar equipment requiring about the same number of operations. Operation of the equipment will be similar to that of other heavy construction-type equipment requiring a skilled and responsible operator, and serious errors or misjudgments are unlikely to occur. These concepts are rated 5 for human error.

Because of the nature of the excavation equipment and the radiation sealing problems of Concept C, the likelihood of operator error is judged to be greater than the other concepts. Concept C will be rated 3 for human error.

Concept F operation is semiautomatic, almost precluding human error. The important aspect of machine alignment, which depends on system controls and human judgment, reduces the rating to 7.0.

9.7 Relative Cost

While not a factor in failure analysis, some weight should be given to relative cost of the retrieval system. Therefore, each retrieval concept is ranked in estimated order of cost from most expensive to least expensive and a factor of relative cost is assigned to each concept.

9.7.1 Relative Cost Evaluation

Concepts A, B and E are similar, the principal difference being in the method of lifting the sleeve and Canister into the transporter. The cost of these systems is judged to be approximately the same with a rating of 3 for cost.

Concept C, using conventional excavating tools, would probably cost less than the previously mentioned systems and is rated 5 for cost.

Concept D would require some additional heavy duty jacking equipment but the drilling machinery would be less costly than that used in Concept A or B. With these costs judged to offset each other, concept D is rated 3 for cost.

Concept F would probably cost approximately the same as Concept C and is rated 5.

9.8 Operating Time

Each concept is evaluated on the basis of the estimated time to retrieve a degraded Canister. A desirable concept is that the rate of retrieval should be the same as or greater than the rate of emplacement. The time estimates are based on well-maintained and cyclically operated machinery operated by well trained and experienced personnel.

9.8.1 Operating Time Evaluation

From the results of the telephone survey of drilling contractors, we estimate the retrieval rate of those concepts involving over-coring to be of the order of one or two Canisters per shift per retrieval machine. This is a slow and tedious rate of retrieval. Concepts A, B, D and E are rated 3 for operating time.

The retrieval rate for Concept C, involving conventional excavating tools, would not exceed one or two Canisters per day due to probable time-consuming procedures required to protect the operator from radiation, since shielded is not feasible. Concept C is rated 2 for operating time.

The retrieval rate for Concept F will be exceedingly fast, approximately 2 hours in duration, and is given a rating of 8.

9.9 Mechanical and Remote Operator Failure

Each concept is judged on the effect of mechanical failure or remote operator failure during the retrieval operation. The basis of comparison is the estimated number of remote operations to be performed during the retrieval operation.

9.9.1 Mechanical and Remote Operator Failure Evaluation

All concepts requiring retrieval of the sleeve with the Canister inside are approximately equal in the complexity of remote operations required. The operations for all concepts are graphically summarized on Figure 8.3.2.

A count of the operations listed on Figure 8.3.1A2 shows twenty-one for Concept A. Figure 8.3.2B2 shows twenty-four operations for Concept B, Figure 8.3.4D2 shows twenty-two operations for Concept D, and Figure 8.3.5E2 shows twenty-six operations for Concept E. Figure 8.3.3C2 shows seventeen operations for Concept C, but this set of procedures is not considered to be significantly less complex. During any one retrieval a mechanical failure is unlikely to occur and these concepts are rated 5.

The seventeen operations listed in Figure 8.3.6F2 for Concept F are significantly less complex than the previous listed concepts and Concept F is correspondingly rated 8.

Figure 9.10.1 SUMMARY OF CONCEPT EVALUATION

Concept	Concept	A	B	C	D	E	F
9.2.2	Technical Feasibility	5	5	1	3	3	4
9.3.1	Radiation Shielding	5	5	1	5	3	5
9.4.1	Reliability	5	5	3	5	5	7
9.5.1	Power Failure	5	5	3	5	5	7
9.6.1	Human Failure or Error	5	5	3	5	5	7
9.7.1	Relative Cost	3	3	5	3	3	5
9.8.1	Operating Time	3	3	2	3	3	8
9.9.1	Mechanical Failure	5	5	5	5	5	8
Totals		36	36	23	34	32	51

9.10 Conclusion

From Figure 9.10.1, the obvious choice for the extraction device for degraded Canisters is Concept F, and Concept C is the last choice.

When a Canister or sleeve is degraded to such an extent that retrieval cannot be performed using Concept F, alternative means must be provided. From the Figure 9.10.1, Concepts A, B and E can be utilized for the extraction of a degraded sleeve. The evaluation matrix, Figure 9.10.1, does not include the sleeve condition necessary for the concept to be feasible. Referring to Figures 8.3.1A1, 8.3.2B1, 8.3.4.D1 and 8.3.5.E1, all concepts except A require a sound sleeve. Concept A is feasible regardless of the sleeve condition and is therefore selected as the standby system to Concept F.

10.0 BASELINE DESIGN FOR RETRIEVAL OF A DEGRADED CANISTER

10.1 Reasons for Retrieval

Retrieval of Canisters may be done soon after emplacement in order to monitor and verify the Depository contents for safety.

10.2 Retrieval Rate

The optimum retrieval rate is faster than the rate of emplacement.

If the Depository facilities are designed for an emplacement rate that takes place over 30 years, then the retrieval of all the emplaced Canisters should take less than 30 years.

In the unlikely event that retrieval takes place simultaneously with emplacement, the retrieval rate will be reduced and will be subject to the rate at which the handling and transfer facilities at the underground receiving facility can coordinate emplacement and retrieval.

10.3 Procedures for Retrieval

The procedures for retrieving a degraded Canister are outlined in the summary and are repeated here as a prologue to the baseline design.

10.3.1 Survey of Emplacement Room, Refer to Figure 1

The survey crew shall locate the Canister and remap the existing emplacement room by various techniques including:

- a) Survey instruments;
- b) Old records;
- c) Ultrasonic instruments;
- d) Radio frequency detection devices;
- e) Radiation monitors;

Using all the methods available to the crew, location diagrams shall be made and data programmed via the vehicle mounted computer remote terminal. The resulting computer-plotter three-dimensional maps shall include:

- a) Coordinates locating the intersection of the Canister axis with the floor of the emplacement room;
- b) The tilt of the sleeve axis;
- c) The position and tilt of the Canister within the sleeve;
- d) The condition of the Canister as determined by radiation monitors and pressure gauge and gas detection probes;
- e) Depth of sleeve and Canister;
- f) Depth of salt cover.

10.3.2 Retrieval for Depository Monitoring

The equipment shall include radiation monitors in the emplacement room to assess the radiologic conditions, so that occupational radiation exposures can be maintained at as low a number as possible.

10.3.3 Remining, Refer to Figure 2

The emplacement room shall be remined as required to accommodate the machines to be used for retrieval of the degraded Canisters.

10.3.4 Ventilation

Sufficient ventilation shall be provided to maintain a temperature in the emplacement room below 100 F to comply with the requirements of the U.S. Bureau of Mines, Mining Enforcement and Safety Administration (MESA). It is projected that ventilation air will be recirculated, and thus will not allow use of diesel engine or similar internal combustion power for the retrieval machinery.

10.3.5 Emplacement Package

The spent unprocessed fuel shall be packaged for emplacement at the surface Canistered Waste Receiving Building (CWRB) to provide a minimum of variation in packaging for emplacement.

10.3.6 Retrieval Machinery

The retrieval machinery will retrieve SURF Canisters which have been emplaced for up to 60 years in a protective steel sleeve, transport the Canisters through the corridors to the Canistered Waste Subsurface Receiving Station (CWSRS) and transfer the Canister to the transfer basket for transfer to the elevator, and hoisting to the Canistered Waste Receiving Building (CWRB) at the surface.

10.4 Baseline Design Concept for Retrieval, Figures 3, 4a, 4b, 4c, 4d, 4e and 4f

For large-scale retrieval of many weakened Canisters, the baseline design concept recommended for retrieval is the concept described in Section 8 as Concept F. A standby machine for sleeve extraction by means of overcoring, described in Section 8 as Concept A, will be provided to perform extraction upon command from the operations center described in Section 4.

Considering the evolution from prior studies, the recommended retrieval operations are based on the following assumptions:

- a) The Canister is weakened by corrosion or accidental damage to such an extent that the stresses induced by lifting the Canister from the top, as in the emplacement, would rupture the cylinder;
- b) Monitoring of internal gas release⁽¹²⁾ would be subject to human error;

c) The conduit for instrument monitoring through the concrete plug is a source for brine intrusion to the interior and radiation leakage, and may not be provided.

Therefore, no distinction will be made between sound and degraded Canisters, and all Canisters shall be retrieved by overpack. It is reasonable to assume that the emplacement machines shall not be used for extraction.

Two machines are required for ordinary Canister extraction. One machine shall be used to remove the concrete shielding plug sitting in the sleeve above the Canister. The other machine will be a combination Canister Extraction/Transporter machine. The retrieval sequence is shown on Figures 3, 4a, 4b, 4c, 4d, 4e, 4f, 5 and 8.3.6F1.

The equipment shall be suitable for operation in a salt mine at elevation minus 1850 feet (assumed) in an ambient temperature 90 F to 120 F (per MESA, see Subsection 10.3.4). The salt will contain small amounts of moisture, but can be considered to be practically dry.

10.4.1 Remote Operation

After the shielded hole cover is installed, all retrieval operations shall be done by remote control. The operator shall control all retrieval operations from a shielded control room remote from the vehicle.

10.4.2 Codes and Standards

The equipment and procedures for retrieval of SURF Canisters shall comply with the requirements of the following regulatory agencies:

Occupational Safety and Health Administration (OSHA) (49CFR1910)

Mining Enforcement and Safety Administration (MESA)

Nuclear Regulatory Commission such as 10 CFR 20 and 10 CFR 100

National Fire Protection Association (NFPA)

Applicable State Codes

10.4.3 Steering Modes

Steering mode for transporter corridor travel shall be manual.

Steering mode for travel in the emplacement room shall be automatic guidance system which may be a wire or laser type (refer to Figure 2.5.5).

10.4.4 Travel Speed

The travel speed of the transporter shall be continuously variable from 0 to 10 miles per hour.

For manual steering, speeds to 10 miles per hour shall be permitted in the corridor. For automatic guidance in the emplacement room, speeds to 5 miles per hour shall be permitted.

10.4.5 Power Supply

Motive power for mobile units shall be supplied by means of on-board mine type locomotive batteries. Electric power for the retrieval operations will be obtained from skid-mounted mining-type power centers set in recesses in the emplacement room walls. Power for the retrieval machinery will be tapped by means of cable plug and receptacle.⁽¹³⁾ The power centers shall be suitably designed for the salt mine environment, sealed and purged by an inert atmosphere. Power from the Depository ground surface elevation to the panels will be supplied from a central power distribution network with full redundancy.

10.4.6 Travel Distance

The maximum travel distance shall be approximately 11,500 feet one-way⁽¹⁴⁾, and 23,000 feet round trip. The average distance one-way is 6,500 feet, as stated in Section 6.8.

10.4.7 Incline

The transporter shall also be required to pull upgrade and brake downgrade at a design limit of 15% grade from elevation minus 1850 feet to elevation minus 1776 feet.

10.4.8 Access to Mine

Parts shall be designed for lowering and assembling at the site using the men and material elevator with an 8 by 16 foot cage and with a capacity of 26 tons.⁽¹⁵⁾

10.4.9 Emergency Power

A receptacle for plugging in emergency power shall be provided on each vehicle. The emergency power shall be used to release brakes and/or provide driving power from a service or rescue vehicle. This vehicle shall be utilized in the event of an operational breakdown or to tow away a defective vehicle in the event of a breakdown while traveling.

An emergency power source on each vehicle shall be provided to maintain critical vehicle functions including lighting, ventilation, cooling and communication. This emergency power shall be provided by a separate battery system capable of sustaining the critical functions until a service vehicle can be dispatched to the breakdown area.

10.4.10 Communication

Communication between vehicles and the operations control center shall be by two-way radio which shall require antenna wire strung in the corridors and emplacement rooms. An emergency alarm system shall alert operations control in the event of a communication failure.

10.4.11 Equipment Design Life

The emplacement operation is assumed to be three 6½ hour shifts or 20 hours per day, 250 days per year. If emplacement stops and retrieval begins after thirty years of emplacement, a total of 228,144 PWR Canisters and 344,862 BWR Canisters will have been emplaced⁽¹⁶⁾, totaling 573,006 Canisters.^(**)

Twelve CET's (8 working, 4 standby) and six PRM's (4 working, 2 standby) are required to each retrieve 2,375 Canisters per year; each vehicle must reclaim 11,875 Canisters in five years, before vehicle replacement. These statements are based on the following assumptions:

- a) An average retrieval rate of 19,000 Canisters per year;
- b) The vehicle life is five years.

Three COT's (2 working, 1 standby) and three POM's (2 working, 1 standby) are required to retrieve the quantity of Canisters abandoned in place after attempts at retrieval by the CET's had failed. These statements are based on the following assumptions:

- a) A CET takes 2 minutes to extract the Canister and a COT and POM will each take approximately 240 minutes to remove this Canister;

** See Appendix 4

b) One out of fifty of the Canisters will be handled by the COTs;

c) The POMs and COTs work in emplacement rooms that have been previously cleared by the PRMs and CETs, and no traffic congestion will occur in the emplacement rooms or the corridors.

d) Work performed by all units is performed sequentially, i.e. the POMs and COTs are moved into an emplacement room after the PRMs and CETs have finished their task therein.

10.5 Canister Extraction/Transporter (CET) Conceptual Specifications, Figures 4c, 4d, 4e and 4f

10.5.1 General

The Canister Extraction/Transporter machine (CET) shall be custom-designed to retrieve the Canister from an intact sleeve, transport the Canister to the Canistered Waste Subsurface Receiving Station (CWSRS) and transfer the Canister to the receiving facility for transfer to the canistered waste elevator.

10.5.2 Design Limitations

The limitations placed on the CET shall include those mentioned in the following subsections:

10.5.2.1 Size

The machine shall be designed to perform its functions within the remined room space dimensions of 18'-0" wide by 30'-0" high and should be able to travel through 25-foot high connecting corridors. The room height is an important limitation since the retrieval mechanism must reach to approximately 27'-0" below the floor, and then fold up in the space above the retrieved canister.

10.5.2.2 Power

Sufficient ventilation will not be available to permit the use of internal combustion engine-powered equipment which contains H_2O and CO in the exhaust. Mining-type electric power centers shall be available for operation of the equipment at the point of retrieval. For transporter travel, the power source shall be mine locomotive-type battery systems.

10.5.2.3 Restricted Travel in the Emplacement Room

First, the CET shall not be able to pass another vehicle in the 18-foot wide room.

Second, the CET shall not be able to turn around in the 18 foot wide room. The vehicle shall have to back in one way.

Third, the CET shall be a long bed unit.

For these reasons and to allow the operator full visual control, the CET shall be equipped with shielded operator cabs on each end of the vehicle. The cabs shall each have a set of controls including redundant circuits to allow the operator to drive the unit from either cab.

10.5.3 Safety and Health Protection

10.5.3.1 Cave-In Protection

The retrieval-transporter machine shall be designed to provide protection for personnel and Canisters in event of a cave-in of the roof or walls of the corridors or emplacement rooms.

10.5.3.2 Roll-Over Protection

Protection for personnel and Canisters shall be provided in event of accidental overturn of the extraction/transporter

10.5.3.3 Radiation Shielding

Shielding shall be provided to protect the occupants of the operator's cab in the event of accidental exposure to an unshielded Canister. Radiation monitoring equipment shall be designed to indicate and enunciate high radiation levels both inside and outside the cab.

10.5.3.4 Fire Protection

Fire protection shall conform to Federal, State and local codes for NFPA classification Class I, Group D, Division 2. The use of fire-resistant hydraulic fluid is mandatory.

Noncombustible materials shall be used in the construction of the extraction/transporter wherever possible. Materials producing toxic or explosive gas, vapors or smoke when burned shall not be used, insofar as possible.

Fire and smoke detectors and alarms shall be provided to alert the extraction/transporter operator and operations control center.

Fire suppression systems shall be provided on the CET and shall be actuated by the CET operator.

10.5.3.5 Noise Control

Permissible noise exposure in the cab of the extraction/transporter shall not exceed 87 dBA under any condition of operation of the extraction/transporter machinery.

Permissible noise exposure during the Canister retrieval operation shall not exceed 100 dBA at any point measured 3 feet from the CET.

Permissible noise exposure during travel of the extraction/transporter at any speed in the emplacement room or the corridor shall not exceed 100 dBA at any point measured 3 feet from the CET.

10.5.3.6 Emergency Equipment

Emergency equipment provided on each vehicle shall include fire extinguishers, first aid kit, portable breathing apparatus with a thirty-minute oxygen supply and a radiation suit for personal exposure protection.

Each vehicle shall have a manually-operated emergency exit door release system to allow the operator's cab doors to be pushed open for emergency escape, with controls to prevent operator escape when radiation levels are too high.

A frangible breakaway at the piston connection point to the retrieval ram shall be activated by the operator to allow disengagement of the unit from an emplacement due to a malfunctioning operation. The actuation shall be limited to when the top of the ram (overpack) is a safe distance below the floor, so the floor flange can be closed completely.

Each cab shall be equipped with a self-contained regenerative recirculating air supply system designed to supply the daily oxygen needs of the operator in the event of vehicle entrapment.

10.5.4 General Design Requirements

Canister Extraction/Transporter shall include the following major subassemblies:

- a) Chassis with cab and transporter drive;
- b) Electric driven hydraulic power supply system;
- c) Cask with raising and axis orientation systems and bottom gate;
- d) Canister retrieval system;
- e) Canister ram unit (overpack);

These main subassemblies shall be made up of many other components and/or subassemblies, each of which shall be selected or designed to optimize the following:

- a) Safety;
- b) Reliability;
- c) Durability;
- d) Ease of maintenance;
- e) Simplicity;
- f) Ease of access for inspection, service and decontamination.

10.5.5 Subassembly Design Requirements

Design requirements for the extraction/transporter subassemblies shall be as described in the following subsections:

10.5.5.1 Chassis and Power Train

The chassis and power train shall be custom-designed and built utilizing stock components of reliable equipment manufacturers wherever possible.

The design will include:

- a) Chassis - custom designed and built;
- b) Wheels - heavy-duty pneumatic rubber-tired wheels as used on heavy construction equipment;
- c) Transporter drive - mine locomotive type;

- d) Power - mine locomotive battery power for the travel drive;
 - e) Emergency power system - separate battery system to supply emergency lighting, cab ventilation, communication, vehicle controls;
 - f) Steering - hydraulic power steering on front end only with manual steering for corridor travel and a controlled guidance system for travel in the emplacement room, and proximity controls for positioning the vehicle for retrieval and unloading of Canisters;
 - g) Operator cabs shall be located at each end of the CET.
- The cabs shall be air-conditioned and designed to meet the life support criterion of Subsection 10.5.3.6.

10.5.5.2 Electric-Driven Hydraulic Power Supply System

The power for the retrieval operation shall come from a power cable connected to the mining type electric power centers located in the emplacement room. The cable shall be unreeled from a cable reel mounted on the vehicle. An electric interlock shall prevent movement of the transporter vehicle when the power is connected.

The following subsystems shall be electric motor driven: cask bottom gate, ram unit Canister bottom latch, motive power drive, and indexing.

The hydraulic system shall be selected from standard components of established hydraulic equipment manufacturers. The hydraulic system shall be a medium pressure, 2500 psig, system.

All hydraulic cylinders and electric motors in the system shall have suitable seals to prevent the debris infiltration of radiation deterioration-resistant material. Cast iron seals with chrome-plated piston rods are acceptable for hydraulic piston seals.

10.5.5.3 Cask with Raising and Axis Orientation Systems

The retrieval cask shall be designed to form a radiation shield and shall be large enough to receive the Canister ram unit and raising system as follows:

- a) Canister ram unit dimensions - length 17'6",
O.D. 11½" (BWR), and
O.D. 15½" (PWR);
- b) Ram unit construction - steel sheet or plate, rolled and welded or steel tubing designed to be annularly guided by interior of sleeve with captive bearings to reduce sliding friction and blunt tapered nose to reduce Canister damage;
- c) Concrete collar placed under Canister at sleeve bottom - design shall be compatible with steel overcan "harpoon grab" device.
- d) Ram unit connection - quick detachable connection and a standby operator-controlled disconnect joint compatible with the telescoping cylinder;

- e) Ram raising system shall consist of mechanical screw jacks with cross head and guises and hydraulic piston designed to extend ram reach to below bottom of Canister.
- f) Ram - sufficient to overpack the Canister and latch onto the concrete collar in the bottom of the sleeve;
- g) Transporter travel - cask position is horizontal;
- h) Cask axis orientation mechanism - a platform mounted on jacks to allow adjustment of the cask tilt angle;
- i) Cask bottom gate - shall be electric motor powered and shall include key latch to engage and open floor flange gate. Gate seals shall be designed to pre-wipe sealing surface free of debris.

10.5.5.4 Canister Retrieval

For Canister retrieval, the cask tilt changes from horizontal to approximately ten degrees past vertical, i.e., from 0° to 100° . The adjustment of the angle from vertical is necessary to match the tilt of the Canister axis. The adjustment of the cask angle provides one plane of tilt, and the other plane of tilt is obtained by tilting the cask platform axis, approximately ten degrees starboard or port.

The Canister retrieval mechanism shall include a quick detachable connection for picking up and releasing the ram unit which serves as a Canister overpack (see Figure 6.3.2).

10.6 Floor Flange Installation Equipment Conceptual Specifications

10.6.1 General

A motorized self-contained multiple drill unit shall be moved to the area to drill the rock bolt holes concentric to the sleeve monument location. This machine shall be in position to drill rapidly at each location, and a second machine shall insert the rock bolts and pressure grout each in place. Immediately following, a floor mounted radiation shield emplacement device shall automatically place a thick flange/gate unit over each hole. The Floor Flange could be the same unit that was specified for emplacement operations. The Floor Flange shall be placed over every Canister with every Canister at this stage being considered degraded. This specially designed Floor Flange emplacement device shall also tighten the Floor Flange to the floor and seal the Floor Flange with pressure grout.

10.6.2 Basic Equipment Description

The Floor Flange installation equipment shall be electrically powered from one of the mining power centers located in the emplacement room. The equipment shall be wheel driven (rather than tracked) for mobility.

Remote handling shall not be required and the personnel can operate the equipment from the floor. Equipment controls shall be mounted on the side of the vehicle to allow operation of the equipment from the floor.

10.6.3 Rock Bolt Drilling Unit Conceptual Specifications

The drilling equipment may be electric or air-driven with electric power supplied from mine power centers. If air-driven equipment is used, the drills shall be provided with silencing devices. Only air shall be used to clean the hole.

Drills shall be mounted on a self-propelled drill jig designed to precisely locate and drill the holes required for anchor bolting the shield. The machine shall be equipped with positioning controls to accurately align the unit over the center of the sleeve. The accuracy of the Floor Flange placement, which consequently affects the operability of the CET, depends on the alignment of the anchor bolts.

10.6.4 Anchor Bolt Placement Unit Conceptual Specifications

(May be Incorporated with the Rock Bolt Drilling Unit)

The anchor bolt placement unit shall be a self-propelled unit with adequate load capacity to convey a sufficient quantity of anchor bolts for all the Floor Flanges in an emplacement room. The unit shall be equipped with bolt holder and powered bolt torque system designed to fasten each bolt to the floor and allow adequate threaded

bolt extension to attach to the Floor Flange. Electric power for bolt placement operations shall be supplied by mine power center and motive power from on board rechargeable batteries.

10.6.5 Floor Flange Emplacement Device Conceptual Specifications

The radiation shield (Floor Flange) will be set by this device onto the anchor bolts, leveled and grouted as follows:

- a) Wax the surface of shield to be in contact with grout to minimize adhesions;
- b) Locate the shield over the emplaced Canisters;
- c) Level the shield;
- d) Grout the shield;
- e) Tighten anchor bolts.

The device shall be a self-propelled unit with adequate capacity to install eight Floor Flanges per trip. The unit shall be equipped with:

- a) Proximity-type positioning controls to accurately align the Floor Flange with the preinstalled anchor bolts;
- b) Powered bolt torque units to install and tighten anchor nuts;
- c) Pressure grouting unit.

The equipment for grouting shall be assembled as a unit and shall include a storage bin and feeder for the dry grout material, a liquid storage tank, a measuring tank, a grout mixer, a grout pump, hose and nozzle. Components in direct contact with the grout shall be assembled to facilitate rapid dismantling for cleaning. Slurry ways shall be shaped to minimize risk of clogging. Grout pump, valves and piping shall be rubber-lined for smooth and uniform flow.

10.7 Plug Removal Machine (PRM) Conceptual Specifications, Refer to Figures 4a and 4b

10.7.1 General

When the SURF Canister is emplaced in the steel sleeve in the floor of the emplacement room, a concrete radiation plug is emplaced in the sleeve above the Canister. Prior to SURF Canister retrieval, the plug must be removed.

10.7.2 Design Limitations

All requirements specified for the Canister Extraction/Transporter, (CET), Subsections 10.5.2 and 10.5.3, shall apply in their entirety except that only one cab will be required since bed is not as long.

10.7.3 General Design Requirements

All requirements specified for the CET, Subsection 10.5.4, shall apply in its entirety except substituting the word "Plug" for "Canister" wherever it appears.

10.7.4 Subassembly Design Requirements

Design requirements for the extraction/transporter subassemblies shall be as described in the following subsections:

10.7.4.1 Chassis and Power Train

The chassis and power train shall be custom-designed and built utilizing stock components of reliable equipment manufacturers wherever possible.

The design shall include:

- a) Chassis - custom designed and built;
- b) Wheels - heavy-duty pneumatic rubber-tired wheels as used on heavy construction equipment;
- c) Transporter drive - mine locomotive type;
- d) Power - mine locomotive battery power for the travel drive;
- e) Emergency power system - separate battery system to supply emergency lighting, cab ventilation, communication, vehicle controls;
- f) Steering - hydraulic power steering on front end only with manual steering for corridor travel and a controlled guidance system with manual override for travel in the emplacement room, and proximity controls for positioning the vehicle for retrieval and replacement of the plugs;

g) Operator cab shall be located at one end of the PRM. The cab shall be air-conditioned and designed to meet the life support criterion of Subsection 10.5.3.6.

10.7.4.2 Electric Driven Hydraulic Power Supply System

The power for the retrieval and reemplacement operations shall come from a power cable connected to the mining type electric power centers located in the emplacement room. The cable shall be unreeled from a cable reel mounted on the vehicle. An electric interlock shall prevent movement of the vehicle when the power is connected.

The following subsystems shall be electric motor driven: cask bottom gate, plug removal unit latch, motive power drive and indexing.

The hydraulic systems shall be selected from standard components of established hydraulic equipment manufacturers. The hydraulic system shall be a medium pressure, 2500 psig, system.

All hydraulic cylinders and electric motors in the system shall have suitable seals to prevent the debris infiltration of radiation deterioration-resistant material. Cast iron seals with chrome-plated piston rods are acceptable for hydraulic piston seals.

10.7.4.3 Cask with Raising and Axis Orientation Systems

The retrieval cask shall be designed to form a radiation shield and shall be large enough to receive the plug and raising system. The systems shall meet the following specifications:

a) Plug lifting system construction - steel sheet or plate, rolled and welded or steel tubing designed to be annularly guided by interior of sleeve with captive bearings to reduce sliding friction and blunt tapered nose to reduce Canister dam;

b) Plug lifting device - lifting attachment of double scissors, grab designed to be compatible with concrete plug lifting ring with a standby operator-controlled disconnect joint compatible with the telescoping cylinder;

c) Hydraulic piston designed to extend ram reach to below bottom of Canister.

d) Ram - sufficient to capacity latch onto the concrete plug ring;

e) Travel - cask position shall be horizontal;

f) Cask axis orientation mechanism - a platform mounted on jacks to allow adjustment of the cask tilt angle;

g) Cask bottom gate - shall be electric motor powered and shall include key latch to engage and open floor flange gate. Gate seals shall be designed to pre-wipe sealing surface free of debris.

10.7.4.4 Plug Removal

For plug removal or plug reemplacement the cask tilt changes from horizontal to approximately ten degrees past vertical, i.e., from 0° to 100° . The adjustment of the angle from vertical is necessary to match the tilt of the sleeve axis. The adjustment of the cask angle provides one plane of tilt, and the other plane of tilt is obtained by tilting the cask platform axis, approximately ten degrees starboard or port.

The plug removal machanism shall include a quick detachable connection for picking up and releasing the plug.

10.8 Transfer Handling and Vertical Lift Equipment Conceptual Specifications

10.8.1 General

The transfer handling and vertical lift facilities⁽¹⁵⁾ used for emplacement shall be used for the Canister retrieval operation.

10.8.2 Description, Figure 5 (Similar Procedures will be Followed for the Canister Overcore/Transporter (COT)

The Canister Extraction/Transporter (CET) approaches the Canistered Waste Subsurface Receiving Station (CWSRS) and proceeds to the transporter unloading area. The transporter operator positions the vehicle over the shielding port in the floor of the transporter level. The cask is repositioned erect, and instrumentation on the transporter permits the operator to adjust alignment of the cask with the shielding port. The operation shall seal the space between

the vehicle and the port, open the CET gate, the shielding port gate and the Canistered Waste Transfer Basket (CTB) gate. The Canister is then lowered into the CTB located below the floor.

The CTB shall be designed to accept the PWR and BWR Canisters with the corresponding ram unit serving as overpack.

After depositing the retrieved overpacked Canister, the operator closes the CET gate, the shielding port gate and the CTB, lowers the CET cask for travel, and repositions the transporter to another receiving chamber for another Canister deposit.

At the other transfer port the CET cask is repositioned erect and the operator adjusts alignment of the chamber with the floor opening. The operator seals the space between the vehicle and the port, opens the chamber and port, lowers the telescoping cylinder, attaches to a new empty ram unit Canister overpack, draws the ram into the chamber, closes the chamber and port, and lowers the CET cask for transport.

The transporter then proceeds through the isolation doors to the emplacement room to retrieve another Canister.

At the CTB, when the basket has accumulated a full set of Canisters, the basket is moved into the cage of the Canistered Waste Cage (CWC) and is hoisted to the surface.

10.9 Overcore Drilling and Sleeve Retrieval Equipment Conceptual Specifications, Figures 6a, 6b, 6c, 7a, 7b, 8a and 8b

10.9.1 General

The overcore retrieval transporter system shall be a machine custom-designed specifically to retrieve a degraded sleeve with a SURF Canister inside by overcoring.

The system shall be required to perform these functions:

a) Overcore the sleeve in two phases, by two machines to approximately one foot below the bottom of the sleeve. The inside core diameter shall be a minimum of four inches larger than the largest diameter of the emplaced sleeve. The first drilling phase performed by the POM shall overcore the sleeve to a depth of nine feet below the floor. The second phase of the drilling shall be performed by the COT, and the sleeve shall be overcored to below its bottom.

b) Clean out the hole; remove the cuttings using air and store all the cuttings within the radiation shield enclosure. The air shall be recirculated within the enclosure; no outside air shall be used.

c) Remove and store the concrete shielding plug for transport to the Canister Waste Subsurface Receiving Station (CWSRS).

d) Cut off the upper portion of the sleeve approximately nine feet below the emplacement room floor or above the top of the Canister, hoist the cut-off sleeve portion out of the hole and store for transport to the CWSRS.

e) Undercut below the lower portion of the sleeve with the overcore drill and extend the lifting finger devices under the sleeve bottom and remove with the Canister inside.

f) Lift the Canister and the lower portion of the sleeve into the transporter cask.

g) Redeposit the cutoff upper portion of the sleeve, the concrete plug and the cuttings back into the cored out emplacement.

h) Transport the lower half of the sleeve with Canister inside to the CWSRS.

i) Unload the Canister and sleeve at the CWSRS.

Two machines shall be used, one machine to do the preparatory work and the other machine to do the retrieval and transport.

The first machine, designated Plug Overcore Machine (POM) shall:

a) Locate over the emplacement open Floor Flange gate and overcore the sleeve to a point approximately one foot below the top of the Canister.

b) Remove the cuttings and debris created by the coring operation and store using air blast and vacuum lift assist methods.

c) Remove the store the radiation plug from the top of the sleeve for transport to the CWSRS.

d) Cutoff the sleeve just above the top of the Canister and remove .

e) Close Floor Flange gate and move forward to allow operating room for second machine.

f) Redeposit the upper sleeve, plug and cutting debris into the hole after lower sleeve with Canister contained therein are removed.

The second machine designated Canister Overcore/Transporter (COT) shall:

a) Locate over the emplacement, open Floor Flange gate and overcore to a point approximately one foot below the bottom of the sleeve.

b) Remove the cuttings and debris created by coring operation and store using air blast and vacuum lift assist methods.

c) At the bottom of the overcoring, the downward travel of the overcore drill shall stop but the rotation shall continue until the undercutting fingers have undercut the bottom of the sleeve.

d) The overcoring drill shall be used to lift the core out of the hole and into the transporter for transport to the CWSRS.

e) Redeposit the cutting debris back into the hole.

f) Close Floor Flange gate

g) Release the core, containing the Canister and lower sleeve into the Canister Transfer Basket (CTB) at the CWSRS for transfer to the canistered waste hoist for hoisting to the surface.

10.9.2 Design Limitations, Safety and Health Limitations and General Design Requirements

The limitations placed on the extraction transporter shall be as specified in Subsections 10.5.2, 10.5.3 and 10.5.4.

10.9.3 Plug Overcore Machine (POM) Design Requirements, Refer to Figures 6a, 6b, 6c, 8a and 8b

Design requirements for the extraction/transporter subassemblies shall be as follows:

10.9.3.1 Chassis and Power Train

The chassis and power train shall be custom-designed and built utilizing stock components of reliable equipment manufacturers wherever possible.

The design shall include:

- a) Chassis - custom design and build;
- b) Wheels - heavy-duty pneumatic rubber-tired wheels as used on heavy construction equipment;
- c) Transporter drive - mine locomotive type;
- d) Power - mine locomotive battery power for the travel drive;
- e) Emergency power system - separate battery system to supply emergency lighting, cab ventilation, communication, vehicle controls;
- f) steering - hydraulic power steering on front end only with manual steering for corridor travel and a controlled guidance system for travel in the emplacement room and for positioning the vehicle for retrieval and unloading of Canisters;
- g) Operator cabs shall be located at one end of the POM.

The cab shall be air-conditioned and designed to meet the life support criterion of Subsection 10.5.3.6.

10.9.3.2 Electric Driven Hydraulic Power Supply System

The power for the retrieval operation shall come from a power cable connected to the mining-type electric power centers located in the emplacement room. The cable shall be unreel from a cable reel mounted on the vehicle. An electric interlock shall prevent movement of the transporter vehicle when the power is connected.

The following subsystems shall be electric motor driven: cask bottom gate, drill unit and sleeve cutter rotational drives, air blower drive, motive power drive and indexing.

The hydraulic systems shall be selected from standard components of established hydraulic equipment manufacturers. The hydraulic systems shall be a medium pressure, 2500 psig, system.

All hydraulic cylinders and electric motors in the system shall have suitable seals to prevent the debris infiltration of radiation deterioration-resistant material. Cast iron seals with chrome-plated piston rods are acceptable for hydraulic piston seals.

10.9.3.3 Cask with Raising and Axis Orientation Systems

The retrieval cask shall be designed to form a radiation shield and shall be large enough to enclose the following subassemblies. The subassemblies shall be mounted on a turntable with indexing drive designed to position each subassembly over the Canister emplacement.

a) Plug removal assembly - shall be identical to the PRM, and including hydraulic ram and "S" hook concrete plug latch (see Subsection 10.7.4.3). Assembly shall be complete with semi-enclosed steel chamber to guide and restrain the plug when raised into and lowered from the POM.

b) Drill assembly - shall consist of steel plate rolled and welded or steel tubing barrel of adequate length with diamond tipped cutterheads. Drill drive, telescoping piston and Kelley bar shall be of conventional drill rig design, track guided with eccentric thrust provision (per Section 10.9.4.3c). Drill shall be designed as specified for the COT, cut inward towards the sleeve at the end of the downward thrust, but should be spring mounted to avoid impacting sleeve.

c) Sleeve grasp and cutting device - shall be a motor driven plasma arc cutter designed to cut through 2" maximum thickness of steel. A peripheral clamp device actuated by hydraulic piston or motor drive shall be provided and designed to grasp and lift the cut sleeve into the POM yet not interfere with the cutter.

d) Debris collection system - see Subsection 10.9.4.3.

The other subassemblies shall be as follows:

- a) Transporter travel - cask position is vertical;
- b) Cask raising and axis orientation mechanism - a platform mounted on jacks to allow adjustment of the cask tilt angle in all planes and raise the cask clear of the Floor Flange.
- c) Cask bottom gate - shall be electric motor powered and shall include key latch to engage and open Floor Flange gate. Gate seals shall be designed to pre-wipe sealing surface free of debris.

10.9.3.4 Plug Overcore and Retrieval

For retrieval, the cast shall tilt approximately ten degrees plus or minus from vertical and approximately ten degrees starboard or port. The adjustment of the angle from vertical is necessary to match the tilt of the Canister axis.

10.9.4 Canister Overcore/Transporter (COT), Refer to Figures 7a, 7b and 7c

Design requirements for the Canister Overcore/Transporter subassemblies shall be as follows:

10.9.4.1 Chassis and Power Train

The chassis and power train shall be custom-designed and built utilizing stock components of reliable equipment manufacturers wherever possible.

The design shall include

- a) Chassis - custom designed and built;
- b) Wheels - heavy duty pneumatic rubber-tired wheels as used on heavy construction equipment;
- c) Transporter drive - mine locomotive type;
- d) Power - mine locomotive battery power for the travel driven;
- e) Emergency power system - separate battery system to supply emergency lighting, cab ventilation, communication, vehicle controls;

f) Steering - hydraulic power steering on front end only with manual steering for corridor travel, and a controlled guidance system for travel in the emplacement room and for positioning the vehicle for retrieval and unloading of Canisters;

g) Operator cabs shall be located at each end of the COT. The cabs shall be air-conditioned and designed to meet the life support criterion of Subsection 10.5.3.6.

10.9.4.2 Electric Driven Hydraulic Power Supply System

The power for the retrieval operation shall come from a power cable connected to the mining-type electric power centers located in the emplacement room. The cable shall be unreel from a cable reel mounted on the vehicle. An electric interlock shall prevent movement of the transporter vehicle when the power is connected.

The following subsystems shall be electric motor driven: cask bottom gate, drill unit rotation drive, air blower drive, motive power drive and indexing.

The hydraulic system shall be selected from standard components of established hydraulic equipment manufacturers. The hydraulic systems shall be medium pressure, 2500 psig, systems.

All hydraulic cylinders and electric motors in the system shall have suitable seals to prevent the debris infiltration of radiation deterioration-resistant material. Cast iron seals with chrome-plated piston rods are acceptable for hydraulic piston seals.

10.9.4.3 Cask with Raising and Axis Orientation Systems

The retrieval cask shall be designed to form a radiation shield enclosing and shall:

a) Be large enough to receive the overcore unit with raising system and coring debris collection system.

b) Sleeve overcore drill barrel construction - steel sheet or plate, rolled and welded or steel tubing. Unit to be of adequate diameter to accommodate drift and surround sleeve and designed to serve as sleeve overpack.

c) Sleeve overcore raising/lowering unit designed to provide downward eccentric thrust in direction of drill rotation to minimize rotationally induced drill drift. Sleeve overcore raising/lowering system shall consist of mechanical screw jacks with cross head and guides and hydraulic piston designed to extend drill barrel reach to below bottom of Canister. Unit shall have adequate capacity to lift sleeve, Canister and core material and downward force to drill below and under sleeve.

d) Sleeve overcore drill - shall be furnished with diamond tipped cutters mounted to push rods designed to fold and cut inward at travel limit thereby cutting under sleeve bottom, and when rotation ceases to lift sleeve with Canister inside.

e) Sleeve overcore unit connection - quick detachable connection to Kelley bar.

f) Sleeve overcore drive - sufficient power to rotate the core drill to below and under the bottom of the sleeve;

g) Transporter travel - cask position shall be horizontal;

h) Cask axis orientation mechanism - a platform mounted on jacks to allow adjustment of the cask tilt angle;

i) Cask bottom gate - shall be electric motor powered and shall include key latch to engage and open Floor Flange gate. Gate seals shall be designed to pre-wipe sealing surface free of debris.

j) Cutting debris collection system - shall be designed to remove the debris, convey it upward, separate it from the air stream and collect it into a hopper. The debris shall be emptied into the emplacement hole after the sleeve is extracted.

10.9.4.4 Canister Retrieval

For sleeve retrieval (with Canister inside), the cask tilt changes from horizontal to approximately ten degrees past vertical, i.e., from 0° to 100° . The adjustment of the angle from vertical is necessary to match the tilt of the sleeve axis. The adjustment of the cask angle provides one plane of tilt, and the other plane of tilt is obtained by tilting the cask platform axis, approximately ten degrees starboard or port.

10.10 General Comments on Retrieval

10.10.1 Floor Flange Grouting - General Comments

Each installation will require approximately two cubic feet of grout for a two-inch grout space after leveling. A quick setting nonshrink epoxy-type grout is recommended.

10.10.2 Floor Flange Removal

Floor Flange removal after extraction of Canister and replacement of sleeve plug will have to be delayed until the radiation level of the irradiated surface of the gate has decreased to ALARA.

The procedure shall be as follows:

- a) Remove the anchor bolts;
- b) Knock the shield loose;
- c) Remove the shield;
- d) Clean the shield;
- e) Break up the grout (optional);
- f) Clean up the debris (optional).

10.10.3 General Procedures

- a) The plug extraction will be common for all methods of extraction, either by the PRM or POM, and as a prelude to the Canister removal, either by the CET or COT.

b) The Floor Flange shall have an adequate throat size to allow core drill operation; in other words, the throat size is determined by the core cutter head outside diameter.

c) All extraction operations will be performed remotely from the machines by the operator located in a shielded chamber. The reliability estimates are based on the assumption that the operation chamber (which could double as a rescue vehicle) is located within 500 feet of the machine.

Some items of consideration which require future study to develop specific procedural guidelines and design parameters are:

a) The CET operation will dictate the size and capacity of the CWSRS hoist, the CTB and the emplacement room configuration. The impact is not assessed in this report;

b) COT and POM operate in time periods independent of CET and PRM and procedural guidelines need to be completed;

c) CET and PRM must clear out the emplacement room before COT and POM enter, and CET and PRM should be incorporated into the procedural outline.

11.0 ACCIDENT ANALYSIS

11.1 General

The types of accidents likely to occur during the retrieval operation are listed in estimated order of most likely occurrence.⁽¹⁷⁾

- a) Accidents that produce no radiation exposure.

An example would be a collision between a transporter and another vehicle with no rupture or puncture of the cask or Canister.

- b) Accidents that result in radiation exposure to personnel.

An example would be a collision between a transporter and another vehicle that resulted in a rupture of the cask containing the Canister.

- c) Accidents that have long-term effects. An example would be an accident that results in abandonment of a Canister in the emplacement room.

- d) Accidents that release radioactive materials that are not recoverable. An example might be a spill of radioactive material that results in radioactivity lost through the ventilation system.

11.2 Accident Prevention

Accidents can be minimized by standard industrial methods including careful selection of operating personnel, adequate training and supervision, development of operating procedures, and incentives.

From a mechanical-electrical equipment approach, systems shall be designed to be less accident prone by including proven industrial features such as interlocks; warning systems; environmental protection systems; bumpers; shock absorbers; guards; fail safe brakes; adequate lighting; safety latches; feedback control systems such as limit switches, overload sensors, strain gauges with alarms; excess temperature, pressure and current limiting devices; insulation; isolation and inherent fail safe system designs.

11.3 Vehicle Collision Prevention

Collisions shall be held to a minimum by having one-way traffic corridors to and from the CWSRS. Collisions in the emplacement rooms shall be minimized by reduced vehicle speed and the use of the controlled guidance system.

11.4 Fire

Fire hazards shall be minimized by:

- a) Designing to prevent fires;
- b) Early detection and alarm systems;
- c) Extraction/transporters having fire extinguishers to put out small fires;
- d) The station fire fighting equipment available for major fires.

12.0 MECHANICAL FAILURE PROBABILITIES OF THE MAJOR RETRIEVAL SUBSYSTEMS

12.1 General

Mechanical failures can be controlled by design, testing, quality control, inspection, maintenance, operator training and operating procedures along with the use of mathematical models to determine the reliability of each component used in the system, as will be explained later in this report.

Most mechanical failures will be inconvenient but not serious. The serious mechanical failures will be those which result in personnel exposure or release of radioactive material outside of the emplacement room, and these shall be thoroughly analyzed to preclude as many failures as possible without incurring exorbitant costs.

12.2 Midmode Failure Discussed

An unlikely but not impossible occurrence would be a mechanical failure during the lifting of the Canister out of the emplacement sleeve so that the operation could not be completed or reversed, or so that the Canister overcan and Canister could not be dropped back in the hole, leaving the Canister partially out of the emplacement sleeve. In these events, the retrieval vehicle may have to be abandoned, and emergency procedures applied.

12.3 Accident Due to Mechanical Failure

Accidental dropping of a Canister/overcan in the emplacement room or CNSRS or while traveling is another unlikely but not impossible occurrence. A shielded forklift with a grabbing device to clamp onto the overcan could be used to pick up the dropped Canister/overcan.

12.4 Published Statistical Data on Failure Probability

A study of numerous documents, (refer to "Source of Data, Parts Failure" Section for listings), substantiates that there are few published figures on failure probability of equipment similar to the equipment being considered here. Therefore, to determine the failure probability of the equipment to be used, the failure rate of each component of these proposed systems or subsystems shall be studied to determine the total reliability and probable failure rate of the equipment.

12.5 Failure Probability Derivation, Reference Figure 12.5 and Appendix 6

The failure probability of the subsystems are shown in Figure 12.5, calculations are in Appendix 6 and derivations are discussed herein.

The expression $R = e^{-\lambda t}$ is used to represent a constant failure rate which depends on time. ⁽²²⁾ We shall use this in the following matrices as the main equation using "t" as the number of hours the components are used, and λ which is the failure intensity per 10^6 hours to arrive at a reliability figure, and λt = probable rate of failure after a certain number of operating hours.

Figure 12.5
FAILURE PROBABILITY
RETRIEVAL EQUIPMENT

EQUIPMENT SYMBOL	EQUIPMENT	LEVEL OF FAILURE INTENSITY	HOURS OF OPERATION		
			1000	3000	5000
CET	Canister Extraction/Transporter	Low	.00846	.02539	.04232
		Medium	.04150	.12451	.20752
		High	.0932	.27979	.46632
PRM	Plug Removal Machine	Low	.00316	.00948	.01580
		Medium	.01535	.04605	.07675
		High	.03459	.10377	.17295
CTB	Canister Transport Basket	Low	.00052	.0015	.00262
		Medium	.0109	.03271	.05452
		High	.03282	.09845	.16408
CWC	Canister Waste Cage (Hoist)	Low	.00356	.0107	.0178
		Medium	.01427	.0428	.07135
		High	.0369	.1108	.1848
COT	Canister Overcore Transporter	Low	.00516	.01547	.02579
		Medium	.03767	.1130	.18834
		High	.09443	.28328	.47214
POM	Plug Overcore Machine	Low	.00757	.02272	.03787
		Medium	.03195	.09586	.15977
		High	.08188	.24565	.40941

Failure intensity rates are from Bibliography reference (23) unless noted. Reliability Expression $R = e^{-\lambda t}$ restated:

R = Reliability

e = Natural logarithm

λ = Product failure rate per 10^6 hours

t = Number of hours a component is used - accumulated from time 0.

m = Mean time to failure = $\frac{1}{\lambda}$

Each individual component will be isolated and the failure intensity found from symposium figures.⁽²³⁾ If actual components are not found in the list, assumptions will be made using the nearest generic component as a guide.⁽²²⁾

After the reliability of the individual components are found, the combined subsystem will be evaluated as a series using the expression $R_s = e^{-(\lambda_1 t + \lambda_2 t + \dots)}$ where λ_1, λ_2 , etc., are the failure rates of the individual components, R_s is the operational system reliability and $(\lambda_1 + \lambda_2 + \lambda_3 \dots) t$ = System Failure Probability. In the "National Symposium" list,⁽²³⁾ there are three values for rates of failure, low, medium and high, which can be evaluated for the most probable rate of failure.

When the components are selected for each subsystem and then respective operation times have been determined, the system's reliability can be calculated. If it is found that the failure probability is

high, a more detailed examination of the system shall be undertaken, and more reliable components selected, if possible. If this is not possible, a parallel system may be added to raise the reliability of the equipment.

Although the equipment contains the components mentioned, a more detailed and clear description of the units will evolve as design progresses and each machine's reliability will be determined.

The equipment selected for evaluation is that which is in contact with the Canisters, casks, plugs, or sleeve, where malfunction would be critical while handling radioactive material.

12.6 Subsystem Machine Failure, Probability Predictions

Assuming 5,000 hours per year (250 days, 20 hours per day), each Canister retrieval-transporter can be operated an average of 5,300 hours before reaching a point of 80% reliability of the total machine considering the time of individual component operations.

12.7 Conclusion

A reasonable average of the probability of failure would be .415 (10^{-4}) for the components, with a maximum probability of failure .88 (10^{-4}) for any major component such as the hydraulic system. Further study is required to absolutely determine in detail the assumed values presented in Appendix 5. The result of the study may indicate that prototype testing of generic subassemblies or the subsystem equipment will have to be performed to yield more accurate data.

APPENDIX 1

Overcoring Telephone Survey

A telephone survey was conducted to verify that overcoring is feasible with existing drilling technology and to obtain some idea of how it would be done, how long it would take and what power source would be best to provide.

The telephone approach to the contractors generally followed this pattern.

After introduction, an explanation of the problem was made as follows:

"Imagine a drift or tunnel in a salt mine. The drift is 18 feet wide by 20 to 25 feet high and approximately 1000 feet long.

"In the floor of the drift are buried 20-inch diameter pipes by 25 feet long in a vertical position about 10 feet apart.

"The pipes are filled with atomic waste for about two-thirds of their length and then are plugged with a concrete to the floor level.

"The problem is to retrieve the atomic material after some years have passed. The pipe sleeve has corroded.

"Due to the heavy pressure on the pipe, it is probably not feasible to pull the sleeve out of the salt by using a pulling device.

"Since it may be feasible to overcore the pipe, our client has requested that we (IECO) contact drilling contractors and drilling equipment manufacturers to find the present state-of-art for large hole core drilling.

"We would appreciate your answers to the following questions:

Q1. "Does such a core drill, with about a 22 inch inside diameter (to allow for drill bit drift) exist? If yes, what type?

A1. _____

Q2. "What type of drill would you use if none exists? (Rotary, Calyx, or one of the more experimental types such as injector imploding/collapsing spheres).

A2. _____

Q3. "Presuming that multiple core barrels would be required, due to the headroom restrictions,

Q_{3A}. What lengths do you estimate each section could be?

A_{3A}. _____

Q_{3B}. Would coupling of each section be a problem in your opinion?

A_{3B}. _____

Q4. "Do you think the drilling would be rapid in salt?

A4. _____

Q5. "How long much time would you estimate for drilling operation?

A5. _____

Q6A. "Since mine ventiation is a problem, do you think a remotely supplied hydraulic or air source is feasible?

A6A. _____

Q6B. "Which power source would you chose - air, hydraulic oil or electric?

A6B. _____

Q7. "Suppose the pipes are installed in granite or basalt formations with native backfull and with the drilling done only in the "disturbed" or backfill region. Do you think that such a core drilling operation would be feasible?

A7. _____

The results of the telephone survey are tabulated on Figure 9.2.1.

APPENDIX 1

Telephone Survey List of Firms

DRILLING CONTRACTORS	LOCATION	PHONE	PERSON CONTACTED
1) Anderson Drilling Co.	Lakeside, Calif.	714-443-3891	Staw Anderson
2) Boyles Bros. Drilling Co.	Salt Lake City, Utah	801-972-3333	Ray Frazier
3) Cannon Drilling Co.	Denver, Colo.	303-988-4243	Roger Michaels
4) Coggins and Son	Englewood, Colo.	303-761-8166	Arnold Coggins
5) Continental Drilling	Los Angeles, Calif.	213-222-7146	Mr. Norak
6) Continental Drilling	Madera, Calif.	209-674-4655	Dean Loftus
7) Gil's Drilling	Phoenix, Ariz.	602-977-6145	Bob Frew
8) John's Drilling Co.	Denver, Colo.	303-423-5246	Mr. Johns
9) Jones Drilling Co.	Boise, Idaho	208-377-2630	Robert Jones
10) Malcolm Drilling Co., Inc.	Redwood City, Calif.	415-365-8766	Ted Robinson
11) Malcolm Drilling Co., Inc.	Redwood City, Calif.	415-365-8766	Ed Noian
12) PC Exploration, Inc.	Roseville, Calif.	916-783-9733	Paris Baker
13) Peterson Bros. Drilling Co.	Salt Lake City, Utah	801-532-1222	Farrel Peterson
14) Pitcher Drilling Co.	Daly City, Calif.	415-992-1500	Mr. Silvera
15) Raymond International, Inc.	Long Beach, Calif.	213-835-3191	Mr. Alley
16) Sammons Drilling Co.	Montrose, Colo.	303-249-7064	Mr. Sammons
17) Shelton Drilling Co.	Phoenix, Ariz.	602-253-8777	Mr. Shelton
18) Weyer Drilling Co.	Gilroy, Calif.	408-847-1441	Mr. Meyer
Not Responding			
James Drilling Co.	Denver, Colo.	303-420-5181	-
Raymond International	Trenton, N. J.	609-667-3323	-
Justice Drilling Co.	Meridan, Idaho	208-888-1281	-

APPENDIX 1

Telephone Survey List of Firms

DRILLING EQUIP. MANUFACTURERS	LOCATION	PHONE	PERSON CONTACTED
1) Acker Drill Co.	Scranton, PA	717-586-2061	Will Acker
2) Calweld Division	Santa Fe Springs, CA	213-723-0881	Buck Smith
3) Chicago Pneumatic Tool, Inc.	Sacramento, CA	916-481-5160	Ed Warner
4) Diamond Drilling & Sawing Co.	San Francisco, CA	415-362-2862	Mr. Cooper
5) Dresser-Oil Field Products Div.	Long Beach, CA	213-479-3993	Bill Anderson
6) Earth Drill Inc.	Los Angeles, CA	213-721-4888	Boone Haddock
7) Gardner Denver Co.	Denver, Colo.	303-425-1700	Mel Eatough
8) Korit Industries	Santa Clara, CA	408-296-0318	Dick Reynolds
9) Morgan Equip. Co.	San Francisco, CA	415-826-9200	Bois Mays
10) Pennsylvania Drilling Co.	Pittsburgh, PA	412-921-5816	Jack McFarlane
11) Schramm, Inc.	West Chester, PA	215-696-2500	Jack Rulon
12) Smith Tool Co.	Irvine, CA	714-540-7010	Dave Blas
13) Sprague and Henwood, Inc.	Scranton, PA	717-344-8506	Dave Price
Not responding:			
Mobile Drilling Co.	Indianapolis, IN	317-787-3671	
Reed Tool Co.	Houston, TX	713-926-3121	

APPENDIX 2

CANISTER RETRIEVAL RATE

Spent fuel receiving rates⁽¹⁶⁾ for the forty years from 1985 to 2025 are anticipated to vary from 593 in 1985 when the Depository is first opened to a maximum in year 2023.

The maximum rate of emplacement (assumed to be the same as spent fuel receiving rates) is 14,261 PWR Canisters and 21,738 BWR Canisters, totaling 35,999 for the year 2023.

If the retrieval rate is to be at least equal to the emplacement rate, and emplacement continues while retrieval begins after thirty years, approximately 36,000 Canisters maximum must be retrieved in one year.

Waste emplacement operations are assumed to be three 6.5-hour shifts 250 days per year and the rate of retrieval then is 48 Canisters per shift or 7.2 Canisters per hour, utilizing 15 operating machines under this condition.

APPENDIX 3 CANISTER EXTRACTION AND TRANSPORT TIME ESTIMATES

Retrieval using a concrete plug handling machine and a retrieval/transporter machine.

Estimated time to retrieve a Canister

<u>A. Plug Removal Machine (PRM), Figures 4a, 4b, 4c, 4d, 4e and 4f</u>		<u>Minutes per Operation, Maximum</u>
1.	Locate overhole	2.5
2.	Engage shielding port	2.5
3.	Open port	.5
4.	Engage sleeve plug, remove plug	2.0
5.	Rotate plug to storage position	2.0
6.	Close port	2.5
7.	Disengage shielding port	2.5
8.	Back off to wait for CET positioning	<u>2.5</u>
		17.0
 <u>B. Canister Extraction/Transporter Machine (CET)</u>		
Travel		
1.	Transporter departs from CWSRS	0
2.	Corridor travel 4600 ft @ 440 fpm	10.5
3.	Room travel 1800 ft @ 220 fpm	<u>8.5</u>
		19.0

B. Canister Extraction/Transporter Machine (CET) (Cont'd)

	<u>Minutes per Operation, Maximum</u>
Extract	
4. Locate over hole	2.5
5. Engage shielding port	2.5
6. Open port	.5
7. Lower retrieval can 25 feet @ 5 fpm	5.0
8. Reverse can engaging retrieval plugs	.5
9. Raise can into transporter 25 feet @ 5 fpm	5.0
10. Close port	.5
11. Disengage shielding port	<u>2.5</u>
	19.0
Travel	
12. Room travel 1800 ft @ 220 fpm	8.5
13. Corridor travel 4600 ft @ 440 fpm	<u>10.5</u>
	19.0

B. Canister Extraction/Transporter Machine (CET) (Cont'd)

Minutes per
Operation, Maximum

Figure 5. At Canister Waste Subsurface Receiving
Station (CWSRS)

14. Locate over shielding	5.0
15 Engage shielding port	2.5
16. Open Canister Transport Basket (CTB) gate and shielding gate	5.0
17. Lower ram overpack with Canister 25 ft @ 5 fpm	5.0
18. Disengage ram unit and raise ram lift apparatus into CET	5.0
19. Close CTB gate and shielding port gate	5.0
20. Disengage from shielding port	2.5
21. Locate over ram overpack storage port	5.0
22. Engage ram overpack storage port	2.5
23. Open ram overpack storage port gate and CET gate	5.0
24. Lower ram lift apparatus and engage new ram unit	5.0
25. Raise ram unit into transporter	5.0
26. Close ram overpack storage port gate	5.0
27. Disengage ram overpack storage port	2.5
28. Transporter departs CWSRS	-
	<hr/> 60.0

Appendix 3
Page 3

APPENDIX 3 Sketch of Time Sequence of Retrieval for 1 Concrete Plug Handling Machine and Two Retrieval/Transporter Machines

1. Plug machine requires 15 minutes to remove or replace plug.
2. Retrieval transporter requires maximum 20 minutes corridor travel and 20 minutes retrieval with 1 hour at the Canister Waste Subsurface Receiving Station (CWSRS).

APPENDIX 4

10-YR OLD SPENT FUEL RECEIVING RATES^a (CYCLE 11)

Year	PWR Canisters ^b		BWR Canisters ^c	
	Annual	Accumulated	Annual	Accumulated
1985	139	139	454	454
1986	555	694	1814	2268
1987	979	1673	2124	4392
1988	1390	3063	2435	6827
1989	1657	4720	2524	9351
1990	1906	6626	2596	11947
1991	2336	8962	3723	15670
1992	2582	11545	4338	20008
1993	2953	14498	4814	24822
1994	3446	17945	5235	30057
1995	4045	21990	6021	36078
1996	4388	26378	6391	42469
1997	4976	31354	7520	49989
1998	5616	36970	8453	58442
1999	6270	43240	9422	67864
2000	6955	50195	10445	78309
2001	7637	57822	11436	89745
2002	8323	66155	12441	102186
2003	9026	75181	13498	115684
2004	9739	84920	14575	130259
2005	10506	95426	15734	145993
2006	11240	106666	16838	162831
2007	11953	118619	17903	180734
2008	12642	131261	18938	199672
2009	13301	144562	19910	219582
2010	13915	158477	20882	240464
2011	13939		20980	
2012	13932		20849	
2013	13932		20917	
2014	13932	228144	20826	344862
2015	13932		20826	
2016	14043		20826	
2017	13877		20826	
2018	14008		20826	
2019	13812		21476	449425
2020	13928	297812	20609	
2021	13951		21594	
2022	13951		21269	
2023	14261		21738	
2024	13728		21667	
2025	13428	367131	21027	556720

^aBased on projections prepared by OWI (July-1977). Assumes 480 GWe by year 2000

^bReference PWR canister contains 1 PWR assembly (0.461 MTHM).

^cReference BWR canister contains 1 BWR assembly (0.183 MTHM).

APPENDIX 5 - Average One-Way Distance Traveled by Transporter

From CWSRS to corridor = 100 ft.

Corridor length of PWR storage area⁽¹⁴⁾

$$1392 + 151 + 132 + 150 + 100 + \frac{5355}{2} = 4,603 \text{ ft.}$$

(summation of lengths)

$$\begin{aligned} 1/2 \text{ room length} &= 3518/2 &= \frac{1,759}{6,462} \\ &&\text{say } \underline{6,500 \text{ ft.}} \end{aligned}$$

FAILURE PROBABILITY
CANISTER EXTRACTOR/TRANSPORTER - CET

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁵			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE		
		HI	MED	LOW			HI	MED	LOW
1.	Traverse from CWSRS	131.78	57.16	11.08	21.5	.179	23.5882	10.2318	1.9883
2.	Cask Rotation	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231
3.	Cask Lowering & Seal	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231
4.	Floor Flange Opening	25.0	9.52	0.53	.5	0.0041	0.1041	0.0396	0.0022
5.	Cask Gate Opening	25.0	9.52	0.53	.5	0.0041	0.1041	0.0396	0.0022
6.	Ram Lower & Connection	88.12	41.48	9.85	5	0.0416	3.6716	1.7283	0.4104
7.	Raise Ram	88.12	41.48	9.85	5	0.0416	3.6716	1.7283	0.4104
8.	Floor Flange Close	25.0	9.52	0.53	.5	0.0041	0.1041	0.0396	0.0022
9.	Cask Gate Close	25.0	9.52	0.53	5	0.0041	0.1041	0.0396	0.0022
10.	Cask Raise	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231
11.	Cask Rotate to Travel Position	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231
12.	Travel to CWSRS & Locate Over Hole	131.78	57.16	11.08	2.4	0.2	26.3360	11.4320	2.2160

FAILURE PROBABILITY
CANISTER EXTRACTOR/TRANSPORTER - CET

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE		
		HI	MED	LOW			HI	MED	LOW
13.	Cask Rotate	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231
14.	Cask Lower and Seal	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231
15.	Cask Gate Open	25.0	9.52	0.53	.5	0.0041	0.1041	0.0396	0.0022
16.	Shield Port Open	25.0	9.52	0.53	2.5	0.0208	0.5208	0.1983	0.0110
17.	Open Basket Port	25.0	9.52	0.53	2.5	0.0208	0.5208	0.1983	0.0110
18.	Lower Ram	88.12	41.48	9.85	5	0.0416	3.6176	1.7283	0.4104
19.	Raise Ram	88.12	41.48	9.85	5	0.0416	3.6176	1.7283	0.4104
20.	Close Basket Gate	25.0	9.52	0.53	2.5	0.0208	0.5208	0.1983	0.0110
21.	Close Shield Port	25.0	9.52	0.53	2.5	0.0208	0.5208	0.1983	0.0110
22.	Close Cask Gate	25.0	9.52	0.53	.5	0.0041	0.1041	0.0396	0.0022
23.	Raise Cask	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231
24.	Move to Retrieval Can Port	131.78	57.10	11.08	5	0.0416	5.4908	2.3816	0.4616
25.	Lower Cask	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.12131
26.	Open Cask Gate	25.0	9.52	0.53	.5	0.0041	0.1041	0.0396	0.0022

FAILURE PROBABILITY
CANISTER EXTRACTOR/TRANSPORTER - CET

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE					
		HI	MED	LOW			HI	MED	LOW			
27	Open Shield Port	25.0	9.52	0.53	2.5	0.0208	0.5208	0.1983	0.0110			
28	Open Can Port	25.0	9.52	0.53	3.5	0.0208	0.5208	0.1983	0.0110			
29	Lower Ram Engage Can	88.12	41.48	9.85	5	0.0416	3.6176	1.7283	0.4104			
30	Raise Ram with New Can	88.12	41.48	9.85	5	0.0416	3.6176	1.7283	0.4104			
31	Close Can Port	25.0	9.52	0.53	2.5	0.0208	0.5208	0.1983	0.0110			
32	Close Shield Port	25.0	9.52	0.53	2.5	0.0208	0.5208	0.1983	0.0110			
33	Close Cask Gate	25.0	9.52	0.53	.5	0.0041	0.1041	0.0396	0.0022			
34	Cask Raise	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231	OPERATION HOURS		
35	Rotate Cask	88.12	41.48	9.85	1.5	0.0125	1.1015	0.5185	0.1231			
							Total % of Failure Intens.			1000	3000	5000
								41.5032		.00845	.02539	.04232
										.04150	.12451	.20752
							93.2628			.0932	.27979	.46632

TOTAL CET FAILURE
PROBABILITY
(TOTAL Σ t)

LOW
MED
HI

Note: Number in first column does not necessarily represent the sequence of operation

FAILURE PROBABILITY
PLUG REMOVAL MACHINE PRM

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE				
		HI	MED	LOW			HI	MED	LOW		
1	Traverse FWD	131.78	57.16	11.08	10	.0833	10.98	4.76	.92		
2	Cask Rotation	88.12	41.48	9.85	2	.0166	1.46	.689	.16		
3	Cask Lowering	88.12	41.48	9.85	4	.0333	2.93	1.38	.33		
4	Floor Flange Opening	25.0	9.52	.53	1	.0083	.207	.079	.0044		
5	Cask Gate Opening	25.0	9.52	.53	1	.0083	.207	.079	.0044		
6	Ram Lower and Connection	88.12	41.48	9.85	2	.0166	1.46	.689	.16		
7	Ram Raising	88.12	41.48	9.85	2	.0166	1.46	.689	.16		
8	Cask Gate Close	25.0	9.52	.53	1	.0083	.207	.079	.0044		
9	Floor Flg Close	25.0	9.52	.53	1	.0083	.207	.079	.0044		
10	Cask Raise	88.12	41.48	9.85	4	.0333	2.93	1.38	.33		
11	Cask Rotate DN	88.12	41.48	9.85	2	.0166	1.46	.689	.16		
12	Traverse Back	131.78	57.16	11.08	10	.0833	10.98	4.76	.92		
							OPERATION HOURS				
							Total % of Failure Intens.	1000	3000	5000	
								3.16	.00316	.00948	.01580
								15.35	.01535	.04605	.07675
							34.49		.03459	.10377	.17895

TOTAL PRM FAILURE
PROBABILITY
(TOTAL λt)

LOW

MED

HI

TOTAL PRM FAILURE
PROBABILITY
(TOTAL λ_t)

LOW
MED
HI

Note: Number in first column does not necessarily represent the sequence of operation.

FAILURE PROBABILITY
CANISTER TRANSPORT BASKET CTB

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE		
		HI	MED	LOW			HI	MED	LOW
1	Traverse CTB FRM CWC to Unload Gate	33.86	10.28	.523	5.0	$\frac{5}{34}=0.1471$	4.9794	1.5118	0.0769
2	Open CTB Gate (CET Remove Drill)	25.0	9.52	.53	1.0	0.0294	0.7350	0.2799	0.0156
3	Traverse CTB to Loading Gate (Load from CET)	33.86	10.28	.523	5.0	0.1471	4.9794	1.5118	0.0769
4	Close CTB Gate	25.0	9.52	.53	1.0	0.0294	0.7350	0.2799	0.0156
5	Traverse CTB to CWC	33.86	10.28	.523	5.0	0.1471	4.9794	1.5118	0.0769
6	Close CWC Door and Raise CTB	-	-	-	-				
7	Open Door	-	-	-	-				
8	Traverse CTB to Surface Unload Point	33.86	10.28	.523	5	0.1471	4.9794	1.5118	0.0769
9	Open CTB Gate (Unload Can)	25.0	9.52	.53	1.0	0.0294	0.7350	0.2799	0.0156
10	Traverse CTB to Drill Loading (Load Drill)	33.86	10.28	.523	5.0	0.1471	4.9794	1.5118	0.0769

120

TOTAL CTB FAILURE
PROBABILITY—
(TOTAL λt)

Appendix 6
Page 6

FAILURE PROBABILITY
CANISTER WASTE CAGE - CWC

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE					
		HI	MED	LOW			HI	MED	LOW			
1	Hoisting	43.65	17.36	4.28	3.5	.39	17.02	6.77	1.67			
2	Door Opening/ Close	13.16	3.28	.46	1.0	.11	1.46	.3644	.111			
3	Lowering	43.65	17.36	4.28	3.5	.39	17.02	6.77	1.67			
4	Door Opening/ Close	13.16	3.28	.46	1.0	.11	1.46	.3644	.111			
							OPERATION: HOURS					
							Total % of Failure Intens.	1000	3000	5000		
									3.56	.00356	.0107	.0178
								14.27		.01427	.0428	.07135
							36.96			.0269	.1108	.1843

TOTAL CONT. FAILURE
PROBABILITY
(TOTAL λ t)

LOW
MED
HI

TOTAL CWC FAILURE
PROBABILITY →
(TOTAL λ t) LOW
MED
HI

FAILURE PROBABILITY
CANISTER OVERCORE MACHINE C.O.T.

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE		
		HI	MED	LOW			HI	MED	LOW
1	Traverse (Locate)	131.78	57.16	11.08	5.0	0.0104	1.3729	0.5954	0.1154
2	Rotate Cask	88.12	41.48	9.85	5.0	0.0104	0.9179	0.4321	0.1026
3	Lower Cask	88.12	41.48	9.85	2.0	0.0042	0.3672	0.1728	0.0410
4	Open Cask Gate	25.0	7.52	.53	.5	0.0010	0.0260	0.0078	0.0005
5	Open Flr. Flg.	25.0	9.52	.53	.5	0.0010	0.0260	0.0078	0.0005
6	Lower O'Core	26.38	10.18	.55	2.0	0.0042	0.1099	0.0424	0.0023
7	Overcore 16'	94.47	36.65	4.33	375	0.7813	73.8047	28.6328	8.3328
8	Undercut	94.47	36.65	4.33	2.0	0.0042	6.3936	0.1527	0.0180
9	Raise O'Core and Can	26.38	10.18	.55	5.0	0.0104	0.2748	0.1060	1.0057
10	Close Cask Gate	25.0	9.52	.53	.5	0.0010	0.0260	0.0078	0.0005
11	Close Floor Flg.	25.0	9.52	.53	.5	0.0010	0.0260	0.0078	0.0005
12	Raise Cask	88.12	41.48	9.85	2.0	0.0042	0.3672	0.1728	0.0410
13	Rotate Cask	88.12	41.48	9.85	5.0	0.0104	0.9178	0.4321	0.1026
14	Traverse to CWSRS	131.78	57.16	11.08	20.0	0.0417	5.4908	2.3317	0.4617
15	Traverse (Locate)	131.78	57.16	11.08	5.0	0.0104	1.3727	0.5954	0.1154

FAILURE PROBABILITY
CANISTER OVERCORE MACHINE C.O.T.

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE			
		HI	MED	LOW			HI	MED	LOW	
16	Rotate Cask	88.12	41.48	9.85	5.0	0.0104	0.9179	0.4321	0.1026	
17	Lower Cask	88.12	41.48	9.85	2.0	0.0042	0.3672	0.1728	0.0410	
18	Open Port Gate	25.0	9.52	.53	.5	0.0010	0.0260	0.0078	0.0005	
19	Open Cask Gate	25.0	9.52	.53	.5	0.0010	0.0260	0.0078	0.0005	
20	Lower Ram and Disconnect	26.38	10.18	.55	5.0	0.0104	0.2748	0.1060	0.0957	
21	Raise Ram	26.38	10.18	.55	2.0	0.0042	0.1099	0.0424	0.0023	
22	Lower Ram Pick Up New Drill	26.38	10.18	.55	2.0	0.0042	0.1099	0.0424	0.0023	
23	Raise Ram and New Drill	26.38	10.18	.55	5.0	0.0104	0.2748	0.1060	0.0957	
24	Close Cask Gate	25.0	9.52	.53	.5	0.0010	0.0260	0.0078	0.0005	
25	Close Port Gate	25.0	9.52	.53	.5	0.0010	0.0260	0.0078	0.0005	
26	Raise Cask	88.12	41.48	9.85	2.0	0.0042	0.3672	0.1728	0.0410	
27	Rotate Cask	88.12	41.48	9.85	5.0	0.0104	0.9179	0.4321	0.1026	
28	Traverse to Emplacement Room	131.78	57.16	11.08	20	0.0417	5.4908	2.3817	0.4617	
OPERATION HOURS										
<div>Note: Number in first column does not necessarily represent the sequence of operation.</div> <div>TOTAL COT FAILURE PROBABILITY (TAOTAL λt)</div> <div>LOW MED HI</div>						Total % of Failure Intens.	1000	3000	5000	
							5.1574	.00516	.01547	.02579
						37.6679	.03767	.1130	.16834	
						94.4278	.09443	.28328	.47214	

Note: Number in first column does not necessarily represent the sequence of operation.

TOTAL COT FAILURE
PROBABILITY
(TOTAL λ_t)

LOW
MED
HI

FAILURE PROBABILITY
PLUG OVERCORE MACHINE P.O.M.

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10-6			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE		
		HI	MED	LOW			HI	MED	LOW
1	Traverse	131.78	57.16	11.08	5	$\frac{5}{240} = .0208$	2.7410	1.1889	0.2305
2	Lower Cask	88.12	41.48	9.85	2	0.0083	0.7343	0.3457	0.0821
3	Open Cask Gate	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011
4	Open Floor Flg	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011
5	Index O'Core Drill	15.99	4.78	.43	2.0	0.0083	0.1327	0.0397	0.0036
6	Overcore	94.47	36.65	4.33	160	0.6667	62.9800	24.1000	6.2200
7	Overcore Ram Raise (Screw Hoist)	26.38	10.18	.55	2.0	0.0083	0.2190	0.0845	0.0046
8	Index for Plug Removal	15.99	4.78	.43	2.0	0.0083	0.1327	0.0397	0.0036
9	Lower Plug Removal Ram	20.98	7.46	.42	2.0	0.0083	0.1741	0.0619	0.0035
10	Raise Ram and Plug	20.98	7.46	.42	2.0	0.0083	0.1741	0.0619	0.0035
11	Index for Cutting	15.99	4.78	.43	2.0	0.0083	0.1327	0.0397	0.0036
12	Lower Sleeve Grab	20.91	7.46	.42	1.0	0.0042	0.0874	0.0311	0.0018
13	Lower Torch	19.63	6.78	.40	2.0	0.0083	0.1629	0.0563	0.0033

FAILURE PROBABILITY
PLUG OVERCORE MACHINE P.O.M.

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE		
		HI	MED	LOW			HI	MED	LOW
14	Cut Sleeve	19.7	6.64	.38	30.0	0.1250	2.4625	0.8300	0.0475
15	Raise Torch	19.13	6.78	.40	2.0	0.0083	0.1629	0.0553	0.0033
16	Raise Sleeve Grab	20.98	7.46	.42	1.0	0.0042	0.0874	0.0311	0.0018
17	Close Cask Gate	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011
18	Close Flg Gate	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011
19	Raise Cask	68.12	41.48	9.85	2.0	0.0083	0.7343	0.3457	0.0821
20	Traverse to Park	131.78	57.16	11.08	5.0	0.0208	2.7410	1.1889	0.2305
21	Traverse to Hole	131.78	57.16	11.08	5.0	0.0208	2.7410	1.1889	0.2305
22	Cask Lower & Seal	68.12	41.48	9.85	2.0	0.0083	0.7343	0.3457	0.0821
23	Open Cask Gate	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011
24	Open Floor Flange	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011
25	Lower Sleeve and Release	20.98	7.46	.42	1.0	0.0042	0.0874	0.0311	0.0018
26	Raise Sleeve Ram	20.98	7.46	.42	1.0	0.0042	0.0874	0.0311	0.0018
27	Index to Plug	15.99	4.78	.43	2.0	0.0083	0.1327	0.0397	0.0035
28	Lower Plug Ram and Release	20.98	7.46	.42	2.0	0.0083	0.1741	0.0619	0.0035

FAILURE PROBABILITY
PLUG OVERCORE MACHINE P.O.M.

NO.	OPERATION	FAILURE INTENSITY OF CONT. OPERATION X 10 ⁻⁶			TIME USED PER CYCLE	FRACTION OF TOTAL TIME	FAILURE INTENSITY % OF CYCLE						
		HI	MED	LOW			HI	MED	LOW				
29	Raise Plug Ram	20.98	7.46	.42	2.0	0.0083	0.1741	0.0619	0.0035				
30	Close Flr. Flg.	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011				
31	Close Cask Gate	25.0	9.52	.53	.5	0.0021	0.0521	0.0198	0.0011				
32	Raise Cask	88.12	41.48	9.85	2.0	0.0083	0.7343	0.3457	0.0821				
33	Traverse to New Hole	131.78	57.16	11.08	5.0	0.0208	2.7410	1.1889	0.2305				
							OPERATION HOURS						
							Total % of Failure Intens.	1000	3000	5000			
TOTAL POM FAILURE PROBABILITY (TOTAL Σt)							LOW			7.5735	.00757	.02272	.03787
							MED		31.9547		.03195	.09586	.19577
							HI	81.8821			.08188	.24565	.46941

TOTAL POM FAILURE
PROBABILITY
(TOTAL λ_t)

LOW
MED
HI

Note: Number in first column does not necessarily represent the sequence of operation.

FAILURE PROBABILITY
HYDRAULIC SYSTEM

NO	ITEM	FAILURE INTENSITY X 10^{-6} HRS.		
		HI	MED	LOW
1	Canister Latch	.6 *	.1 *	.01 *
2	Hoist Latch	.05	.02	.001
3	Latch to Stem Conn.	2.6	1.625	.65
4	Hoist Stem	.2 *	.02 *	.006 *
5	Hoist Seals	3.0	.345	.140
6	Hoist Piston Conn.	.049	.025	.001
7	Hoist Supports	.70	.175	.015
8	Hoist Piston	.35	.2	.08
9	Hoist Piston Rings	.35	.2	.08
10	Hoist Cylinder	.12	.008	.005
11	Hoist Hydraulic Connection	1.348	.69	.027
12	Hoist Cylinder Head	.16 *	.08 *	.02 *
13	Flexible Connection	5.22	3.94	.157
14	Hyd. Piping	.04 *	.02 *	.01 *
15	Solenoid Valve	.660 *	.175 *	.118 *
16	Pressure Switches	.660 *	.175 *	.118 *
17	Valve (Ball)	7.7	4.6	1.11
18	Pump	27.4	13.5	2.9
19	Motor	7.5	.625	.15
20	Check Valve	10.2	6.5	1.98
21	Control Valve	19.8	8.5	1.68
				9.85
			41.48	
		88.12		

Total Failure Probability →

LOW

MED

HI

* Assumed values

Appendix 6
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**FAILURE PROBABILITY
POWER STEERING**

NO	ITEM	FAILURE INTENSITY X 10^{-6} HRS.		
		HI	MED	LOW
1	Seals	3.0	.345	.14
2	Piston	.35	.2	.08
3	Piston Rings	.35	.2	.08
4	Cylinder	.12	.008	.005
5	Hydraulic Connection	1.348	.69	.027
6	Flexible Connection	5.22	3.94	.157
7	Hydraulic Piping	.04 *	.02 *	.01 *
8	Pressure Switch	.660 *	.175 *	.118 *
9	Valve	7.7	4.6	1.11
10	Pump	27.4	13.5	2.9
11	Motor	7.5	.625	.15
12	Check Valve	16.2	6.5	1.98
13	Control Valve	19.8	8.5	1.68
14	Gears	4.3	2.175	.087
15	Bearings	3.53	1.8	.072
16	Mechanical Connection	2.6	1.625	.65
17	Control System	2.13	1.4	.37
18	Universal Joints	12.0	2.5	.12
Total Failure Probability				
		LOW		9.74
		MED	48.758	
		HI	108.25	

* Assumed Values

FAILURE PROBABILITY SCREW HOIST

NO	ITEM	FAILURE INTENSITY X 10 ⁻⁶ HRS.		
		HI	MED	LOW
1	Elect Motor	7.5	.125	.15
2	Gear Reducer	4.3	2.175	.087
3	Screw	4.3 *	2.175 *	.087 *
4	Electrical Connection	4.7	2.0	.03
5	Slide	.7 *	.3 *	.1 *
6	Connection (Mechanical)	1.348	.6875	.027
7	Bearings	3.53	1.8	.072
Total Failure Probability				
				.55
			10.18	
		26.38		

* Assumed Values

FAILURE PROBABILITY
RAM UNIT
CASK BOTTOM GATE OPERATOR

NO	ITEM	FAILURE INTENSITY X 10 ⁻⁶ HRS.		
		HI	MED	LOW
1	Electric Motor	7.5	.625	.15
2	Gear Red	4.3	2.175	.087
3	Screw Operator	4.3 *	2.175 *	.087 *
4	Electrical Connection	4.7	2.02	.03
5	Slide	.7 *	.3 *	.1 *
6	Clamp	.049	.025	.001
7	Bearings	3.53	1.8	.072
Total Failure Probability				
		LOW		.53
		MED	9.52	
		HI	25.0	

* Assumed Values

FAILURE PROBABILITY

INDEXING

NO	ITEM	FAILURE INTENSITY X 10 ⁻⁶ HRS.		
		HI	MED	LOW
1	Electrical Motor	7.5	.625	.15
2	Gear Reducer	4.3	2.175	.087
3	Bearings	3.53	1.8	.072
4	Limit Switch	.660	.175	.118
Total Failure Probability				
				.43
			4.78	
		15.99		

LOW
MED
HI

FAILURE PROBABILITY

DRIVES

NO	ITEM	FAILURE INTENSITY $\times 10^{-6}$ HRS.		
		HI	MED	LOW
1	Transport Drive Motor	7.5	.37	.15
2	Transport Drive Gears	4.3	2.175	.087
3	Bearings	3.53	1.8	.072
4	Wiring and Connections	4.7	2.0	.03
5	Hyd. System for Power Steering	108.95	98.758	9.74
6	Tires, Wheel and Bearings	3.0 *	2.0 *	1.0 *
Total Failure Probability				
				11.08
			57.16	
		131.78		

* Assumed Values

FAILURE PROBABILITY
SLEEVE CUTTING DEVICE

NO	ITEM	FAILURE INTENSITY X 10 ⁻⁶ HRS.		
		HI	MED	LOW
1	Electrical Motor	7.5	.625	.15
2	Gear Reducer	4.3	2.175	.087
3	Hoist Screws	4.3	2.175	.087
4	Bearings	3.53	1.8	.072
5	Clamps (Mechanical Connection)	1.348	.6875	.027
	Total	20.98	7.46	.42
6	Electrical Motor	7.5	.625	.15
7	Gear Reducer	4.3	2.175	.087
8	Hoist Screws	4.3	2.175	.087
9	Bearings	3.53	1.8	.072
	Total	19.63	6.78	.40
10	Electrical Motor	7.5	.625	.15
11	Gear Reducer	4.3	2.175	.087
12	Bearings	3.53	1.8	.072
13	Hose Connection	1.15	.04	.021
14	Flex Hose	3.22	2.0	.05
	Total	19.7	6.14	.38
Total Failure Probability —				
				1.20
			20.88	
		60.31		

FAILURE PROBABILITY OVERCORE DRILL MECHANISM

NO	ITEM	FAILURE INTENSITY X 10 ⁻⁶ HRS.		
		HI	MED	LOW
1	Electrical Motor	7.5	.625	.15
2	Gear Reducer	4.3	2.175	.087
3	Belt Drive	15.0	3.88	.142
4	Bearings	3.53	1.8	.072
5	Electrical Connection	4.7	2.0	.03
6	Screw Drive	4.3	2.175	.087
7	Gear Reducer	4.3	2.175	.087
8	Bearings	3.53	1.8	.072
9	Core Drill Breakage (Wear not included)	3.22 *	2.0 *	.05 *
10	Mechanical Connection	1.348	.6875	.027
11	Slide	.7 *	.3 *	.1 *
12	Electrical Motor	7.5	.625	.15
13	Blower	16.1	9.0	1.9
14	Motor	7.5	.625	.15
15	Flex Hose	3.22	2.0	.05
16	Receiving Tank	.324	.18	.10
17	Valves	7.4	4.6	1.08
Total Failure Probability				
				4.53
			36.65	
		94.47		

* Assumed Values

FAILURE PROBABILITY
CANISTER TRANSPORT BASKET DRIVE

NO	ITEM	FAILURE INTENSITY X 10^{-6} HRS.		
		HI	MED	LOW
1	Transport Drive Motor	7.5	.625	.15
2	Gear Reducer	4.3	2.175	.087
3	Bearings	3.53	1.8	.072
4	Belt Drive	15.0	3.88	.142
5	Wheel Bearings	3.53	1.8	.072
Total Failure Probability				
				.523
			10.28	
		33.86		

FAILURE PROBABILITY
HOIST

NO	ITEM	FAILURE INTENSITY x 10 ⁻⁶ HRS.		
		HI	MED	LOW
1	Gear Mechanism	4.3	2.175	.15
2	Pulleys	12.0	2.5	.12
3	Connections	2.6	1.625	.65
4	Cables	.6*	.1*	.05*
5	Motor	7.5	.625	.15
6	Counter Weights	.545	.3375	.13
7	Starter	16.1	10	3.03
Total Failure Probability —				
		LOW		4.28
		MED	17.36	
		HI	43.65	

* Assumed Values

BIBLIOGRAPHY
NUCLEAR WASTE DEPOSITORY

1. Kibbe, R. K. and Boch, A.L. eds., "Technical Support for GEIS: Radio-active Waste Isolation in Geologic Formations", Office of Waste Isolation/ Union Carbide, Y/OWI/TM-36, Volume 8 (April 1978) prepared by Parsons Brinckerhoff, Quade & Douglas Inc.
2. Sandia Laboratories, "WIPP Conceptual Design Report, Waste Isolation Pilot Plant (WIPP), Conceptual Design Report Part I: Executive Summary, Part II: Facilities and System," SAND77-0274-P1-P2 (June 1977).
3. Kibbe, R. K. and Boch, A.L. eds., "Technical Support for GEIS: Radio-active Waste Isolation in Geologic Formations", Office of Waste Isolation/ Union Carbide, Y/OWI/TM-36, Volume 9 (April 1978) prepared by Parsons Brinckerhoff, Quade & Douglas Inc.
4. Kohn, Harold W. and U. Young Park, "Spent Nuclear Fuel: Prospects for Output, Storage and Reprocessing"; Power Engineering/April 1977 pp. 84-86.
5. Russell, James E., "Underground Storage of Nuclear Waste"; Underground Space. Vol. 2 No. 2 Pergamon Press, Great Britain; pp. 84 and 91-97.
6. Bradshaw, R. L. and W. C. McClain eds., "Project Salt Vault: A Demonstration of the Disposal of High - Activity Solidified Wastes in Underground Salt Mines"; Oak Ridge National Laboratory, ORNL-4555 (1971).
7. Fairchild, P. D. and J. E. Russell eds., "In Situ Experiments Related to Waste Repository Design", Office of Waste Isolation, Y/OWI/TM-25 (1977).

8. Kibbe, R. K. and Boch, A.L. eds., "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations", Office of Waste Isolation/ Union Carbide, Y/OWI/TM-36, Volume 1 (April 1978) prepared by Parsons Brinckerhoff, Quade & Douglas Inc.
9. Ludeman, W. D., Abrego L., McCright, R.D., "Corrosion Studies on Retrievable Spent Fuel Containers: A Progress Report" Lawrence Livermore Laboratory, UCID-17917.
10. Nickell, Robert E. Dr., "Retrievable Storage Concept Designs" by Pacifica Technology for Lawrence Livermore Laboratory, PTU 78.0243.
11. Martin, R. W., Lawrence Livermore Laboratory, Interdepartmental Letter dated August 10, 1978 to H. R. Ralston, numbered WM 78-701.
12. Fuller, M.E., Lawrence Livermore Laboratory, Interdepartmental Letter dated February 2, 1979 to H. Cheung, numbered WM 79-127-D.
13. General Electric Company Mine Power Center Catalog, No. GEA-10253.
14. Ibid. 1, drawing D25 only.
15. Ibid. 3 and 8, compilation of description and drawing data.
16. Ibid. 1.
17. Sandia Laboratories, "WIPP Conceptual Design Report" Addendum G, SAD77-0274 (June 1977).

18. "Contribution to Draft Generic Environmental Impact Statement in Commercial Waste Management: Radioactive Waste Isolation in Geologic Formation." Office of Waste Isolation, Oak Ridge, Tennessee, U.S. Department of Energy. Y/OWI/TM-44 (April 1978).
19. "High Level Waste Canister Emplacement and Retrieval Concepts Study." Office of Waste Isolation, Oak Ridge, Tennessee, U.S. Department of Energy; Publication Y/OWI/Sub-76/16509 (September 1976) prepared by Boeing Corp.
20. "Waste Isolation Pilot Plant (WIPP) Conceptual Design Report." National Technical Information Service, U.S. Department of Commerce; Publication SAND 77-0274-P1-P2 (June 1977).
21. "Waste Isolation Facility Description, Bedded Salt." Office of Waste Isolation/Union Carbide Corp. Nuclear Division, Oak Ridge, Tennessee; Publication Y/OWI/SUB-76/16506 (September 1976) prepared by Parsons, Brinckerhoff Quade and Douglas, Inc.
22. Amstadter, Bertram L., Reliability Mathematics, McGraw-Hill, Inc., New York, 1971.
23. "Seventh National Symposium on Reliability and Quality Control," January 1961. Pages 161-166.

SUPPLEMENTARY
DATA SOURCES
NUCLEAR WASTE DEPOSITORY

Cagnetta, John P., "Spent Fuel Storage," Combustion, June 1978, pp. 27-28.

Cohen, Bernard L., "The Disposal of Radioactive Wastes From Fission Reactors", Scientific American, June 1977, Vol. 236 No. 6, pp. 21-86.

Dau, G. and Williams, R., "Secure Storage of Radioactive Waste", June 1977, Combustion, pp. 24-32.

Deonigi, D. E., "Evaluation Methodology of Waste Management Concepts," Nuclear Technology, Vol. 24, Dec. 1974, pp. 331-338.

McClain, W. C., "Status of AEC Project to Establish a Salt Mine Radioactive Waste Repository", Oak Ridge National Laboratories, Oak Ridge, Tennessee, pp.337-342.

Moore, E. L., Calmus, D. B., eds., "Radioactive Waste Package Acceptance Criteria", Rockwell International, Rockwell Hanford Operations Energy System Group, RHO-CD-568, October 12, 1978.

Rippon, Simon, "Germany Plans Integrated Fuel Cycle Complex", Near News, October 1978.

Trall, Susan, "Belgian Report Proposes Regional Nuclear Fuel Centres", EEC Affairs Correspondent, October 1978.

Von Horst Keese, Hanau, "Abtransport Bestrahlter Brennelemente und Radioaktiver Abfälle", Atom + Strom, Jg. 23 (1977), Heft 1, pp. 12-15

Supplementary
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"Development Activities on Shallow Land Disposal of Solid Radioactive Waste", LA 6856-PR, Progress Report Los Alamos Scientific Laboratory of the University of California, Jan. - Dec. 1976.

"High Level Waste Canister Emplacement and Retrieval Concepts Study", BOEING - D272-10008-1 OWI-V/OWI/SUB-76/16509, Sr .. 1976, pp. 1-81.

Introduction and Overview "Report of Task Force for Review of Nuclear Waste Management", U.S. Department of Energy, February 1978.

"Storage and Retrieval of Waste ^{133}Xe ", Technical Notes, Dec. 1976, pp. 603-605.

Supplementary
Page 2

SUPPLEMENTARY
DATA SOURCES
CORE DRILLING

Acker, W. L. III, "Basic Procedures for Soil Sampling and Core Drilling",
Acker Drill Co., Scranton, PA, 1974.

Grams, William H. and Gnirk, Paul F., "An Analysis of the Custom Design/
Fabrication/Testing Requirements for a Large Hole Drilling Machine for
Use in an Underground Radioactive Waste Repository ", Y/DWI/SUB-4269/21.

Maurer, "Novel Drilling Techniques", Pergamon Press, Oxford, N.Y., 1968.

Rogert, Torgny and Andersson, S. Bertil, "Atlas Copco Manual", Atlas
Copco AB, Stockholm, Sweden, Dept S-10523, Edition 2, 1976.

'Big-Hole Drilling Technology", E/MJ Operating Handbook of Underground
Mining.

"Drilling: Faster Penetration and Larger Holes", Engineering Mining
Journal, June 1978.

"Large Diameter Coring Bulk - Samples Ore at Australian Find", Engineer-
ing Mining Journal, May 1974.

"Rotary Drills Dominate in Open Pits", Engineering Mining Journal,
June 1976.

SUPPLEMENTARY

DATA SOURCES

PARTS FAILURE

Barbour, Gilbert L., "Failure Modes and Effects Analysis by Matrix Method", Proceedings, 1977 Annual Reliability and Maintainability Symposium, 1423 77RM019, pp. 114-119.

Bazovsky, Igor, Sr., "Fault Trees, Block Diagrams and Markov Graphs, Proceedings, 1977 Annual Reliability and Maintainability Symposium, 1427 77RM023, pp. 134-141.

Bennett, John A., "What We Can Learn from the Examination of Service Failures", National Bureau of Standards Special Publication 423, April 1976, pp. 3-11.

Butorin, Yu. M. and Garrilenko, V. A., "Some Aspects of the Reliability of Drilling Equipment", Donetsk Scientific - Research Coal Institute, UDC 622.233.6.004.62, 1976, pp. 62-65.

Christiansen, Donald, "What Went Wrong?", IEEE Spectrum, Oct. 1976, pp. 33-100.

Cohn, M.Z. and Parimi, S. R., "Multi-Criteria Probabilistic Structural Design", Journal: Struct. Mech. 1 (4), 1973, pp. 479-496.

Compton, W. Dale, "Mechanical Reliability - Implications for Engineering, Manufacturing and Design", National Bureau of Standards Special Publication 423, April 1976, pp. 199-208.

Elfving, G. "Geometric and Game - Theoretic Methods in Experimental Design", pp. 291-299.

Feld, Jacob, "Public Safety and Construction Surety", National Bureau of Standards Special Publication 423, April 1976, pp. 165-170.

Hirth, John P., "Mechanical Failures: Implications for Science", National Bureau of Standards Special Publication 423, April 1976, pp. 181-191.

Kruger, Jerome, "Failure by Stress Corrosion Cracking - Current Approaches Toward Failure Prediction", National Bureau of Standards Special Publication 423, April 1976, pp. 27-40.

Lipton, Charles, "Bending Fracture," Machine Design, November 27, 1969, pp. 140-143.

Malik, M.A.K., "Average Life of Equipment Subject to Compound Failures", Journal of Engineering for Industry, Transactions of the ASME, May 1977, pp. 431-433.

McEvily, A. J., "Failure by Fatigue", National Bureau of Standards Special Publication 423, April 1976, pp. 13-24.

Morris, Peter A., "Nuclear Power Plant Safety", National Bureau of Standards Special Publication 423, April 1976, pp. 143-151.

Newendorp, Paul D., "Risk Evaluation Helps Make Better Decision", The Oil and Gas Journal, Oct. 18, 1976, pp. 55-58.

Newendorp, Paul D., "Use of Decision Trees Can Help Simplify Complex Problems", The Oil and Gas Journal, Oct. 25, 1976, pp. 98-102.

Onken, R., "System Integrity by Use of Self-Diagnosing Failure Detection",
Deutsche Forschungs-und Versuchsanstalt für Luft-und Raumfahrt e. V.
(DFVLR) pp. 10-1 10-18.

Rubinshtein, B. Sh, "Some Aspects of the Reliability of Mining Equipment",
Karaganda Scientific - Research Coal Institute, July 1973, pp. 349-353.

Smith, Craig F. and Kastenber, William E., "On Risk Assessment of High
Level Radioactive Waste Disposal", Nuclear Engineering and Design, 39,
(1976), pp. 293-333.

Sullivan, J. L., "Fatigue Life Under Combined Stress", Machine Design,
January 25, 1979, pp. 125-127.

Tsclikov, A. I., Konovalov, L. V., "Use of Fatigue Strength Criteria
to Insure the Reliability Characteristics of On-Off Machines at the
Design State", Russian Engineering Journal, Vestnik Mashinostroeniya,
Vol. 56, Issue 5, 1976, pp. 3-6.

Uhlig, F. J., "The People Considerations of Automotive Service",
National Bureau of Standards Special Publication 423, April 1976,
pp. 171-178.

Wakeland, Henry H., "Mechanical Failures and Public Expectations of
Safe Transportation", National Bureau of Standards Special Publication
423, April 1976, pp. 153-163.

Westerdale, Thomas H., "An Application of Fishers Theorem on Natural
Selection to Some Reinforcement Algorithms for Choice Strategies",
Journal of Cybernetics, 1974, 4,4 pp. 31-42.

Widner, R. L. and Littman, W. E., "Bearing Damage Analysis", National Bureau of Standards Special Publication 423, April 1976, pp. 67-84.

Wilde, R. A., "Failure in Gears and Related Machine Components", National Bureau of Standards Special Publication 423, April 1976, pp. 55-66.

"Reliability Prediction", Military Standard MIL-STD-756A, 15 May 1963.

"Reliability Prediction of Electronic Equipment", Military Standardization Handbook, MIL-HDBK-217B, 17 March 1978.

"IEEE Guide to the Collection and Presentation of Electrical, Electronic, and Sensing Component Reliability Data for Nuclear-Power Generating Stations", ANSI/IEEE Std 500-1977.